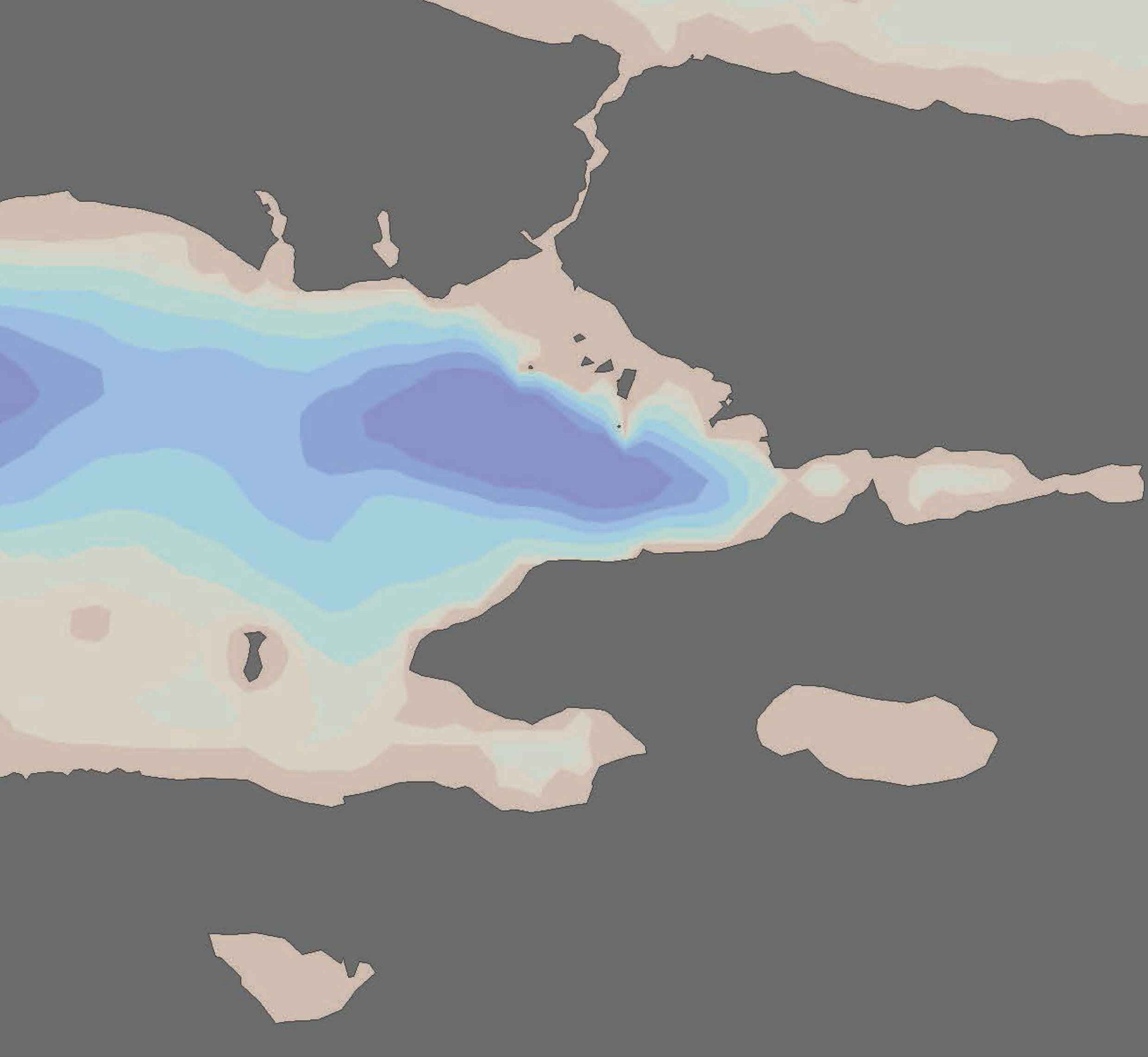

# THE SEA OF MARMARA

## MARINE BIODIVERSITY, FISHERIES, CONSERVATION AND GOVERNANCE

EDITORS: Emin ÖZSOY, M. Namık ÇAĞATAY, Neslihan BALKIS, Nuray BALKIS, Bayram ÖZTÜRK

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**Edited by**

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M. Namık ÇAĞATAY- Istanbul Technical University
Neslihan BALKIS – Istanbul University
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## PREFACE

This book aims to compile the studies on the Sea of Marmara in terms of biodiversity, fisheries, pollution, conservation and governance. Needless to say, it shows how importance the Marmara Sea is, not only for Turkish people but also for our neighbors. Besides, simply, the Sea of Marmara is a bedroom for Turks which needs protection.

The Sea of Marmara, together with the Istanbul Strait (Bosphorus) and Çanakkale Strait (Dardanelles), is called the Turkish Straits System and it forms a transtion region between the Black Sea and the Aegean Sea. One of the distinguishing features of the Sea of Marmara is that permanent oxygen deficiency exists below the halocline. Such peculiarities of the Sea of Marmara are very important in many ways such as biogeography of the species, fish migration, pollution load and governance etc.

Biodiversity, fisheries, conservation and governance of the Sea of Marmara, which is a part of the sea series of Turkish Marine Reseaerch Foundation (TUDAV), reflects some current topics covered in 70 articles of 5 chapters by 95 authors from 29 various institutions and universities. I'm so happy to see sincere contribution and cooperation of all scientists for this volume.

The publication of this book was decided by the editors at the begining of 2016 and the book has been completed in one year. I hereby thank all of the authors and editors for their full support and valuable contribution to this book as well as Ms. Tuğçe Gül for her techincal assistance.

Finally, we beleive that this work is unique in many ways due to its content based on wide range of information and original outputs of many surveys in the Sea of Marmara. We are pleased to present this publication to our scientific community, fishermen, decision makers and all stakeholders who are interested in saving the Sea of Marmara for future generations in a more sustainable way.

Prof. Bayram ÖZTÜRK
The Turkish Marine Research Foundation

December 2016

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**INTRODUCTION TO GEOGRAPHICAL, HISTORICAL AND SCIENTIFIC IMPORTANCE OF THE TURKISH STRAITS SYSTEM**

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## 1. Geography

We refer to the region extending from the Aegean Sea to the Black Sea as the "Turkish Straits System" (TSS). The TSS is unique in its geographical features, connecting two large marine basins and medium sized inter-continental water body of the Marmara Sea by means of the Dardanelles and Bosphorus Straits, which are among the few narrowest and longest straits in the European-Mediterranean region (Figure 1).


**Figure 1.** Narrow straits in Europe. Of the 12 narrowest sea straits in Europe, the Turkish Straits System (#12) is one of the most unique physical / ecological characteristics, and a historical role with great socio-economic implications.

The TSS (Figure 2) covers the Sea of Marmara (surface area 11,500 km2), the Dardanelles Strait (length 75 km, min. width 1.3 km) and the Bosphorus Strait (length 35 km, min. width 0.7 km). The Marmara Sea is a deep basin adjoining continental shelves. The deeper part has three elongated depressions (max. depth 1350 m) separated by sills (depth ~600 m).


**Figure 2.** Geography of the Turkish Straits System

**Figure 3.** An old geographical map of the TSS issued by the Turkish Republic after ending the Ottoman rule and before the acceptance of the modern Turkish scripture. (1927, TBMM Kütüphanesi Açık Erişim Koleksiyonu http://acikerisim.tbmm.gov.tr:8080/xmlui/handle/11543/2012).

The TSS, a natural wonder and a lively marine habitat of the old world, has seen many ages of human influence and civilizations since the beginning of history serving as a main passageway between the continents of Europe and Asia / Africa, and between Mediterranean and Black Seas and their hinterlands. It has seen development of great cultures as well as conflicts, and continued to serve as a sea of intense natural, cultural and economic activity since the last century (Figures 3 and 4), though what is now threatening the TSS are the risks of unprecedented environmental degradation, navigation accidents, pollution and earthquakes unless we can protect it from further damage.


**Figure 4.** An old geographical map of the Bosphorus issued by the Turkish Republic after ending the Ottoman rule and before the acceptance of the modern Turkish scripture. (TBMM Kütüphanesi Açık Erişim Koleksiyonu http://acikerisim. tbmm.gov.tr:8080/xmlui/handle/11543/1200).

The most critical element of the TSS controlling the exchanges between the Black Sea and the Mediterranean is the Bosphorus, because of the narrow geometry of the Strait and its topographical features establishing the first order physical constraints. The

Bosphorus of course is also the most beautiful and naturally exquisite part of the whole domain attracting the admiration of humanity, subject of the historical attraction of Venice which modeled itself after İstanbul, a part of the natural and cultural heritage and one that is also most fragile, increasingly in need of urgent environmental protection that arise from uncontrolled population growth, industrial and socio-economic pressures. The TSS also has been the center of historical conflicts in the past, presently secured and protected from international political pressures by the Montreaux Convention of 1936 that established navigation rules and rights of passage in a peaceful and just way.

The Dardanelles and Bosphorus Straits are shallow waterways having complex topography. The Dardanelles (Figure 5a) extends from the Aegean Sea to the Marmara Sea, with two strong right angle turns at the narrows of the Nara Pass (26º 22.5' E). A deep channel of 75 m depth runs through the Strait and later turns east (26º 45' E) along the southern part of the widening strait where it joins the western depression of Marmara Sea.

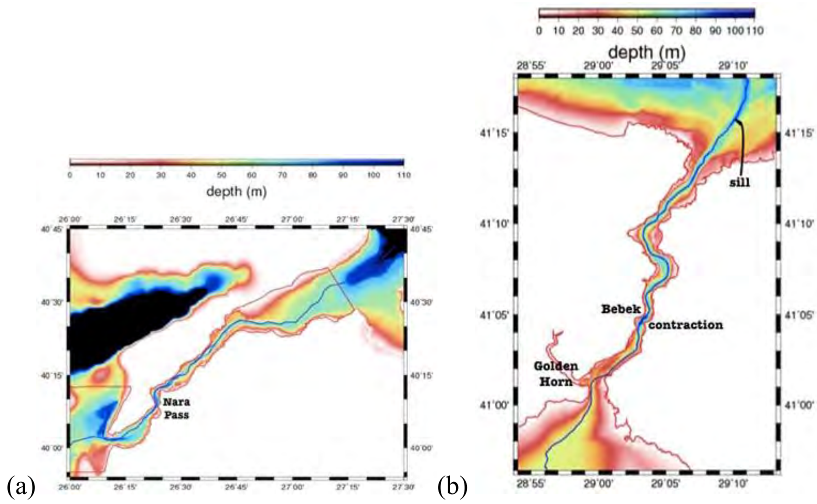


**Figure 5.** Location and bottom topography maps for the (a) Turkish Straits System (TSS) including the (b) Dardanelles and (c) Bosphorus Straits. The blue line denotes the thalweg along the strait channels.

The Bosphorus (Figure 5b) starts from the Marmara Sea with a deep channel rising north and past the junction with the Golden Horn estuary (41º 01.5' N) where it meets with the complex southern sill of 30 m depth flanked by deeper channels of 40 m on its two sides (41º 02' N). The deep channel then meets the contraction (41º 04.5' N) at the deepest (110 m) and narrowest section of the Strait, coinciding with right angle turns of the channel. From here towards north, the channel first has a straight section, then swings first to the northeast, then to the northwest and once more to the northeast, past a few shallow banks and headlands before the exit to the Black Sea, where the thalweg depth is

75m. A shallow cut canyon then extends northeast from the Strait, and later swings to the northwest across the Black Sea shelf. Shortly after exit into the Black Sea, a shallow area elevated to 60 m depth inside the canyon (41º 16' N) constitutes the northern sill of the Bosphorus.

The TSS has its own local dynamics, becomes influenced by the adjacent seas, and also regulates what happens in the adjacent seas, by controlling the currents passing through it in both directions.

## 2. Recognition of the TSS in the 'Old World'

The key geographical role of the TSS at the confluence of the European, Asian, African continent, has attracted the first civilizations, especially the seafaring ones living on the coasts of the 'Old World'. Trade along the ancient 'Silk Road' and across the sea linked civilizations of three continents and two seas converging upon the essential meeting point of the Turkish Straits. The historical venue of İstanbul (Constantinopolis) served civilizations and east-west transfers of knowledge and cultures throughout history, and especially during the Eastern Roman (Byzantian) and Ottoman Empires, which in total lasted for about two millennia, till the beginning of the 20th century. The cultural tradition, knowledge, resources and material wealth of the east was on high demand of the west throughout the middle ages, motivating the Crusades in the 11th to 13th centuries and notably Marco Polo in the 13th century. The conquest of İstanbul in mid 15th century had a major impact on the west, starting the search for alternative sea routes that would re-connect with the Silk Road. Instead, Christopher Columbus landed on America, taking advantage of a good knowledge on winds and currents in his travels within the Mediterranean. The search for the control of trade routes motivated the development of naval powers and eventually the scientific discoveries that followed up.

From the 15th century onwards, isolario (island books) became common, reciting geographical maps, pictures, stories about Mediterranean locations based on travelers' accounts (Harley and Woodward, 1987). To a great extent based on the much earlier stories of Anaplous Bosporou of Dionysios of Byzantion (5th century AD), the isolario of Gilles (1561) gives an account of the Bosphorus.

One of the fine details about Bosphorus currents noted by Polybios (203-120 BC) and Pliny the elder (23-79 AD) and also re-discovered by Gilles (1561) was the interception the surface currents by the protrusion of Seraglio Point (Byzantium) which then diverted the currents towards the Golden Horn (Keras), forming a local recirculation cell southward of Beşiktaş filling the Golden Horn, which is well-known today. The entrapment of bonito schools coming from the Black Sea and very easily fished in this small estuary for millennia gave support to the strong local seafood economy and exports of dried salted fish and fish sauce, historically known to be a major source of income for

İstanbul since ancient times (Bekker-Nielsen 2005; Bursa 2010; Tekin 2010; Thompson 2010).

The recirculating currents could lead the fish into the Golden Horn in the past when there was no obstruction at its mouth. The construction of Galata Bridge in 1875, resting on pontoons preventing free circulation of the surface waters and heavy pollution in the 20th century had barred fish from entering the Golden Horn until the recent environmental recovery programs starting in the late 1980's that brought additional flushing of the estuary by pumping water into it and also the final replacement of the old bridge in 1994. In addition to the recirculating currents south of Beşiktaş, Gilles (1561) has noticed other areas of recirculating currents in the many bends and turns of the Bosphorus, referring to them with their historical names. These recirculating currents are well known today, and demonstrated by our measurement programs, near Çengelköy, Bebek Akıntıburnu, Yeniköy, Çubuklu, Beykoz, Umuryeri and Büyükdere. Ships challenging the mainstream currents are often caught up in these zones of rapid change in currents at the various bends and narrows, resulting in the many ship accidents that occur in the strait. In addition to the recirculations and eddies, the transient reversal in direction of the surface currents known as "Orkoz" during southwesterly winds ("lodos") of approaching storms increases pollution and creates havoc in the Bosphorus.

The seasonal spawning migrations of some fish between the Black and the Mediterranean Seas are adapted to the fast currents and stratified waters of the Bosphorus. Until the later part of the last century, the fish were so plentiful that ancient methods of fishing were efficiently used on the shores of the Bosphorus. For instance, simple nets lowered from the elevated wooden 'dalyan' structures, often inhabited by entire fishing families, described in Anaplous Bosporou of Dionysios, and 'ığrıp' nets encircling fish schools and hauled by people at the coast were quite sufficient to catch plenty of fish at any time (Ertan 2010).

Gilles (1561) also noted the reversal of currents with depth in the Bosphorus. The drift towards the Black Sea of fishing nets submerged in the deeper waters of the Bosphorus was already well-known by fishermen and recorded much earlier by Procopius in the 6th century (Gill 1982; Deacon 1982; Korfmann and Neumann 1993), until the 17th century when significant advances were made by Marsili (1681) in understanding of the essential physics.

### 3. First in ocean science: Ferdinando Luigi Marsili (1658-1730)

During 1679-1680 Luigi Ferdinando Marsili (1658-1730), made the first quantitative measurements of sea-water density en route to İstanbul from Venice, followed up by other measurements in the Bosphorus during his residence in İstanbul. These measurements, interpreted with the help of a laboratory 'fluid dynamics' experiment he performed later in Rome, proved the existence of a counter-current transporting Mediterranean water below the surface current of Black Sea water (Marsili, 1681). Marsili's inquiry identified the hydrostatic pressure difference, proportional to water densities of the adjacent seas, as the main agent driving the strait exchange flows. The experimental verification of a theory by Marsili, following the "scientific method" of Galileo, in fact was the start of ocean science in the waters of the Bosphorus (Defant 1961; Soffientino and Pilson 2005; Pinardi 2009; Pinardi *et al.* 2016).

## 4. Early developments in the last century

Further exploration in the region in the late 19th and early 20th centuries (Makarov 1885; Shpindler 1896; Nielsen 1912; Möller 1928) led to further understanding of the regional seas and the role of Turkish Straits System within the marine environment. The exchange flow of counter-currents in the upper and lower layers of the Bosphorus Strait explained for the first time by Marsili have since been verified by instrumental measurements, first carried out in 1918 and 1921 and reported by Merz, and Möller (1928), Möller (1928) and interpreted by Defant (1961) in his pivotal book on physical oceanography.

Local development of marine science that would create first interests on marine science in Turkey had to wait until the 1930's till after the founding of the Turkish Republic in 1923 by the Anatolian Revolution that ended the Ottoman rule. During the earlier period of 1940-1970 however, there were not enough qualified scientists. Ulyott and Ilgaz (1944) and Pektaş (1953, 1956) carried out few measurements in the Bosphorus, with the limited means available to them at the time, facing the task to rediscover and demonstrate what was already known about the exchange flows. However, these measurements were quite insufficient to create a healthy physical understanding of the Bosphorus flows.

Because of the lack of evidence that needed to rest on observations, it was vainly discussed whether there was an underflow in the Bosphorus, and if it existed, whether or not it reached the Black Sea. In fact, it is surprising that even the earlier measurements of Merz, and Möller (1928), Möller (1928) did not seem to improve this understanding and the controversy about the existence of an undercurrent continued till the later part of the 20th century. The basic facts about the exchange flows of the Bosphorus exchange flows established by Alfred Merz and three centuries earlier by Marsili (1681) were still questioned at this time because new observations could not be made with the required accuracy and detailed coverage.

## 5. The present state of TSS research

By the 1980's technically gifted people such as engineers made new studies approaching the problems of the TSS. However, as experts in hydrodynamics, Çeçen *et al.* (1981) and Bayazıt and Sümer (1982) made new studies including mathematical formulations that acknowledged but failed to detect the outflow of the Mediterranean water into the Black Sea, because there was insufficient knowledge of the narrow canyon and northern sill topography leading into the Black Sea and insufficient sampling to locate its position. It was therefore argued whether the lower layer flow was continuous or perhaps intercepted during some time.

Modern oceanographic research unfortunately had yet to wait until the 1980s, when an active scientific research agenda and research programs including extensive measurement campaigns in the Turkish seas were created for the first time, both at national level and through international scientific collaboration. The first studies were performed by the only group of physical oceanographers at the Institute of Marine Sciences of the Middle East Technical University, established at the end of the 1970's. International scientific research programs such as the Physical Oceanography of the Eastern Mediterranean (POEM) program, followed later by a similar series of programs such as CoMSBlack and NATO programs in the Black Sea immensely elevated the level of scientific understanding of the regional seas.

During this new period, the first studies by Gunnerson and Özturgut (1974), Tolmazin (1985), Latif *et al.* (1991) and Yüce *et al.* (1996) have revealed further facts both about the functioning of the Bosphorus and about the exit conditions, to permanently settle the question of the outflow of the "Mediterranean Effluent" to the Black Sea.

The knowledge base on the Turkish Straits System existing at the time was extensively reviewed by Ünlüata *et al.* (1990) who also presented results of the first studies, including an assessment of fluxes through the TSS. Continued surveys with plenty of observations by oceanographers in the last decades including better and more accurate measurements and synergetic interpretation of results once again revealed fine details of the flow and the underlying physics (e.g. Ünlüata *et al.* 1990; Gregg *et al.* 1999; Özsoy *et al.* 2001; Gregg and Özsoy 2002; Tutsak 2012).

Short reviews on the TSS and its role in coupling two larger Seas have been provided by Beşiktepe *et al.* (1993, 1994, 2000) and Schroeder *et al.* (2012), while other details such as its influence on the Black Sea and the Mediterranean Sea can be found in reviews by Özsoy and Ünlüata (1997, 1998) and Jordà *et al.* (2016). Particular information based on experimental studies of the Bosphorus Strait and its exit regions can be found in the works by Ünlüata *et al.* (1990), Latif *et al.* (1991), Özsoy *et al.* (1995, 1996, 1998, 2001), Gregg *et al.* (1999), Gregg and Özsoy (1999, 2002), and the more recent works by Jarosz *et al.* (2011a,b, 2012, 2013), Book *et al.* (2014) and Dorrell *et al.* (2016). Measurements in the Bosphorus and Dardanelles Straits and their exit regions have revealed rapid currents and hydraulic controls with high shear and turbulence zones involving many different time-scales of motion in the TSS, ranging from inertial, semi-diurnal, diurnal to several day periods influenced by the adjacent basins.

The northern sill outside the Bosphorus standing at 60m depth in the canyon cutting across the Black Sea shelf, as well as the contraction in the southern Bosphorus are understood to be the main geometrical constrictions in the path of the flow where hydraulic controls are expected (Latif *et al.* 1990, Dorrell *et al.* 2016) and verified by model results (Sözer 2013; Sözer and Özsoy 2016) to be responsible in establishing a maximal exchange regime as predicted by Farmer and Armi (1986). A single contraction at the Nara Pass subjects the flow in the Dardanelles Strait to sub-maximal hydraulic control (Latif *et al.* 1990; Ünlüata *et al.* 1990).

## 6. The road forward

As indicated by the above review on the state of matters regarding the TSS, it is very evident to scientists that great new efforts are needed to fully understand the very complex nature of the TSS, both from the physical, ecological and socio-economics points of view. Despite recent scientific developments we are still at the beginning, and our pace may still be too slow in countering or preventing the environmental damage to this precious system that is a heritage of all humanity.

Today, the old world centered on the Mediterranean and Black Seas region is the common heritage of all peoples living around the Seas of the Old World. The shared civilization and culture of the Mediterranean (e.g. Braudel 1996) are integral parts of today’s world, as it has been for the ancient world. Therefore, it is necessary to assimilate all that is brought to us from previous civilizations, preserve the environment and to extend knowledge across the region whether it originates from the east or the west in order to peacefully share and protect this unique habitat, while advancing the science that would hopefully ensure the survival of the heritage. Oceanography, a modern science often claimed to have developed after the world wars, but now understood to have had precursors of development since the middle ages, not always given recognition in those times, but since then have promised to be a pillar of civilization in the modern world.

As we have touched upon some features of the high energy environment of the Turkish Straits, a unique passage that connects and regulates contrasting ecosystems both on land and at sea, it is essential that we poise to think to do what science would dictate on the projected ‘Canal İstanbul’ craze that potentially endangers these precious ecosystems, in direct contrast with international agreements such as the Montreaux, Barcelona and Bucharest Conventions. Such drastic intervention would threaten the environment that supports liveliness of the millions of people living on the already over-populated coasts and emerging mega-cities in the region. Danger of imminent collapse of the ecosystems, which already has greatly deteriorated in the last century and already defying a healthy understanding of their survival in the present age of anthropogenic climate change, can only be stopped by conscientious efforts based on scientific research results.

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# A REVIEW OF HYDROGRAPHY OF THE TURKISH STRAITS SYSTEM

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## 1. Introduction

We base this review of the hydrography of the Turkish Straits System (TSS) on the CTD and ADCP data obtained on various cruises performed from 1985 till the present, combining the data from the research vessels R/V BİLİM of the Institute of Marine Sciences (IMS-METU) and R/V ARAR and lately R/V ALEMDAR 2 of the Institute of Marine Sciences and Management (IMSM-IU).

## 2. Data sources

Consistent observational data sets covering the TSS have been collected with the R/V BİLİM of the IMS-METU during 1985-2001 and sporadically in many other scientific cruises since then. The set of TSS measurements carried out before 1990 were obtained from a national Marine Monitoring Program. The later extensive measurement campaign carried out for Municipality of İstanbul Water and Sewerage Administration (İSKİ) during the early 1990's aimed to determine the environmental fate of the marine waste discharges of the city of İstanbul.

Detailed mapping of the Bosphorus currents and hydrography was later undertaken by the IMS-METU for the TURBO administration in the years 1998-1999, when detailed ADCP and CTD measurements were extended to small bays and bends using a small diving boat Atmaca II as well as the R/V BİLİM. Although measurement campaigns were less frequent during the 2000's, further measurements have been acquired from ships and automated coastal meteorology, sea level and ADCP stations operated under the coastal network established in the MOMA project (Özsoy *et al.* 2009). Additional measurements were obtained during the 2007-2008 campaigns of the SESAME European project in an unprecedented multi-national collaborative sampling program covering the Mediterranean and Black Seas in addition to the TSS.

Based on measurements by the R/V ARAR, the IMSM-IU has carried out a monthly water quality monitoring program for İSKİ between 1996-2010, aiming guide the ISKI Wastewater Master Plan studying the marine environmental effects of the wastewater treatment and marine outfall facilities discharging into the TSS. In the monitoring program, monthly CTD profiles and ADCP transects were obtained at the north and south exits of the Bosphorus and at a total of 28 stations (Figure 1a). Additional measurements were obtained at Golden Horn stations (Figure 1b).

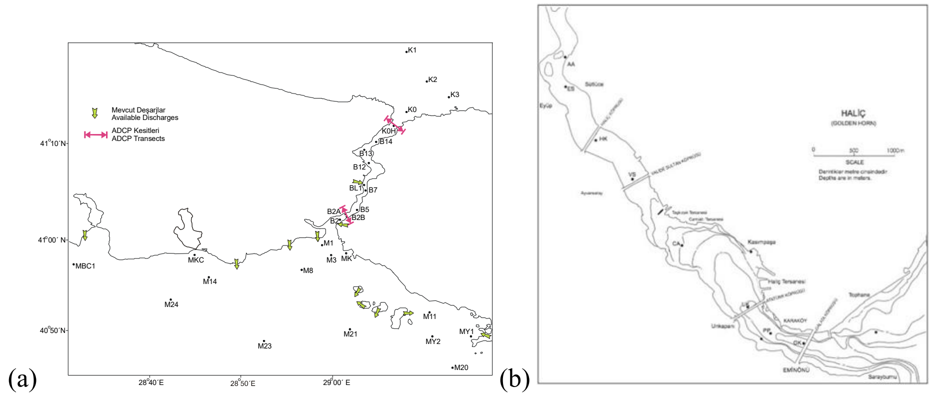



**Figure 1.** Station locations of the monitoring program (a) Bosphorus and exit regions (CTD stations are shown by dots and ADCP transects are marked by the double-sided arrows, while locations of sewage discharges are indicated by arrows), (b) Golden Horn topography and CTD stations.

## 3. Hydrographic Variability of the TSS

### 3.1. Variation across the TSS

Selected transects showing variations of temperature and salinity across the TSS in Figures 2 and 3 are used to exemplify the evolution of water properties along the main axis of the system in different seasons. The largest slopes of the interface separating the upper and lower layers, carrying waters typical of the Black Sea and Mediterranean Sea, occur in the two straits. On the other hand, the variation of the interface is much less inside the Marmara Sea and most often it is observed to have relatively constant depth of about 25m in the Sea of Marmara. Figure 2 illustrates extreme cases of winter cooling with uniform cold upper layer. The relatively calmer case of temperature and salinity sections across the TSS in Figures 2a,c,e represents conditions after strong cooling in March 1990, though indicating a relative steady state situation. The waters in the Black Sea end of the TSS are exceptionally uniform till the bottom, with temperature of about 6ºC and salinity of about 17. While the two-layer exchange through the Bosphorus with small amount of mixing and a sloping interface, the subsequent mixing and circulation in the Marmara Sea are responsible for the horizontal variation of properties until values about 10ºC in temperature and 25 in salinity are reached until the Dardanelles Strait. Once again the interface slopes up in the Dardanelles Strait with a transition to shallow depth at the Nara Pass, with the upper layer water exiting to the Aegean Sea with warmer and saltier conditions due to eventual mixing. The lower layer Mediterranean water entering from the Dardanelles with temperature of about 13ºC and salinity of about 39 evolves more gradually along the entire basin. It is also observed in this winter case that the cold and saline waters entering from the Aegean Sea sink towards the lower depths in the Marmara Sea after passing through the Dardanelles Strait, against an interior background of 14.5ºC temperature and 38.5 salinity in the intermediate depths.

An extreme case in February 1993 is illustrated in Figure 2b,d,f, where very cold waters of 5ºC temperature and 17 salinity entering from the Black Sea have pushed into the Bosphorus, blocking the lower layer and pushing it till the southern entrance of the Strait. The upper layer water from the Black Sea floods the Marmara Sea and preserves its temperature of 5ºC until the Nara Pass of the Dardanelles Strait, while the salinity rises until reaching a value of 30 at the same location by entrainment of lower layer waters. The undisturbed temperature of the upper layer surviving through the Bosphorus and the Marmara Sea despite a lot of mixing and entrainment from the lower layer waters demonstrates the extreme atmospheric cooling during the winter conditions of this case. The reserve of this cold water partially survives through the spring and summer months when a residual cold layer remains below the surface waters influenced by warming.

What is even more outstanding in this case is the wild variations in interface depth in the Marmara Sea, indicating transient dynamical situation of internal sloshing as well as what must have been a very strong transient circulation in the Marmara Sea. In the lower layer, a similar situation to the former case is observed, with the cold waters of about 12ºC temperature and 39 salinity entering from the Aegean Sea and passing through the Dardanelles sink to greater depths in the Marmara Sea observed in contrast to the interior waters. The outflow of the lower layer waters into the Bosphorus and therefore to the Black Sea is totally blocked at this instance.

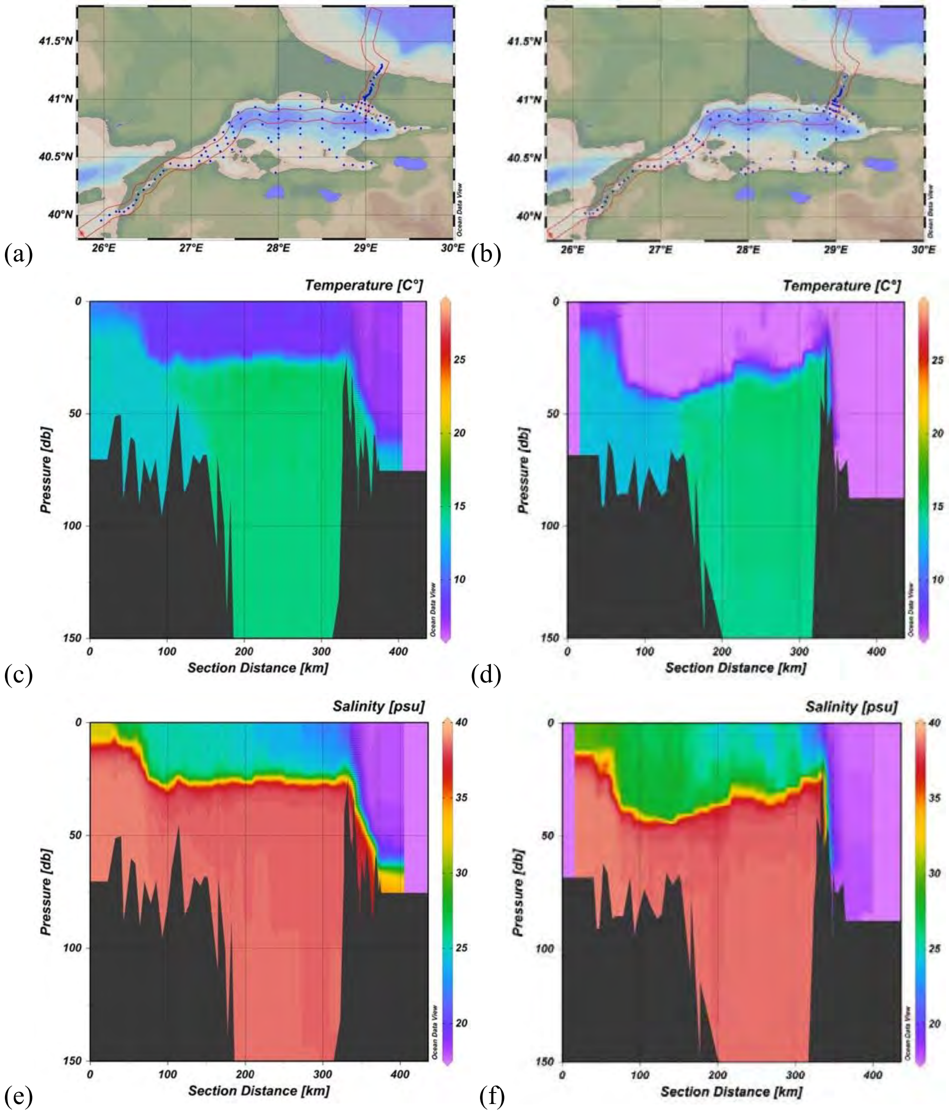



**Figure 2.** Stations occupied along the main transect of the TSS in (a) March 1990, (b) February 1993, (c,e) temperature and salinity sections in March 1990, (d,f) temperature and salinity sections in February 1993. The transect follows the main axis of the TSS extending from the Aegean Sea to the Black Sea along the Dardanelles Strait at 0-130 km, Marmara Sea at 130-330 km and the Bosphorus Strait at 330-370 km ranges.

The summer and autumn situations are shown in Figure 3. In the first case of August 1987 in Figures 3a,c,e, the Cold Intermediate Water (CIW) of the Black Sea defined with core temperatures of less than 8°C, and in this case with a core as cold as

5°C in temperature invades the Bosphorus and later continues as a submerged tongue transiting across the Marmara Sea, surviving until the Nara Pass (Figure 3c). As demonstrated in the former winter sections of Figure 2, it is believed that local cooling in the Marmara Sea contributes to the cold-water above and at about the pycnocline depth, largely maintained later in the deeper part of the upper layer by remnants of local winter cooling while the near surface waters are re-stratified by surface warming. The upper layer salinity in Figure 3d increases steadily from the Black Sea to the Aegean, with the highest rate in the southern part of the Bosphorus, and western part of the Dardanelles due to hydraulic adjustments. In this case, Aegean lower layer water of 17°C temperature entering from the Dardanelles Strait is warmer than the 15°C water at the same level in the Marmara Sea interior, but because of its higher salinity it is still denser, so that the inflow sinks down as a gravity current. The winter events of dense water sinking have also been shown by earlier observations (Beşiktepe *et al.* 1993, 1994) and modeling (Hüsrevoğlu 1999).

In the autumn case of November 1997 in Figures 3b,d,f, there is hardly any temperature differences between the upper and lower layers of the TSS exchange flows, and the trace of the CIL in the Black Sea below a mixed layer extending to 50 m depth does not seem to be able to penetrate into the Bosphorus or the TSS. Any remnants of the cold-water tongue in summer seem to have been totally mixed. However, the salinity difference between the upper and lower layers are still sufficiently large to determine a two-layer exchange. During these calm conditions of summer and autumn the upper layer salinity in the Marmara Sea is at the level of about 22-24. It is also now observed that the warm and saline waters entering from the Dardanelles are not sufficiently dense to sink to greater depth; instead the entering waters disperse as a subsurface tongue of low density to spread between the upper and lower layers of the interior stratification as shown in Figures 3d,f.

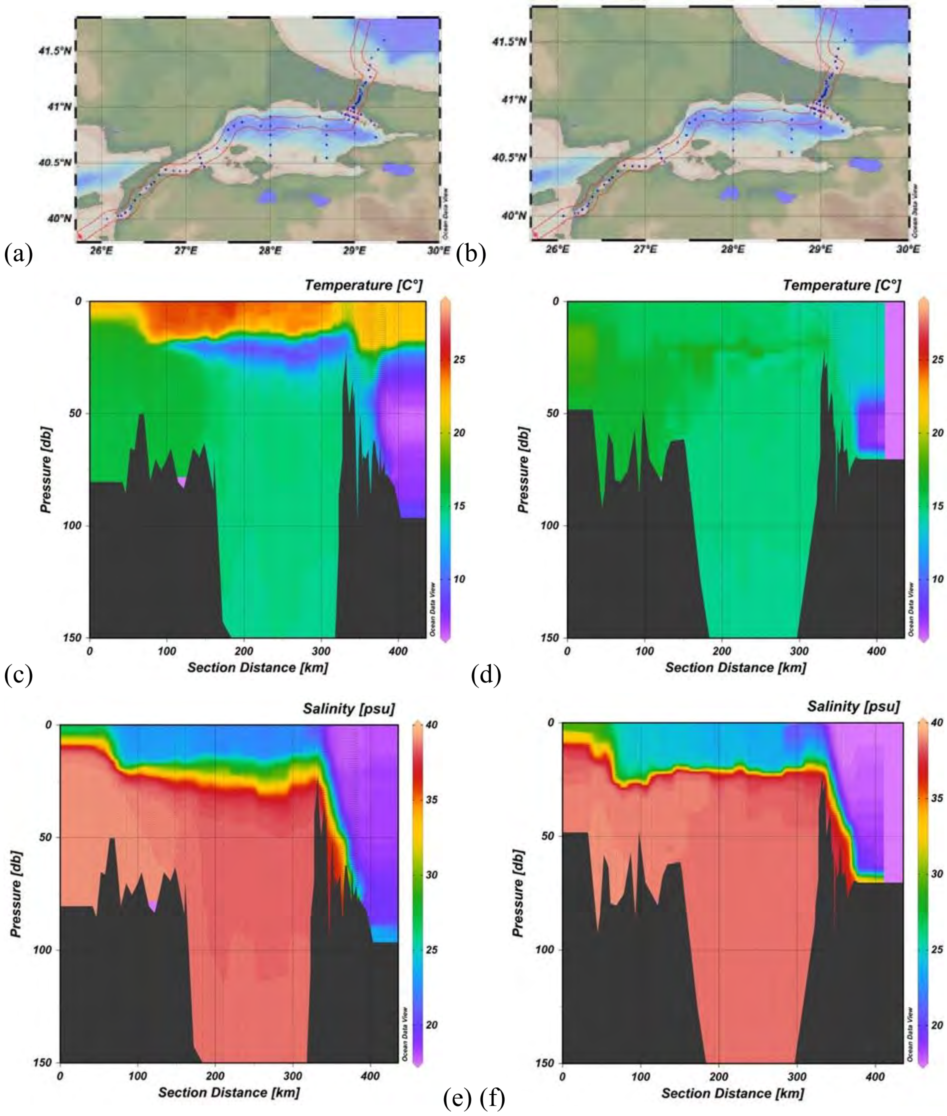



**Figure 3.** Stations occupied along the main transect of the TSS in (a) August 1987, (b) November 1996, (c,e) temperature and salinity sections in August 1987, (d,f) temperature and salinity sections in November 1996. The transect follows the main axis of the TSS extending from the Aegean Sea to the Black Sea along the Dardanelles Strait at 0-130 km, Marmara Sea at 130-330 km and the Bosphorus Strait at 330-370 km ranges.

### 3.2. Bosphorus and Dardanelles Straits

The first scientific study of the Bosphorus Strait by Marsili (1681) in the 17th century established the counter-current of Mediterranean water below the surface flow of Black Sea water (Defant 1961; Soffientino and Pilson 2005; Pinardi 2009; Pinardi *et al.* 2016), although this fact was first revealed to Marsili by local fishermen, also referred to in the sixth century note of Procopius of Ceasarea (Gill 1982; Deacon 1982; Neumann 1993) and by Gylii (1561) based on *Anaplous Bosporou* by Byzantios (Gungerich 1958) as early as 5th century AD, but still until recently debated. Early exploration up to the early 20th century (Makarov 1885; Shpindler 1896; Nielsen 1912; Möller 1928) established further understanding of the TSS.

Tidal oscillations are exceptionally small, on the order of ~10 cm in the TSS, especially east of the Nara Pass of Dardanelles. Basin oscillations with periods of 2-5 h have been observed in sea level records (Alpar and Yüce 1998). Coupled Helmholtz mode oscillations of the Black Sea and the TSS (e.g. Ducet *et al.* 1999) with 14.7 d and 1.9 d periods and a two-layer exchange adjustment time scale of 42 d have been estimated (Özsoy *et al.* 1998). Current-meters and both ship-mounted and bottom mounted ADCP measurements in the Bosphorus (Pektaş 1953; De Filippi *et al.* 1986; Gregg *et al.* 1999; Çetin 1999; IMS-METU 1999; Özsoy *et al.* 1998, 2009, 1999; Gregg and Özsoy 2002; Yüksel *et al.* 2008; Güler *et al.* 2006; SHOD 2009; Jarosz *et al.* 2011a,b) and Dardanelles (Jarosz *et al.* 2012) have revealed many different time-scales of oscillations in the TSS, ranging from inertial, semi-diurnal, diurnal to several days periods influenced by the adjacent basins (Yüce 1993; IMS-METU 1999).

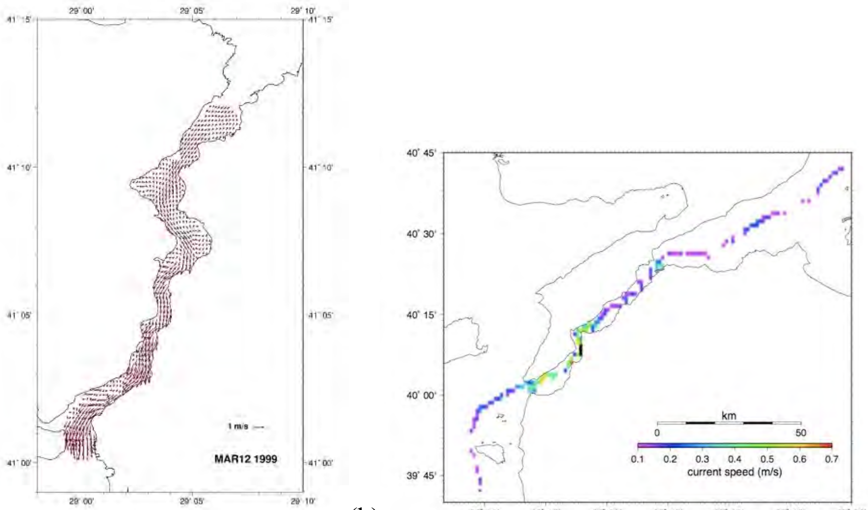
A sill standing at 60m depth on the canyon cutting across the Black Sea shelf and a contraction in the southern Bosphorus (Latif *et al.* 1991) are the expected locations of two hydraulic controls, establishing the unique maximal exchange regime of Farmer and Armi (1986), while a single contraction at the Nara pass subjects the Dardanelles Strait to submaximal hydraulic control (Latif *et al.* 1991; Ünlüata *et al.* 1990). The exchange flows in both straits have many small-scale features linked to turbulence, interfacial instabilities, hydraulic transitions and downstream “jumps” revealed by high-resolution measurements (Özsoy *et al.* 2001; Gregg and Özsoy 2002).

The northern and southern sills control the lower and upper layer flows causing maximal exchange and are occasionally impacted by extreme hydrological events (Oğuz *et al.* 1990). On the other hand, Gregg *et al.* (1999) claim that the hydraulic control is quasi-steady. Additionally, Gregg and Özsoy (2002) have revealed that the exchange is also partially controlled by friction. In the Bosphorus, it is well known that the strong northerly winds occasionally cause the lower layer blockage during the high sea levels in the Black Sea, whereas the strong southerly winds cause the upper layer blockage (so-called Orkoz) during the low sea levels in the region (Alpar and Yüce, 1998; Alpar *et al.* 1999; Latif *et al.* 1991; Özsoy *et al.* 1986).

The surface currents often exceed 1 m/s past the contraction in the southern Bosphorus (Figure 4a) and reach 2-3 m/s at the southern exit. Similarly, surface currents of about 1 m/s occur past the narrows (Nara Pass) of the Dardanelles Strait (Figure 4b). The flows along along the straits create meandering streams and recirculation zones, for instance at the S-shaped area of bends in the northern part (Büyükdere and Beykoz bays) and north of the Golden Horn Estuary (Beşiktaş) in the southern part (Figures 4a,b), evident in current-meter and ship-mounted ADCP measurements (IMS-METU 1999; Özsoy *et al.* 2002), but also in model simulations. The last one of these recirculation cells at Beşiktaş, described by Marsili (1681) and Möller (1928), was recognized earlier in *Anaplous Bosporou* of Byzantios (5$^{th}$ century AD) and recorded by Gyllii (1561), who attributed it to the interception of the flow by the protruding Sarayburnu (Byzantion Pt.). The eddy diverted schools of Pelamydes (palamut, bonito) into the Keras (Golden Horn) estuary, caught to benefit the fish trade from ancient until recent times (Bursa 2010; Tekin 2010).

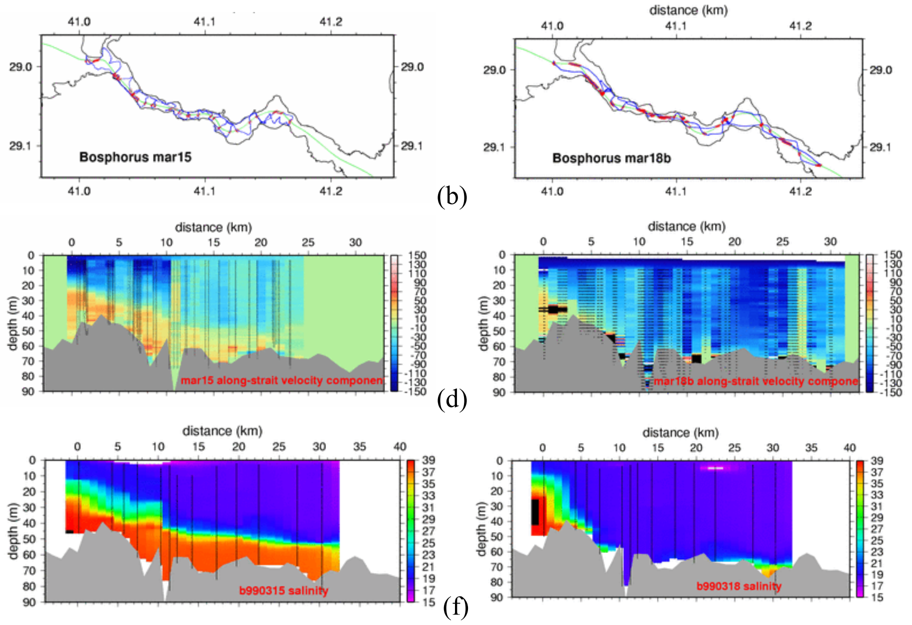
Short-term blocking of the flows in either layer is a well-known phenomenon in the Bosphorus (Ünlüata *et al.* 1990; Latif *et al.* 1991; Özsoy *et al.* 1995, 1996, 1998, 2001; Özsoy and Ünlüata 1997, 1998; Jarosz *et al.* 2011a,b) in response to transient events in the adjacent basins. Oğuz *et al.* (1990) contended that a sea-level difference of more than 50 cm and less than 10 cm would be needed, respectively for the upper or the upper layers to be blocked, although barometric pressure, winds and net water fluxes of adjacent basins are indicated as dynamical forces creating blocking conditions (Özsoy *et al.* 1998, Gregg and Özsoy 1999).

The lower layer is occasionally blocked in spring and summer, with increased Black Sea influx, mostly under the effect of northerly winds. Chosen as examples from the many similar sets of measurements, the March 15, 1999 the ADCP current and salinity vertical sections in Figure 5 (left) indicate exchange flows across the Bosphorus, with currents of about 0.5 m/s in either layer, the upper layer currents increasing to about 1.5 m/s past the contraction region, where the halocline also becomes thicker. The lower layer was completely blocked on March 18 (Figure 5, right) after northerly winds, creating southerly currents of 1 m/s almost completely flushing out the Mediterranean water, replaced by Black Sea water. Upper layer blocking events (‘Orkoz’) coincide with the reversal of the net flow in response to southerly winds (‘Lodos’) in the fall and winter (Gunnerson and Özturgut 1974; Ünlüata *et al.* 1990; Latif *et al.* 1991), often causing a three-layer situation with the Marmara waters backed up into the strait.




(a) (b)

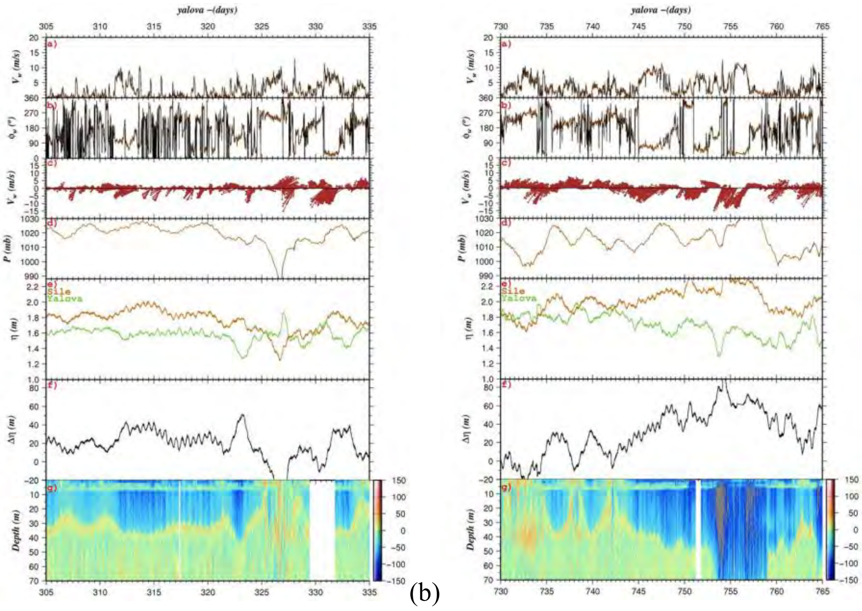
**Figure 4.** Surface currents based on (a) ADCP measurements on March 12, 1999 (interpolated to grid) and (b) ADCP current magnitude on March 22, 1999 in the Dardanelles (IMS-METU 1999).




(a) (b) (c) (d) (e) (f)

**Figure 5.** ADCP current and CTD measurements along the Bosphorus on March 15 (left) and March 18 (right), 1999, top: details of the channel crossing routes followed by the ship (blue), the thalweg (green) and stations where ADCP vector current data are projected and rotated along the thalweg (red), middle: ADCP current velocity aligned along the thalweg (cm/s), bottom: salinity at CTD stations projected along the thalweg.

Time series of the bottom-mounted ADCP currents at Baltalimanı, sea level, wind velocity and barometric pressure at stations in adjacent seas are presented in Figure 6 for selected monthly periods, to illustrate typical variations in the Bosphorus currents as a function of environmental conditions. During the initial part of the record in Figure 6a, rather steady currents of 0.5-1.0 m/s are observed in the upper 30m under calm weather conditions. The sudden drop of barometric pressure (30 mb in about 30 h) of an atmospheric disturbance creates temporary reversals in flow direction and subsequent oscillations. The oscillatory and mixing effects created by this particular storm have been likened to a ‘meteorological bomb’ (Book *et al.* 2014), based on an extensive set of measurements by Jarosz *et al.* (2011a,b, 2012, 2013). Interestingly, during the event, the sea level rises in the Marmara Sea and falls in the Black Sea in response to the southwesterly winds of the storm, resulting in a negative sea-level difference of about 40 cm, with the Marmara Sea being higher than the Black Sea, as opposed to the positive difference of about 10-50 cm earlier. Sustained northerly winds in January 2010 (Figure 6b), following an initial period of reversals in the first days, result in the sea level difference building up to about 1m, with currents of up to 2 m/s covering the entire depth, leading to blocking of the lower layer currents.



(a) (b)

**Figure 6.** Monthly time series of wind, pressure, sea-level and ADCP currents in (a) November 2008 and (b) January 2010. In each panel, the wind speed and direction (measured from east), wind vector and barometric pressure at the Yalova station, inverse barometer corrected sea level at Şile (red) and Yalova (green) stations and their differences, the magnitude and sense of ADCP currents in the north-south direction (north is positive) at Baltalimanı are shown from top to bottom.

Somewhat similar behavior is expected at the Dardanelles Strait. Under typical conditions represented by 21 May 1987 (Figure 7, left), the halocline is located at 25 m depth east of the Nara Pass and remains about the same in the rest of the Marmara Sea, but rises sharply at the narrows so that it remains at a depth of about 5-10 m upon exit to the Aegean Sea. The cold intermediate water (Marmara CIW) of about 8°C sneaks in from the east, but terminates past Nara Pass where it encounters intensive mixing.

During the exceptional cold winter of 17 February 1993 (Figure 7, right), temperatures of less than 4°C are observed, when the upper layer depth increased to 40 m in the eastern part the Marmara Sea in response to wind stirring, decreasing to about 20 m after the Nara Pass where the temperature is increased to about 8°C by mixing with the warmer waters below. The lower layer water entering from the Aegean entrance with a temperature of 12°C terminates at the plunge point at the exit of the strait where it sinks to the depths of the Marmara Sea. While the lower layer salinity is about 38.5 in both dates illustrated above, the upper layer salinity is about 24 near the surface on 21 May 1987, while it increases up to 28 at entry to the Dardanelles and to about 32 at exit into the Aegean Sea on 17 February 1993, as a result of mixing processes.

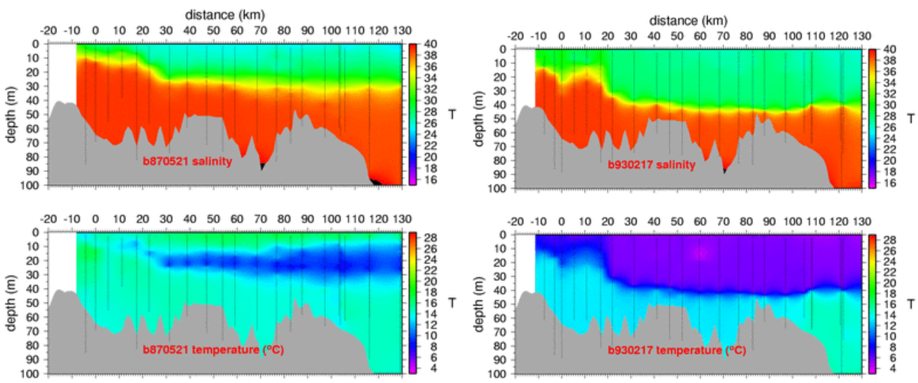



**Figure 7.** Salinity (top) and temperature (bottom) on the dates 21 May 1987 (left) and 17 February 1993 (right) in the Dardanelles Strait based on CTD measurements.

In the Marmara Sea, the property variations in the lower layer are indeed very small, with typical mean values of about 14.2-14.5 and 38.5 in temperature and salinity respectively, despite some small changes due to long-term instrument and climate drifts. A temperature maximum of 14.5-15°C is often observed at depths of 50-70m, surviving after the summer-autumn influx of the Dardanelles inflow below the halocline. Further below, the temperature monotonically decreases to 14.2-14.3°C at mid-depth. The salinity on the other hand reaches a minimum at about 200m and is either uniform or increases slightly till the bottom (Beşiktepe *et al.* 1994).

The relatively small but significant changes in the lower layer of the Marmara Sea reflect deep-water renewal processes in the Marmara Sea (Beşiktepe *et al.* 1993, 1994, 2000). The dense water entering via Dardanelles entrains water and sinks to the depth of equilibrium with the interior. Depending on the initial density contrast Dardanelles and the weak interior density stratification of the interior, the renewal process has inter-annual dependence. A reduced gravity model has shown the influx to reach the bottom of the western basin in winter, later to overflow into the central basin in a time frame of few months. In summer, with a smaller density contrast, the flow is found to first proceed preferentially along the shallow depths of the southern shelf, eventually overflowing into the interior (Hüsrevoğlu 1999).

### 3.3. The Golden Horn (Haliç)

The Golden Horn, is the estuary of Kağıthane and Alibeyköy Rivers, is influenced from the hydrodynamic conditions of the Bosphorus. It is 7 km long, and 750 meters wide at its widest section and has a maximum depth is about 40 meters (Ergin *et al.* 1990). Its maximum depth and widest part is placed in downstream, where it flows into the Bosphorus. The bottom depth is about 5 meters in 1 km inside from the downstream (Figure 1b).

The total volume fluxes of the Alibeyköy and Kağıthane Rivers have been decreased from its former value of $3x10^5 m^3/d$ (Kor, 1963) to about $3x10^5 m^3/y$ (Öztürk *et al.* 1998) in recent years. Today, the amount of the fresh water coming from these rivers is high when the rainfall is heavy. Since 2012 October the salty water taken from the Bosphorus upper layer (almost 4 meters depth) have been carrying via Alibeyköy River to the Golden Horn. The volume flux of this water is not regular. According to flow values obtained from İstanbul Water and Sewerage Administration (İSKİ) of İstanbul Metropolitan Municipality the average flux is $1.8x10^5 m^3/d$ for July and August 2013.

Studies related to oceanographic features of the Golden Horn were revealed to be closely related to characteristics of the Bosphorus. Temperature and salinity across the estuary given in Figure 8 shows two-layer hydrographic structure in the deeper part of the estuary. The top layer temperature showed large changes in salinity (18-21 psu) within the year, depending on atmospheric conditions, the waters of the Bosphorus originating from the Black Sea, and the influence of rivers and rainfall. The lower layer of Mediterranean origin has high salinity (~37 psu) and warm temperatures (~15°C) in which very little change is evidenced during the year and the temperature (Ergin *et al.* 1990). The transition layer separating the two layers can be of different thickness and depth due to the impact of mixing by the wind.

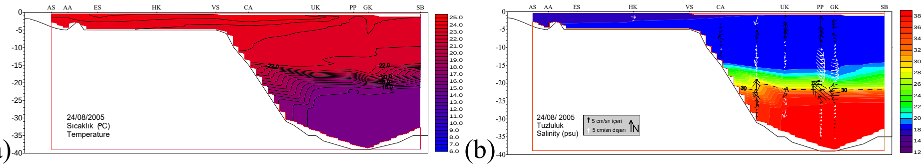
(a) (b)



**Figure 8.** Temperature, salinity and current variations in the Golden Horn, August, 2005 (Müftüoğlu 2008).

The vertical structure of the Golden Horn can be characterized as a three-layer system under the influence of the discharge system of its small rivers, the Bosporus and atmospheric conditions. These layers consist of the upper layer of Black Sea origin, the lower layer of Mediterranean origin and the transition layer between them. Waters from the Alibeyköy and Kağıthane streams can reach the throat of the freshwater estuary at the surface. Although these waters of river origin can be detected at the top layer of water on the surface of the 2-3 m layer the Bosphorus origin water just below does not carry the same characteristics; the surface water being distinguished by low levels of dissolved oxygen and high concentrations of suspended matter (Sur *et al.* 2001). Surface salinity is lower by about 2 psu from the upper layer salinity. As a result of limited light penetration below the surface waters with high suspended matter concentration, the surface water is typically warmer than the water just below (Özsoy *et al.* 1988).

## 4. Trends and Variability

### 4.1 Temporal Variability in the TSS and neighboring Seas during 1985-2015

We next examine temporal hydrographic variability in the TSS and its neighboring domains by examining collective oceanographic data merged together from IMS-METU and IMSM-IU sources. The 30-year data set covers the period 1985-2015, from which we produce the analyses in Figures 9-11. The CTD station positions in the TSS region are shown in Figure 9a.

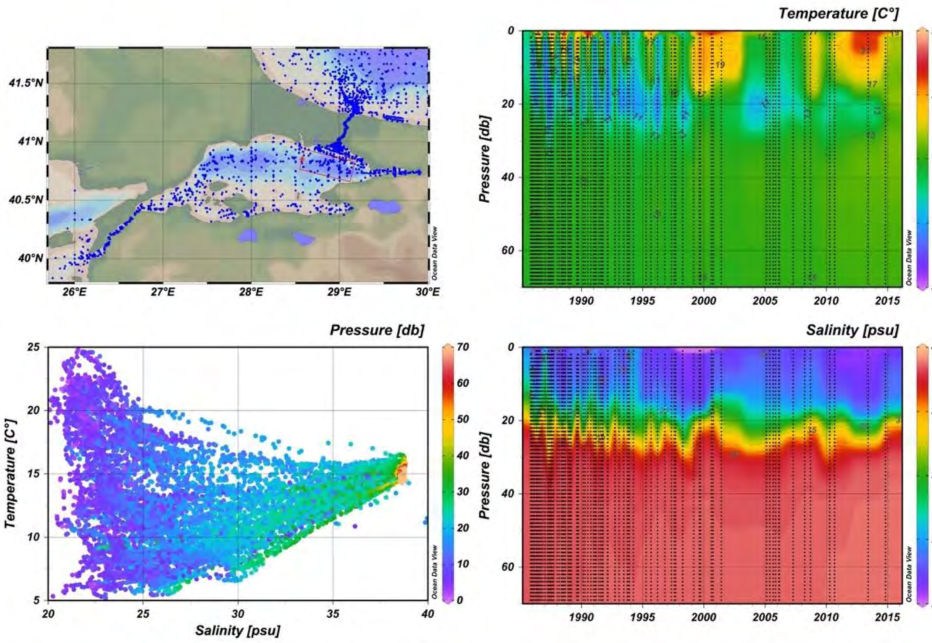



**Figure 9.** (a) Locations of oceanographic stations in the TSS and its neighboring domains, with the selected area of analysis in the eastern Marmara Sea marked by the rectangular box encircled by the red line, (c) the corresponding T-S diagram with depth of data points indicated on a color scale, (b) temperature and (d) salinity time series of depth profiles.

We sample the data within the eastern Marmara Sea box bounded by a red line in Figure 9a for analysis. The temperature and salinity versus depth time series are shown in Figures 9b,c, where the data in the first 15 years until 2000 appears more abundant than the later years. In the temperature time series, seasonal changes are well captured in the first 15 years. It is evident that the cold intermediate waters of the Marmara Sea that were shown to be present from late winter until summer are cyclically observed in the first part of the record, but seem to be reduced in strength after the 2000's, despite the reduced number of profiles in this period. It is also seen in the first 15-year period that the average depth of the core of this cold water in the upper layer has been slightly increased from about 20 m to about 25 m, possibly indicating slight changes in stratification in the longer term. The same trend appears in the salinity time series showing a shift in the mean depth of the halocline within the same range in the first period of 15 years, later leveled off at 25 m depth, with superposed seasonal oscillations.

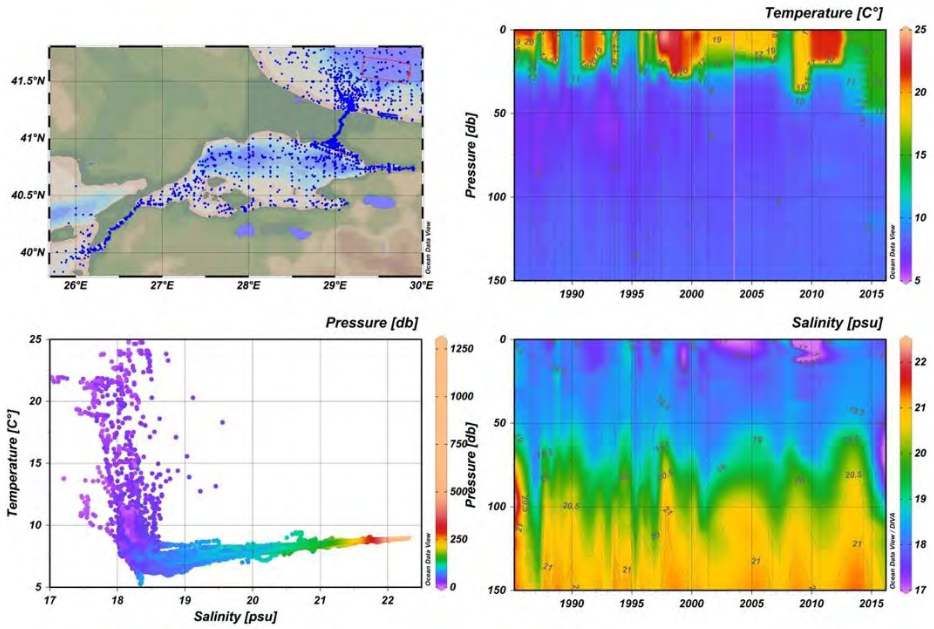



**Figure 10.** (a) Locations of oceanographic stations in the TSS and its neighboring domains, with the selected area of analysis in the adjoining Black Sea region marked by the rectangular box encircled by the red line, (c) the corresponding T-S diagram with depth of data points indicated on a color scale, (b) temperature and (d) salinity time series of depth profiles.

The conditions in the adjacent seas in the same period are reviewed in Figures 10 and 11. In the Black Sea for stations within the box chosen for analysis in Figure 10a, the situation is similar to that observed in the Marmara Sea; once again the number of samples until the 2000's are greater than the observations available later. However, it is quite significant that the Cold Intermediate Layer (CIL), defined to consist of waters colder than 8ºC in the Black Sea, appears to be colder in the first period with core temperatures as low as 5ºC, which however is observed to become warmer after the 2000's despite the decreased number of available data. Recently, there is increasing evidence that the CIL water mass formation by winter cooling is on the decrease. The volume of CIL in the Black Sea has been variable over the last decades as a function of winter mixing, with a decreasing trend in recent years linked to increasing surface temperature (0.6°C/decade from 1982 to 2002; Belkin 2009) influenced by climate variability and change (Oğuz *et al.* 2003; Stanev *et al.* 2013, 2014; Capet *et al.* 2016; Miladinova *et al.* 2016).

The comparable analysis for the Aegean Sea box immediately outside the Dardanelles Strait as shown in Figure 11 does not seem to indicate consistent patterns of long term changes. It should be noted however that the analyses should be further extended to include basin-wide data to conclude on trends in the adjacent basins. At present we only compare changes in adjacent areas to the TSS.

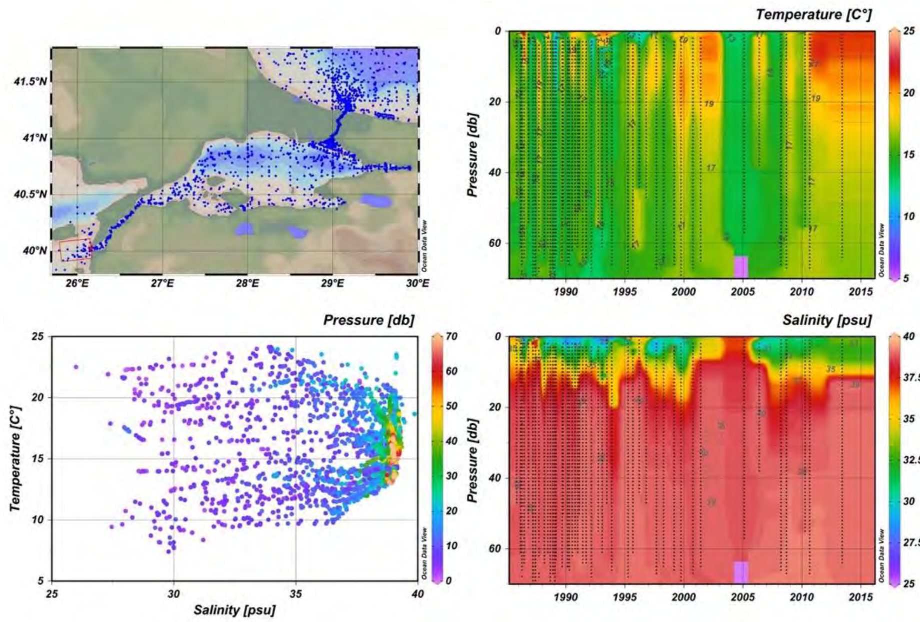



**Figure 11.** (a) Locations of oceanographic stations in the TSS and its neighboring domains, with the selected area of analysis in the adjoining Aegean Sea region marked by the rectangular box encircled by the red line, (c) the corresponding T-S diagram with depth of data points indicated on a color scale, (b) temperature and (d) salinity time series of depth profiles.

### 4.2. Temporal Variability in the Bosphorus during 1995-2005

Hydrodynamic conditions in the Bosphorus Strait determine the characteristics of the water masses, which are also the boundary conditions for these two seas. As both the Black Sea and the Sea of Marmara, are semi-enclosed basins, they experience restricted water exchange. A hydraulic controlled maximal exchange flow system defined by Farmer and Armi (1986) carries two very different water masses in the strait. The long term changes of temperature and salinity of these water masses and their trends are useful information about climatic investigation for the Marmara Sea and neighbouring seas. The monitoring program of the IMSM-IU for İstanbul Water and Sewerage Administration (İSKİ) provided high resolution data collected monthly from 28 stations in the strait and the junctions (Figure 1a). Temperature and salinity variation and volume fluxes through the Bosphorus were analyzed using the long-term monthly time series of temperature, salinity and current profiles obtained from this monitoring program (Altıok and

Kayışoğlu 2015). Influence of local meteorology is inferred from air temperature and barometric pressure measured at Kumköy and Florya meteorological stations (Figure 12).

The mean values and trends obtained from the CTD and meteorological variables are provided in Table 1.

**Table 1.** The means and trends of CTD and meteorological variables

| **Station / depth** | **temperature, T** | | **salinity, S** | | **density, $\sigma_0$** | |
|---|---|---|---|---|---|---|
| **oceanographic station** | mean (ºC) | trend (ºC $y^{-1}$) | mean | trend ($y^{-1}$) | mean | trend ($y^{-1}$) |
| **B2 at 5 m** | 14.02 | 0.153 | 18.48 | -0.019 | 13.27 | -0.040 |
| **K0 at 5 m** | 15.10 | 0.073 | 17.36 | -0.010 | 12.16 | -0.020 |
| **B2 at 37 m** | 14.74 | 0.072 | 37.07 | 0.086 | 27.62 | 0.052 |
| **K0 at 67 m** | 14.36 | 0.060 | 35.80 | 0.037 | 26.71 | 0.016 |
| | **air temperature, $T_{air}$** | | **barometric pressure, $P_{bar}$** | | | |
| **Meteorological station** | mean (ºC) | trend (ºC $y^{-1}$) | mean (mb) | trend (mb $y^{-1}$) | | |
| **Florya** | 14.81 | 0.097 | 1012.08 | -0.048 | | |
| **Kumköy** | 14.32 | 0.104 | 1012.26 | -0.033 | | |

The minimum air temperature in both meteorological stations and the upper layer temperature in the Bosphorus were observed in February 2003. The higher air temperature and upper layer temperature values were observed for the years 2001, 2002 and 2006. The temperature of the upper layer in the strait fluctuated in the range of 2.3-27.0 °C at the northern exit of the Bosphorus and 2.7-25.7 °C at the southern exit during the 14-year period (Figure 13).

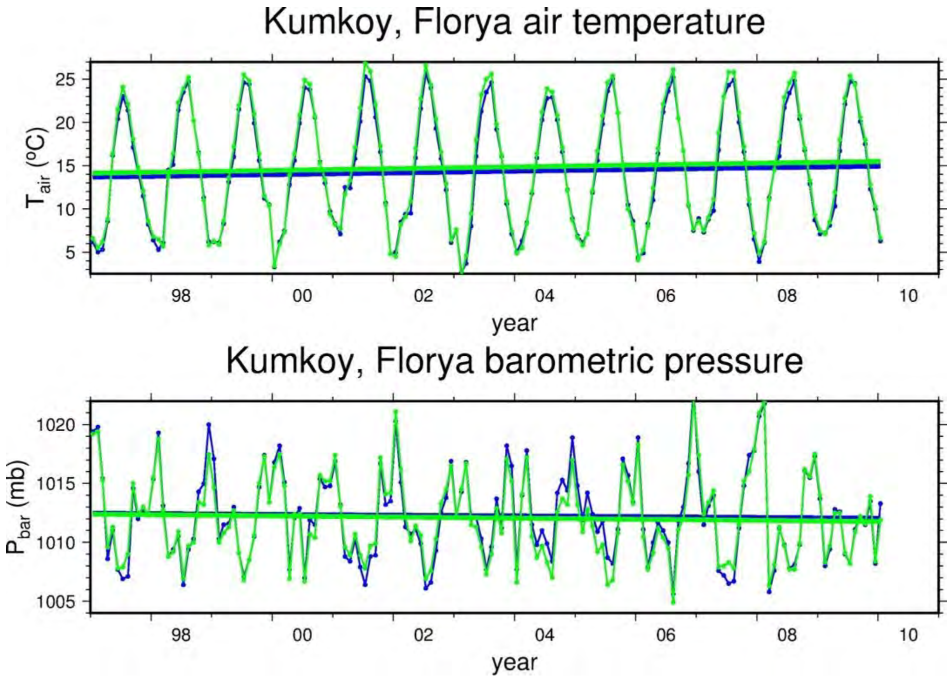
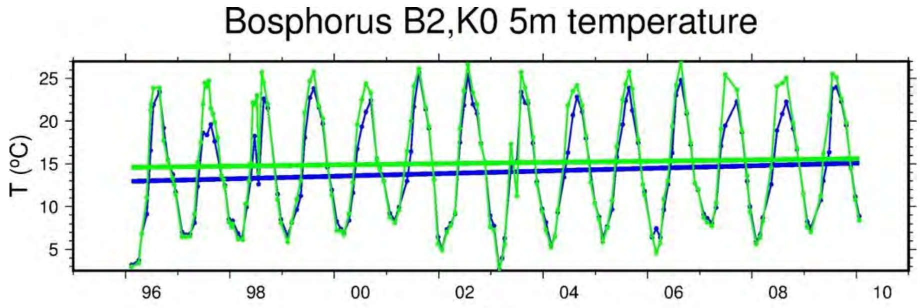



**Figure 12.** (a) Air temperature and (b) barometric pressure at Kumköy (blue) and Florya (green) meteorology stations.

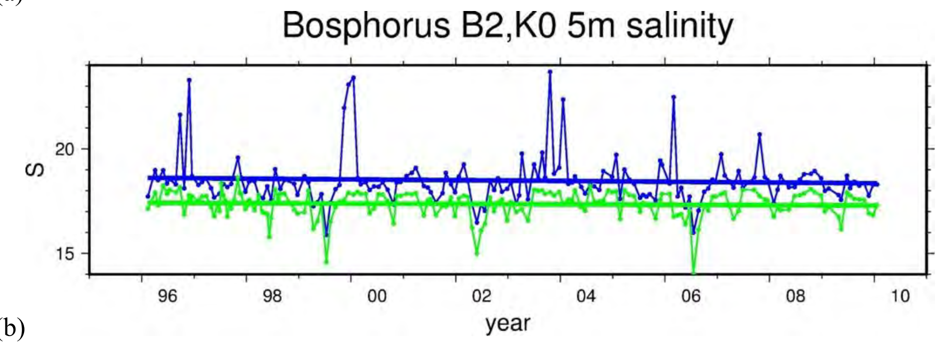
Besides these interannual changes, which are in keeping with the air temperatures, it was observed that sudden changes in the time series were due to the oceanographic conditions in the strait and adjoining seas. The upper layer temperature decreased abruptly at the northern exit of the strait in July 1998 and in June 2003. In July 1998, cold water patches were found in the vicinity of the strait (Altıok *et al.* 2012) as the anticyclonic eddy formations caused an increase in the CIW at the Black Sea exit (Sur *et al.* 1997). A similar feature was observed in June 2003. Although variations in the upper layer temperature at the both ends of the strait were usually parallel to each other, huge differences were observed during some months, especially in July 2007, July 2008 and August 2008. The CIW coming from the Black Sea with the upper layer in the strait causes a decrease in the upper layer temperature at the southern exit of the strait in the summer months (Altıok *et al.* 2012). The hydrodynamic conditions in the strait were the main drivers for the differences in temperature in both these stations. On the other hand, the higher temperature and salinity values which were observed in the upper layer in March 2006 were due to the flow blockages and the resultant mixing with the lower layer waters in the southern part of the strait.

Ginzburg *et al.* (2004) estimated a value of 0.08°C$y^{-1}$ for the western Black Sea region during 1982 and 2000. The monthly time series of the upper layer temperature at the northern exit of the strait revealed a positive linear trend of about 0.07°C$y^{-1}$ (Table 1 and Figure 13). The upper layer temperature increased during the 14-year period by about 0.98 °C in the northern exit of the strait. At the southern exit of the strait, however, the positive linear trend was two times greater than that of the northern exit of the strait. The trend was 0.15°C$y^{-1}$ at the southern exit of the strait, indicating that the temperature increased in the 14-year period by about 2.1°C (Figure 13). This upward trend might have been caused by the variability of the CIW along the strait and a mixing between the layers.

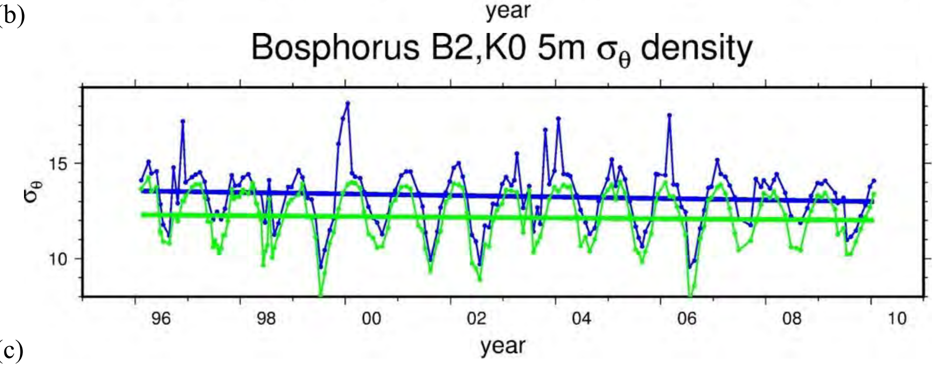
The ranges of the monthly upper layer salinity at the both ends of the strait were 14.03-18.62 psu and 15.88-23.67 psu, respectively (Figure 8). The difference between these value ranges indicates the distinct influences of the dynamics of the Black Sea and Marmara Sea on the upper layer salinity. Low salinity (<17.5 psu) waters were influenced by the Danube River (Sur *et al.* 1994). In the summer months, the salinity values at the northern exit were usually lower than 17.0 psu. The minimum salinity at the northern exit, namely 14.03, 14.59 and 15.02 psu were observed during July 2006, July 1999 and May 2002, respectively. In the southern exit of the strait, relatively higher salinity values were driven by the upper layer flow blockages resulting from the strong southerly winds, which were observed during the low air pressure conditions during the autumn and winter months (Figure 9a). Recently, the relationship between the southerly winds and low atmospheric pressure was examined in the Sea of Marmara by Book *et al.* (2014). The highest salinity values at the southern exit were observed in December 1999, January 2000, October 2003, January 2004 and March 2006. The upper layer salinity was always higher at the southern compared with the northern exit due to the mixing along the strait (Ünlüata *et al.* 1990; Oğuz *et al.* 1990).




(a)




(b)




(c)

**Figure 13.** Time series of (a) temperature, (b) salinity and (c) $\sigma_\theta$ density at 5 m depth at station B2 (blue) near the southern exit and at station K0 (green) at the northern sill outside the northern exit of the Bosphorus Strait. Straight lines indicate respective linear trends.

The monthly upper layer salinity at the northern exit (Figure 8) features a negative trend of around 0.01 psu $y^{-1}$, indicating that the upper layer salinity decreased during the 14-year period by about 0.14 psu. The trend in the upper layer salinity at the southern exit was -0.02 psu $y^{-1}$ indicated that a greater degree of freshening occurred at the southern exit of the strait compared with the northern counterpart.

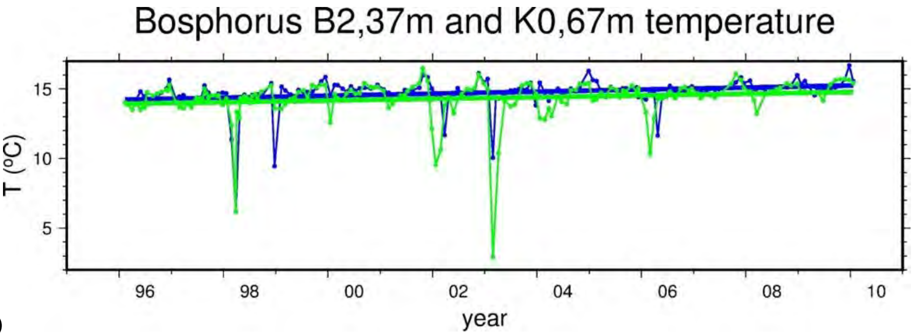
### 4.3. Trends in Bosphorus Lower Layer Temperature and Salinity

The time series of the monthly temperature and salinity of 67 m depth at the northern exit of the strait and 37 meter depth at the southern exit of the strait reveal minor variations with sudden peaks and their long-term trends (Figures 10a,b). During the 14 year-period the temperature values in the strait were in the range of 2.9-16.5 °C and 6.2-16.7 °C, while the monthly salinity range was 17.4-37.7 psu and 17.8-38.5 psu, at the lower layer of the north and south exits of the strait, respectively. The lower layer, characterized by warm and saline waters, exhibits slight variations for most part of the year (Figures 10a,b). However, the temperature and salinity values indicate sudden peaks during the blockage events.

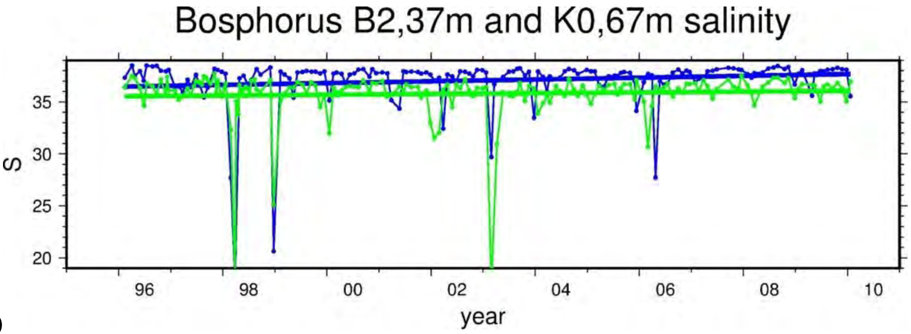
The temperature values of the lower layer at both ends of the strait were close to each other with just a few exceptions. During some months due to the presence of the cold intermediate layer in the northern section of the strait, the lower layer of the northern exit of the strait values were lower than those of the temperature of the lower layer at the southern exit of the strait. When the cold layer was absent in the strait, the lower layer temperature values of the northern exit were slightly higher than those of the southern exit because of being in direct contact with the overlying warm upper layer (Altıok *et al.* 2012), as observed in October 2001, 2006, September and October 2007.

The salinity of the lower layer at the southern exit of the strait was greater by nearly 2 psu at the northern exit of the strait. However, during some months the less saline lower layer could be observed at the southern exit of the strait. This feature is related to the upper layer blockage. When the upper layer blockage begins at the southern exit of the strait it produces the thicker lower layer and increases the vertical mixing between the layers. The lower layer salinity decreases while the upper layer salinity increases due to the vertical mixing and intrusion of the upper layer of water into the strait from the Marmara Sea (Altıok *et al.* 2014). The lower layer salinity continues to decrease at the northern exit of the strait during the upper layer blockage. The lower salinity values (<34 psu) indicate intense mixing due to the upper layer blockage in the strait. On the other hand, during the complete lower layer blockage as seen in March 1998, December 1998 and February 2003, the lower layer salinity at the northern exit showed the same value as the Black Sea upper layer water salinity, which was less than 18.5 psu.

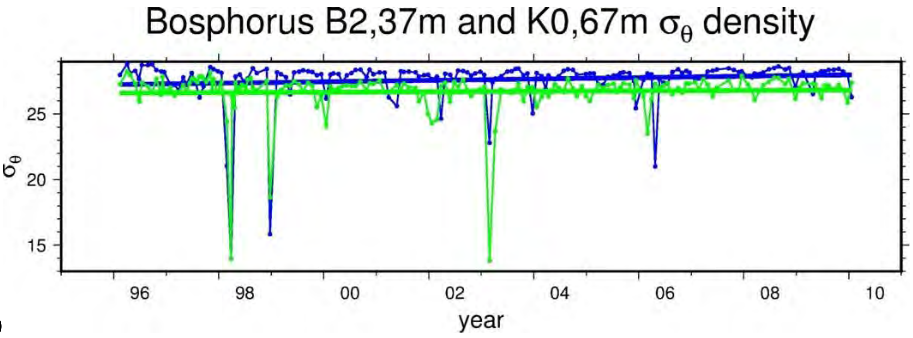
The monthly time series of the lower layer temperature and salinity at the northern exit of the strait showed a positive trend of about 0.06 $°Cy^{-1}$ and 0.04 psu $y^{-1}$, respectively. In the southern exit of the strait, the lower layer temperature and salinity trends were 0.07 $°Cy^{-1}$ and 0.09 psu $y^{-1}$. The temperature trends in the lower layer were less than in the upper layer. On the other hand, unlike the upper layer the salinity trends were positive in the lower layer (Figure 10).




(a)




(b)




(c)

**Figure 14.** Time series of (a) temperature, (b) salinity and (c) $\sigma_\theta$ density at 37 m depth at station B2 (blue) near the southern exit and at 67 depth at station K0 (green) near the northern sill outside the northern exit of the Bosphorus Strait. Straight lines indicate respective linear trends.

### 4.4. Time-dependent changes of surface salinity in the Golden Horn

The Golden Horn has been subject to various attempts of reclamation to recover its health. Vertical mixing of the highly polluted surface waters is limited due to the strong density stratification of the estuary. The old pontoon bridge of Galata has been removed in 1992 to provide faster recirculation of the surface water near the estuary mouth. After the completion of dredging work at the entrance of the mouths of the small streams feeding the estuary in 2000, the fresh water input has been increased. through the river estuary shortly after completion in 2000. Starting from October 2012, additional water of about 18psu salinity withdrawn from the Bosphorus is pumped into the upper part of the estuary.

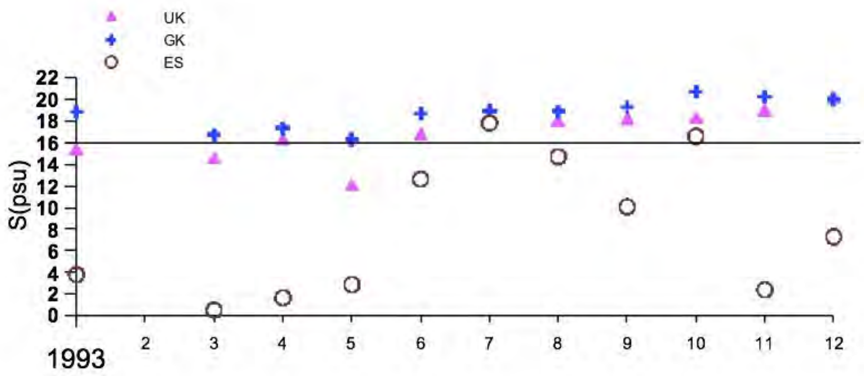



**Figure 15.** Monthly variation of Golden Horn surface salinity in 1993 (Emin, N. 1994)

In a study conducted on a monthly basis in 1993, at stations GK (Galata Bridge), UK (Unkapanı Bridge) and ES (Eyüp Sütlüce section) of surface salinity values large salinity differences have been found between the head and the mouth of Golden Horn (Figure 1). In the ES station near the head of the estuary, surface salinity in spring and winter has a minimum of 8 psu, as a result of rainfall. This fresh water effect can also be observed at the UK and GK stations during the same season, with salinity values dropping to less than 16 psu.

Since the period of accelerated reclamation in the Golden Horn, when the mud was being dredged up until 2005, monthly values of surface water salinity measurements obtained by the IMSM-IU in the Water Quality Monitoring Project are given in Figure 11. Salinity measurements at the same station from 2009 until today by the Water and Waste Administration of the Municipality of İstanbul (İSKİ) are also shown on the same plot. In addition, values measured by IMSM-IU in summer (July, August and September) in the scope of this project are shown in the same Figure. An SBE25 Sealogger CTD device was used from May 2000 until the end of 2005 in the salinity measurements by the Institute, excluding shallow stations with depth less than 0.5m. Despite noticeable variations in the surface salinity at shallow stations indicating the influence of freshwater input, surface salinity during the 2000-2005 period at the GK station had a maximum of 20.6 psu. The effects of the rainy season can be seen in the time dependent observations since 2009 (Figure 12). The annual average values at the GK station varied from 17.63 psu in 2009 to 18.4 psu in 2012 and 2013

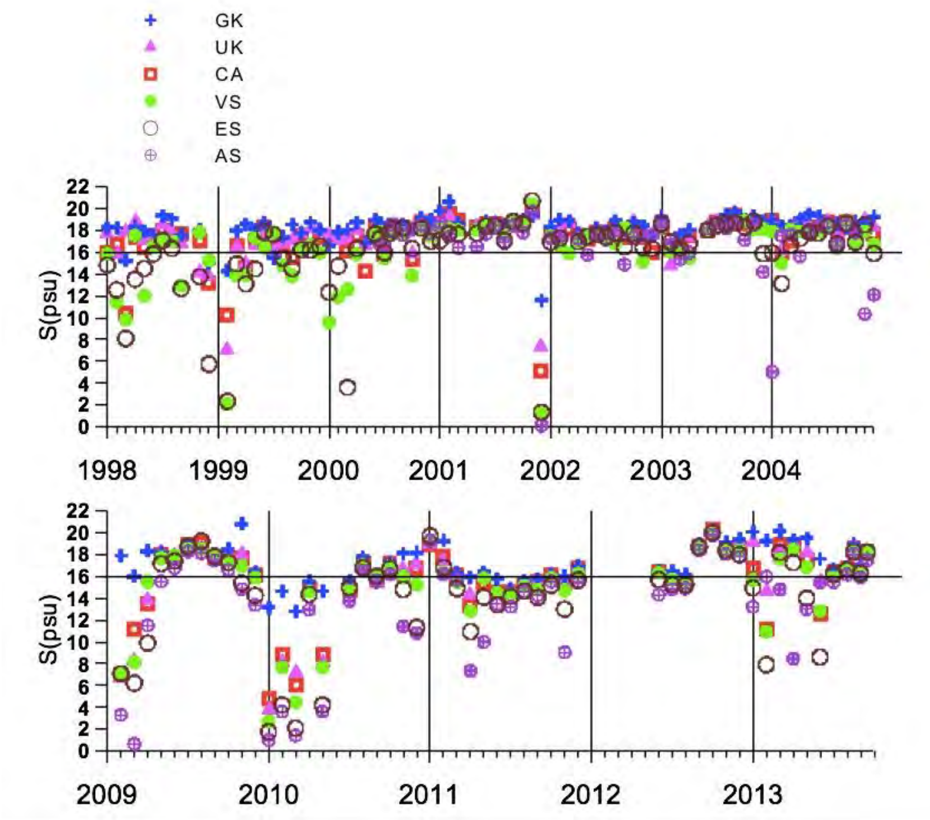



**Figure 16.** monthly surface water salinity changes between 1998-2005 and 2009-2013

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**A REVIEW OF WATER FLUXES ACROSS THE TURKISH STRAITS SYSTEM**

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## 1. Inroduction

The exchange flow at the Bosphorus is determined by the water budget of the Black Sea. The conservation of mass for the Black Sea requires that the net water flux through the Strait is balanced by the rate of mean sea level change and the other water imports / exports. It is therefore important to establish the annual and seasonal average water flux to and from the Black Sea through the Bosphorus. A critical review of the available data and estimates of the fluxes have been given by Ünlüata *et al.* (1990). In the present report, we review the existing sources of information for an updated understanding of the exchange.

Long term measurements of volume fluxes are essential for the calculation of the seasonal export rates of nutrients and organic carbon in the straits. The nutrient fluxes coming from the Black Sea by upper layer flow in winter is about at least 2-3 times greater than in the autumn due to changes in both nutrient concentrations and volume fluxes (Polat and Tuğrul 1995; Tuğrul *et al.* 2002).

In reality the inter-basin exchange through the TSS is sensitive to conditions in the adjacent basins (changes in the net water flux entering the Black Sea, as well as sea-water density, atmospheric forcing and sea-level difference), and on the average, has to balance the net annual water budget of the coupled system. Because the ratio of runoff to basin volume is much larger for the Black Sea compared to the Mediterranean, TSS water exchange is more sensitive to changes in Black Sea river runoff. With a catchment area five times as large as the sea surface area, the Black Sea amplifies global climate signals (Stanev and Peneva 2002).

Measurements to date seem to indicate that the mean values of fluxes through the TSS are difficult to establish with certainty. This is because the mean values are actually masked by the great variability observed in currents on daily to inter-annual time scales, the typical experiment duration possibly being too short to establish statistics.

## 2. Flux estimates based on mass balance

By making use of the average salinity measured at the Straits and the water fluxes of the Black and Marmara Seas, the annual average fluxes are computed from the Knudsen relations expressing a steady state mass balance of the TSS. Climatological estimates of the TSS have been given in Ünlüata *et al.* (1990), Beşiktepe *et al.* (1993, 1994), Tuğrul *et al.* (2002), as reviewed in Schroeder *et al.* (2012) and Jordà *et al.* (2016), Mavropoulou *et al.* (2016) and others. These computations show greater fluxes at the Dardanelles relative to the Bosphorus, and large entrainment fluxes across the halocline throughout the TSS (Figure 1).

The annual average upper and lower layer fluxes of the Bosphorus respectively were estimated as 650 and 325 km3/y (20500 and 10300 m3/s) in the above references, in agreement with the long-term salt budget of the Black Sea requiring an approximate ratio of ~2 between the output and input mass fluxes (Özsoy and Ünlüata 1997). The mean net flux of water exiting the Black Sea is therefore estimated to be about 325 km3/y (10300 m3/s).

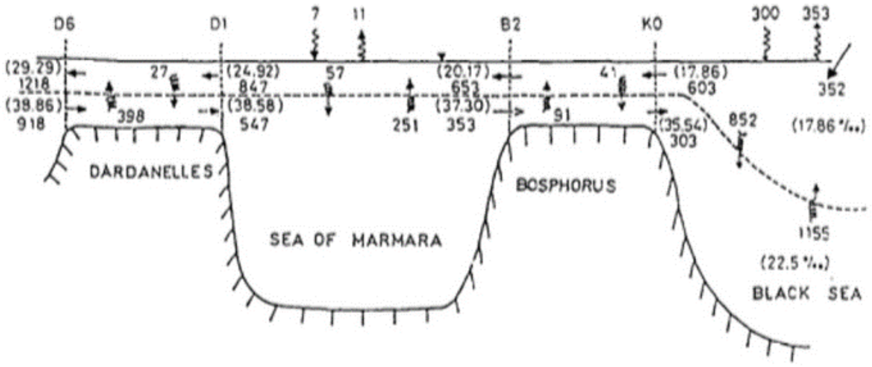



**Figure 1.** Volume fluxes of the Turkish Straits System in units of km3/y (1km3/y = 31.7m3/s), after Beşiktepe *et al.* (1994). Numbers in parentheses are average salinity values used in the computations.

There are also large transports of water between the layers by turbulent entrainment processes. In the Bosphorus, about 25% of the Mediterranean water influx is entrained into the upper layer, and about 7% of the Black Sea water is entrained into the lower layer flow. The computations show that 45% of the Aegean inflow is entrained into the upper layer in the Dardanelles; a further 45% of the amount reaching the Marmara Sea is lost to the upper layer by basin-wide entrainment.

The exchange flows of the TSS, observed at the Bosphorus, are found to increase in the spring and early summer, and weaken markedly in the autumn (within a margin of about 40% of the annual mean) in response to the fresh water input to the Black Sea

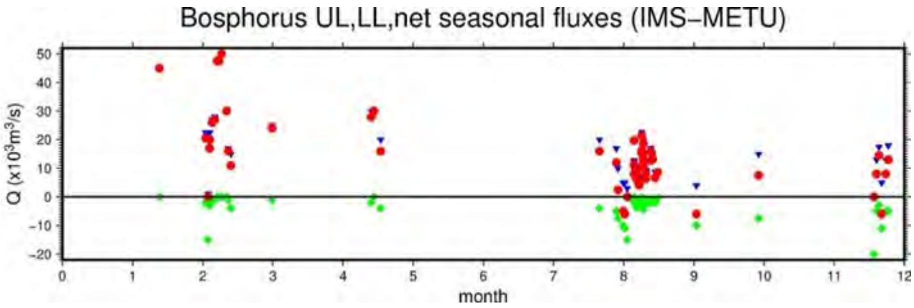
(Tuğrul *et al.* 2002). Indirect estimates (Stanev and Peneva 2002) indicate seasonal anomalies which are hard to validate and compare with estimates by Tuğrul *et al.* (2002) obtained from realistic seasonal mass budgets on the one hand and fluxes inferred from indirect methods on the other.

### 3. ADCP Flux Measurements

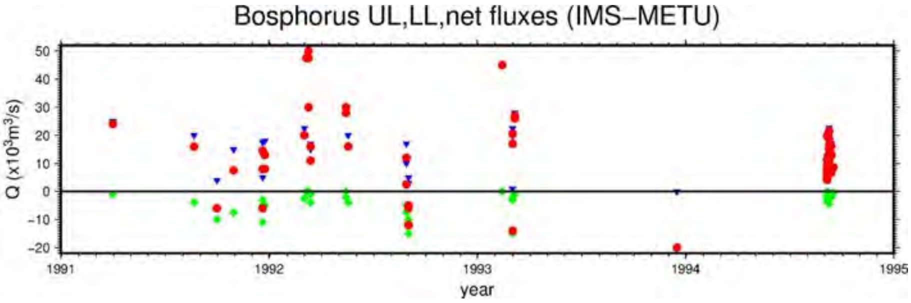
Direct measurements of fluxes are performed by taking transects across the strait with the research vessel recording the current measurements in real-time obtained by a vessel-mounted ADCP. There are losses of data in the shallow zones adjacent to the coast, and for about 15% of the total depth near the surface and the bottom. The current profile data are extended by a constant value upwards to the surface and a linear extrapolation to zero velocity at the bottom from the nearest reliable data in the profile in each case. The methodology has been used first by (Özsoy *et al.* 1996, 1998) and later by Altıok and Kayışoğlu (2015) to compute fluxes at the Bosphorus Strait.

The first set of fluxes computed from ship mounted ADCP measurements in the Bosphorus (Özsoy *et al.* (1996, 1998) shown in Figure2a revealed measured maxima of about Q1 = 1600 km3/y (50000 m3/s) and Q2 = 630 km3/y (20000 m3/s) for the upper and lower layers respectively, including blocked cases, indicating instantaneous fluxes 2-3 times larger than the annual mean. Despite large scatter in data due to sampling, average values of Q1 = 540 km3/y (17000 m3/s) and Q2 = 115 km3/y (3500 m3/s) were computed, the latter value possibly being underestimated as a result of data loss near the bottom. Maderich and Konstantinov (2002) have compared these data with their simple model. Accordingly, blocking of either the upper or lower layer flows were indicated for net flux exceeding Q = -580 km3/y (18500 m3/s) or Q = 800 km3/y (25000 m3/s) in the respective directions.

These measurements have shown the same seasonal trends as the mass budget calculations, although the measurements were clustered at certain times of the year not sufficiently sampling the seasonal cycle. Yet it is clearly seen in Figure 2b that the winter and spring fluxes are larger than during the summer and autumn. A number of upper and lower layer blocking cases are evident in Figures 2a and 2b, where the corresponding fluxes vanish, not only in winter and spring months but also in summer.




(a)

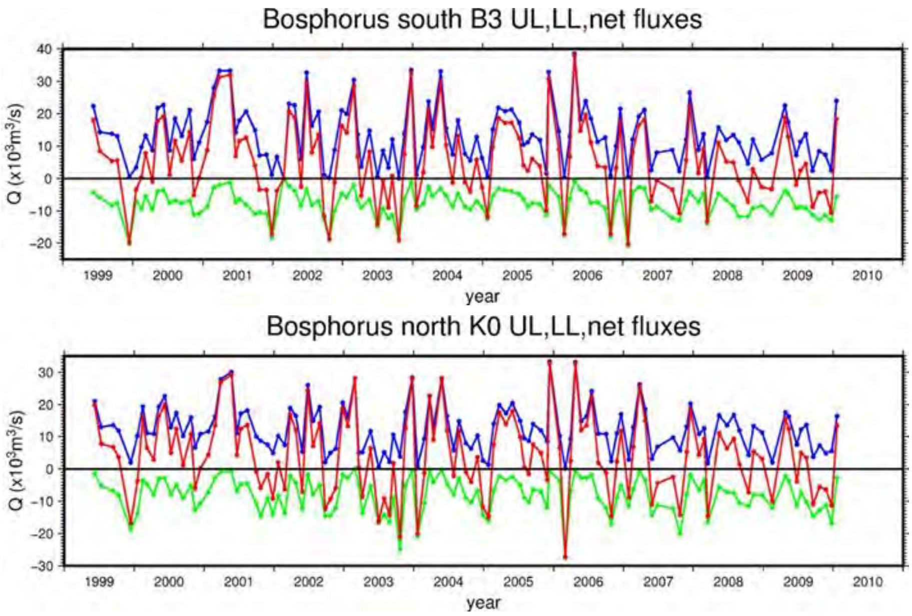



(b)

**Figure 2.** Fluxes computed from ADCP measurements in the Bosphorus during 1991-1994 by the IMS-METU, (a) time variations during the same period and (b) seasonal variations. Averages for the upper-layer (blue inverted triangles), lower-layer (green diamonds) and net (red dots) fluxes have been computed such that positive fluxes are associated with the upper layer.

A 10-year monthly measurements campaign has been carried out by Altıok and Kayışoğlu (2015) to monitor the Bosphorus fluxes at the two ends of the Strait using vessel-mounted ADCP measurements obtained on sections across the Strait. The time series of the monthly upper layer volume flux measurements at stations B3 at the southern end and station K0 at the northern end of the strait exhibited a wide range of variability (Figure 3a). The larger variability occurs in the upper layer fluxes, while the lower layer is less variable.

During the 1999-2010 campaign, the maximum values of measured upper-layer volume fluxes were 38560 m3 s-1 at the southern section of the strait and 33313 m3 s-1 at the northern section of the strait. Often the very small values of fluxes (<10 km3 y-1 or 330 m3 s-1 which is negligible) are considered as blocking cases for the upper layer. In the southern section of the strait, the upper layer flow blockage was observed more frequently than the upper reaches. In addition to the October 2003 upper layer blocking case investigated earlier by Altıok *et al.* (2014), other cases of blockage occurred also in October 2002 and March 2006. In October 2002 and 2003, the upper and lower layers and a thick interfacial layer was observed to flow north altogether. In these events the limited increase of salinity in the northern part of the strait suggested transient blocking that did not reach the north. In March 2006, the upper layer blockage was observed to reach the northern exit of the strait as well, and the corresponding volume flux was the overall minimum for this section.




(a)

(b)

**Figure 3.** Fluxes computed from monthly ADCP measurements at stations B3 and K0 respectively at the southern and northern ends of the Bosphorus during 1999-2010 by the IMSM-IU. Time-series at (a) station B3 and (b) station K0. The upper-layer (blue), lower-layer (green) and net (red) fluxes have been computed such that positive fluxes are associated with the upper layer flowing south.

The maxima of the monthly lower layer volume fluxes at both ends of the strait were 27460 m3s-1 (866 km3y-1) and 20750 m3s-1 (654 km3y-1), respectively. The low values (<1000 m3s-1) of the lower layer volume fluxes indicate lower layer blockage or near blockage, while the higher volume fluxes (>13,000 m3s-1) of the lower layer typically indicate the upper layer blockage. In fact, the maximum values of the volume fluxes at the two ends of the strait were observed in March 2006 when the upper layer volume fluxes were very low at the two ends of the strait. During the upper layer blockage, the volume fluxes of the lower layer were greater than 13,000 m3s-1 (~400 km3y-1) and/or the lower layer salinity values were less than 34 in January 2000, December 2001 and January 2002, as well as February 2002, April 2003 and March 2006.

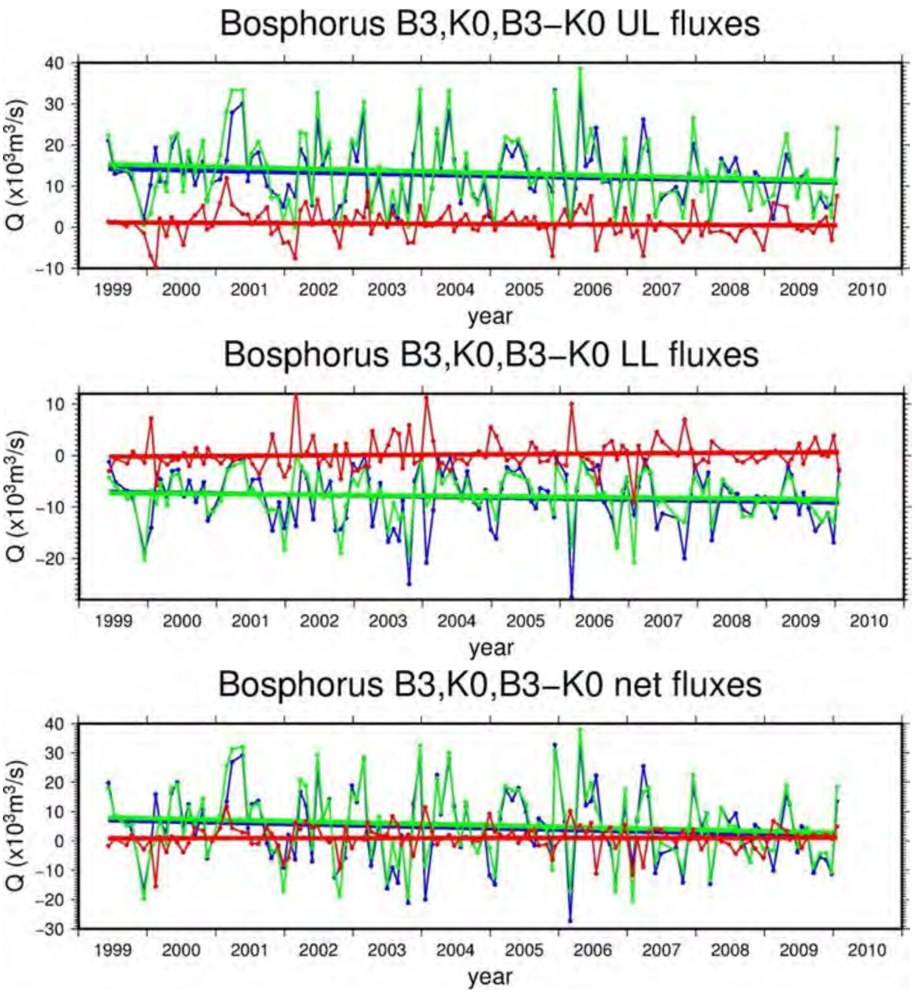
The details of a lower layer blockage at the northern exit of the strait in February 2003 has been described by Altıok *et al.* (2014). Cases of diminished volume flux (<1000 m3s-1 30 km3y-1) occurred in the March-May periods of 2001, 2002, 2004, 2006, 2007, as well as in December 2003 and 2005. In all of these dates, the lower layer temperature and salinity values reflected the Mediterranean water, that is, they showed salinity values greater than 35 and temperature values ranging between 13.5-15 °C.

The average volume fluxes computed from the long-term campaign of monthly measurements by Altıok and Kayışoğlu (2015) established a relatively better basis for statistical evaluations, despite the extreme variability observed in the Strait. The means and trends of volume fluxes calculated for stations B3, K0 and also the difference B3-K0 are given in Table 1, and the time series for the layer and net fluxes with calculated trends are given in Figure 4. The results of the measurements produced mean upper, lower layer and net fluxes of 12540, 8100, 4440 m3/s at the northern exit (K0) of the Bosphorus Strait and 13310, 7900, 5420 m3/s respectively at the southern exit (B3) of the Strait. The increase of the upper layer flux from the upper layer flux from north to south and the increase of the lower layer flux from south to north are as expected, the result of entrainment fluxes for which mass flux estimates were given in the above sections and in Figure 1. In fact, based on estimates provided in Figure 1, one should expect larger differences, which may be obliterated by the approximations used in the computations and the essential data losses. On the other hand, the net flux should be absolutely conserved between the two ends of the Strait, in an average sense. This expected behavior however is only approximately fulfilled by the observations since upper, lower layer and net flux differences in B3-K0 are respectively found to be 770, 210 and 980 m3/s, as a result of instrumental and methodological inaccuracies that are involved in the measurements.

**Table 1.** Means and trends of volume fluxes of Bosphorus Strait (positive values of the means imply southward flow)

| Section | Upper layer | | Lower layer | | Net (total) | |
|---|---|---|---|---|---|---|
| | Mean ($m^3/s$) | Trend ($m^3/s/y$) | Mean ($m^3/s$) | Trend ($m^3/s/y$) | Mean ($m^3/s$) | Trend ($m^3/s/y$) |
| **B3** | 13314 | -373 | -7896 | -110 | 5417 | -484 |
| **K0** | 12543 | -306 | -8101 | -191 | 4442 | -497 |
| **B3-K0** | 771 | -67 | 205 | 80 | 976 | 13 |

The trends of the monthly volume fluxes are also given in Table 1. Accordingly, both the upper layer volume flux showed negative linear trends. The upper layer trend average of the two stations is about ~350 m3s-1y-1 (10 km3y-2), while the lower layer average is ~150 m3s-1y-1 (5 km3y-2). Over the 10-year period of the measurements, it appears that the upper layer volume flux decreased by about ~100 km3/y and the lower layer volume flux increased by about ~50 km3/y. These significant changes could be related to the climatic changes in precipitation, river runoff and evaporation of the Black Sea.




(a)

(b)

(c)

**Figure 4.** Upper, lower layer and net fluxes and their differences computed from monthly ADCP measurements at stations B3 and K0 respectively at the southern and northern ends of the Bosphorus during 1999-2010 by the IMSM-IU. Time-series at (a) station B3 and (b) station K0, and (c) the difference B3-K0. The upper-layer (blue), lower-layer (green) and net (red) fluxes have been computed such that positive fluxes are associated with the upper layer flowing south.

The seasonal variations of the fluxes measured through the 10-year program of the IMSM-IU at the northern (K0) and southern (B3) sections of the Bosphorus are shown in Figure 5. There are significant seasonal variations in both layer fluxes, influencing the seasonal variations of the net flux. Although the seasonal signal is very clear in these measurements, the extremely dynamic behavior of the Bosphorus Strait influenced by its internal hydraulics as well as the remote atmospheric and oceanic events in the

Mediterranean and Black Seas are hidden in the seasonal plots. The upper layer volume flux is typically very high in the late spring and early summer months (May, June and July). In addition to the spring and early summer increases in fluxes related to the increased river discharges in the Black Sea, the other time when extreme fluxes are observed is the winter months starting with December. In general, the higher upper layer flux values are observed during the lower layer blockage events of the spring and winter months (December and February-May). The lower layer appears relatively more steady and less influenced by the seasonal variations.

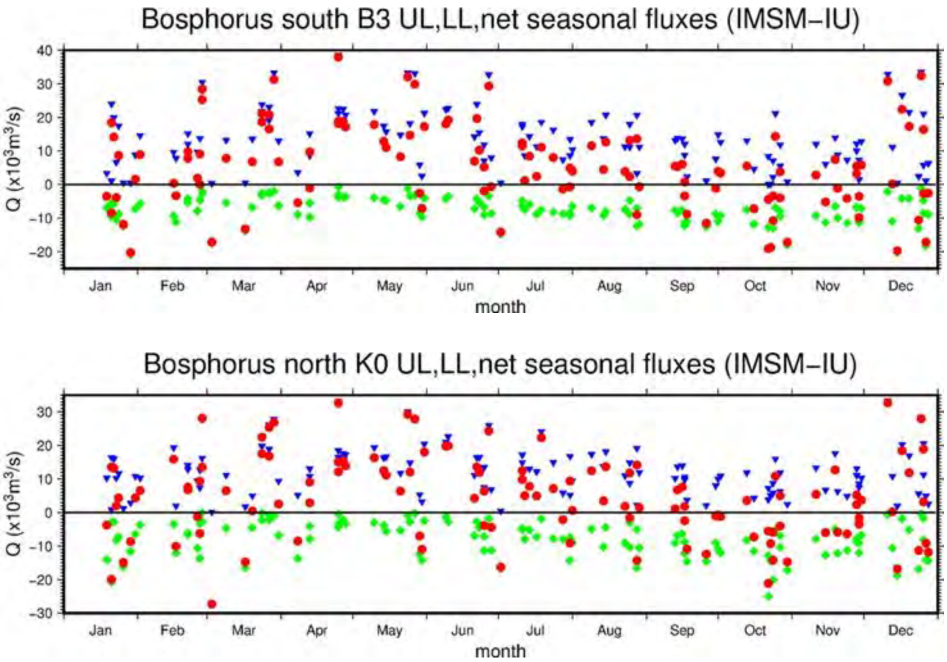



**Figure 5.** Seasonal variations of the upper (blue, inverted triangles), lower (green, diamonds) layer and net (red, circles) volume fluxes at sections B3 and K0 respectively at the southern and northern exits of the Bosphorus Strait.

The summary of all past flux estimates, based on historical as well as mass balance calculations and those obtained from vessel-mounted ADCP measurements presented in the above sections are parametrically replotted in Figure 6, with the net flux in the abscissa and the upper and lower layer fluxes in the ordinates. The net flux, a measure of currents integrated across the whole section, is actually the main forcing of the strait, while the layer fluxes represent the response. There appear clear relationships between primary flux variables confirmed by different sets of measurements, although a lot of scatter in the data is also present as a result of the deficiencies in measurement instruments and flux estimation methodologies. It is also evident from Figure 6 that either the upper or the lower layer currents are blocked beyond certain limiting values of the net flux.

Approximate limits for the net current to block the upper and lower layers respectively are -20000 m3/s (630 km3/y) and 30000 km3/s (950 km3/y) according to the results from all measurements reported above. These limits are consistent with modelling results of Sözer and Özsoy (2016) and Sannino *et al.* (2016) evaluated in the latter, though not presented here.

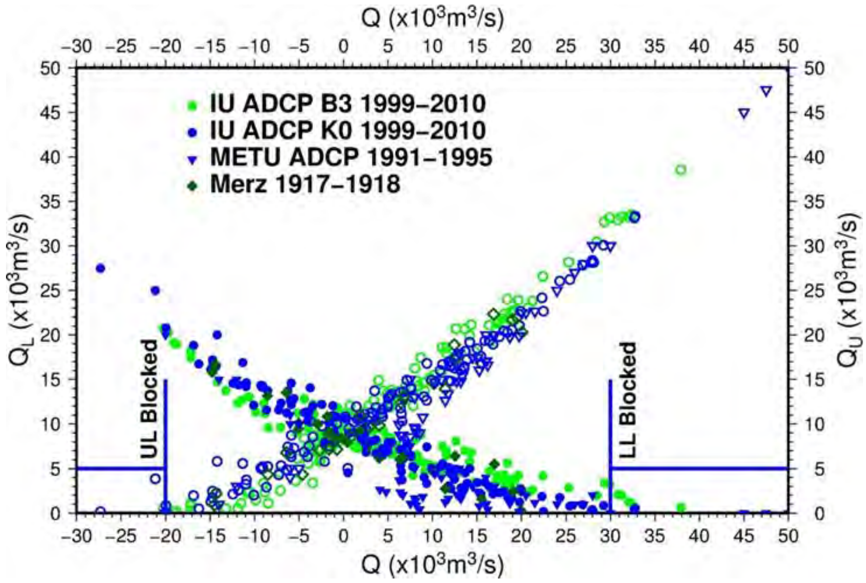



**Figure 6.** Upper and lower layer fluxes as a function of the net flux in the Bosphorus Strait. The sign convention in this figure sets both the upper layer and the lower layer fluxes to have positive values in their respective general flow directions.

### 4. Continuous Flux Measurements

More recent volume flux estimates based on continuous current measurements at the Bosphorus and Dardanelles Straits are documented in a series of papers presented by Jarosz *et al.* (2011a,b, 2012, 2013) and Book *et al.* (2014).

The monitoring of the currents have been based on pairs of moorings containing acoustic Doppler current profilers (ADCPs) deployed at each end of the Bosphorus Strait as a part of the United States Naval Research Laboratory's "Exchange Processes in Ocean Straits (EPOS)" project, and the deployments facilitated by the joint program TSS-08 of the NATO Undersea Research Center(NURC) and the Turkish Navy Navigation, Hydrography and Oceanography Office (NHO). The continuous measurements by moored instruments at the two ends of the Bosphorus covered about six months, while the same at the Dardanelles covered more than a year during the 2008-2009 period. We evaluate these data with respect to layer and mean fluxes which have been shared by the experimental group, although the full data set has not been shared to date.

Time series of the measured volume fluxes are shown in Figure 7, with trends represented by the straight lines. While a great amount of variability is observed in both straits, the Dardanelles time series shows much greater variability over a longer period of measurement. A greater winter-time variability is also evident in the Dardanelles time-series. Comparing the two ends of each strait, the differences are larger in the Dardanelles as compared to the Bosphorus.

The Bosphorus Strait also displays more regular motions as compared to the Dardanelles. The upper layer of the Bosphorus responds to various forcing factors both local and remote, to vary around a mean positive (southward) flux only interrupted during typical 'Orkoz' or upper layer blocking events, which often end up with the currents being totally reversed to flow north. On the other hand, the lower layer is more steady and when lower-layer blocking events occur the flow is completely stopped in the lower layer. The relatively steady pattern in the Bosphorus in fact suggests strong hydraulic control at the northern sill especially stabilizing the lower layer. During some strong upper layer blocking events, the lower layer currents towards the Black Sea are considerably increased to differ strongly from the otherwise steady pattern. One of these strong events occurred in late November 2008 when an 'explosive storm' passed over the region with a large drop in barometric pressure and strong southerly winds on November 21, as documented by Book *et al.* (2014).

Comparing with the Bosphorus, both layers of the Dardanelles Strait are more variable. However, one is forced to observe some basic differences in behavior. For instance, the upper layer blocking occurs several times in the winter period, but the currents do not reverse direction as much, staying positive most of the time. On the contrary, the lower layer of the Dardanelles Strait fluctuates much dissimilar to the steady behavior of the Bosphorus lower layer. In the southern Dardanelles, the lower layer appears to be intermittently blocked for long periods in winter, while the lower layer flux at the northern (Marmara) side fluctuates in negative and positive directions, continuing to flow towards the Aegean Sea during blocking events detected in the Aegean side, showing the inertia of the flow possibly compensated by the large upward entrainment.

Furthermore, comparing the Dardanelles and Bosphorus records on the same time period, a great degree of similarity exists in the time series, especially for the stronger events related to the dynamic response pattern of the entire TSS.

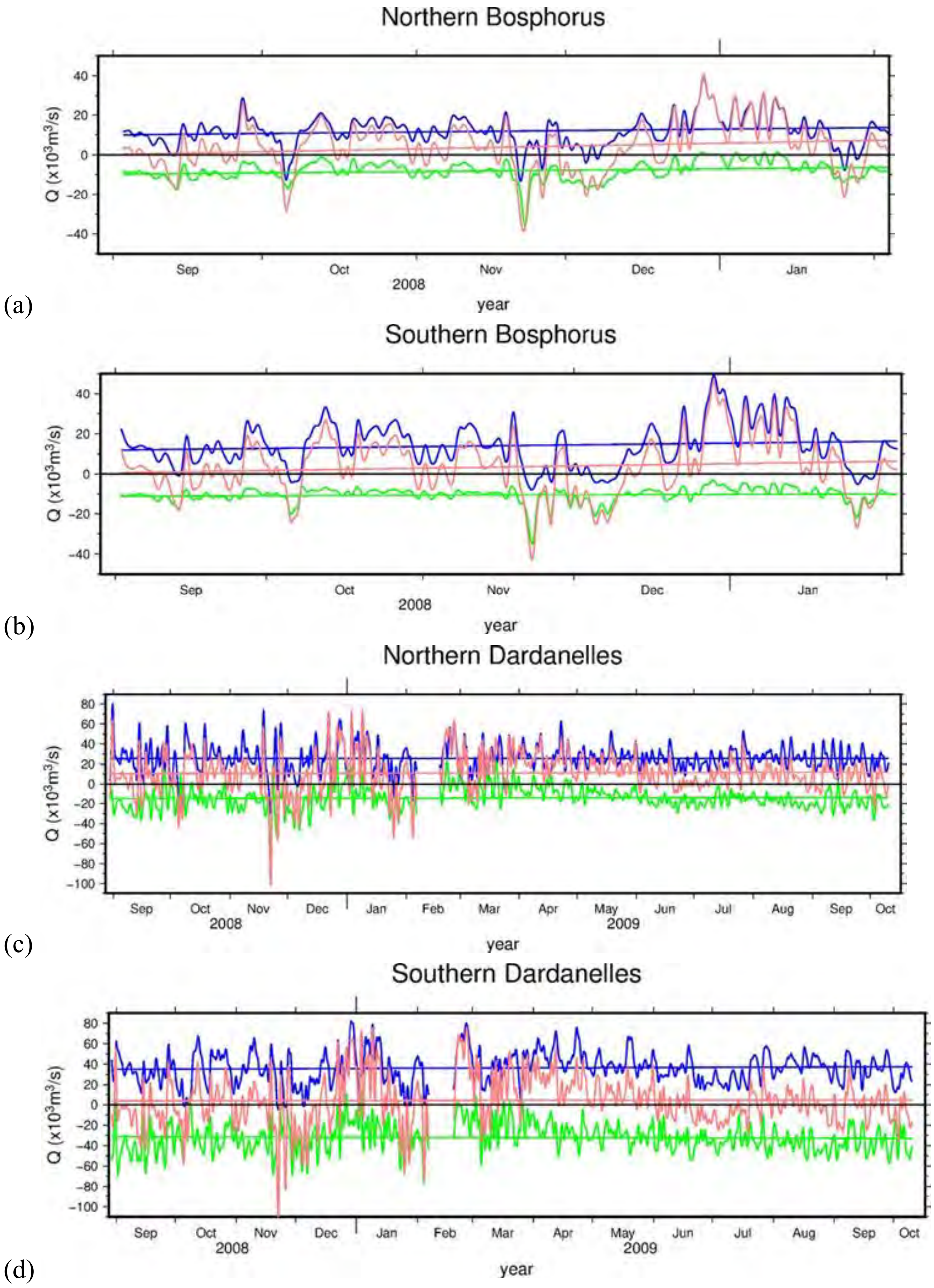



**Figure 7.** Upper (blue), lower (green) layer and net (red) flux time-series at the (a) northern (and (b) southern ends of the Bosphorus Strait, (c) northern and (d) southern ends of the Dardanelles Strait, based on measurements of the NURC TSS-08 campaign. Fluxes are positive in the southward direction. Straight lines indicate trends.

The mean upper, lower layer and net (total) volume fluxes at the two ends of the straits obtained from the continuous measurement campaign and their differences between these two ends of each strait are given in Table 2. Mean values of the upper, lower layers and the total flux respectively were found to be 11900, 8000, 3900 m3/s in the northern Bosphorus, and 14100, 10600, 3500 m3/s in the southern Bosphorus (Jarosz *et al.* 2011b). Based on similar but year-long data, the upper, lower layer and total (net) fluxes were 25600, 14500, 11100 m3/s in the eastern (Marmara) section and 36300, 31100, 4200 m3/s in the western (Aegean) section of the Dardanelles Strait (Jarosz *et al.* 2013). The reason for the relatively low net fluxes compared to other measurements is a result of the measurement period covering mainly the late summer season when river inputs to the Black Sea are usually at a minimum level. The mean flux increases towards the winter, as demonstrated by the analyzed trend in Figure 7a.

**Table 2.** Mean Layer and Net fluxes at the Bosphorus and Dardanelles Straits and Flux Differences between two ends of each strait (positive sign implies southward flow)

| **Layer** | **Bosphorus** | | **Difference** | **Dardanelles** | | **Difference** |
|---|---|---|---|---|---|---|
| | South ($m^3/s$) | North ($m^3/s/$) | South-North ($m^3/s$) | South ($m^3/s$) | North ($m^3/s/$) | South-North ($m^3/s$) |
| **Upper** | 14071 | 11875 | 2217 | 36329 | 25560 | 10844 |
| **Lower** | -10564 | -8018 | -2559 | -32129 | -14473 | -17673 |
| **Net** | 3508 | 3857 | -342 | 4200 | 11087 | -6829 |

These measurements have confirmed the great variability in fluxes, but more importantly showed noticeable differences of the net fluxes between the two ends of the Straits. For instance, the net flux respectively at the southern and northern ends of the Bosphorus are 3500 and 3900 m3/s with south-north difference of -342 m3/s, while the same for the Dardanelles are 4200 and 11200 m3/s with a difference of -6829 m3/s. The difference of net fluxes for the Bosphorus may be acceptable in view of the accuracy of the measurement and computation, though the net flux difference for the Dardanelles is quite larger, on the same order as the mean fluxes, pointing to the inefficiency of the experiment design to measure fluxes in the much wider sections of the strait. With differences of net flux between sections obtained to be on the order of or even larger than the mean value of the net fluxes, it is very difficult to explain the disparity by sources/sinks of water between sections, as they are scarce in the region.

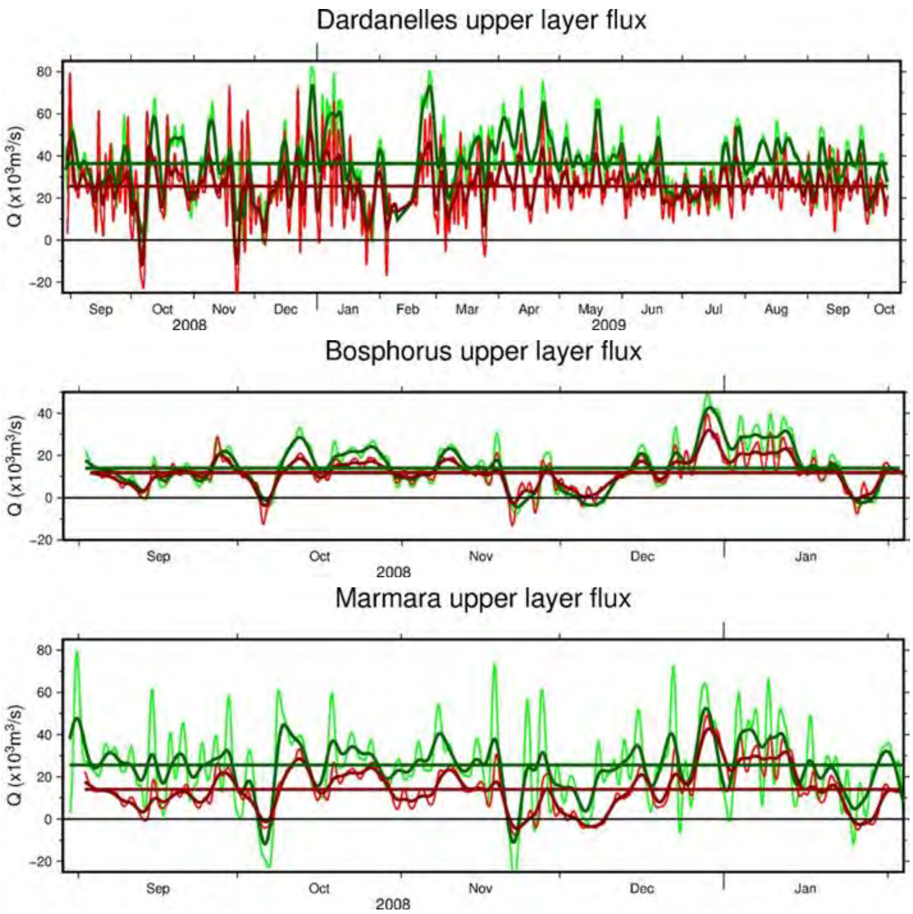
On the other hand, the sense of the change in upper and lower layer volume fluxes between the two ends of the straits seems to be consistent with the estimates given in Figure1. The difference of the upper layer fluxes is positive in a southward direction and for the lower layer it is negative in the southward direction, which implies upward entrainment fluxes. The upward entrainment is reasonable for the Bosphorus, being about the same in both the upper and lower layers, with an average 2300 m3/s, accounting for about 18-24 % of the entering fluxes at the two ends. On the other hand, the upper and lower layer upward entrainment estimates for the Dardanelles Strait differ much between 10800 m3/s and 17700 m3/s with an unreasonable difference of 6800 m3/s between them. This would indicate the ratio of the upward entrainment to entering fluxes to be about 42-55 %.

The measurements essentially confirm in orders of magnitude the results of the earlier measurements and provide essential and detailed characterization of the multiple scales of motion in the TSS. However, this independent evaluation of the Jarosz data set clearly shows that net fluxes computed at four different locations, i.e. the two ends of the two straits, especially for the wider Dardanelles Strait fail to give comparable results between themselves, e.g. the average net flux magnitudes of the time series are very different between different sections, although the average net fluxes should in fact be strictly identical between different sections, in view of the continuity equation of fluid dynamics, unless a significant volume of water is added by external sources such as precipitation minus evaporation.

Time series of the differences in upper, lower layer and net fluxes computed between pairs of sections respectively are shown in Figure 8-10, where the upper panels (Figure 8-10a) represent differences between south and north sides of the Dardanelles, the middle one (Figure 8-10b) corresponds to the same for the Bosphorus, and the lower one (Figure 8-10c) to the difference between the Marmara sides of the Dardanelles and Bosphorus Straits. Time series filtered with a time window of 150 hr (~17d) are also shown. The mean values of time series are indicated by the horizontal lines.

It is clearly shown that large differences exist between the two ends of the Dardanelles and Marmara segments, while these differences are smaller for the Bosphorus sections.

The upper layer fluxes compared in Figure 8 indicate differences in all four sections which explicable both because of the entrainment fluxes between layers and the surface fluxes by atmospheric or land-based sources. The larger differences are between the two ends of the Dardanelles and the Marmara Sea segments, and smaller for the Bosphorus which is shorter. On the other hand, it is significant that the lower layer fluxes compared in Figure 9 indicate comparable magnitudes between the two ends of the Bosphorus and Marmara segments, the mean lower layer fluxes between the two ends of the Dardanelles are larger, the difference being on the same order as the mean inferred from all sections. The means of the Marmara and Bosphorus lower layers are consistent because there could not be too great effects of downward entrainment as the upper layer is faster, and there could not be any external water sources as well. Therefore the Dardanelles measurements are possibly less internally consistent.




(a)

(b)

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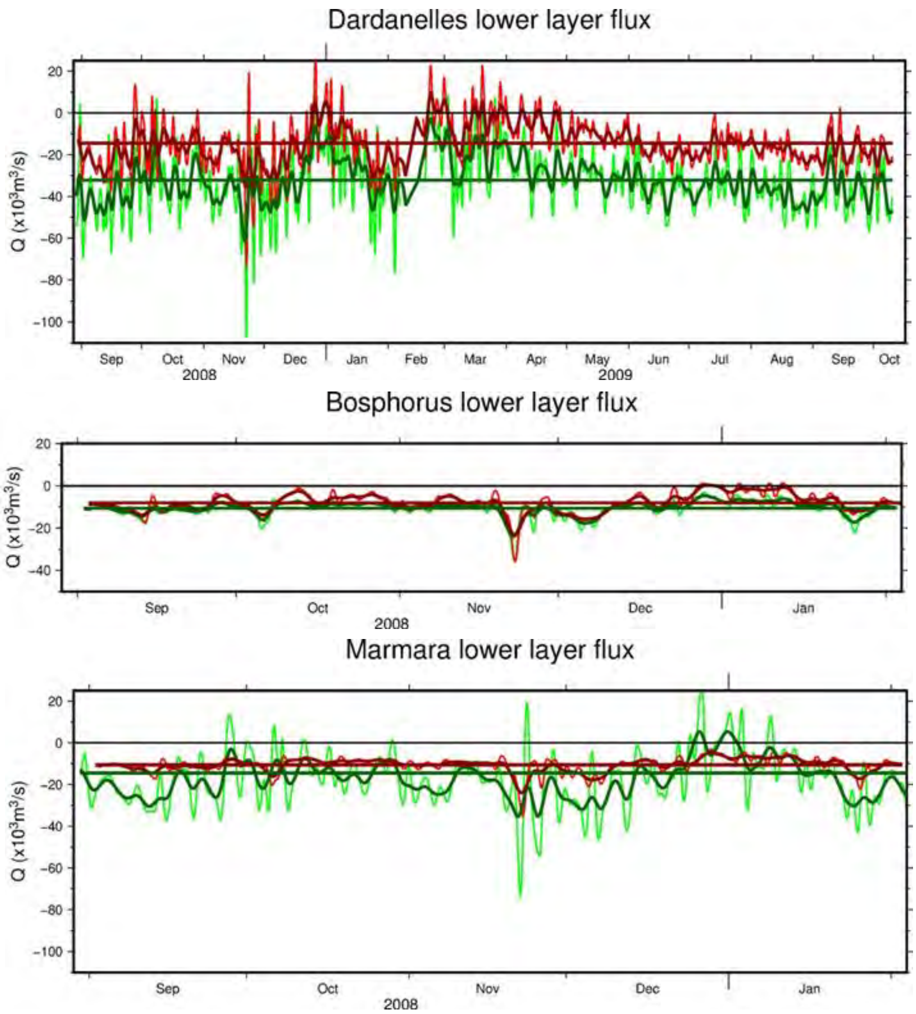
**Figure 8.** Time series and means of the upper layer fluxes for segments of the TSS compared at pairs of southern (green) and northern (red) sections, based on measurements of the NURC TSS-08 campaign. The superposed darker lines of the same colour show time series filtered with a time window of 150 hr. Fluxes are positive in the southward direction. Straight lines indicate mean values of the original time series.




(a)

(b)

(c)

**Figure 9.** Time series and means of the lower layer fluxes for segments of the TSS compared at pairs of southern (green) and northern (red) sections, based on measurements of the NURC TSS-08 campaign. The superposed darker lines of the same colour show time series filtered with a time window of 150 hr. Fluxes are positive in the southward direction. Straight lines indicate mean values of the original time series.

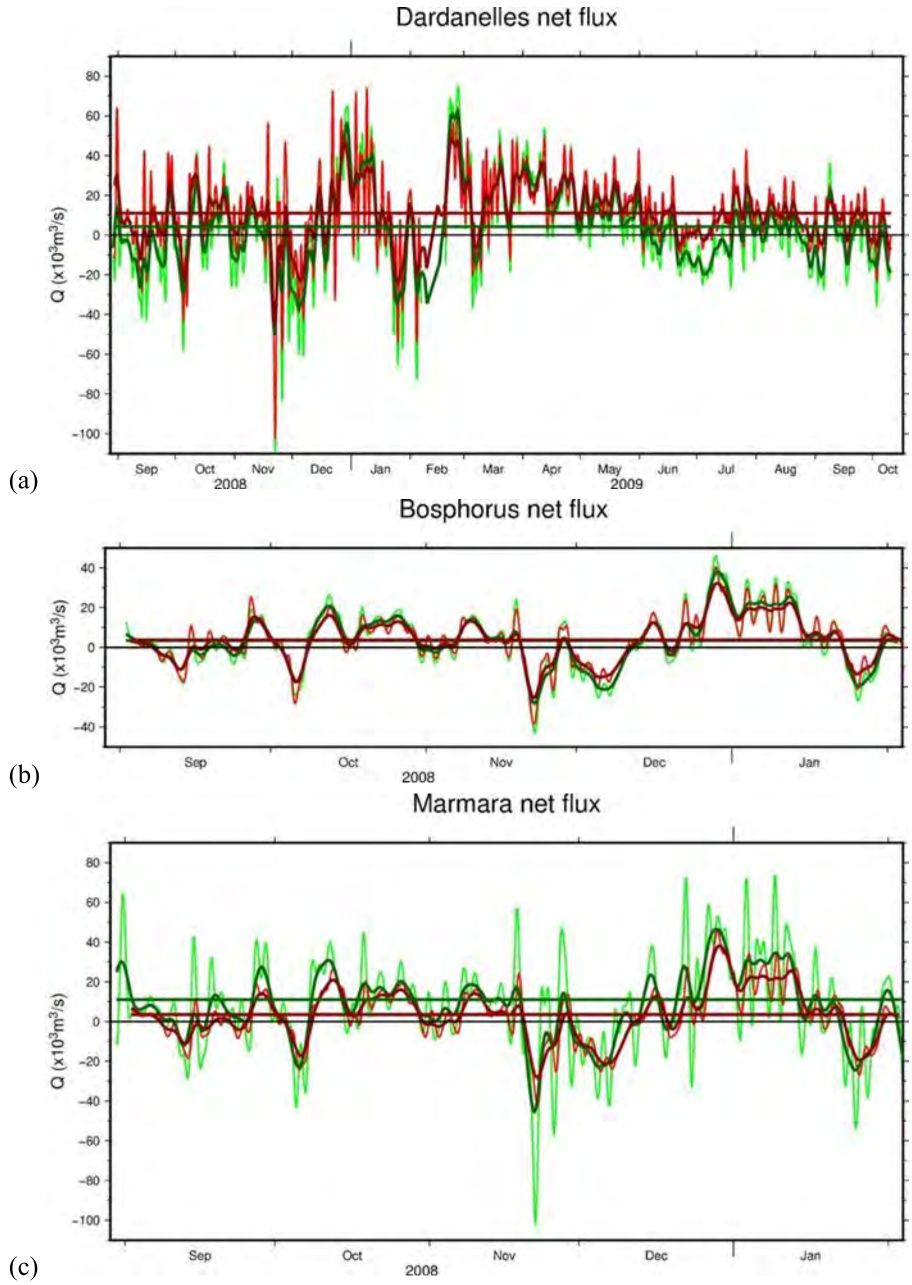


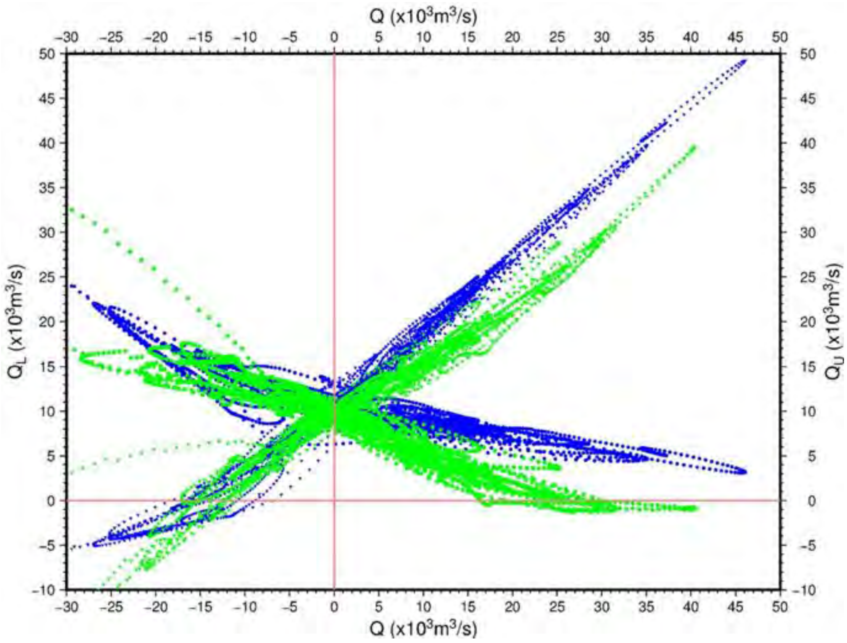

**Figure 10.** Time series and means of the net (total) fluxes for segments of the TSS compared at pairs of southern (green) and northern (red) sections, based on measurements of the NURC TSS-08 campaign. The superposed darker lines of the same colour show time series filtered with a time window of 150 hr. Fluxes are positive in the southward direction. Straight lines indicate mean values of the original time series.

The net fluxes at two ends are compared in Figure 10 for the Dardanelles, Bosphorus and Marmara segments, all of which are showing positive net fluxes towards the Aegean Sea. The agreement of the net flux is better for the Bosphorus compared to the Dardanelles, which once again shows a greater level of difference. In fact the greatest difference is displayed in the net fluxes between the two ends of the Marmara segment, which could be explained both by external water fluxes, but not by entrainment from the lower layer, because the lower layer differences in Figure 9c were not that large. It seems that the larger error in the Dardanelles measurements are associated with the section at the exit to the Marmara Sea.

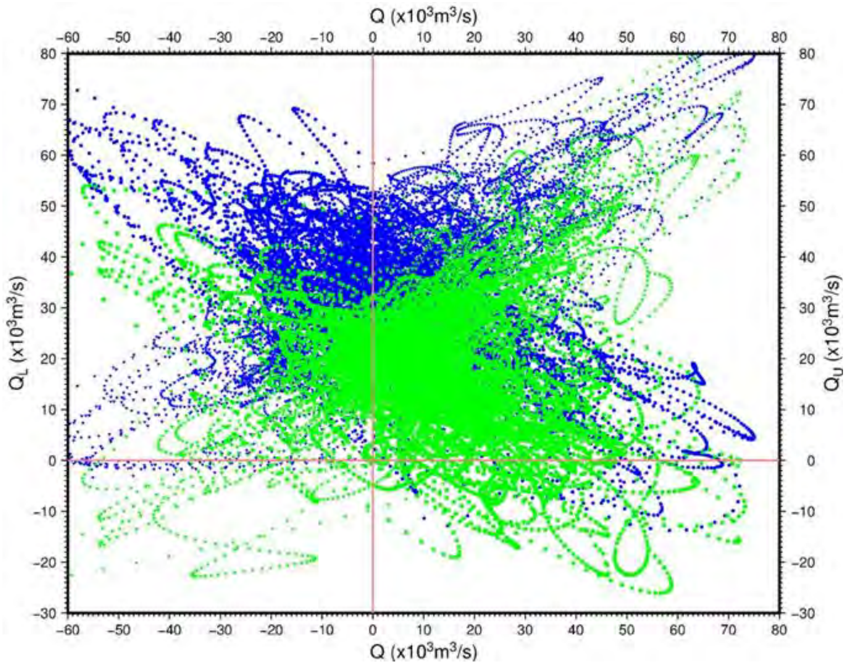
Finally, we make parametric plots of the EPOS/NURC flux time series data in Figure 11, in a similar manner we have done for the other experimental data in Figure 6. While the data presented in Figure 6 have random sampling times, these time-series data are based on continuous sampling obtained from moored instruments at strategic sections of the TSS. Therefore they represent the dynamic response of the TSS. In Figure 11a we plot the characteristics of the two ends of the Bosphorus Strait, while in Figure 11b we do the same for the Dardanelles Strait.

It is in fact not very surprising that the response of the Bosphorus Strait differs in appearance from the Dardanelles Strait. What is surprising is that the response in the Bosphorus Strait follows a very clear pattern as compared to the response in the Dardanelles Strait, considering that the time-series represent a dynamical response of a system. We would normally expect a parametric dependence fluxes in a statistical sense by plotting time averaged or randomly sampled characteristics, and that is what was done in Figure 6. In Figure 11 summarizing the dynamic responses of the two straits, one would therefore expect a large scatter about some mean values, and this is more apparent in Fig11b relative to Figure 11a. In fact, if we consider these figures to be similar to phase diagrams of a nonlinear dynamical system, then the phase trajectory of the Bosphorus follows a regular pattern, while the phase trajectory of the Dardanelles is more irregular.

We believe the regular behavior observed at the Bosphorus (Figure 11a) is due to the strict hydraulic controls at the two or more sections of the strait constituting a "maximal exchange" response, while the relatively less orderly behavior of the Dardanelles (Figure 11b) indicating greater freedom in its response because of the "sub-maximal" nature of the control existing only at the Nara Pass. The differences of response between the two ends of either strait in Figure 11 are due to the difference in upper and lower layer fluxes between the two ends as remarked earlier, resulting from either entrainment processes transporting material between layers or external effects of evaporation, precipitation and runoff. Letting alone the external sources, which should have limited influence during the rapid transit of upper layer waters through the straits, the generally greater flux found at the southern sections indicate entrainment to be directed towards the upper layer.




(a)




(b)

**Figure 11.** Correlograms of upper and lower (green) layer fluxes with the net flux time series for the (a) Bosphorus and (b) Dardanelles Straits. The blue dots are for the southern end and the green dots are for the northern end sections for both straits.

**Acknowledgements**

We thank the great number of people from various institutions responsible for collecting the data analyzed in this review, essentially the faculty, students, technicians and captains from the IMS-METU and the IMSM-IU, who have spent great efforts over the many years since the very beginning of TSS research in the 1980's. We also thank Ewa Jarosz for providing the volume flux data of the TSS-08 experiments. Various kinds of support have been provided by İSKİ and TURBO projects..

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## SEA LEVEL AND FIXED ADCP MEASUREMENTS FROM TURKISH STRAITS SYSTEM DURING 2008-2011

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### 1. Introduction

The Turkish Straits System (TSS) is a unique channel system between the Black Sea and the Mediterranean Sea, which plays key role in exchanging water and materials through the Dardanelles (DS) and Bosphorus Straits (Ünlüata *et al.* 1990). The channel system is vital for both the Black and the Mediterranean Seas, since the TSS is sensitive to climatic changes and contrasts (Özsoy 1998). It is also capable of driving environmental changes in the adjacent basins disproportionate to its relative size (Özsoy *et al.* 2001). Mass balance estimates of the fluxes through the system and dynamical factors leading from daily to inter-annual variability in the currents have been reviewed in the past literature (Ünlüata *et al.* 1990; Latif *et al.* 1991; Özsoy *et al.* 1996; Özsoy *et al.* 1998; Gregg *et al.* 1999; Gregg and Özsoy 2002).

The main objective of the present study is to obtain long-term surface atmospheric and ocean data in an attempt to understand and quantify regional climatic variability in the Turkish Straits System as well as assess the effects of such variability on the Mediterranean-Black Sea coupling through the Turkish Straits System. We provide some salient results here, while the full details can be found in Tutsak *et al.* (2010) and Tutsak (2012).

### 2. Materials and Methods

### 2.1. Datasets

Measurements from 6 coastal stations located in the Turkish Strait System were obtained between January 2008 and December 2011. The coastal stations are in Gökçeada (Aegean Sea), Erdek, Marmara Ereğlisi and Yalova (Marmara Sea), Şile and İgneada (Black Sea). These stations were installed within the framework of the Turkish Meteorology and Oceanography Network of Excellence (MOMA) project in order to observe sea level and meteorological parameters, namely; atmospheric pressure, air temperature, air humidity, wind velocity and wind direction. In addition to these parameters, current profile data were collected at Baltalimanı (Bosphorus) between 2008 and 2011 using ADCP instrument deployed at 70m depth connected to the shore with a cable for data acquisition. The MOMA project has been described by Özsoy *et al.* (2009).

## 3. Results and Discussion

### 3.1. Sea level

The seasonal variations of monthly mean sea level at all stations, based on a common datum, are plotted in Figure 1. The seasonal maximum of sea level in the Mediterranean occurs in the period July-August, while the lowest sea level occurs in the period March-April, with a difference of 17 cm between the lowest and highest monthly value in the Mediterranean. A great amount of this variation is attributable to the seasonal steric affect that is the thermal expansion of sea water. On the other hand, this situation is not valid for the Turkish Straits System and especially in the Black Sea where the lowest monthly mean sea level values are found in autumn whereas the highest occurs in March-April. As for Marmara Sea, the highest monthly sea level is seen in June and the lowest means are observed in the autumn season.

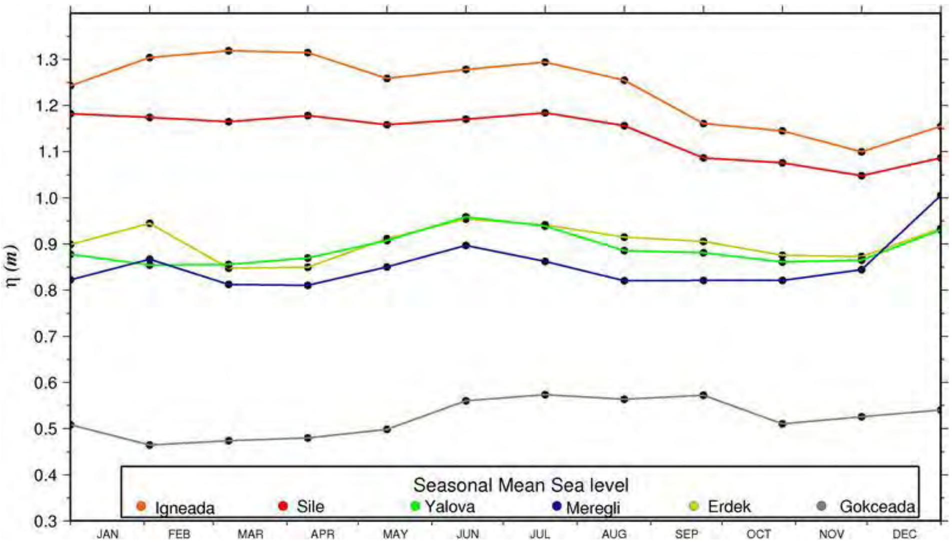


**Figure 1.** Monthly mean average sea level at TSS stations between 2008 and 2011.

With respect to inter-annual variability, the annual mean sea level in 2010 is higher than other years at all stations. In the Mediterranean Sea there is about 4.5 cm difference between 2010 and other years such that the annual mean of 2009 and 2011 is almost same in the Mediterranean. In the Marmara Sea, the mean of 2010 is greater, by 10.2 cm from 2009 and by 13.5 cm from 2011, respectively. Lastly, the mean of Black Sea in 2010 is 12.3 cm and 14.8 larger than 2009 and 2011, respectively. The year 2008 is not taken into account on annual scale due to the low data coverage during this year. On the other hand, the records indicate abnormal sea level rise in the year 2010, especially in the Black Sea.

The possible relationship of the increased sea level to the North Atlantic Oscillation (NAO) is examined in Figure2, indicating mostly negative NAO index during 2010, when the sea level is at its maximum. The NAO index measures pressure differences of air masses between Azore high and Iceland low. Positive winter NAO index often results in the arrival of cold and dry air masses to southern Europe and the Black Sea region by strong northwesterly winds whereas the negative winter NAO brings milder winters with warmer air temperatures and more wet atmospheric conditions transported over the Black Sea from the southwest (Hurrell *et al.* 2003). Stanev (2002) has shown the coincidence of maxima in river runoff with the negative extremes in the NAO index, based on several decades of observations. We infer that the possible reason for the increased sea level in 2010 could be related to increased runoff, since our records do not indicate abnormal changes in the mean atmospheric pressure and winds.

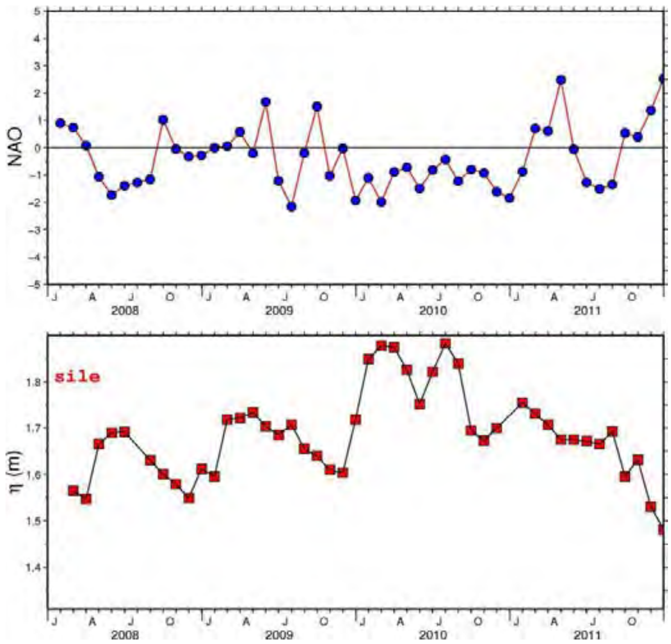


**Figure 2**. North Atlantic Oscillation monthly index (upper panel); Şile monthly sea level from 2008 to 2011 (lower panel).

### 3.1.2. Case studies of short term sea level variations

We display only few cases of temporal variations of significant events in this paper, one of which is displayed in Figure 3 for the Yalova Station in the Marmara Sea. Persistent northeast winds during 15-18 February 2008 (days 46-49) with wind velocity reaching about 17 m/s are observed to result in about 50 cm decrease in the sea level.

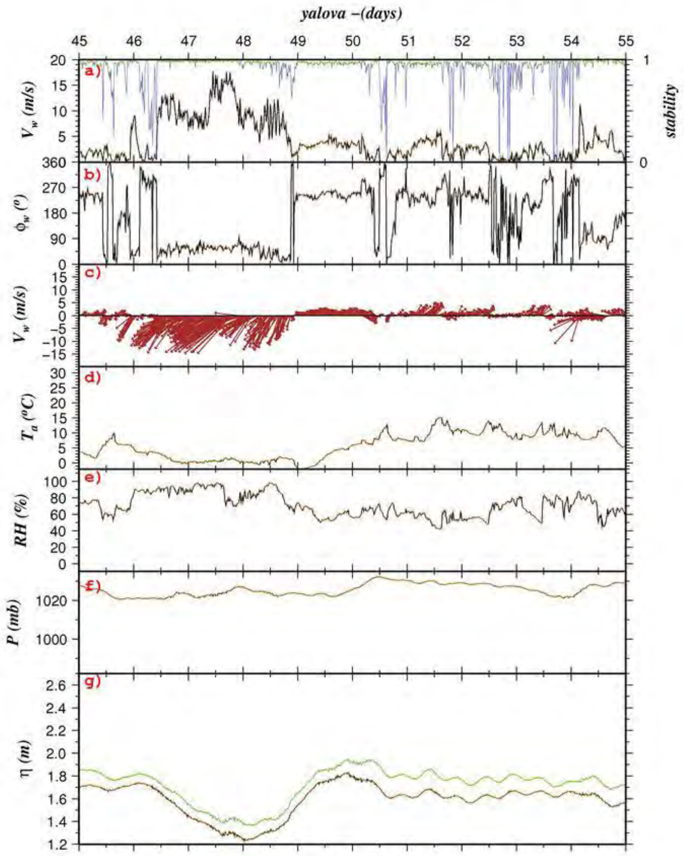


**Figure 3.** Time-series at Yalova station during 14-24 February 2008 (days 45-55) for (a) wind speed (upper part: wind vector stability), (b) wind direction (measured from east), (c) wind vector, (d) air temperature, (e) relative humidity, (f) barometric pressure and (g) sea level (with and without barometric pressure adjustment).

At the same time in Figure 3, it is noted that the sustained winds causing a sea level drop during 15-18 February 2008 are not associated with a passing storm as no significant drop is detected in the barometric pressure signal. This is an event when unidirectional steady winds sustained from the northeast has resulted in the free surface piling up towards the west in the Marmara Sea and dropping at Yalova in the east.

In comparison to the above description of the effects of steady winds, the events during 20-30 November 2008 (days 325-355) at Yalova in the Marmara Sea (Figure 4) show some contrasts in behavior under combined effects of atmospheric pressure and winds created by passing storms. There is approximately 50 cm increase in the sea level at the Yalova station during 20-23 November 2008 (day 325-328), when a very intense storm center passed the region, during which the atmospheric pressure dropped very rapidly from 1015 mbar to 982 mbar and southwest winds with 8 m/s velocity prevailed.

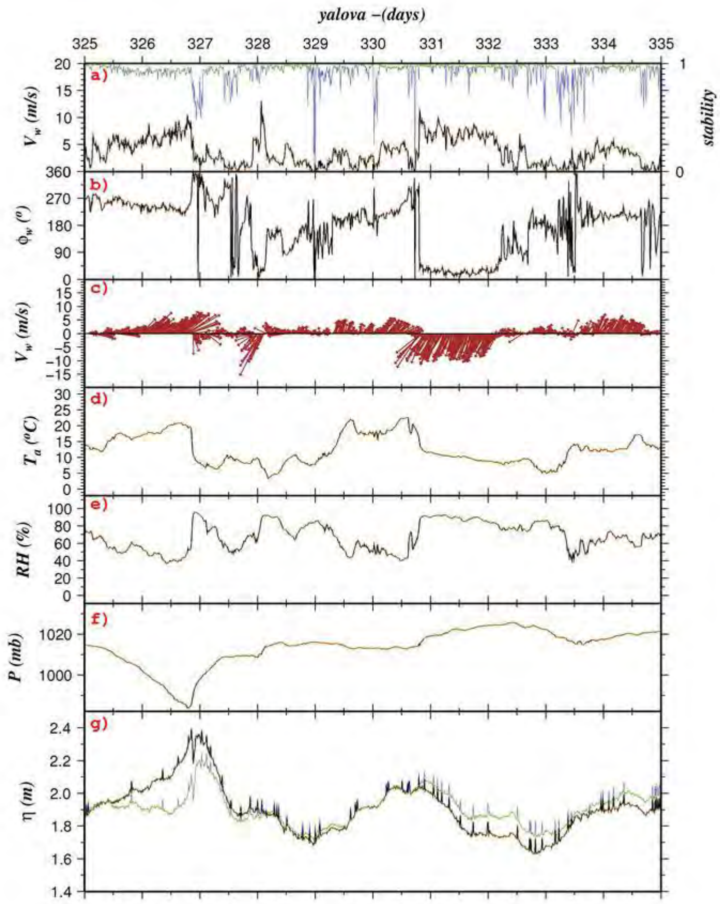


**Figure 4.** Time-series at Yalova station during 20-30 November 2008 (days 325-355) for (a) wind speed (upper part: wind vector stability), (b) wind direction (measured from east), (c) wind vector, (d) air temperature, (e) relative humidity, (f) barometric pressure and (g) sea level (with and without barometric pressure adjustment).

In this event of 20-23 November 2008 (day 325-327), the southwesterly wind forcing of the approaching storm and the strong pressure drop at the cyclone center are responsible for the notable increase in sea-level at Yalova. The event, characterized by an "explosive" cyclone, has been studied by Book *et al.* (2014) who conclude that the response of the TSS has been dominated by a variable pressure distribution across the straits and the Marmara Sea, which has forced not only a sharp sea-level response, but also an internal sloshing of the two-layer density stratified volume of the Marmara Sea, with large fluxes through the Straits. Many examples of wind and barometric pressure effects on sea-level are also observed for storms of lesser amplitude.

Cross-correlation between sea level with atmospheric pressure and wind components at Yalova station are given in Figure 5. There is negative correlation between sea level and barometric pressure for time lags of up to one day, and at no lag due to inverse barometer effect, which however should differ from what is usually assumed in the open ocean. The east-west wind component shows strong positive correlation with sea level, while correlation is not found with the north-south wind component. This suggests that the piling up of the water towards the east is effective during westerly winds at Yalova which is at the eastern end of the elongated Marmara Sea.

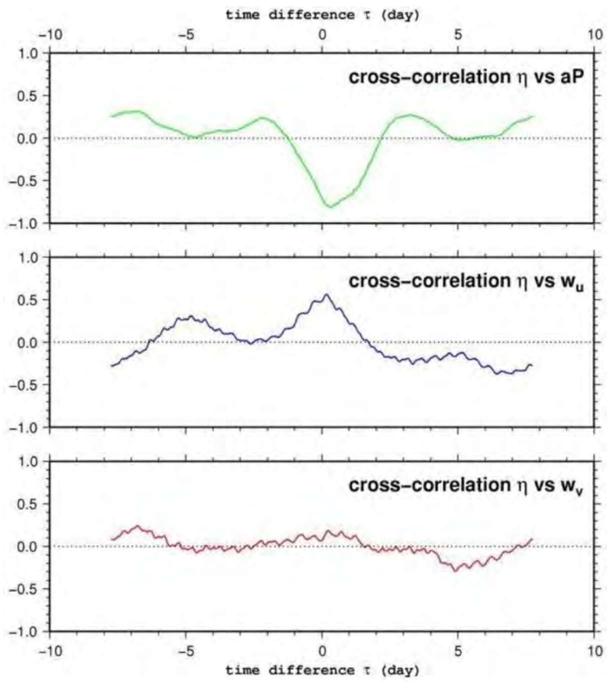


**Figure 5.** Cross-correlation between sea level and atmospheric pressure (upper panel); sea level and east-west wind component (middle panel); sea level and north-south wind component (lower panel) at Yalova station.

### 3.2. ADCP Data

The measurements of current profiles at Baltalimanı on the Boshorus has been carried out by a fixed ADCP installed at 70 m depth. Although a uniform section of the Bosphorus exists in this locality and the instrument has been placed close to the deepest point on the section, the channel is narrow in the deeper section and with the loss of data near the bottom by the ADCP methodology relying on Doppler shifts of acoustic signals in currents, there is usually a loss of few meters at the bottom, further increased by reverberation effects in the v-shaped narrow bottom channel geometry. Therefore, our current measurements in the lower layer may not be representative of the total lower layer currents and fluxes computed from them, due to these measurement problems. Instead we present results for the upper layer, which has been better sampled.

The time series for the upper layer current measurements obtained by the ADCP moored in the Bosphorus and the sea level difference across the Bosphorus, between the Black Sea station Şile and the Marmara Sea station Yalova during 2008-2011 are shown in Figure 6.

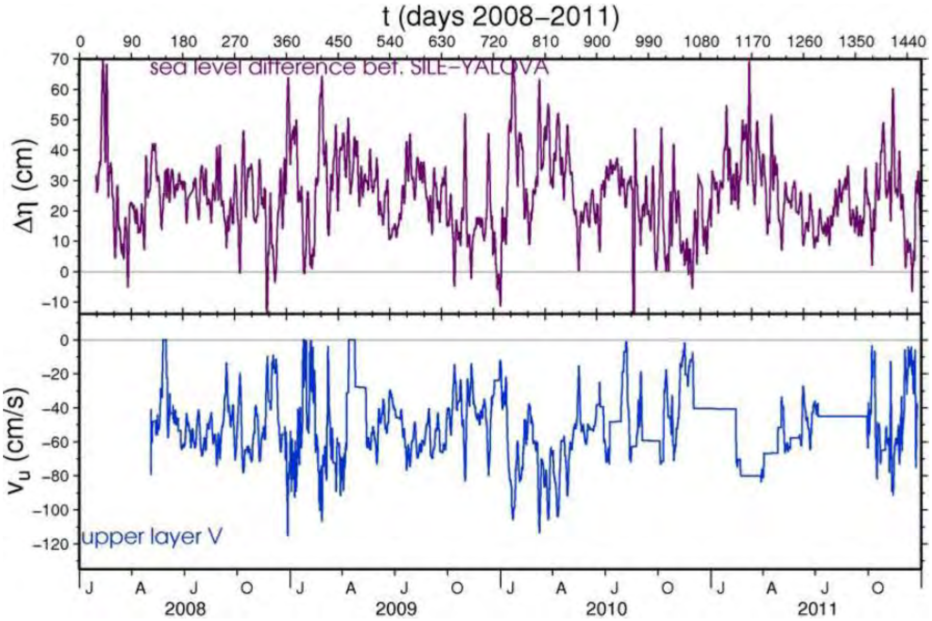


**Figure 6.** Time series of sea level difference Şile-Yalova (upper panel) and the depth average of the upper layer velocity component in the north-south direction at Baltalimanı in the Bosphorus (lower panel).

Despite some gaps in the current data due to non-operational states of the remotely controlled instrument caused by site problems such as electricity cuts and cable repair, the measurements have been continued over a total period of about four years. Comparison of the current data with the sea level difference indicates significant relations between them, with negative currents towards the Marmara Sea increasing at times of higher sea level difference and decreasing when the sea level difference decreases. When the sea level difference becomes very small, zero or negative, the upper layer is blocked, with velocity decreasing to small values or becoming zero.

Summary information on the monthly values of depth averaged upper layer velocity in the north-south direction (positive to the north) is given in Table 1. In March and April, the highest means of upper layer current are found, with a range 0.1 to 0.2 m/s greater than the other monthly means (Table 1). The maximum velocity in upper layer occurs during winter and early spring. The standard deviations of means indicate high temporal variability of the upper layer flow. The annual mean of the upper layer current for the years 2008, 2009 and 2010 are found respectively as -0.515 m/s, -0.507 m/s and -0.552 m/s. Although one is tempted to exclude the annual mean of 2011 due to low data coverage during this year, a mean value of 0.483 m/s is still calculated. The mean value of -0.552 m/s for the year 2010 was in fact distinctively high compared with the other years.

**Table 1.** Monthly average values of the depth averaged Bosphorus upper layer current velocity in the north-south direction (m/s). Positive value is to the north.

| Month | Number of samples | Mean Current (m/s) | Standard Deviation (m/s) | Range (m/s) |
|---|---|---|---|---|
| **January** | 16987 | -0.46 | 0.30 | -1.75 – 0.07 |
| **February** | 15738 | -0.52 | 0.31 | -1.75 – 0.07 |
| **March** | 12954 | -0.68 | 0.23 | -1.65 – 0.04 |
| **April** | 8938 | -0.62 | 0.32 | -1.5 – 0 |
| **May** | 9232 | -0.47 | 0.27 | -1.1 – 0.03 |
| **June** | 9598 | -0.47 | 0.20 | -1.17 – 0 |
| **July** | 7411 | -0.56 | 0.17 | -1.16 – 0.11 |
| **August** | 7504 | -0.54 | 0.19 | -1.13 – 0.05 |
| **September** | 5892 | -0.51 | 0.18 | -1.21 – 0.03 |
| **October** | 15364 | -0.48 | 0.22 | -1.23 – 0.1 |
| **November** | 15945 | -0.49 | 0.24 | -1.25 – 0.08 |
| **December** | 12886 | -0.41 | 0.30 | -1.65 – 0.11 |

### 3.2.1 Upper layer Volume flux

Quantifying the volume flux from vertical profiles obtained at a single location from the bottom-mounted ADCP in the Bosphorus is challenging since the measurements do not provide information on the horizontal distribution of currents. It is assumed that the upper layer velocity and the upper layer thickness is the same along the cross-section, and integrated over the vertically variable width of the channel, possibly resulting in underestimation or overestimation of the upper layer flux. The original 15 min time series and the 3-day low pass filtered version are shown in Figure 7, in the same way as the earlier Figure 6 is obtained.

The original time series calculated from 15 min sampled currents in Figure 7 actually shows great variability, the details of which cannot be fully displayed in this compressed figure. The extreme variability of the upper layer currents on short term is such that fluctuations in volume transport are often two or three times greater than the mean values. Both very high negative values (towards the Marmara Sea) outside the limits of display and zero or positive values (towards the Black Sea), the latter occurring during "Orkoz" events, are found in the original time series. By applying a low pass filter a lot of the variability is removed to show the essential features on scales longer than 3 days, but at the cost of simplifying the original variability showing many extreme but frequent conditions of both very high fluxes and the occurrences of short term upper layer blocking events.

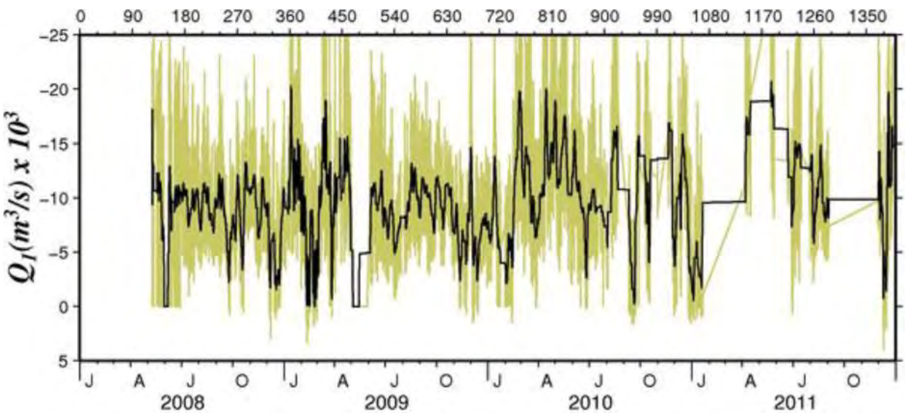


**Figure 7.** Time series of the upper layer volume flux during the study period (yellow=15 minutes data, black= 3-day low pass filtered data)

A summary of the calculated monthly mean upper layer fluxes is given in Table 2. Based on these results, the largest transport in the upper layer appears to occur in the spring and early summer, especially in March whereas the lowest transport in the upper layer takes place in the fall and winter. The annual mean of upper layer volume flux in the years 2008, 2009 and 2010, respectively are -9028 $m^3/s$, -8549 $m^3/s$ and -10341 $m^3/s$. We note once again that the upper layer volume flux for 2010 is larger compared with other years.

**Table 2.** Monthly average values of the depth averaged Bosphorus upper layer volume flux in the north-south direction ($m^3/s$). Positive value is to the north.

| Month | Number of samples | Mean Volume flux ($m^3/s$) | Standard Deviation ($m^3/s$) | Range ($m^3/s$) |
|---|---|---|---|---|
| **January** | 16987 | -7608 | 5208 | -49407 – 3373 |
| **February** | 15738 | -8894 | 5603 | -46887 – 1884 |
| **March** | 12954 | -11605 | 4478 | -51175 – 1081 |
| **April** | 8938 | -10931 | 6006 | -41491 – 0 |
| **May** | 9232 | -9306 | 5626 | -28457 – 680 |
| **June** | 9598 | -9525 | 4439 | -28960 – 0 |
| **July** | 7411 | -10413 | 3712 | -28241 – 792 |
| **August** | 7504 | -9577 | 3715 | -24496 – 1689 |
| **September** | 5892 | -8900 | 3258 | -26492 – 849 |
| **October** | 15364 | -9641 | 4979 | -29761 – 4014 |
| **November** | 15945 | -10234 | 5611 | -32640 – 3076 |
| **December** | 12886 | -7570 | 5527 | -41441 – 2314 |

### 3.3. Bosphorus Upper Layer Current versus Sea Level Difference between Marmara and Black Seas

The sea level difference between the Black Sea and the Marmara Sea with ancillary data such as atmospheric pressure, atmospheric pressure and wind velocity are examined using data from coastal stations. The sea level difference between the Black Sea and The Marmara Sea based on the the measurements at Yalova and Şile coastal stations over the study period varied from -14 cm to 71 cm with a mean of 26 cm. The sea level difference between the Black Sea and the Marmara often responds to the winds over the region. The northerly winds increase the sea level north of Bosphorus, while the while southerly winds do the reverse by increasing sea level south of the Bosphorus. Since the wind setup is enhanced in shallower regions, increasing inversely with the water depth, it is not surprising to observe that the sea level change due to the wind setup in the South of the Bosphorus, in the shallower Marmara Sea is relatively greater than in the north of Bosphorus, in the Black Sea. The barometric pressure difference between the two seas at stations at the two ends of the Bosphorus varies at most by about 3 mbar, which is not enough to create the observed total changes in sea level differences. However, the barometric pressure averaged over the Black and the Mediterranean Seas area should be great enough to be one of the drivers of the exchange.

The present results for the sea level difference between the Marmara Sea and the Black Sea are different from previous observations reported by others. The average annual sea level difference between the ends of Bosphorus was estimated as 35 cm by Gunnerson and Özturgut (1974), as 33 cm by Çeçen *et al.* (1981). Büyükay (1989) found the annual average sea level difference to be 28 cm in 1985, 29 cm in 1896, and 13 cm in 1987. These observations suggest that the average mean sea level difference is typically about 30 cm. The average 26 cm obtained in this study is smaller than these estimates but coincide better with the Büyükay (1989) results.

Time series of Bosphorus averaged upper layer current and sea level differences (Figure 6) indicate that upper current of Bosphorus responds to the sea level differences. An increase of the sea level difference results in accelerating the upper layer current. A linear regression with the least squares approach between sea level difference and upper layer current results in the plot of Figure 8. Although a linear relationship seems to exist, large scatter in the data indicates a more complex dynamic response to be in action.

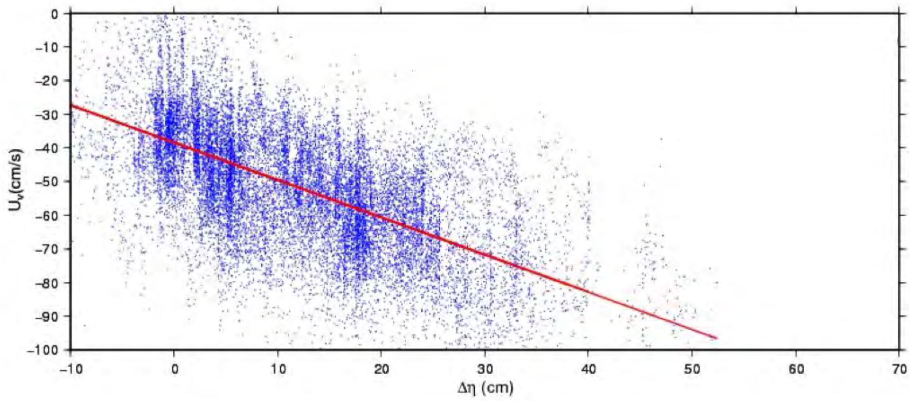


**Figure 8.** The north-south velocity component of the Bosphorus upper layer current versus sea level differences between Şile and Yalova stations.

Time series of the bottom-mounted ADCP currents at Baltalimanı, sea level, wind velocity and barometric pressure presented in Figures 9 and 10 for selected monthly periods illustrate typical response of the Bosphorus as a function of environmental conditions.

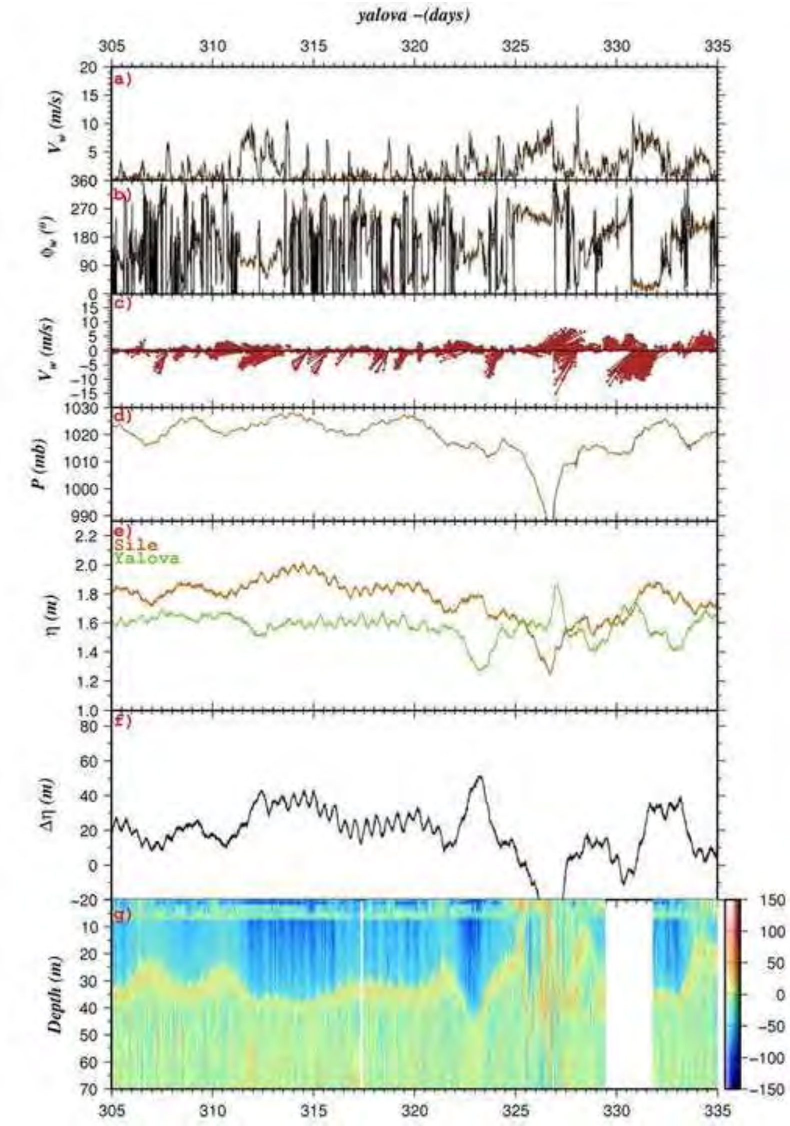


**Figure 9.** Time series of 01-30 November 2008 (days 305-335) for (a) wind speed, (b) wind direction (measured from east), (c) wind vector and (d) barometric pressure at the Yalova station, (e) inverse barometer corrected sea level at Şile (red) and Yalova (green) stations (f) their differences Şile-Yalova, (g) the magnitude and sense of ADCP currents in the north-south direction (north is positive) at Baltalimanı.

During the initial part of the record in Figure 9, rather steady currents of 0.5-1.0 m/s are observed in the upper 30m under calm weather conditions. The sudden drop of barometric pressure (30 mb in about 30 hr) of an atmospheric disturbance creates temporary reversals in flow direction and subsequent oscillations. The oscillatory and mixing effects created by this particular storm have been likened to a “meteorological bomb” (Book *et al.* 2010), based on an extensive set of measurements by Jarosz *et al.* (2011). Interestingly, the sea level rises in the Marmara Sea and falls in the Black Sea in response to the southwesterly winds of the storm, resulting in a negative sea-level difference of about 40 cm with the Marmara Sea being higher than the Black Sea, as opposed to the positive difference of about 10-50 cm earlier.

Our observations of ADCP currents in Figure 9 indicate complete flow reversal at the whole depth of the Bosphorus during 20-24 November 2008 (days 325-328), subject to oscillations. The fact that the whole Bosphorus flowing towards the Black Sea must have completely altered the outflow of dense water referred to as the “Medierranean Effluent” in the Black Sea exit region studied by Özsoy *et al.* (2001) and others. Book *et al.* (2014) point to the greatly increased outflow in the same occasion and Falina *et al.* (2016) find the anomalous intrusions of the resultant transport in the intermediate depths travelling to remote areas of the Black Sea.

According to the ADCP data records, upper layer blockage events lasting for one or two days are seen starting on 13 September, 5 October, 21 November, 5 December of 2008, 25 January, 5 February, 13 October, 12 November of 2009, 01 January, 07 January, 11 January, 17 May, 30 November of 2010 and 7 October, 4 December and 10 December of 2011. The effect of southerly winds on blockage events of Orkoz are clearly documented. Sometimes different local wind conditions are observed simultaneously at both ends of Bosphorus. In such case, the differences between wind setup at each end of Bosphorus govern the exchange flow. According to this study, the blockage events are observed when the sea level difference between two ends are almost equalized and the results demonstrate that the upper layer flow returns to the usual state as soon as blocking conditions vanish. The water column profile indicates that the depth average upper layer current speed can vary between 0.2 m/s and 0.5 m/s during Orkoz. In spring and summer the blockage events aren't observed. This is possibly caused by the weak southerly winds and the increase of the sea level in Black Sea idue to the river input during that period.

Sustained northerly winds in January 2010 (Figure 10), following an initial period of reversals in the first days, result in the sea level difference building up to about 1m, with currents of up to 2 m/s covering the entire depth, leading to blocking of the lower layer currents. This is a very strong case of lower layer blocking observed in the ADCP data and also confirmed by sea level observatins.

The lower layer blockage is also observed on 29 December of 2008, 22 February of 2009 and 22 January, 3 February, 8 March, 8 April, 27 April of 2010. In terms of duration of events, the lower layer blockages typically last longer than the upper layer blockages, but it can be noted that the lower layer blockages were observed to occur less frequently than upper layer blockages during this study. In addition, lower layer blockage events are often accompanied by a sea level difference greater than 60 cm.

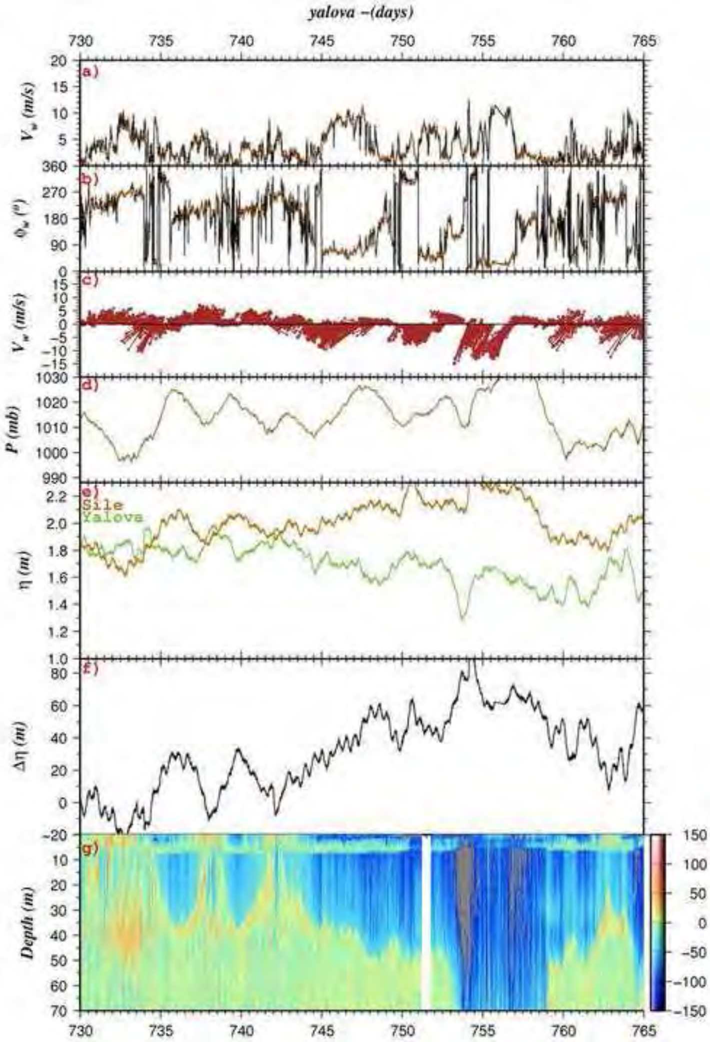


**Figure 10.** Time series of 01 January – 03 February 2010 (days 731-765) for (a) wind speed, (b) wind direction (measured from east), (c) wind vector and (d) barometric pressure at the Yalova station, (e) inverse barometer corrected sea level at Şile (red) and Yalova (green) stations (f) their differences Şile-Yalova, (g) the magnitude and sense of ADCP currents in the north-south direction (north is positive) at Baltalimanı.

## 4. Conclusions

Time series of meteorological and marine data analyzed in this study allow characterization of motion time scales. The sea level is highly variable in the Turkish Strait System. In addition to diurnal and semidiurnal oscillations in sea level, the analyses reveal oscillations varying from several days to weeks owing to winds and barometric pressure differences, although there is very limited penetration of tidal oscillations. The response to atmospheric pressure in either the Black Sea or the TSS cannot be characterized as an inverted barometer response at all. On the other hand, in the Marmara Sea, both atmospheric pressure and winds affect sea level. Annual mean sea level difference between the Black and Marmara Sea is found to be around 26 cm during the study period. However, during upper layer blockage events often the sea level difference vanishes, while the sea level differences of up to 1 m can occur during lower layer blockages. The blockage events are mainly associated with meteorological events such as wind and atmospheric pressure, as well as the net through-flow which is a function of the hydrological situation. The lower layer blockages usually occur in spring due to the increasing of sea level in Black Sea whereas the upper layer blockage events occur in winter due to the southwesterly winds.

## Acknowledgments

The authors acknowledge that this study has been made possible by TÜBİTAK project 105G029, alias MOMA, which was one of the first projects assigned by the Public Research and Development Group (KAMAG) in the 2005-2008 period. One only wishes that this initiative could have been continued its development in a follow-up project. We thank the scientific and technical personnel and captains of the IMS-METU for the extensive efforts they have spent for the field work and at the laboratories. The professional expertise and efforts of the director Amil Turgay and the technical divers of the Derin Dalgıçlık Ltd. company in the installation and replacement of the cabled ADCP system at a deep location in the Bosphorus enabled successful completion of marine operations, while Ejder Varol and Selçuk Karamağara of İdealteknoloji Ltd. company participated in instrument deployment and operation. We also thank the various government organizations that were either part of the project or contributed to it, among them the Ministry of Environment, Undersecretariat of Marine Affairs, Office for Navigation, Hydrography and Oceanography and the General Command of Mapping and their technical personnel who took part in this project.

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## A REVIEW OF BOSPHORUS MEASUREMENTS DURING THE TÜRBO CAMPAIGN (1999-2000)

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### 1. Introduction

A detailed measurement program promoted by the İstanbul Technical University Foundation, Defense Studies Center (İTÜV/SAM) contracted by the Turkish Straits (TÜRBO) administration of the Turkish Government in the 1999-2000 period was carried out by the IMS-METU (1999) to investigate surface currents in the Bosphorus, a key element of enormous importance for navigation and shipping accident risks in the Turkish Straits.

A small ship specially fitted with on board ADCP was used to monitor currents in the Bosphorus, including its many small embayments, shallows and turns in channel orientation, while the research vessel R/V BİLİM collected CTD and ADCP data at stations and transects across the Strait. The experiments were performed on several days during 3-6 September 1998, 4-22 March 1999 and 22 July – 3 August 1999. The magnetic anomalies in compass direction created by the steel hull of the small ship ATMACA II hired from a diving company, as well as the GPS positions and consequently ship course had to be corrected for accurate positioning, by making use of independent measurements of the GPS and bottom tracking.

Current meter and sea-level measurements at fixed stations shown in Figure 1 provided additional information on the flow characteristics. A current-meter at 4.5 m depth was placed at Beylerbeyi near the Small Officers Preparatory School (station CM1/BL: 41º02'36"N 29º02'14") in the southern Bosphorus and two current-meters at 5 and 11 m depths at the headland of Selvi Burnu in the northern Bosphorus (station CM2/SB: 41º08'42"N 29º04'12"E), all of which were Aanderaa RCM7 rotor type recording current-meters. Sea level stations close to these locations were established, installing Aanderaa Water Level Recorders of the WLR7 type on the coast of the Yusuf Kalkavan Mariner High School at Beşiktaş (station SL1/BS: 41º02'19"N 29º01'06"E) and at the pier of the Rumelikavağı Pilot Station (station SL2/RK: 41º10'33"N 29º04'22"E). The positions of the sea level instruments were levelled, yielding +0.818m for SL1/BS and +1.681m for SL2/RK stations. Currents and sea level were measured at 5 min nominal sampling and recording intervals.

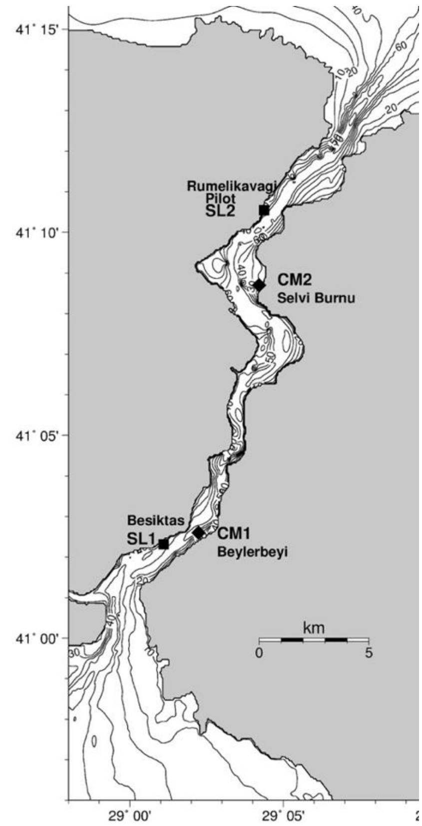



**Figure 1.** Positions of current-metering and sea level stations in the Bosphorus

## 2. ADCP measurements of surface currents

The primary aim of the measurements was to determine surface currents and the associated surface circulation in the Bosphorus, especially to collect elaborate information showing areas of rapid changes in direction and magnitude of currents, meandering and re-circulations in the various bends, corners, deep channels, shallow banks and embayments of the Strait, which are extremely important in general navigation and shipping in this critical high energy region. In order to collect the ADCP data used to construct maps of surface currents, the small boat had to enter shallow areas and travel along the Bosphorus along a route that challenged the very same dangers of navigation in the congested traffic of the Strait. The measurements actually represent near-surface currents at about a depth of about 5 m because of the loss of data near the surface.

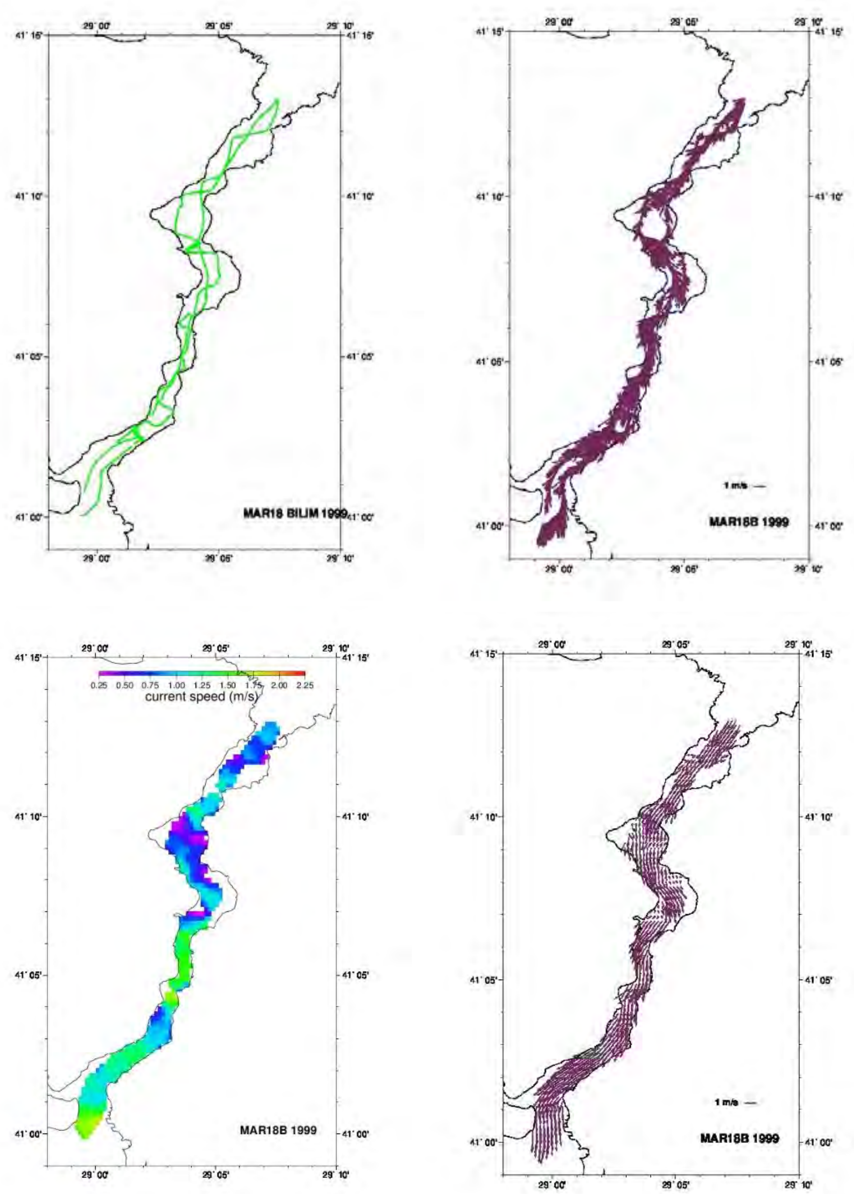



**Figure 2.** Example display of the travel path of the boat ATMACA II along the Bosphorus, the vectors of surface currents sampled along the route, and the interpolated amplitude and vectors of surface currents on March 18, 1999.

An example of the ADCP near-surface (10m) currents obtained by the boat along its path in the Bosphorus and the interpolated fields of current amplitude and vectors are provided in Figure 2. The series of daily surface current maps are provided in Figure 3.

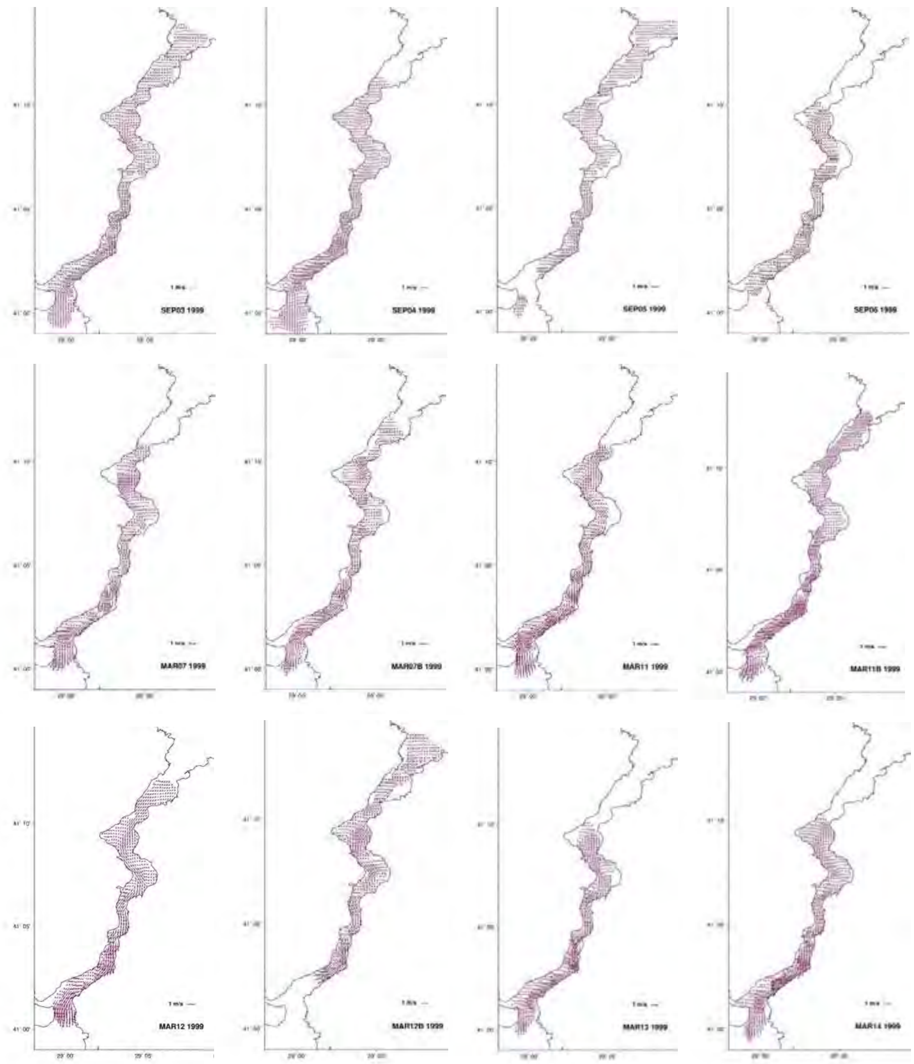



**Figure 3.** Surface currents based on daily measurements horizontally interpolated to the Bosphorus area.

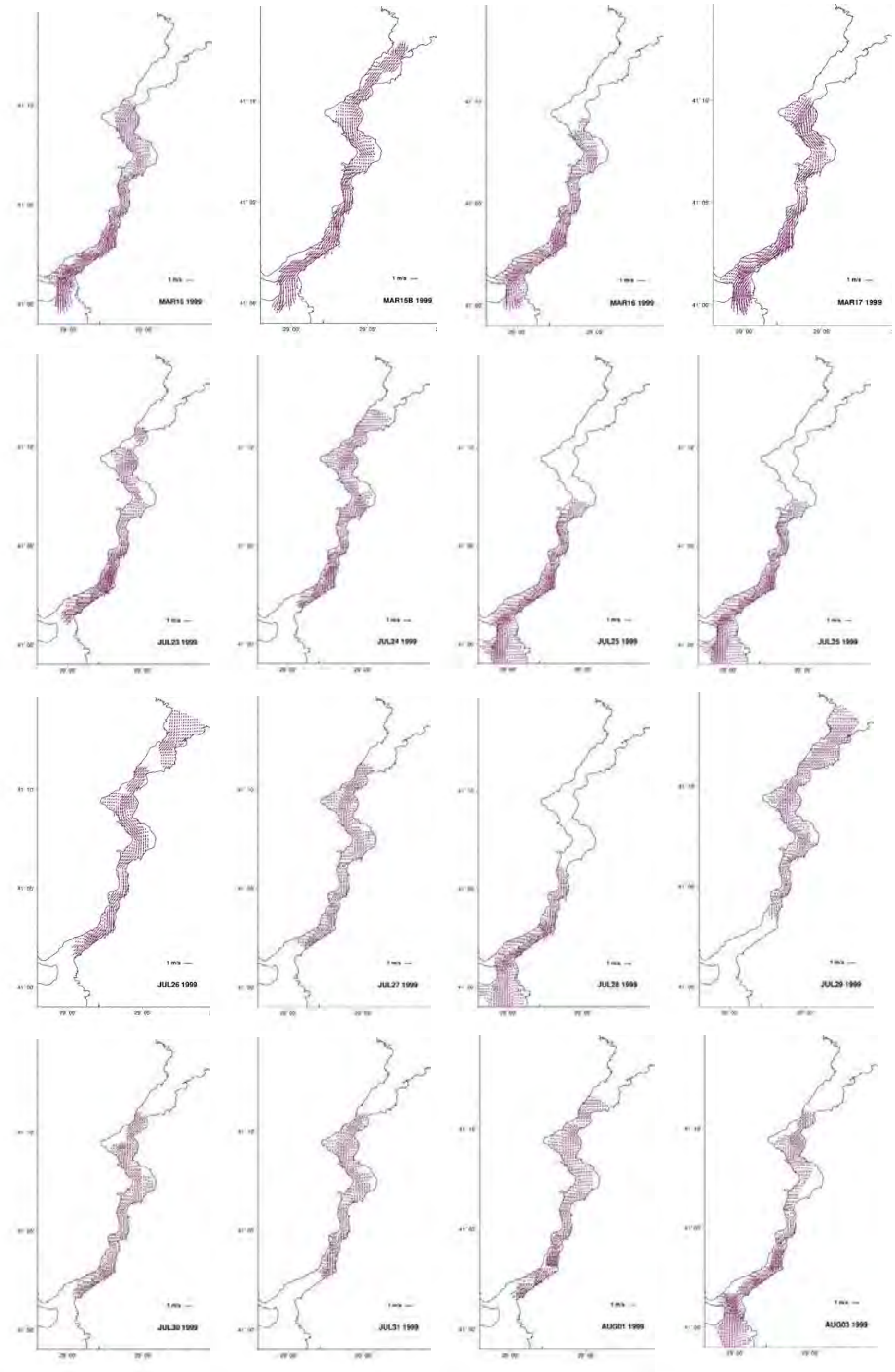


**Figure 3.** continued

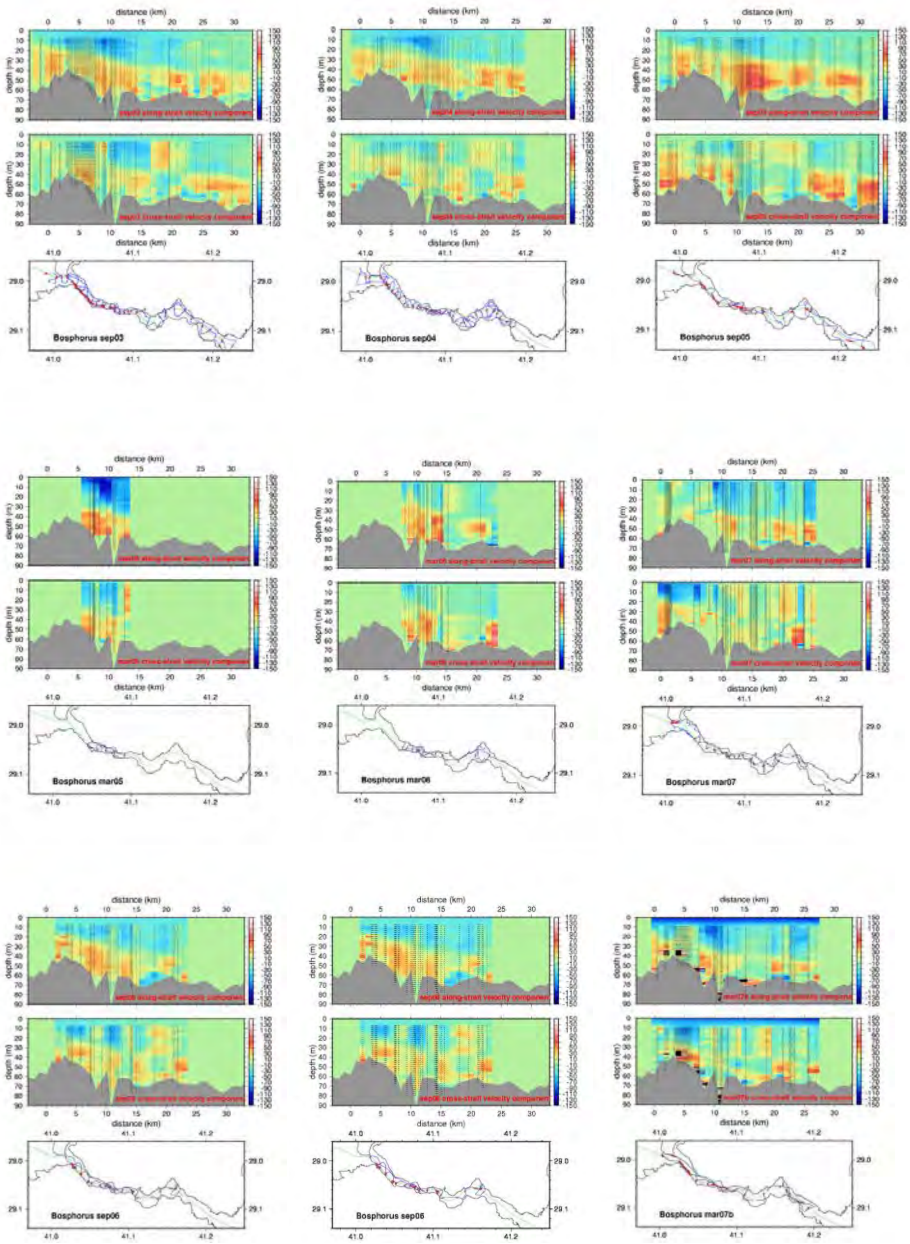
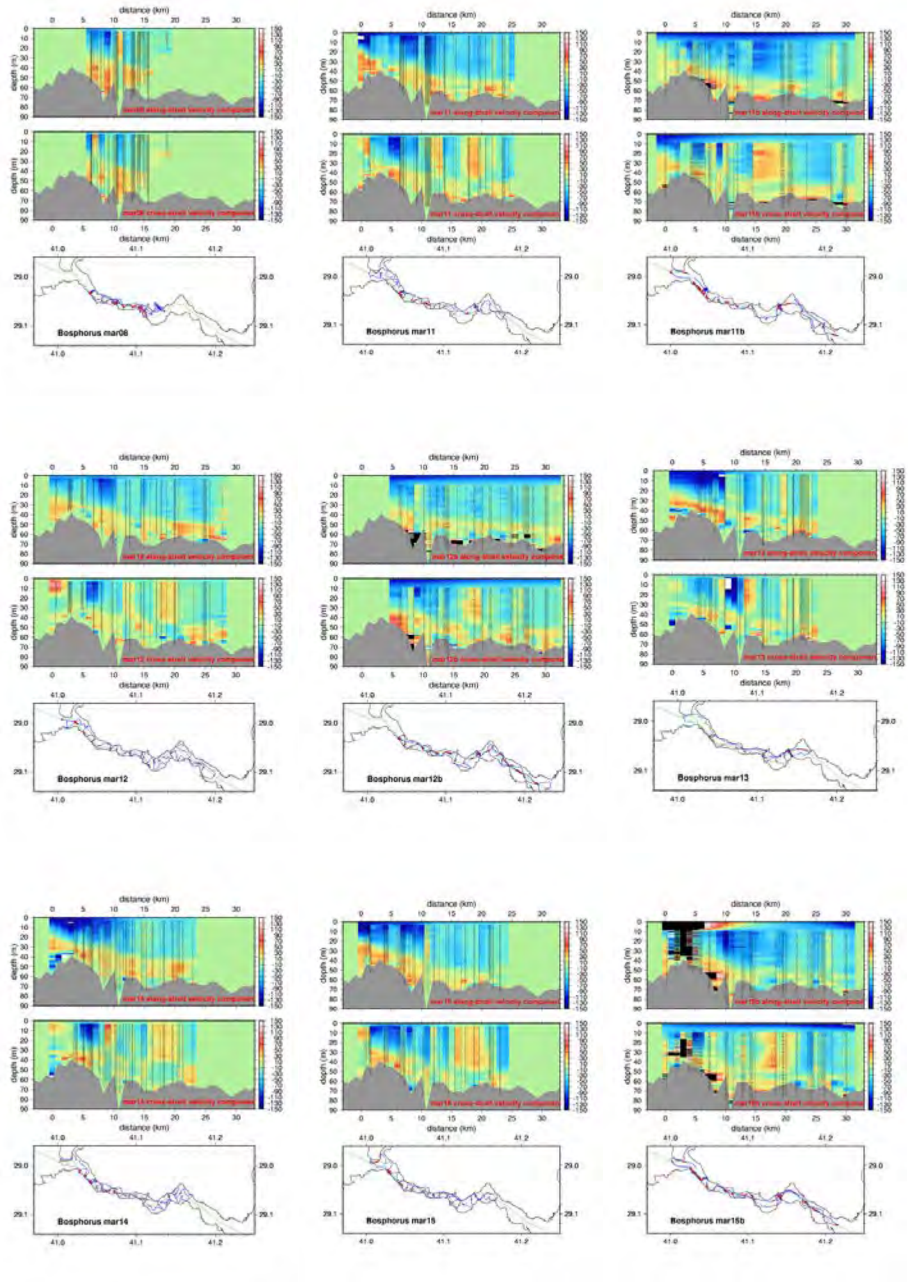



**Figure 4.** Transects of ADCP currents along the Bosphorus. The upper panel in each set is the along-strait component of velocity (positive towards the Black Sea) and the middle panel is the cross-strait component. The boat path, the thalweg line and crossing points (red) used in interpolation to transects are shown in the lower panel.

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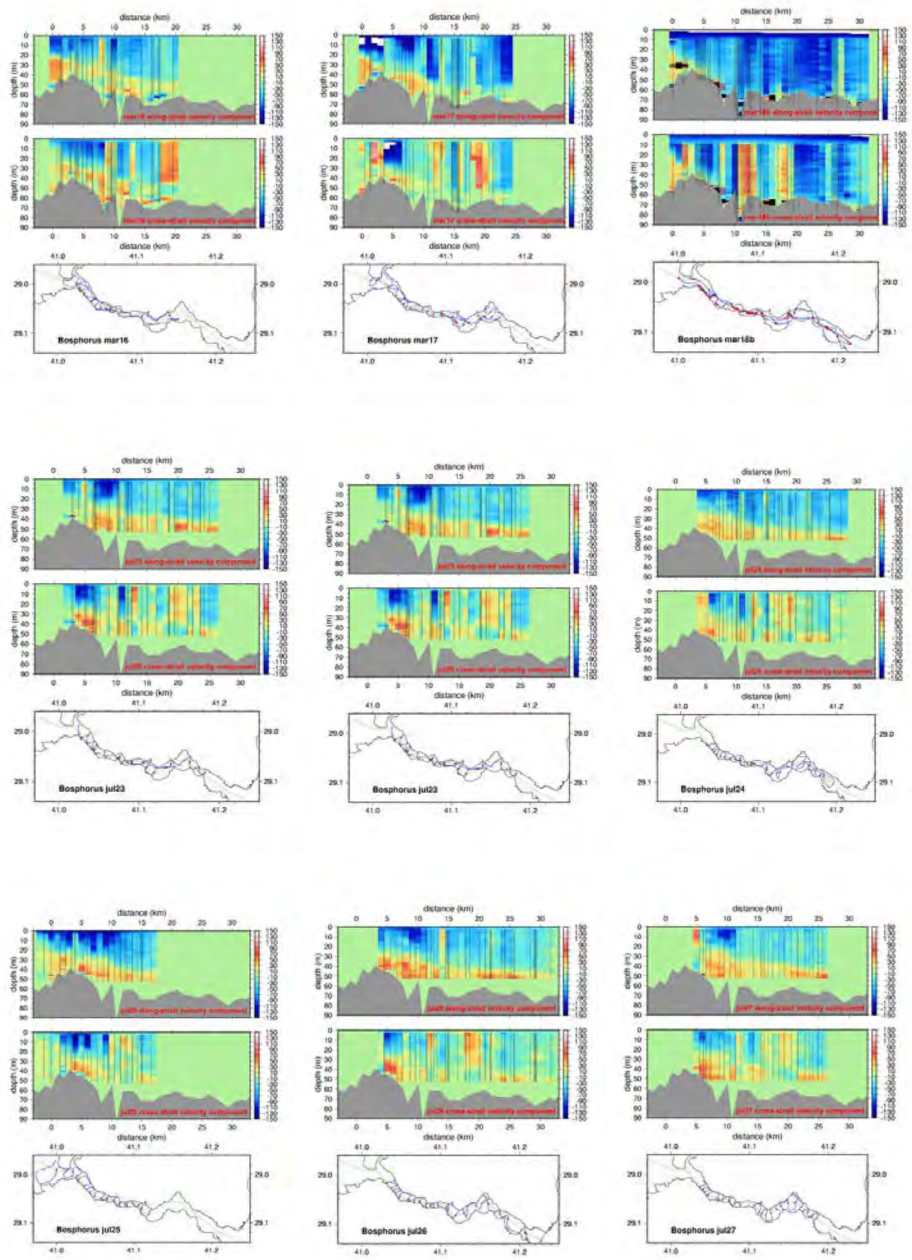

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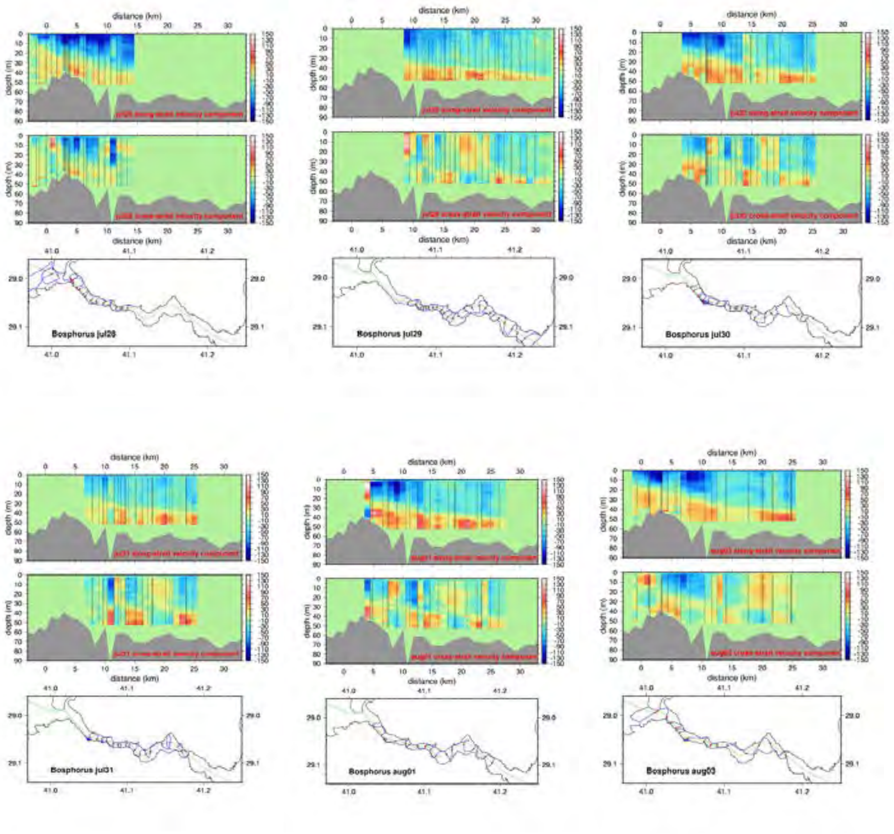


**Figure 4**. continued

### 3. ADCP and CTD sections

The ADCP current profiles obtained along the travel path of ATMACA II (e.g. Figure 2) were projected on the mid-Bosphorus transect following the thalweg, by using the data at the intersections of the boat path with the thalweg. The current vector data were then rotated to align the along-strait component to the thalweg line, and the other component perpendicular to it. The along-strait and cross-strait components are shown on the upper two panels in Figure 4, and the boat path crossing points with the thalweg are also shown.

A great variety of flow configurations are shown in Figure 4, with high currents of up to 1.5 m/s and higher are observed especially in the southern Bosphorus. In the lower layer, currents reaching 1 m/s in amplitude are observed. The measurements during March 15-18 demonstrate a case of lower layer blocking, with the emmmmntire Bosphorus swept by southward currents on March 18.

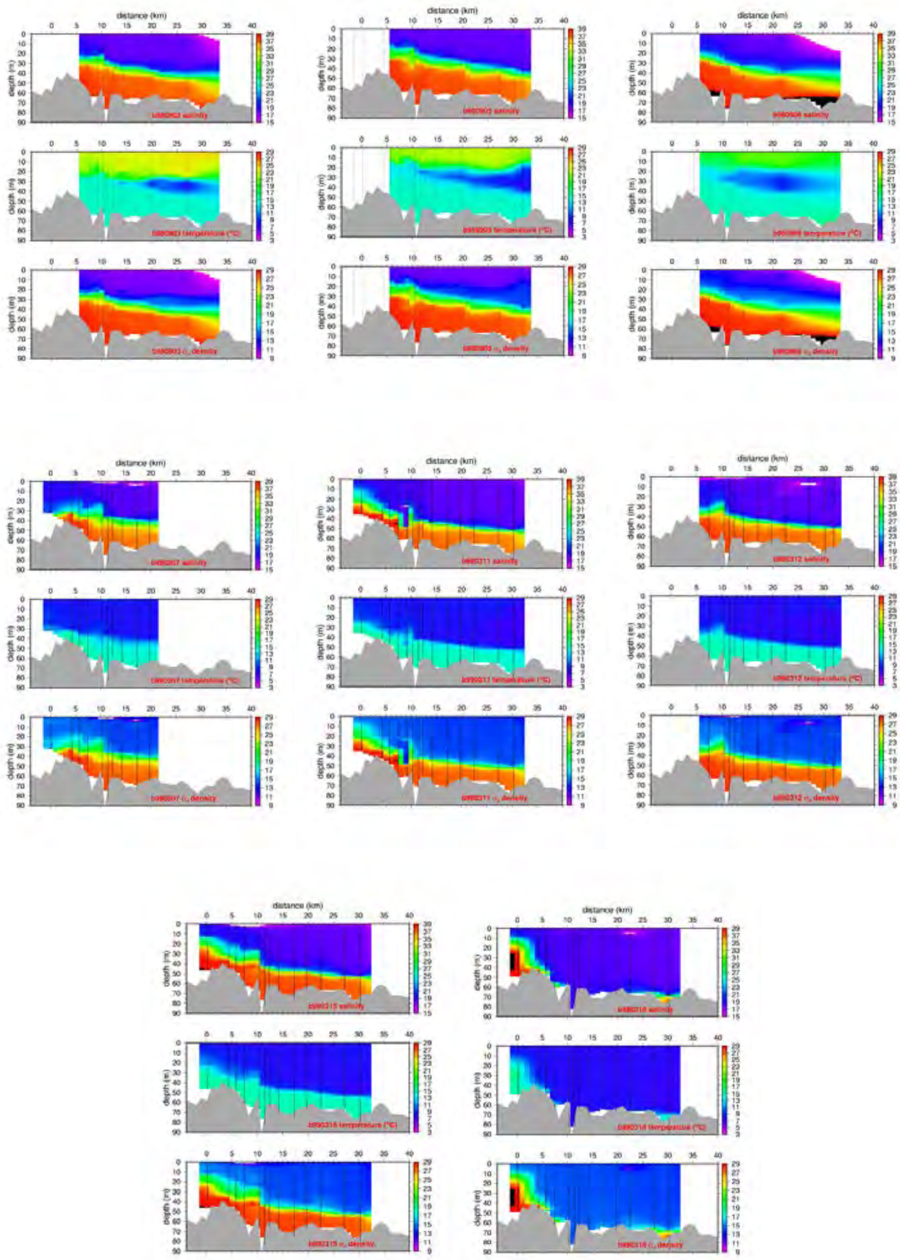


**Figure 5.** CTD cross sections along the Bosphorus obtained by R/V BİLİM on several days during which ADCP measurements of Figure 4 were obtained by ATMACA II. In each figure the upper, middle and lower panels respectively display salinity, temperature and density sections.

CTD data at stations were obtained by R/V BİLİM during some of the days when ADCP data from the boat ATMACA II. The temperature, salinity and density sections are provided in Figure 5 for comparison with the ADCP data in Figure 4. In most of the cases, two layer flow structure and the change in interface characteristics past the hydraulic control at the contraction in the southern part appear as well known features, except the last one on March 18, 1999 when the lower layer is blocked and pushed all the way to the south, past the southern sill of the Bosphorus.

ADCP measurements were also obtained in the Dardanelles Strait by the R/V BİLİM during its return to the Mediterranean Sea, as shown in Figure 6. A crossing pattern was followed along the Strait to enable horizontal interpolation of surface currents. The cruise path of the ship, its intersections with the thalweg line and the projected along-strait and cross-strait velocity componetns are shown on the left-hand side panels. The original velocity measurements and the horizontally interpolated surface circulation are shown on the right-hand side. The sections indicate the highest upper layer currents past the Nara Pass, while the lower layer currents are significantly lower in magnitude.

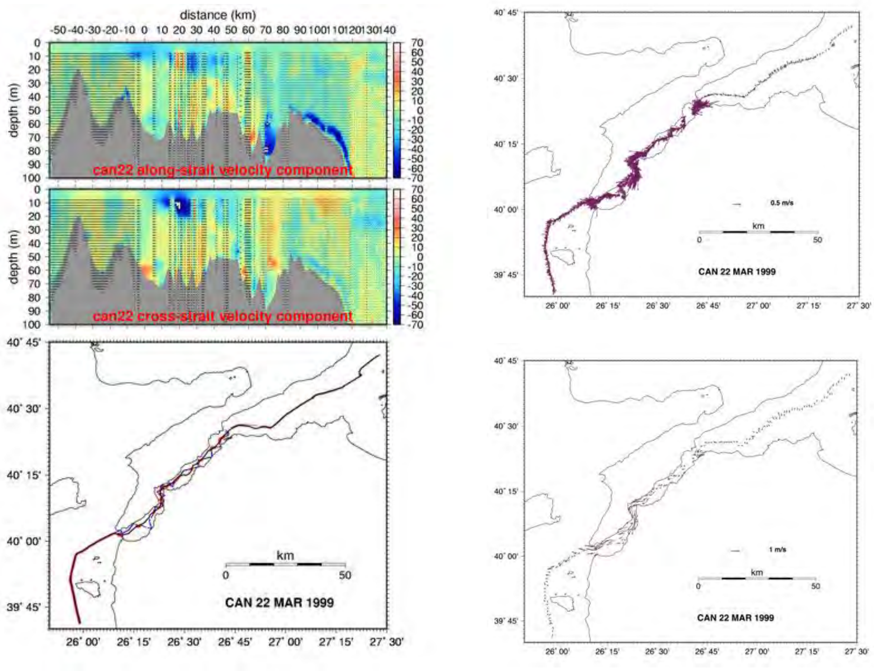


**Figure 6.** Along-strait (positive towards the Black Sea) and cross-strait velocity components along the Dardanelles Strait (upper two panels) and the path of R/V BİLİM intersecting the thalweg line (red) in the lower panel on the left hand side. The original velocity vectors sampled along the cruise path and horizontally

interpolated to show surface current distribution are shown on the two panels on the right-hand side.

## 4. Current and sea level measurements

Currents at fixed stations were measured for several monthly current-meter deployment periods. An example of current measurements at stations CM1 and CM2 is provided in Figure 7, with current components rotated to align with the main flow axis, temperature and salinity.

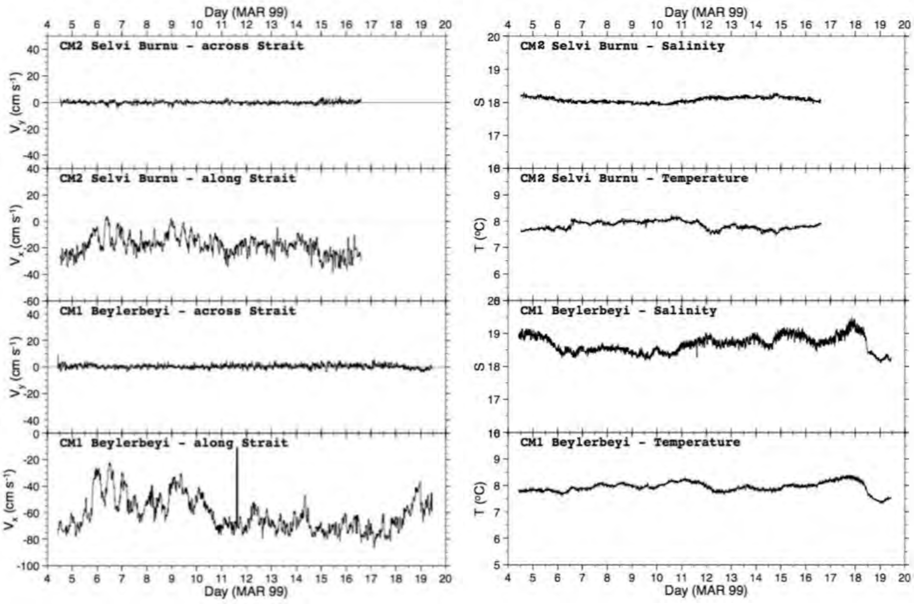


**Figure 7.** Current-meter measurements starting on 04 March 1999 of current components aligned along the main strait direction and temperature and salinity records.

Mean currents of 0.2-0.6 m/s and instantaneous values reaching up to 1m/s are observed in the records. Spatial and temporal correlations and spectral analyses provide estimates of spatial and temporal scales of motion. Spectral estimates using fft periodogram and maximum entropy analyses are given in Figure 8 for the currents displayed in Figure 7, showing diurnal and semi-diurnal tidal signals as well as 2-5 d periods corresponding to motions driven by meteorological factors, and small fluctuations in the high frequency band.

Sea level measurements obtained for about eight months by repeated deployments of tide gauges at Beşiktaş (BS) and Rumelikavağı (RK) stations show local and remote effects of the regional hydro-meteorology influencing the dynamics of the TSS as well as the neighboring seas. Spectra for sample records at the two stations are given in Figure 9.

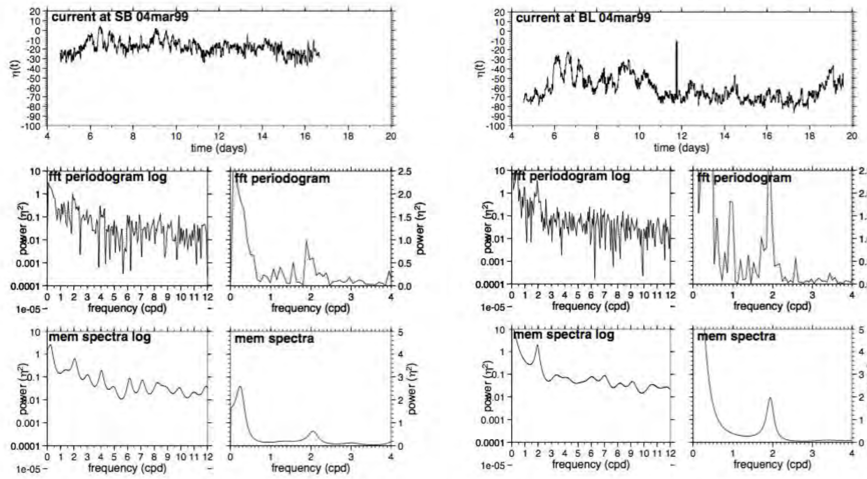


**Figure 8.** Time series, periodogram and maximum entropy spectra for the along-strait current components of time-series starting on 04 mar 1999 at the SB and BL stations.

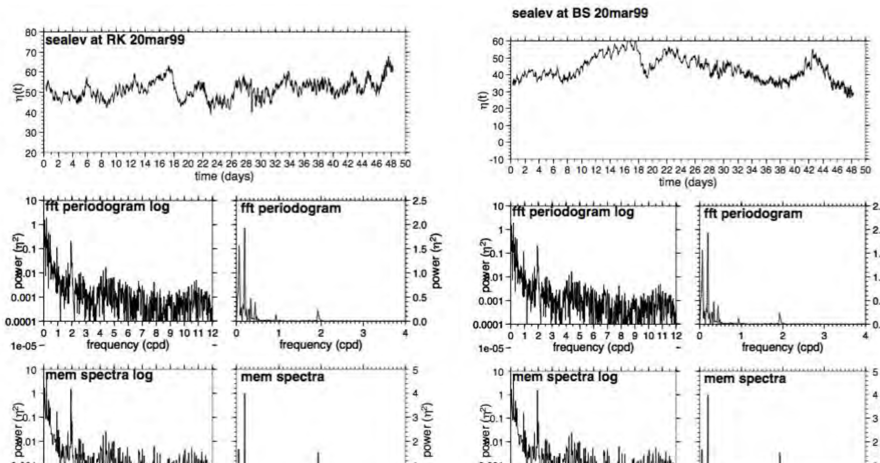


**Figure 9.** Time series, periodogram and maximum entropy spectra for the sea level time-series starting on 20 mar 1999 at the RK and BS stations.

## 5. Sea level annual time series

Sea level measurements were obtained for almost about a year by repeated deployments of tide gauges at Beşiktaş (BS) and Rumelikavağı (RK) stations along the

Bosphorus. The complete time series obtained by joining the various records are shown in Figure 10.

Sea level changes at the two ends of the Bosphorus are linked to local and remote hydro-meteorological driving factors such as the net water fluxes in the Black Sea that determine the net flux of the Bosphorus in an average sense, but also the dynamic loadings by winds, barometric pressure and tidal effects in addition to the net water budget. In fact the correlation and spectral analyses of the time series part of which are represented in the above section have shown oscillations at sub-inertial and tidal frequencies that are typical of such motions.

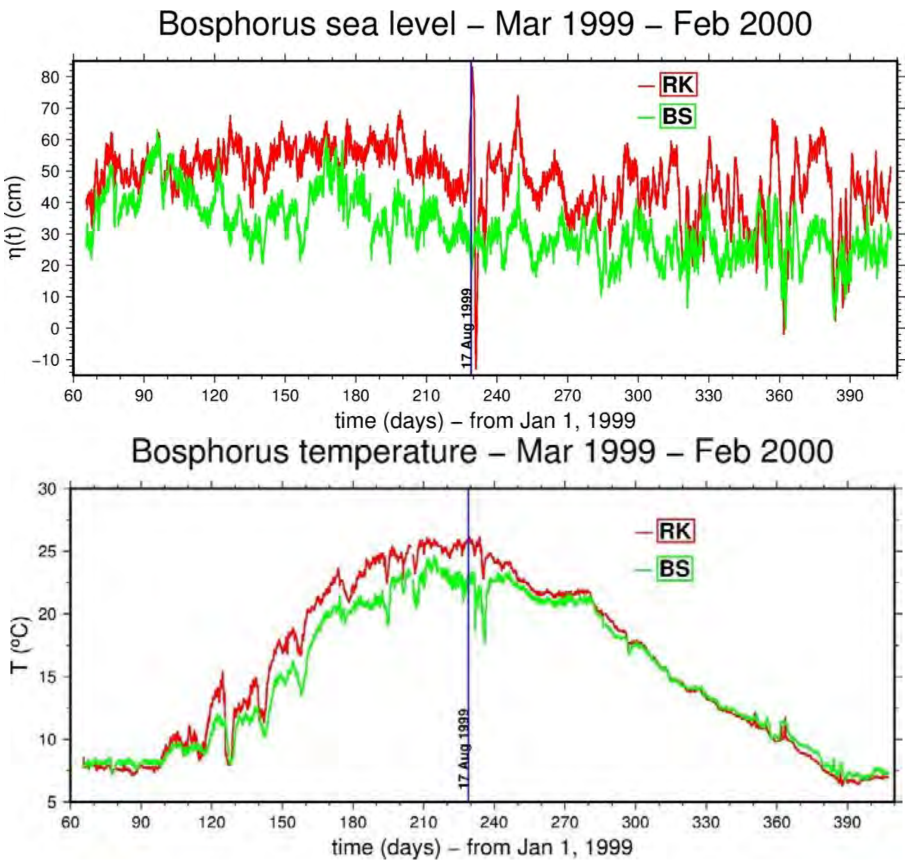


**Figure 10.** Time series of sea level and surface temperature at stations Rumelikavağı (RK) and Beşiktaş (BS) obtained from tide-gauges during March 1999 – February 2000.

What can be observed from these time series is the great oscillatory motions of the sea level on both the northern and the southern instrument sites in the Bosphorus. Oscillations of several days in period typically varying from daily to weekly frequencies typically resulting from hydro-meteorological events and tides are well known in the region. There is a long-term, seasonal sea level difference between the two stations possibly closely following the difference between the Marmara and Black Seas, that actually governs the transport through the Strait. The sea-level difference on the average is about 20-30 cm, but goes up to about 60 cm during dynamic changes. During certain occasions in winter and spring seasons the difference is seen to vanish, corresponding to upper-layer blocking or “Orkoz” events that are well known in the Bosphorus.

A spectacular event in the record is observed during the August 17, 1999 Richter scale 7.4Mw earthquake that struck the region and created great damage and loss of lives. While the measurements were primarily concerned with sea level variations linked to local and remote meteorological forcing and the water balance of the Black Sea, the measurements at Rumelikavağı revealed a completely different response that probably belongs to a process of tectonic origin connected with the 1999 Marmara earthquake.

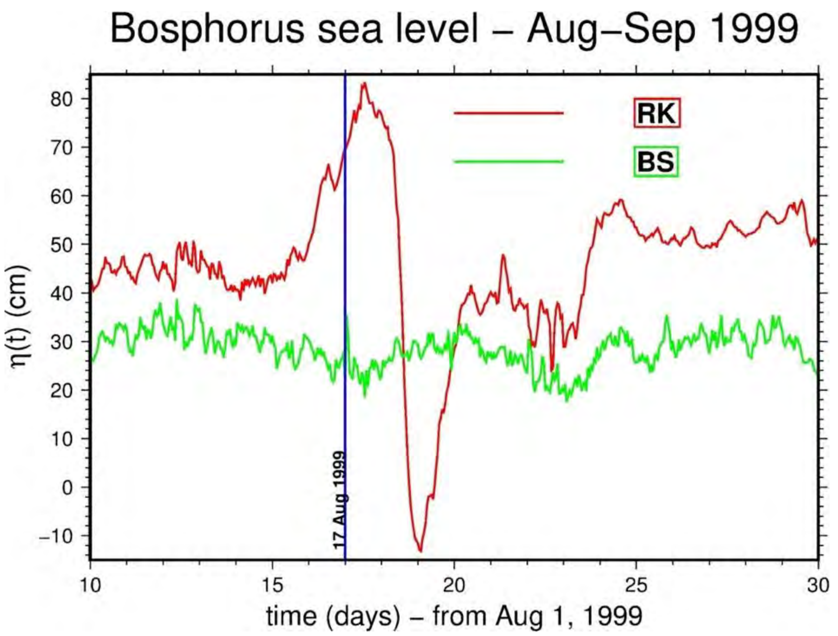


**Figure 11.** The sea level records at Rumelikavağı (RK) and Beşiktaş (BS) on and expanded time scale, covering the August 17, 1999 earthquake event.

The expanded scale plots of the sea level response at the two stations are shown in Figure 11. While the sea level at Beşiktaş (BS) fluctuates as often observed, the sea level at Rumelikavağı (RK) first starts to rise from a level of 0.40 m on 14$^{th}$ with increasing rate in the following three days to reach a peak of more than 0.84 m at about 3 am on the morning of the 17$^{th}$, which is the exact time of one of the greatest earthquakes of the recent past, that took place in Gölcük, further south of the Bosphorus in the İzmit Bay area of the Marmara Sea. From then on a steady drop of sea level for the next two days follows, by about ~1 m to reach a minimum of -0.14 m past the midnight of the 19th, after which the sea level once again starts to recover until mid-day on the 20th, coming back to the constant level of 0.40 m, finally with a still further daily increment to reach about 0.60 m on the 23rd. This behavior is very different from other times shown in Figure 10, and could only be related to earth movements that are much slower than water movements.

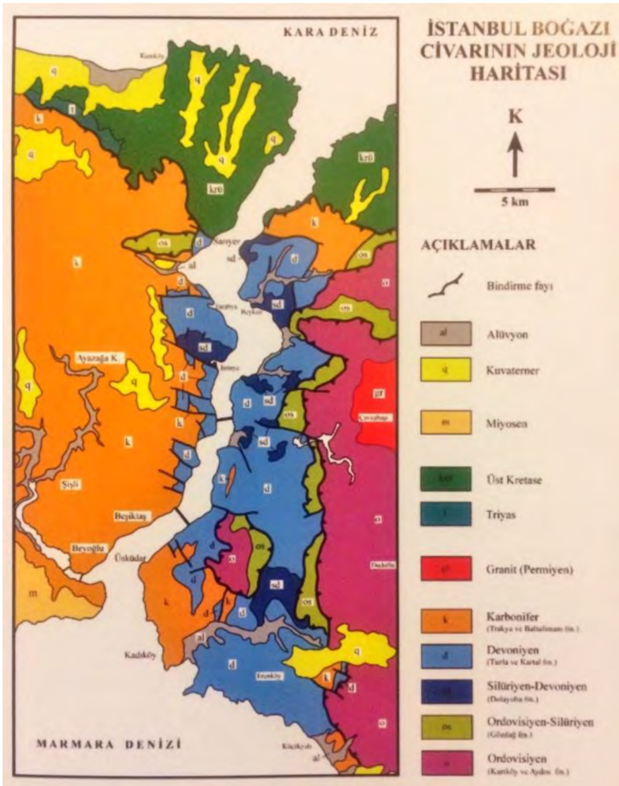


**Figure 12.** A summary of the geology of the Bosphorus Strait (İstanbul Technical University)

Because we could not explain such great variations at the time of the experiments, we did not publish them. The report on the experiment was given to the TÜRBO administration by taking out the set of measurements from the graphical displays of the results and details were not discussed of the particular period, in order to exclude and not claim responsibility for any scientific results that did not seem to be explicable. We believe that the phenomenon could only be evaluated and understood from the point of view of solid earth science, although no one has yet offered such an explanation. In this respect we only remark that, perhaps the overlaid fault line in Figure 12, passing through exactly the same point as the sea level measurements were made (compare Figure 1), or the sharp change in the rock structure across this fault could have a role to play, although the fault is not an active one.

We knew that the particular response that has been observed could not be associated with hydrodynamics because it was only observed at one of the two sea- level stations operating at the same time, and further, the great changes in sea level lasting for more than several days observed at the Rumelikavağı station north of the Bosphorus could not be explained by tsunamis or some similar process which should have been of higher frequencies of oscillation. Similarly, the observed record could not be related to some kind of instrument malfunction, because the pressure sensor of the WLR7 is a mechanical one and the recording system is an old-fashioned cassette type with stable electronics. However, our contacts with geologists and geophysicists to seek for a possible explanation at the time unfortunately did not produce any credible explanation.

It is striking that this different behavior has occurred more than 60km from the source of the earthquake and not concurrently observed at the Beşiktaş sea level station which was actually closer to the earthquake epicenter. Although a scientific explanation for this recording of anomalous sea level change has not been found to date, the event now deserves attention because it should be revealed possibly to trigger further investigations leading to a scientific explanation and possibly additional means to monitor the effects of earthquakes in the region.

**Acknowledgements**

We will always remember the primary roles of Admirals Güven Erkaya and Şevket Güçlüer for the TÜRBO initiative and Prof. Nejat İnce who acted on behalf of İTÜV/SAM to support this essential study to help set the basis for evaluating environmental conditions with respect to the critical influence of currents on navigation through the Bosphorus Strait. We thank all past personnel of the IMS-METU who took part in these studies at sea and at the office.

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# A REVIEW OF THE ISKI DYE STUDY OF THE BOSPHORUS 1991-1993

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In this short review, the dye study in the Bosphorus performed as part of the İSKİ wastewater studies in the 1990's, originally reported by Özsoy *et al.* (1994, 1995a) and Beşiktepe *et al.* (1995), are briefly re-described for the present context.

Starting with the 1960's till the present time, what to do with the wastes of the growing megapolis of İstanbul has been a major problem for the millions of people living in and around the city and on the coasts of the whole Turkish Straits System (TSS) and adjacent seas. The design and development of a waste collection and disposal system has been an urgent objective of the city administrations, so far partly achieved through veritable efforts on the part of the İstanbul Water and Waste Administration (İSKİ), possibly in need of further updating against the uncontrolled growth of population and industrial pressures. The initial design of the marine waste disposal system, at least for the greater part of İstanbul has relied on the existing physical mechanisms of the TSS. In the two-layer current system of the TSS, it has been proposed that the wastes discharged into the Bosphorus would be carried to the Black Sea by the lower layer flow, with only a small amount possibly making its way to the surface by mixing, which in any case would be low because of the strong stratification. It was also hoped that the wastes remaining in the TSS system would be reprocessed by the marine biogeochemical processes, although bio-treatment of the wastes would also be needed.

However, the TSS with its very small domain and inertia, as well as the adjoining Black Sea are almost closed water bodies receiving huge amounts of nutrients via rivers and the atmosphere as well as wastes from the encircling hinterland. Because the Black Sea ecosystem is already threatened by eutrophication, concerns have been expressed whether the export of wastes to the Black Sea would add to the problems there. Similar concerns existed for the possibility of the pollution of surface waters in the Bosphorus and the Sea of Marmara. The effective role of the TSS in the transport to and from the adjacent Black and Mediterranean Seas have been studied by Polat and Tuğrul (1995) from the above viewpoint. At the same period of time the existing studies Ünlüata *et al.* (1990), Özsoy *et al.* (1995a, 1996, 1998, 2001), Gregg *et al.* (1999), Gregg and Özsoy (2002) provided the background information necessary to understand the basic dynamical setting and transport aspects of the Bosphorus currents. The above concerns have actually proved to be right by the present state of the environment which has deteriorated ever since, especially in the Marmara Sea and the TSS despite the efforts to resist the rising tide of pollution effects by the waste discharge system at the forefront of its defenses.

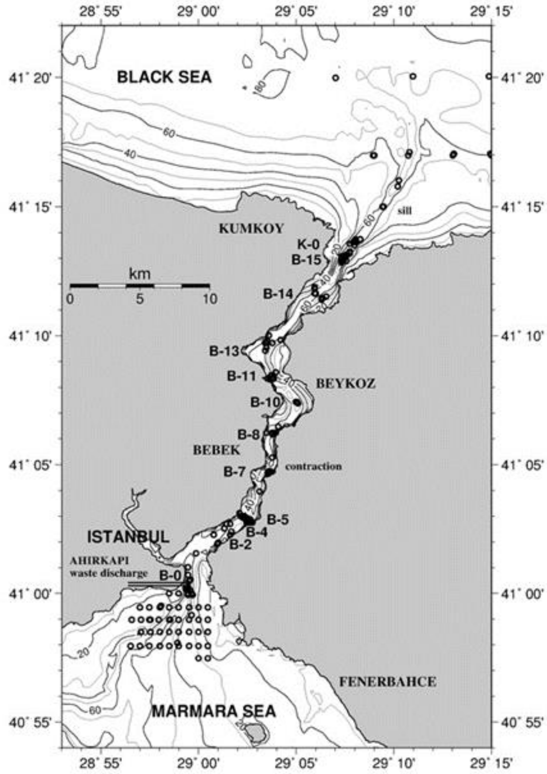


**Figure 1.** Location map for the İSKİ project of the IMS-METU showing the Bosphorus topography, regular measurement stations and the network of stations used in the dye dispersion study making use of the two ships, R/V BİLİM of Middle East Technical University and R/V ARAR of İstanbul University.

The measurement campaign was carried out for İSKİ during the early 1990's to determine the environmental fate of the marine waste discharges of the city of İstanbul. The location of the study and stations are shown in Figure1. In addition to an in-depth investigation of the TSS through an intense campaign of in-situ oceanographic measurements, the IMS-METU had also taken the incentive to perform a large-scale dye dispersion experiment based on ship-based measurement of dyes introduced to the İSKİ wastewater discharged into the marine environment. The dispersion patterns of the dye patches were monitored by two ships the R/V BİLİM and R/V ARAR using CTD, ADCP echosounding, water sampling and fluoroemeter concentration measurements, assisted by a small boat equipped with a separate fluorometer to locate the dye patch in the Bosphorus Strait and its exit regions in the Marmara and Black Seas.

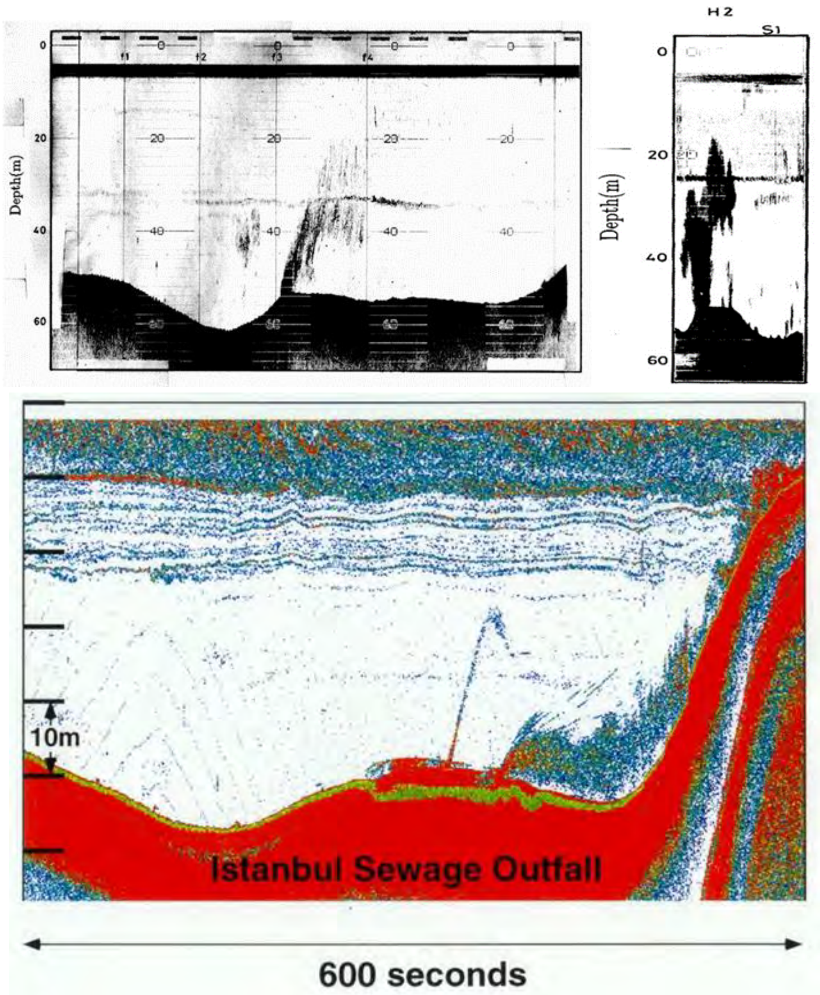


**Figure 2.** Images of the waste plume issuing from the Ahırkapı diffuser obtained by the echosounder on board the R/V BİLİM during the dye study in the Bosphorus.

Shortly before the IMS-METU study, with the operation of the waste water disposal system in 1987, the city of İstanbul had already started discharging a significant proportion of its waste through diffusers on the seabed of the Bosphorus at Ahırkapı (Figure 1). At the time of the study, the Baltalimanı diffusers and others built later were not yet operative. The experiments were to describe the behaviour of the discharge both during the normal two-layer flow of the Bosphorus and also under extreme conditions when either the upper or the lower layers could become blocked.

The ship-based experiments used echo-sounding and acoustic backscattering measurements to visualize the plume of wastewater (Beşiktepe *et al.* 1995). Examples of the echosounding records are shown in Figure 2. In all similar images, almost at all times the buoyant plume of wastewater discharging from the diffusers was seen to be bending towards the north swept by the strong lower layer currents. In cases of weaker flows the plume would be rising to the interface levels, but was never observed to penetrate the strong density gradient at the interface and become incorporated into the upper layer flow.

Absolute acoustic backscatter in the water column was measured and extracted from the ADCP measurements as the ship moved along paths crossing it, as shown in Figure 3 and described in detail by Beşiktepe *et al.* (1995). These measurements additionally ensured us of the position of the buoyant wastewater plume, which was never observed to reach the surface even under the most adverse conditions.

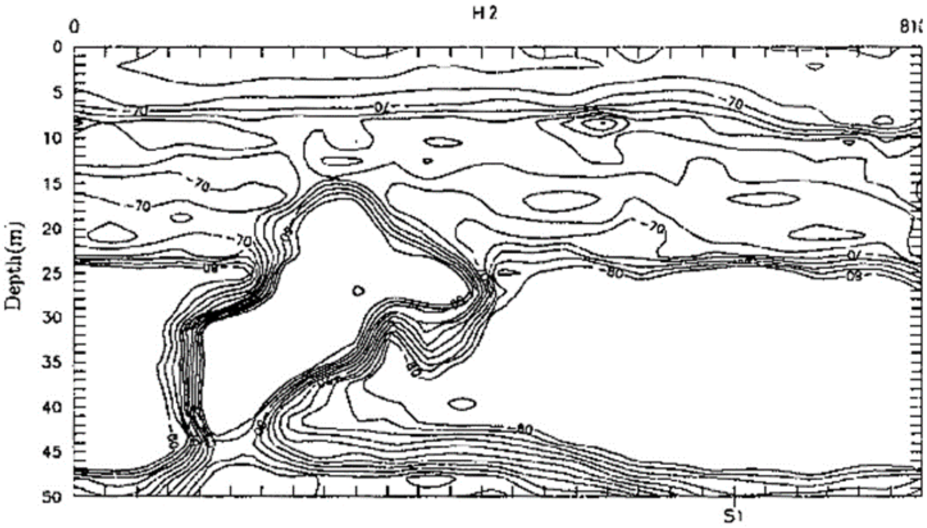


**Figure 3.** Absolute backscatter measured by the on-board ADCP of the R/V BİLİM near the Ahırkapı diffuser on 18 May 1992.

The dye study was performed by mixing dyed water of given fluorescent Rhodamine dye of given concentration to the wastewater at the İSKİ treatment facility at Yenikapı and later measuring the concentration in the water discharged into the Bosphorus through a vigorous tracking and sampling program in real-time along the Strait and its adjoining exit regions by two oceanographic ships and a small vessel. The measurements were carried out for instantaneous and continuous releases, repeated under normal and adverse conditions of flow blocking in the Bosphorus during several experiments outlined in Table 1.

**Table 1.** Dye release experiments

| date | release method | dye mass (kg) | waste water flux ($m^3/s$) | lower layer flux ($m^3/s$) | tank conc. (ppb) | calculated source conc. (ppb) | measured source conc. (ppb) |
|---|---|---|---|---|---|---|---|
| **Aug. 1992** | Instantaneous | 180 | 2 | 7500 | 100 | 54 | 52 |
| **Sep. 1992** | Continuous | 408 | 2 | 12000 | 1.7 | 1 | 4 |
| **Mar. 1993** | Instantaneous | 312 | 6 | 5000 | 130 | 31 | 21 |
| **Dec. 1993** | Instantaneous | 312 | 2 | 19000 | 86 | 36 | 79 |

ADCP measurements of currents together with fluorometric measurements of dye concentration (Figure 4) delineated the dye patches moving with the exchange flows in the Strait, as shown by the analyses of the measurements and computations presented in Özsoy *et al.* (1994, 1995). During the measurements, the fluxes of both layers changed over a wide range, including several cases of short-term blocking.

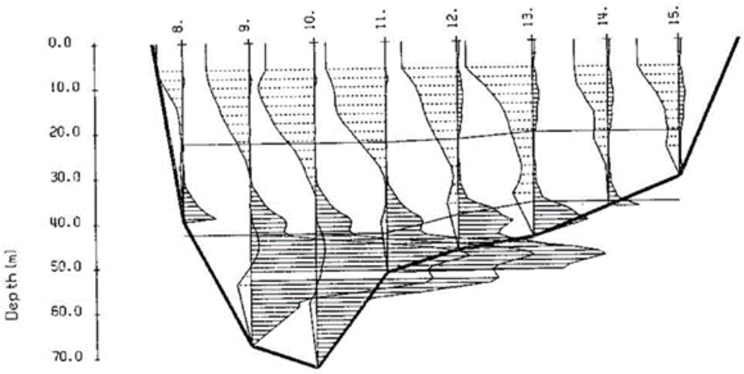


**Figure 4.** An example of a section of ADCP current (dotted line fill) and dye concentration (solid line fill) profiles at Section B5, 5 March 1993, used in the computation of dye mass transiting the Strait.

Normal discharge conditions prevailed in the first two dye release experiments, with upper and lower layer discharges respectively of Qu = 10000− 17000 m3/s, Qℓ = 5000 − 7500 m3/s in August 1992, and Qu = 3000 − 5000 m3/s, Qℓ = 11000 − 15000 m3/s in September 1992.

In March 1993, the upper layer flux was increased significantly (Qu = 20000− 27000 m3/s), leading the lower layer discharge to be significantly reduced (Qℓ = 1000 − 3000 m3/s), almost to the level of lower layer blocking. The transit time for the dye cloud in the lower layer was therefore considerably larger than the first experiment in Figure 3.

In December 1993, the identification of the layers was less straightforward because the upper layer was actually blocked (Qu = 0). The Black Sea water (Su < 18) was found only at the north end of the Bosphorus before the dye release started but then receded to the contraction area during the dye measurements. Elsewhere Marmara surface water ($S \simeq 24 - 26$) and the underlying Mediterranean water flowed towards the Black Sea (total Qℓ = 20000 m3/s), and submerged under the low salinity wedge of Black Sea water.

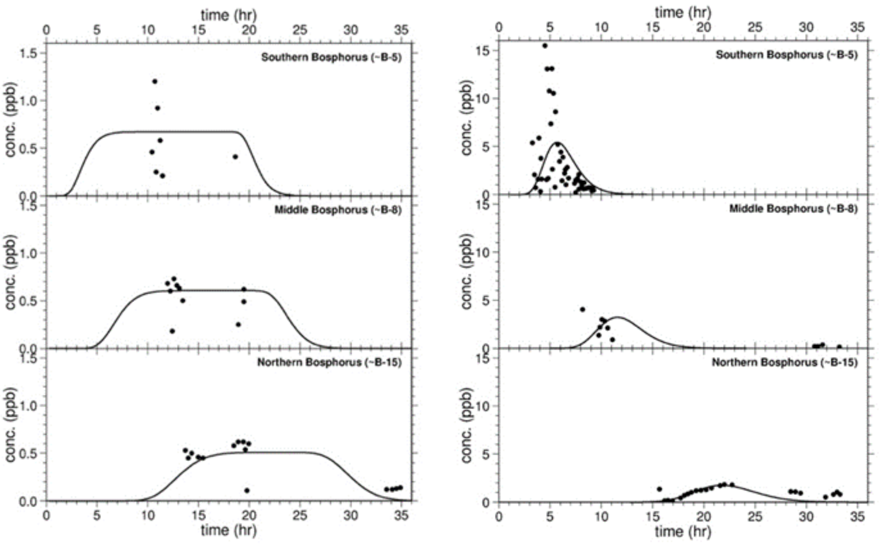


**Figure 5.** Lower layer average Rhodamine-B concentration at different locations along the Bosphorus, after (a) continuous dye release, September 1992, and (b) instantaneous release, March 1993. Data points are measurements, and the solid lines are the predicted concentrations at the 7.5, 15 and 28 km distances from the source (respectively near stations B5, B8 and B15) obtained from diffusion model calculations.

In Figures 5 and 6, measurements of the lower layer average dye concentration at various stations along the Bosphorus are compared with model calculations following Özsoy and Ünlüata (1988) for the several cases of continuous and instantaneous release experiments.

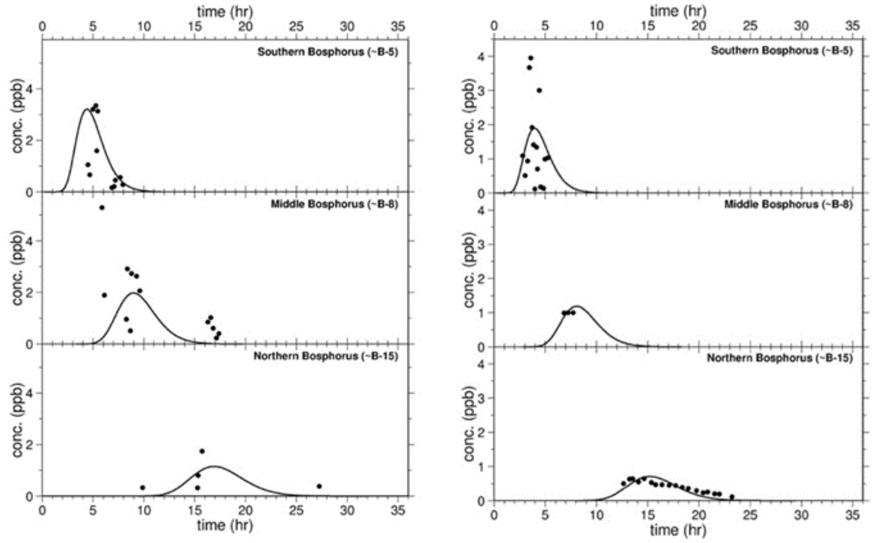


**Figure 6.** Lower layer average Rhodamine-B concentration at different locations along the Bosphorus, after (a) instantaneous dye release, August 1992, and (b) instantaneous release, December 1993. Data points are measurements, and the solid lines are the predicted concentrations at the 7.5, 15 and 28 km distances from the source (respectively near stations B5, B8 and B15) obtained from diffusion model calculations.

Measured fluorescence intensities following the addition of Rhodamine B to the waste showed the dye, and therefore the waste water, to be dispersed to become almost uniform in the lower layer at a distance of 6-8km from the discharge. Measurements of the dispersion showed the mixing times to be about 2.5 days, 9 hours and 5 minutes along, across and in the vertical direction respectively within the lower layer of the Bosphorus, suggesting that the lower layer mixed patch would reach the Black Sea without finding time to be entrained into the upper layer and carried back to the Marmara Sea. Simultaneous measurements of current velocity and of Rhodamine concentrations across the Bosphorus confirmed the soundness of the observations and of their analysis, the mass of dye computed to be passing the cross section of the Bosphorus; being of the same order of magnitude as that known to have been dissolved in the wastewater initially. When the Rhodamine was added instantaneously dilution factors of $10^{-5}$ to $10^{-6}$ were observed. Continuous release of Rhodamine gave dilution factors of $10^{-3}$ to $10^{-4}$ and it was evident that the concentration of water soluble waste became approximately constant throughout the bottom layer of the Bosphorus and tailed off upwards towards the halocline. The fluorescence due to the transport of Rhodamine from the bottom to the top layer of the Bosphorus was little larger than the background fluorescence observed before the release of the dye. The background level was equivalent to 0.4ppb of Rhodamine in the Bosphorus. Consequently it was difficult to determine dye concentrations in the upper layer accurately. All our observations are consistent with dye - and hence soluble waste being transported into the upper layer of the Bosphorus in the same manner as salinity. In an experiment in which Rhodamine was injected continuously into the city waste for 17 hours 12% of the lower layer flux appeared to be transported into the upper layer. The fluorescent dye concentrations in the upper layer remained at low levels throughout the Bosphorus and its adjacent areas. Under blocked flow conditions, contamination of the surface waters was minimal, and flushing of the wastes out of the system was rapid. Longitudinal dispersion coefficients governing the transport of waste along the Bosphorus were estimated by the measurements. The turbulent plume of waste is found to be capped by the pycnocline, and therefore the transport of waste into the top layer of the Bosphorus is small under all conditions. The results showed limited surfacing of the wastes discharged from diffusers at the bottom of the Bosphorus. The total quantity of dye computed by integrating the dye patches in transit through the system confirmed recovery of the injected amount, checking the consistency of the measurements.

The most significant pathway of entrainment of lower layer material into the upper layer would in fact be expected in the southern part of the Bosphorus in the dissapative region south of the central constriction, where the Ahırkapı diffuser is located. Despite this expectancy, the levels found in the upper layer were confirmative of the design, which showed that the estimates based on mass budgets were not exceeded in any way.

The accompanying measured distributions of halocarbons have been reported in Fogelqvist *et al.* (1996), and faecal coliforms were counted in addition to the dye study based on Rhodamine dye added to the waste and dispersion patterns of waste followed throughout the Bosphorus, as reported by Özsoy *et al.* (1994, 1995), Beşiktepe *et al.* (1995).

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# MODELLING OF WIND WAVES IN THE SEA OF THE MARMARA

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## 1. Introduction

Wind generated waves propagating on the ocean surface represent a potentially serious hazard to life and property in various maritime and coastal activities. Hence, it is necessary to develop the capability to forecast wave conditions over global and regional ocean domains to minimize loss of life and property (Tolman *et al.* 2002). The Sea of Marmara is a very active sea in terms of marine activities. Therefore, a proper knowledge of the expected wave conditions is important for coastal studies, safe navigation purposes and offshore activities. Therefore, we developed a SWAN model to accurately hindcast wave conditions in the Sea of Marmara. The model results were calibrated with the measurements at one buoy and validated with the observations at two buoys moored along the northern coast of the Sea of the Marmara. One-year of observed data in 2013 at Silivri were firstly used for the calibration of the SWAN model using both wind forcings. Hereafter, short-term data observed in 1990 and 2003 at Marmara Ereğli and Ambarlı respectively, were used for validation of the SWAN model using both wind forcings. The SWAN model performance was evaluated by using the significant wave height ($H_{m0}$) at all buoys. For setting-up a proper SWAN model implementation, attention was paid to the deep water physical formulations for whitecapping dissipation, quadruplets, and the shallow water formulations for triads, bottom friction, and depth-induced wave breaking.

## 2. Study area

The Sea of Marmara, is an inland and practically closed sea (Figure 1) that is located between 40º - 41.25º north latitudes and 26º - 30º east longitudes. It connects the Black Sea in the north via the Bosphorus strait, to the Aegean Sea in the south through the Dardanelles strait. It has approximately an area of 11,500 km² with a 240 km length and a 70 km width. Its greatest depth reaches -1,270 meters. The study area and its bathymetry are illustrated in Figure 1. It also presents the stations of the TPAO (Anonym Association of Turkish Petroleum) Silivri buoy (wind and wave measurement station), Marmara Ereğli and Ambarlı buoys (wave observation stations) used in this study.

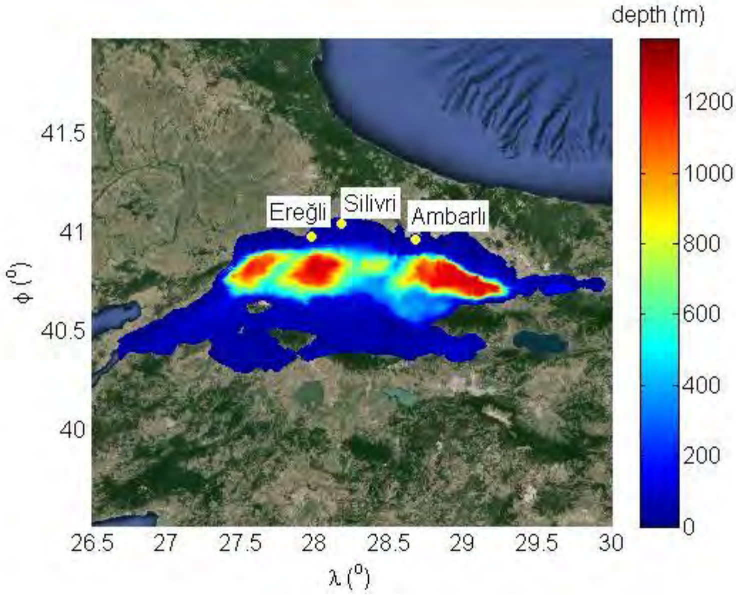



**Figure 1.** Study area and wind and wave observation stations

## 3. Materials and Methods

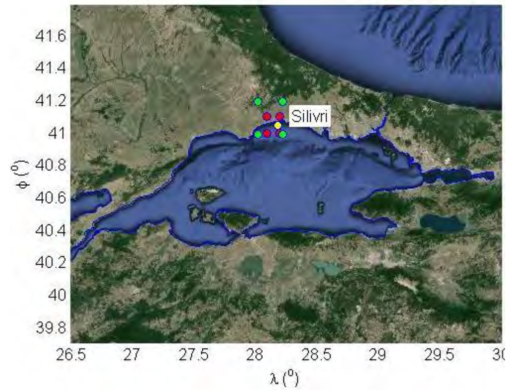
In this study, the SWAN cycle III version 41.01 model (Booij *et al.* 1999; Ris *et al.* 1999) was used to perform the hindcast study. It was run in third generation and non-stationary mode with a time step equal to 30 minutes and four iterations per time step. The model domain covers the entire Sea of Marmara, from 26.6958°E to 29.9958°E of longitude and from 40.2042°N to 41.0942°N of latitude. The domain was discretized with a regular grid of 500 × 135 nodes in spherical coordinates with a uniform resolution of 0.0066° (about 1/15°) in each direction. The directional wave variance density spectrum function was discretized using 36 directional bins and 35 frequency bins logarithmically spaced between 0.04 Hz and 1.0 Hz. The numerical scheme was the slightly dispersive BSBT (first order upwind; Backward in Space, backward in Time) scheme. For our wave model computations we have used different formulations for wind growth and whitecapping and calibrated the tunable $C_{ds}$ parameter. Quadruplet interactions are estimated using the Discrete Interaction Approximation (DIA) by Hasselmann *et al.* (1985) using $\lambda$=0.25 and $C_{nl4}$=3x10$^7$. The JONSWAP bottom friction formulation is used with $C_{fjon}$=0.038 $m^2s^{-3}$ according to Zijlema *et al.* (2012). Depth-limited wave breaking is modelled according to the bore-model of Battjes and Janssen (1978) using $\alpha$=1 and $\gamma$=0.73. The triad wave-wave interactions using the Lumped Triad Approximation (LTA) of Eldeberky (1996) in the SWAN were activated.

For the modelling of the wind waves in the Sea of Marmara, the SWAN model needs a bathymetry and input wind fields. In this study, the ERA Interim winds from the ECMWF and the CFSR winds from the NCEP are used as wind inputs. The wind fields of the ERA Interim data set were provided for an area covering 39.700º - 41.800º North latitudes and 26.100º - 30.000º East longitudes, with a spatial resolution of 0.100º x 0.100º and a 6-hour temporal resolution. The data for the CFSR winds was obtained for an area covering 39.353º - 41.603º North latitudes and 25.568º - 30.272º East longitudes. The CFSR winds had a spatial resolution of 0.2045º x 0.2045º and a 1-hour temporal resolution. For both wind sources, u and v wind components at 10 m high were provided. The bathymetry of the Sea of Marmara was obtained from GEBCO, General Bathymetric Chart of the Oceans (GEBCO, 2014) with a spatial resolution of 0.008333° in both directions.

For the assessment of the accuracy of the CFSR and ERA Interim wind data sets and the calibration and validation of the SWAN models using two different winds, we used the measured data at three buoy stations available in the Sea of Marmara. Wind and wave measurements at Silivri buoy station (TPAO-MGM ODAS-01TR), which is owned by TPAO, were used to assess the accuracy of the CFSR and ERA Interim wind data sets and to calibrate the SWAN model because it has the data with the longest period in comparison with the other two buoys. This buoy is located on the coordinates 41.043889º N and 28.186944º E which has a depth of 50 m and 3 km from the shore of Silivri district in Istanbul province. At this station, a total 17,103 half-hourly wave measurements from 1 February 2013 till 6 May 2013 (4,560 data), 7 May 2013 till 23 January 2014 (12,543 data) were provided by TPAO. Besides, a total of 479,996 wind measurements at 10-m height from 1 February 2013 till 31 December 2013 are also provided from TPAO. Wind observations have a 1-minute temporal resolution.

For the validation of the SWAN model the short-term measured $H_{m0}$ data at Marmara Ereğli and Ambarlı were used. At Marmara Ereğli, wind and wave measurements were collected at an LNG terminal site by Akyarlı and Öner (1991). It is located at 40.976369º N and 27.977285º E. The measurement station is about 1 km from the coast, where the water depth is 17 m. The data were digitized from Özhan and Abdalla (1993). At this station, a total of 298 wave measurements were available at three periods: from 14 to 17 March 1990 (66 data in total), 21 to 31 August 1990 (156 data in total), and 17 to 20 December 1990 (76 data in total), The third buoy station, known as Ambarlı, is situated at a water depth of 17 m and about 500 m distance from the coast at 40.9631º N and 28.684968º E. At this station, a total of 233 wave measurements between 30 August 2003 and 26 September 2003 were provided. The data is summarized in Yüksel *et al.* (2004).

The accuracy of both CFSR and ERA Interim winds was evaluated against the measured winds at the Silivri buoy station, obtained by bi-linear interpolation of the wind speed components from the four closest surrounding grid points of both wind fields. The accuracy of both wind fields (CFSR and ERA Interim) was assessed in four ways; (1) the data obtained by bi-linear interpolation in wind speed component from the closest surrounding grid points (as implemented in the SWAN model)-(2) the data of the nearest (wind) grid point to the buoy station, (3) the data computed with the inverse squared distance weighted (ISDW) interpolation using data of the four grid points, and (4) the data computed with inverse area weighted (IAW) interpolation using data of the four grid points. The details of applying these three different interpolation methods were given in Çakmak (2015). Distances from the buoy station and coordinates of four corner points of the area encompassing the observation station for both the wind data sources and Silivri buoy station are shown on the map in Figure 2, and as a table in Figure 2.




| Station | Latitude ° N | Longitude ° E | Distance * (m) |
|---|---|---|---|
| BUOY | 41.044 | 28.187 | 0 |
| ERA 1 | 41.00 | 28.10 | 8,788 |
| ERA 2 | 41.00 | 28.20 | 4,996 |
| ERA 3 | 41.10 | 28.20 | 6,327 |
| ERA 4 | 41.10 | 28.10 | 9,603 |
| CFSR 1 | 40.989 | 28.022 | 15,120 |
| CFSR 2 | 40.989 | 28.227 | 6,967 |
| CFSR 3 | 41.194 | 28.227 | 21,670 |
| CFSR 4 | 41.194 | 28.022 | 17,030 |

*: from the buoy station

**Figure 2.** Silivri buoy station (yellow circle) and the nearest grid points of the CFSR (red circles) and ERA Interim winds (green circles) to the buoy station

In order to test both the accuracy of wind data sets and the performances of the SWAN wave forecasting models, an analysis of simultaneously measured and simulated data was performed. This required collocating the measurement and estimated data in time (wind speed and wave height) in overlapping time intervals to calculate the errors. The performance of the models was evaluated based on the following statistical error indicators; mean absolute error (MAE), root mean square error (RMSE), bias, scatter index (SI), and coefficient of correlation (r). The formulas of these statistical error variables used in this study are given below:

$$MAE = \frac{1}{N}\sum_{i=1}^{N}\left|Y_i - X_i\right| \quad \textbf{(1)}$$

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Y_i - X_i\right)^2} \quad \textbf{(2)}$$

$$Bias = \left(\overline{X} - \overline{Y}\right) \quad \textbf{(3)}$$

$$SI = \frac{RMSE}{\overline{X}} \quad \textbf{(4)}$$

$$r = \frac{\sum_{i=1}^{N}\left(X_i - \bar{X}\right)\left(Y_i - \bar{Y}\right)}{\sqrt{\sum_{i=1}^{N}\left(X_i - \bar{X}\right)^2 \sum_{i=1}^{N}\left(Y_i - \bar{Y}\right)^2}} \quad \textbf{(5)}$$

where $X_i$ and $Y_i$ are, respectively, observations and hindcasts, N is the number of data, $\bar{X}$ and $\bar{Y}$ are the means of the observations and hindcasts, respectively.

## 4. Accuracy of the CFSR and ERA Interim winds

Error statistics of simultaneous analysis for ERA Interim and CFSR winds compared with the observed wind data of TPAO Silivri buoy station, means of the measurements and estimated values are given in Table 1. Considering the statistical error indicators for both CFSR and ERA Interim winds, it is observed in Table 1 that bi-linear interpolation used in the SWAN model gives the best results, as expressed by the bold numbers with the lowest MAE, RMSE, bias, and SI values and highest correlation. This shows that the interpolation technique used by SWAN worked better than the other methods used here. It is also observed that the error statistics in Table 1 for both winds are very close to those of the measurement data. Figures. 3 and 4 present, respectively, time series and scatter diagrams of the CFSR and ERA Interim winds against buoy wind speed data at Silivri. The colour scheme in Figure 4 represents the log10 of the number of entries in a square box of 0.5 m/s normalized with the log10 of the maximum number of entries in a box. In this way the clustering of data points is highlighted. Each scatter plot contains 3 lines of which the first two are obtained by a least squares analysis. The solid blue line is the linear regression line according to the model y = a + bx, the red line according to the model y = cx and the line of perfect agreement is the dashed line. The number of samples N is shown in the title. In Figure 3 it can be seen that both wind products underestimate many peaks but the CFSR winds are better than the ERA Interim winds.

**Table 1**. Simultaneous error analysis of the CFSR and ERA Interim winds against the measurements at Silivri.

| | CFSR Winds | | | | ERA Interim Winds | | | |
|---|---|---|---|---|---|---|---|---|
| **Index** | **Inverse squared distance weighted interpolation** | **Inverse area weighted interpolation** | **Nearest grid point** | **Bi-linear interpolation** | **Inverse squared distance weighted interpolation** | **Inverse area weighted interpolation** | **Nearest grid point** | **Bi-linear interpolation** |
| MAE | 1.61 | 1.56 | 1.75 | 1.52 | 1.55 | 1.55 | 1.56 | 1.52 |
| RMSE | 2.07 | 2.01 | 2.23 | 1.96 | 2.06 | 2.06 | 2.08 | 1.97 |
| Bias | -0.71 | -0.62 | -0.93 | -0.52 | 0.09 | 0.07 | 0.20 | 0.16 |
| SI | 0.47 | 0.46 | 0.51 | 0.44 | 0.47 | 0.47 | 0.47 | 0.44 |
| r | 0.72 | 0.72 | 0.72 | 0.73 | 0.63 | 0.63 | 0.62 | 0.65 |
| $Y_{mean}$ | 5.12 | 5.03 | 5.33 | 5.01 | 4.30 | 4.32 | 4.19 | 4.33 |
| $X_{mean}$ | 4.41 | 4.41 | 4.41 | 4.49 | 4.39 | 4.39 | 4.39 | 4.49 |

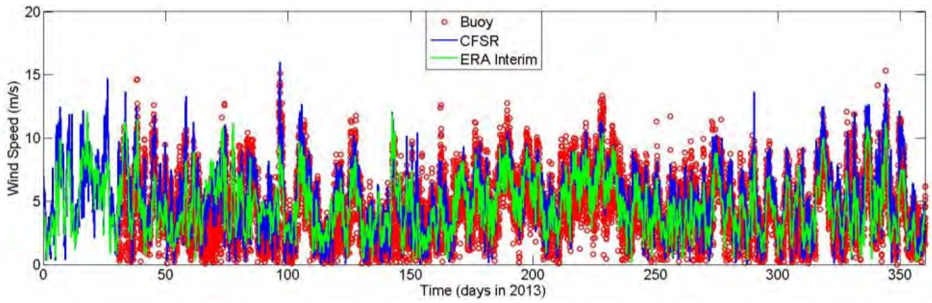



**Figure 3.** Time series of SWAN model outputs (wind speed) using the CFSR and ERA Interim winds against buoy wind speed data at Silivri for 2013.

## 5. Calibration of the SWAN Model using the CFSR and ERA Interim winds

The calibration of SWAN model forced with both the ERA Interim and CFSR winds was carried out using one-year of wave data recorded in Silivri (Figure 1). The data observed in the other two stations was used in the validation analysis. The calibrations of the SWAN models using the ERA Interim and CFSR winds were performed based on minimizing the error (scatter index) only in the simulated $H_{m0}$ because the wave period measurements are not reliable due to the active marine transportation and other effects. The rate of whitecapping dissipation was used as the tunable parameter for calibration because previous studies (e.g. Moeini and Shahidi, 2007; Appendini *et al.* 2013) in the literature found that it is the most effective parameter. The SWAN model had two options (Komen *et al.* 1994 and Janssen, 1991a; 1991b) for both wind growth and whitecapping. Therefore, we firstly performed the simulations for four different combinations (Komen & Komen; Komen & Janssen; Janssen & Janssen; and Janssen & Komen for wind growth & whitecapping, respectively) with the default setting ($C_{ds}$=4.5 for the tunable whitecapping parameter of Janssen and $C_{ds}$=2.36 x $10^{-5}$ for the tunable whitecapping parameter of Komen). And then, SWAN simulations were performed by an applying wide range (increasing or decreasing around the default) of the tunable whitecapping parameter ($C_{ds}$). The SWAN model setting with the lowest error for $H_{m0}$ was selected as the best model setting at the end of the calibration process. Based on the calibration results, the rate of whitecapping dissipation for SWAN model forced with the CFSR winds was found to be 1.0 while it was determined as 0.5 for the SWAN model using the ERA Interim winds.

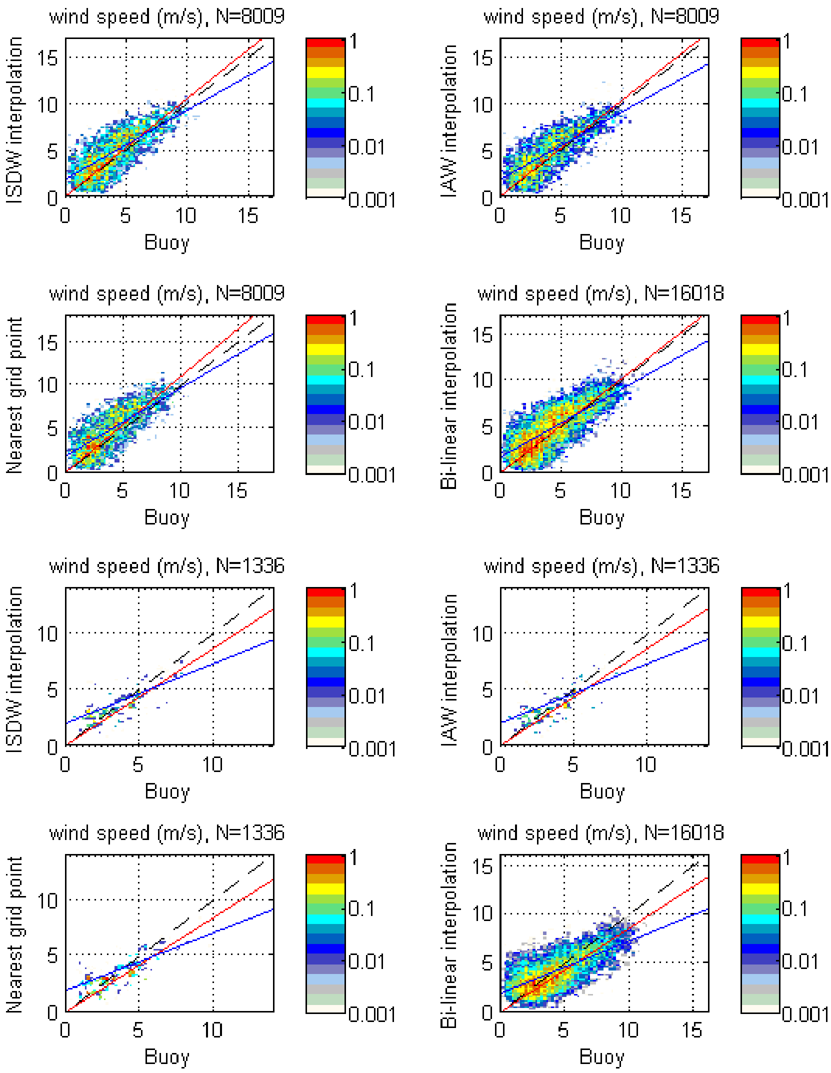



**Figure 4.** Scatter diagrams of the CFSR (upper two panel) and ERA Interim (lower two panel) winds against buoy wind speed data at Silivri.

Here, comparison results of the best and the default SWAN models for both wind sources are given. The SWAN model using the recommended default setting (SWAN team, 2014) is based on the whitecapping expression by Komen *et al.* (1994), in which δ= 1 according to Rogers *et al.* (2003), the formulation of Komen *et al.* (1994) for wind. The best SWAN model setting (Kutupoğlu, 2016) determined after the calibration at Silivri is based on the whitecapping expression by Janssen (1991a; 1991b), in which delta = 1 and $C_{ds}$=1.0 for the CFSR winds and the whitecapping expression by Komen *et al.* (1994), in which $C_{ds}$=0.5 for the ERA Interim winds, the formulation of Komen *et al.* (1994) for wind, triads activated, and the same setting for other processes. Qualitative comparisons of the time series and scatter diagrams of modeled $H_{m0}$ against the measurements are displayed in Figures. 5 and 6.

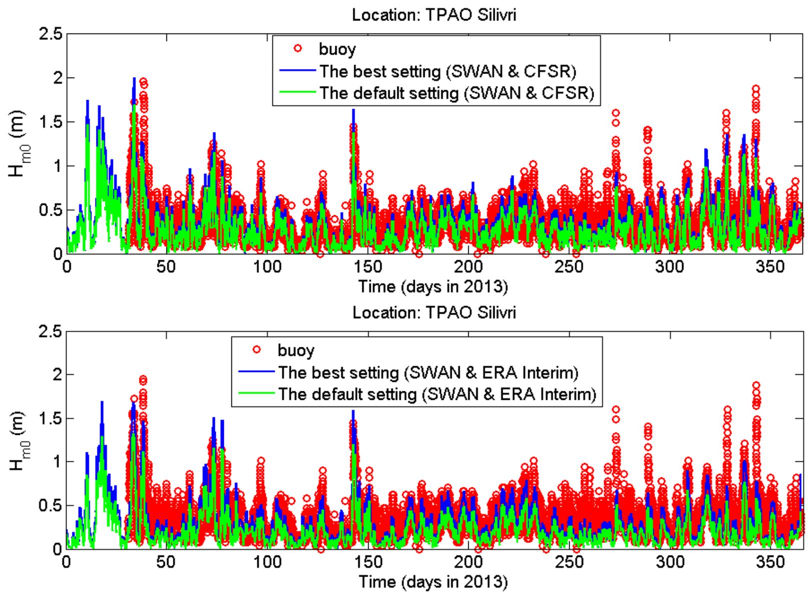



**Figure 5.** Time series comparison of the default and best setting SWAN model hindcasts using the CFSR winds (upper panel), the default and best setting SWAN model hindcasts using the ERA Interim winds (lower panel).

The summary of the statistical error analysis of wave prediction results is given in Table 2. As seen from the scatter diagrams, the best SWAN model results forced with the CFSR is closer to the line of perfect fit in comparison with the others. The other three SWAN models underestimated $H_{m0}$ values. According to the statistical error parameters in Table 2 it can be seen that the best SWAN model forced with the CFSR winds has the lowest bias (0.03 m) and lowest SI (48%) while the SWAN models using the CFSR winds have lower MAE and RMSE values (0.12 m and 0.16 m, respectively), and higher coefficient of correlation (0.77) than the SWAN models forced with the ERA Interim winds. On the other hand, the best SWAN model ($Y_{mean}$ = 0.30 m) had the nearest estimation to the observations with regard to means of simulated and measured ($X_{mean}$ = 0.33 m) data in comparison with other three SWAN models. In the scatter indices of the models the best SWAN models for both CFSR and ERA Interim winds had have about 1% and 9% improvement in the predictions of $H_{m0}$ in comparison with the default setting SWAN models using both winds, respectively. Although improvement in the SWAN model results forced with the CFSR winds are small, the calibrated SWAN model forced with the CFSR winds has a better performance than the SWAN model results forced with the ERA Interim winds.

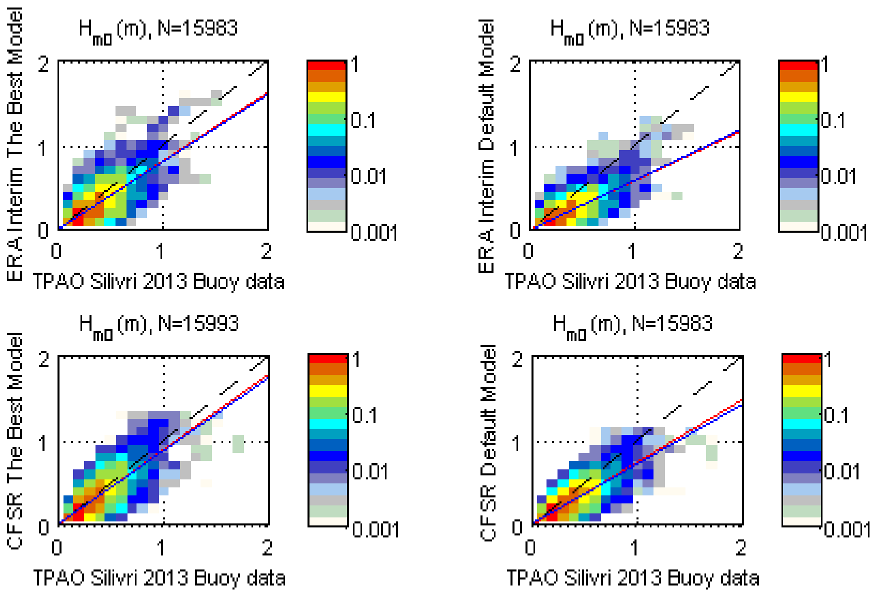



**Figure 6.** Scatter diagrams of the best setting SWAN model hindcasts using the CFSR and ERA Interim winds against Silivri buoy $H_{m0}$ observations

**Table 2.** The error statistics of the SWAN simulations ($H_{m0}$) at Silivri

| Wind | Model | MAE | RMSE | Bias | SI | r | $Y_{mean}$ | $X_{mean}$ |
|---|---|---|---|---|---|---|---|---|
| CFSR | The Best Model | 0.12 | 0.16 | 0.03 | 0.48 | 0.76 | 0.30 | 0.33 |
| CFSR | The SWAN Default | 0.12 | 0.16 | 0.08 | 0.49 | 0.77 | 0.25 | 0.33 |
| ERA Interim | The Best Model | 0.13 | 0.17 | 0.06 | 0.52 | 0.73 | 0.27 | 0.33 |
| ERA Interim | The SWAN Default | 0.16 | 0.20 | 0.14 | 0.61 | 0.74 | 0.19 | 0.33 |

## 6. Validation of the SWAN Model using the CFSR and ERA Interim winds

The measured $H_{m0}$ values at Marmara Ereğli and Ambarlı buoy stations were used in the model validation. The measurements were available at Marmara Eregli station in different months in 1990, while at Ambarlı buoy station, the measurements were available in the months of August and September in 2003. The SWAN model configurations were setup and ran for the best cases determined in the calibration analysis. The analysis results of the SWAN simulations ($H_{m0}$) at Marmara Ereğli and Ambarlı are presented in Table 3. Examining the scatter indices for the 1990 data at Marmara Ereğli, it is noted that the calibrated SWAN model forced with the ERA Interim winds shows 14% improvement in comparison with the default SWAN model while the improvement is 6% for the calibrated SWAN model forced with the CFSR winds. Considering the coefficient of correlation, RMSE, and SI values, however, it is observed that the best SWAN model using the CFSR winds has better results (r=0.81, RMSE=0.35 m, and SI=43%). This is also observed in time series comparisons in Figure 7.

In the error analysis results for 2003 data at Ambarlı, it is found in all statistical parameters that the SWAN model forced with the ERA Interim winds has better results than the SWAN model forced with the CFSR winds. Calibration of SWAN model using the ERA Interim winds shows a 13% improvement while there is a 5% improvement with the calibrated SWAN model using the CFSR winds. However, Saracoglu (2011) reported that since the wave measurements in Ambarlı station only include 3-month of data conducted between the period of July-September, the wave heights are quite small. Thus, these results represents a calm period and therefore are not representative for the wave conditions included in the calibration. Results of earlier studies also show that the verification of results with the data in 2003 do not match well with the calibrated results.

**Table 3.** The error statistics of the SWAN simulations ($H_{m0}$) at Marmara Ereğli (data of 1990) and Ambarlı (data of 2003)

| Wind | Model | MAE | RMSE | Bias | SI | r | $Y_{mean}$ | $X_{mean}$ |
|---|---|---|---|---|---|---|---|---|
| | | | Marmara Ereğli (1990) | | | | | |
| CFSR | The Best Model | 0.31 | 0.35 | 0.31 | 0.43 | 0.81 | 0.52 | 0.83 |
| CFSR | The SWAN Default | 0.36 | 0.41 | 0.36 | 0.49 | 0.80 | 0.46 | 0.83 |
| ERA Interim | The Best Model | 0.28 | 0.37 | 0.27 | 0.44 | 0.65 | 0.56 | 0.83 |
| ERA Interim | The SWAN Default | 0.43 | 0.48 | 0.43 | 0.58 | 0.65 | 0.40 | 0.83 |
| | | | Ambarlı (2003) | | | | | |
| CFSR | The Best Model | 0.11 | 0.13 | 0.11 | 0.67 | 0.55 | 0.09 | 0.20 |
| CFSR | The SWAN Default | 0.12 | 0.14 | 0.12 | 0.72 | 0.55 | 0.08 | 0.20 |
| ERA Interim | The Best Model | 0.09 | 0.12 | 0.08 | 0.59 | 0.53 | 0.12 | 0.20 |
| ERA Interim | The SWAN Default | 0.12 | 0.14 | 0.12 | 0.72 | 0.53 | 0.08 | 0.20 |

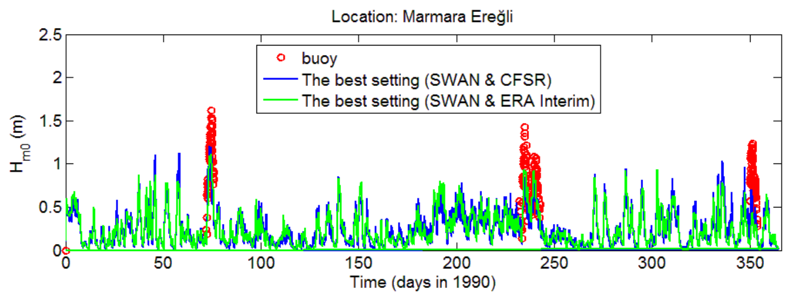



**Figure 7.** Time series comparison of the best setting SWAN model hindcasts using the CFSR and ERA Interim winds against Marmara Eregli buoy $H_{m0}$ observations

## 7. Conclusions

In this study, we performed a calibration and validation of the SWAN model in the Sea of Marmara to predict long-term wave parameters. In order to do so, the quality of CFSR and ERA Interim wind data fields, which are used as inputs in SWAN model were examined using TPAO Silivri buoy data. The results show that bi-linear interpolation used in the SWAN model gives the best results. The calibration of the SWAN model against the Silivri data showed that when forced with the CFSR winds the best setting was to the Komen formulation for wind growth and the Janssen whitecapping formulation with $C_{ds}$=1.0. For the SWAN model driven by the ERA Interim winds the best setting was the Komen formulation for wind growth and the Komen whitecapping formulation with $C_{ds}$=0.5. Also, the SWAN model forced with the CFSR winds has better performance than those using the ERA Interim. The peaks of the winds were underestimated by both CFSR and ERA Interim winds but the CFSR estimated also much better the peaks of the winds in comparison with the ERA Interim. Consequently, although the SWAN model using the CFSR winds has better performance in the hindcast of the wave height peaks, the SWAN model using both wind sources underestimated the wave height peaks during the storms.

To improve the SWAN wave model performance in the Sea of Marmara we will assess the main sources of uncertainty in the predicted winds and waves. This will include the role of land-sea effects on the nearshore wind field and the spatial and temporal resolution of the wave model. In addition we will investigate whether high resolution WRF wind will improve the SWAN model performance. Further, we want to explore the added values of the recently developed source terms for whitecapping (Rogers *et al.* 2012). Hereafter, we will study the long-term wind and wave analysis using the calibrated SWAN model forced with the CFSR winds in the Sea of Marmara.

### Acknowledgements

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## ON WATER TRANSPORT VARIABILITY OF THE BOSPHORUS STRAIT


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### 1. Introduction

The exchange of water between the Black Sea and the Aegean Sea occurs through the Turkish Straits System (TSS) (Figure 1). The properties and volume of the transported water crucially depend on the circulation and mixing processes throughout the system, as well as the water, heat and salt fluxes and mixing in the adjacent basins (Yüce 1993; Özsoy 1993; Özsoy *et al.* 1995, 1996, 1998; Jarosz *et al.* 2011a, 2011b, 2012).

Fast counter-flowing currents as a function of depth develop especially in the narrow Bosphorus and Dardanelles Straits and their exit regions. The exchanges in the two straits are stratified turbulent flows creating entrainment and mixing between the oppositely directed currents (Gregg and Özsoy 1999, 2002; Özsoy *et al.* 1996, 1998, 2001). Surface buoyant jets and bottom gravity currents develop in the exit regions of straits joining the adjacent basins (Oğuz 1990; Latif *et al.* 1991; Beşiktepe *et al.* 1993; 1994; Özsoy *et al.* 2001). All these studies show that the greatest modifications in seawater properties occur inside the straits and in their exit regions, as a result of turbulence, buoyant spreading and mixing processes.

Since dynamical processes and mixing at the two straits influence the interior circulation and material transports in the coupled basins of the Aegean, Marmara and Black Seas (e.g. Beşiktepe *et al.* 1993, 1994; Özsoy *et al.* 1993; Özsoy and Ünlüata 1997, 1998; Rank *et al.* 1998; Özsoy *et al.* 2002; Androulidakis *et al.* 2012a; Delfanti *et al.* 2013), they also imply how open boundary conditions should be applied in individual models of the Mediterranean and Black Seas. The understanding and accurate estimation of the volume and properties of the water transport through the Bosphorus and Dardanelles Straits are therefore essential for proper modeling of the adjacent seas, and the same is even more true for the particular case of the Marmara Sea. Further critical applications can be in relation to influences on the Mediterranean, such as in the case of the Eastern Mediterranean Transient (EMT) (Roether *et al.* 1996). One of the possible mechanisms leading to the EMT has been claimed to be the decrease in the amount of the BSW entering the Aegean Sea during the EMT period (Zervakis *et al.*

2000; Androulidakis *et al.* 2012b). Understanding the variability of the BSW outflow to the North Aegean Sea is therefore essential for understanding of the regional hydro-climatic processes.

The inflow-outflow at the two Straits are shown to be the primary drivers of the quasi-permanent surface circulation in the Marmara Sea, based upon a model simulation integrated for 18 years (Demyshev *et al.* 2012). Because the surface circulation is confined within the upper layer of 25 m depth throughout the year, the response to wind-stress forcing tends to be rapid, resulting in smaller scale eddies with short-term variations, as shown by the observations (Beşiktepe *et al.* 1994) and modeling (Chiggiato *et al.* 2011). The latter authors implemented a three-dimensional ocean model (ROMS), which indicated excessive diapycnal mixing as compared to the sharp interface often observed at the halocline of the TSS.

The Black Sea Water (BSW) entering from the Black Sea to the Bosphorus Strait at the surface has salinity of 16-18, while the Mediterranean Water (MW) entering from the Aegean Sea at the Dardanelles Strait in the lower layer flow has salinity of about 38-39, reaching the Bosphorus lower layer flow with a salinity of about 38.5. Mass conservation at the Bosphorus implies a ratio of about 2 between the upper and lower layer volume fluxes, reflecting the excess of fresh water inputs (runoff and precipitation) into the Black Sea as compared to evaporation losses (Ünlüata *et al.* 1990). Similar to Bosphorous Strait, the properties of the water entering to the Dardanelles Strait experience strong physical modification during its course. The Nara passage is the only hydrolic control on the water in this Strait. The upper and lower layer waters are mixed strongly in this narrow passage.

The circulation of the Marmara Sea is strongly coupled to the flow dynamics at the two Straits, where buoyancy and pressure forces are dominant. In addition to the simplified models individually applied to the Bosphorus (Oğuz *et al.* 1990; Ilıcak *et al.* 2009) and Dardanelles Straits (Oğuz and Sur 1989; Staschuk and Hutter 2001), modern three-dimensional primitive equation models have recently been developed for the Straits of Bosphorus (Sözer and Özsoy 2002; Oğuz 2005; Sözer 2013) and Dardanelles (Kanarska and Maderich 2008). Only a few of the model studies performed so far have attempted to realistically resolve either the complicated physics of the flow in the Straits, or its fine details as influenced by the steep topography; until the recent work of Sözer (2013), who used a high resolution 3-D model (The Regional Ocean Modelling System (ROMS)) for the Bosphorus, including a free surface and turbulent mixing parameterization. Observations of mixing along the Bosphorus Strait and reduced gravity modeling of the Mediterranean water outflow into the Black Sea by Özsoy *et al.* (2001) showed the importance of the hydraulic controls in the Strait and the narrow canyon (the 'pre-Bosphorus channel') leading up from the Black Sea entrance.

During exceptional conditions especially in winter time, the upper layer flow may be blocked (locally known as “Orkoz”) (Latif *et al.* 1991). Although there is modeling effort to create the blocking conditions by Sözer 2013, there is no clear understanding of the required forcing to generate the blocking events and mechanism behind the blocking conditions.

Modeling the TSS and its influence on the adjacent seas is a grand challenge for modelers (Chiggiato *et al.* 2013, Sözer 2013) because of the ultimate need to better resolve the coupled dynamics of the two large marine basins, the smaller Marmara Sea and narrow straits between them, subject to highly contrasting hydrological properties, complicated physics, extremes of climatic variability and the influences of the major hydro-meteorological drivers acting on the system. The modeling efforts concerning the TSS have so far only been able to surmount some of the initial aims of this potentially immense undertaking, through process oriented studies trying the limits of applicability of present ocean models. These studies consistently show the dynamical complexity of the exchange flows of the TSS.

Yet, there has been few attempts if any, to model the entire TSS as a coupled system with open boundary conditions specified at the adjacent Aegean and Black Seas, while keeping account of all the fine details of the narrow channels and topographic features at full resolution, the hydraulic controls, shallow shelf regions versus deep basins, at the same time adequately representing the turbulent mixing in the entire system. One of the difficulties inevitably to arise in the model is the ability to control of the sharply stratified density interface against excessive diapycnal mixing that would result from the possible inadequate representation of turbulence in the highly stratified environment.

In the present study we use the HYbrid Coordinate Ocean Model (HYCOM) as the model of choice, utilizing its simplified near-isopycnal dynamics and powerful vertical coordinate system most easily adapted to the existing conditions of the TSS. Making use of the unique features applicable to the highly stratified Marmara Sea, the high-resolution ocean model is configured for the entire TSS including the two Straits and its adjacent domains. By conducting model experiments, water transport and upper layer blocking dynamics at the Bosphorous Strait will be investigated.

## 2. Model Features and Set-up

### 2.1. Numerical Model

The HYCOM (Bleck 2002) is a three dimensional, isopycnal ocean model solving five prognostic equations: two for the horizontal velocity components, a mass continuity or layer thickness tendency equation and two conservation equations for a pair of thermodynamic variables, such as salt and potential temperature or salt and potential density. The HYCOM uses a generalized (hybrid isopycnal/terrain-following (sigma/z-level) coordinate system, so that it behaves like a conventional sigma coordinate (terrain-following) model in shallow regions, like a z-level (fixed-depth) coordinate model in the mixed layer or other unstratified regions, and like an isopycnic-coordinate model in stratified regions (e.g., Bleck 2006). The model uses the layer continuity equations to make a dynamically smooth transition to z-levels in the unstratified surface mixed layer and sigma levels in shallow water (Kara *et al.* 2010). The optimal coordinate is chosen at every time step, using a hybrid coordinate generator. The thickness of the model layers is adjusted according to target densities and the type of vertical coordinate. Figure 2 shows an example for the adaptation of the model layers. The model layer thickness changes in every model time step, as in the two cases shown in the figure for October 15 and November 10. The top four layers are based on z-levels following the topography near the coast, and in the deeper regions they approach isopycnal layers. The preservation of the stratification is evident in this figure. A time series of salinity in a station in the Marmara Sea (not shown) prove that the stratification conserved during the model integration.

The HYCOM model has been used in a wide range of applications varying from global oceans to regional seas. Among the recent studies using HYCOM, we can cite Chassignet *et al.* (2009) implementing a global system; Mehra and Rivin (2010), setting up a model of the North Atlantic Ocean; and Kara *et al.* (2005), who set up a regional version of HYCOM in the Black Sea. Gündüz and Özsoy (2014) studied the climatological Caspian Sea circulations by using HYCOM.

### 2.2 Application of HYCOM to the Marmara Sea

The model domain in Figure 1 a includes the TSS (Marmara Sea, Bosphorus Strait, Dardanelles Strait) accompanied by the western Black Sea and North Aegean Sea domains partially included to represent the influences of the neighboring seas. The model bathymetry is the combination of various sources, in which the GEBCO topography (Becker *et al.* 2009) has been blended with the available local data sets of high resolution. Detailed explanation for the processing of the bathymetric data can be found in Özsoy *et al.* (2001). Figure 1 b shows the detailed bathymetry of the Bosphorus Strait, where a good representation has been obtained of the contraction and sills of the Bosphorus Strait. It should be noted that the model bathymetry was smoothed by averaging the four neighboring points around the selected grid.

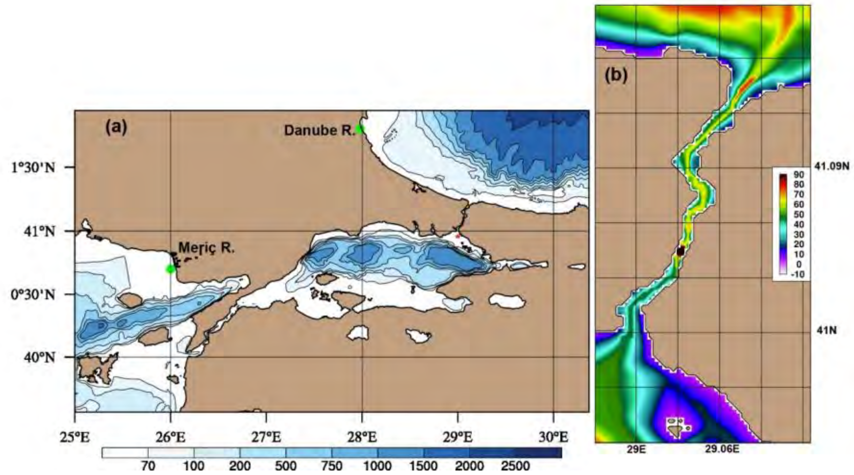


**Figure 1.** Geographical settings of TSS with (a) HYCOM-Marmara model domain and bathymetry (m), the green dots show the location of the river mouths used in the model and the red star at the Marmara Sea exit of the Bosphorus Strait is the station to generate the Figure 6. (b) detailed bathymetry of the Bosphorus Strait.

The model has 1/225° horizontal resolution, which nominally corresponds to about 400 m at the latitude of interest. The HYCOM TSS model has 10 vertical layers; four of which are at z-levels (mostly at the surface), while the rest are isopyncal layers. The model uses spatially varying isopycnal target densities, set between 11 to 28.6 in the Marmara Sea. The minimum thickness of the z-levels was set to 1.5 m, and the maximum was set to 15 m. Vertical mixing is parameterized by the Price-Weller-Pinkel Dynamical Instability Model (Price *et al.* 1986), with the critical Richardson number set to a value of 0.25. This parameterization performed better (not shown) than the other available parameterizations available in HYCOM (such as the K-Profile parameterization mixed layer model (KPP) and the NASA Goddard Institute for Space Studies (GISS) model). The baroclinic and barotropic time steps were set to 30 s and 1 s respectively.

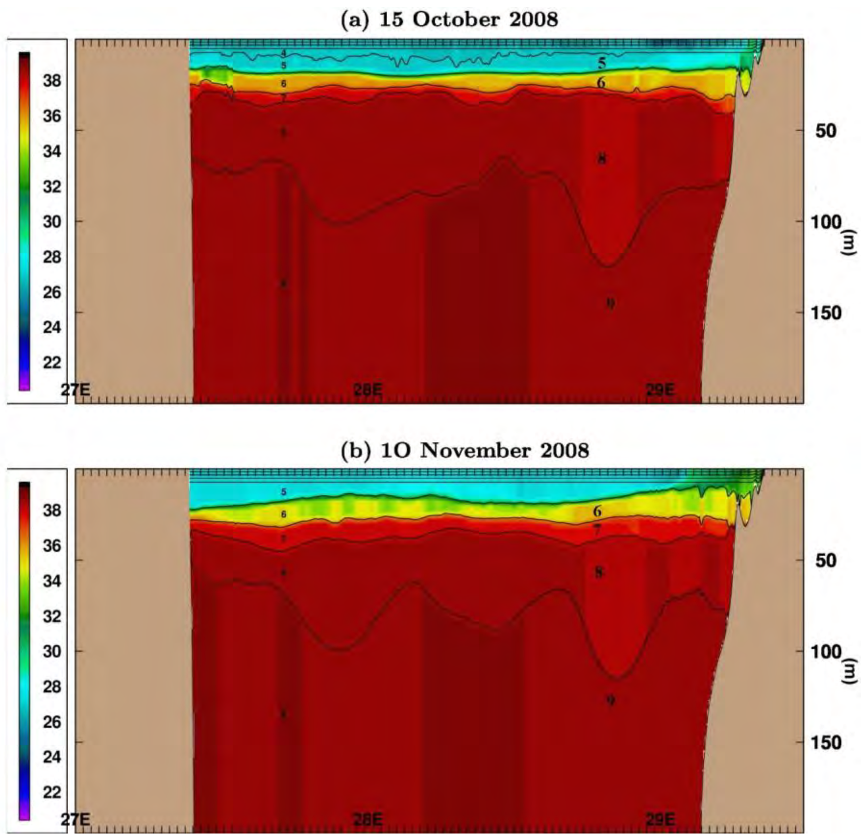

**Figure 2.** Zonal cross-section of salinity at 40.8° N (Northern Marmara Sea) for (a) 15 October 2008 (b) 10 November 2008. The layer numbers of the HYCOM–Marmara model were also shown.

The model was initialized with the in-situ CTD observations obtained during the September 2008 cruise (in the framework of the NATO TSS project, "Exchange Process in Ocean Straits", Book *et al.* 2014). The distinct properties of the adjacent basins of the Aegean, Marmara and Black Seas were represented by three profiles selected and applied uniformly in each of these seas. Figure 3 shows the temperature and salinity (T/S) profiles used to initialize the model. The salinity profiles indicate a strong pycnocline at a depth of ~20 m in the Marmara Sea (top), and a weaker one in the Black Sea (middle), while the Aegean Sea (bottom) has high salinity water with milder stratification.

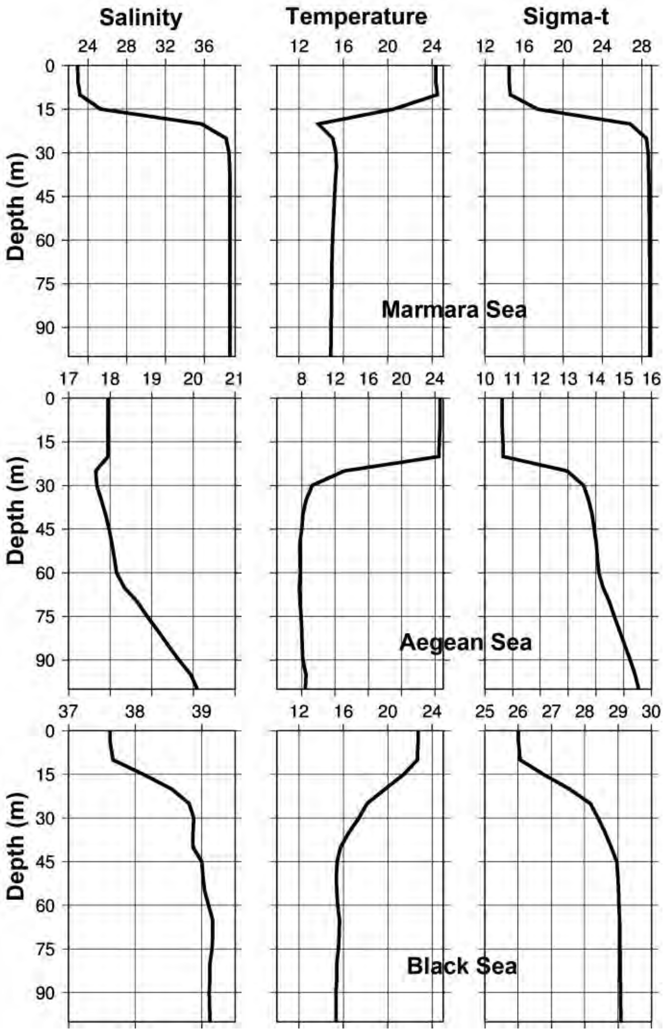


**Figure 3.** Temperature, salinity (used to initialize the model) and density (sigma-t) profiles. Upper: Marmara Sea, middle: Black Sea, lower: Aegean Sea. The profiles were selected from TSS September-2008 field experiment (NATO TSS project, “Exchange Process in Ocean Straits”).

The World Ocean Atlas 2005 (WOA05 Antonov *et al.* 2005, Locarnini *et al.* 2005) gridded climatology data set (78 depth levels and 0.25° horizontal resolution) was used to specify temperature and salinity at the open boundaries in the Black and Aegean Seas, where the model variables were relaxed over the twenty rows of grid points along the boundaries with e-folding time varying from 3 days to 30 days in the different runs. Since there is no available data for sea surface elevation, zonal and meridional velocities to force the model at the open boundaries, the model relax only temperature and salinity at the OBs.

The Danube River was included in the model, and treated as a precipitation source on the western Black Sea coast. The river discharge has been divided among the three branches of its delta and the river mouths have been extended up to 10 grid points for each branch. Considering the fact that the Danube river mouth is located out of model domain, half of the real climatological discharge was used. The climatological discharge rates were obtained from the RivDAS data (Vorosmarty *et al.* 1998).

The atmospheric forcing was specified based on the ECMWF Interim Re-Analysis (ERA-Interim, Dee *et al.* 2011) product, which has 1.125$^{o}$ horizontal resolution at 3 hours time interval. The HYCOM only needs wind stress, precipitation, net heat flux and short-wave radiation to be specified for the calculation of air-sea bulk fluxes according to the methods explained in Kara *et al.* (2005).

Each model experiments integrated for five months starting from September 2008 until end of January 2009 which coincides with the available observations made by Jarosz *et al.* (2011).

**Table 1.** Calculated mean water transport (km$^3$/yr) in the Bosphorus Strait based on mass budget and long term salinity measurements estimation. Özsoy (1998) and Jarosz *et al.* (2011a) used ADCP observations to calculated the transport. Observation periods are shown in parenthesis.

| | **Upper Layer** | **Lower layer** | **Net** |
|---|---|---|---|
| Ünlüata, 1990 | 612 | 312 | 300 |
| Beşiktepe *et al.* 1994 | 603 | 303 | 300 |
| Tugrul *et al.* 2002 | 639 | 318 | 321 |
| Özsoy 1998 (six month) | 540 | 115 | 425 |
| Jarosz *et al.* 2011a (Sept. to Jan.) | 375 | 253 | 122 |

### 3. Results

Past studies using different techniques have shown significant variations in transport in response to time-dependent hydro-meteorological events. Based on water balances of the Black and Marmara Seas and long term salinity measurements Ünlüata *et al.* (1990); Beşiktepe *et al.* (1994) and Tugrul *et al.* (2002) performed calculations of average water fluxes at exit sections of the straits. The fluxes at the Bosphorus Strait based on these studies are summarized in Table 1, indicating roughly about 600 km$^3$/yr for the upper layer flux, and about 300 km$^3$/yr for the lower layer flux. However, calculations based on various current measurements and modeling results show smaller values of transports. For example, ship-borne ADCP measurements (Özsoy *et al.* 1998) have found average fluxes of 540 km$^3$/yr for the upper layer and 115 km$^3$/yr for the lower layer. Based on six months of ADCP measurements, Jarosz *et al.* (2011) found an average upper layer flux of 375 km$^3$/yr and lower layer flux 253 km$^3$/yr. We note however, that ADCP measurements usually suffer from a loss of data near the bottom and the surface, which influences the accuracy of the flux estimates.

In general, the model generated volume fluxes are smaller than the average values obtained from measurements. There may be couple of explanations for this. First of all, the model integration periods coincide with the summer and autumn periods when the Black Sea outflow flux is at its lowest level (Beşiktepe *et al.* 1994), while the other values reported in Table 1 are based on annual averages. It should also be noted that the offset between the model and the observations may be related to the model, which underestimates the transport as a result of the artificially confined nature of the adjacent basins. Another important constrain of the model is that the model is non free surface which could influence the water transport significantly.

Figure 4 showing the model daily time series of Bosphorus fluxes display high levels of variability (negative values indicate flows in the direction from the Black Sea to the Marmara Sea). Time dependence of the flows in the Bosphorus may often result in short-term blocking events, resulting in the flow being stopped in either the upper or the lower layers, as shown by Latif *et al.* (1991) and Özsoy *et al.* (1998).

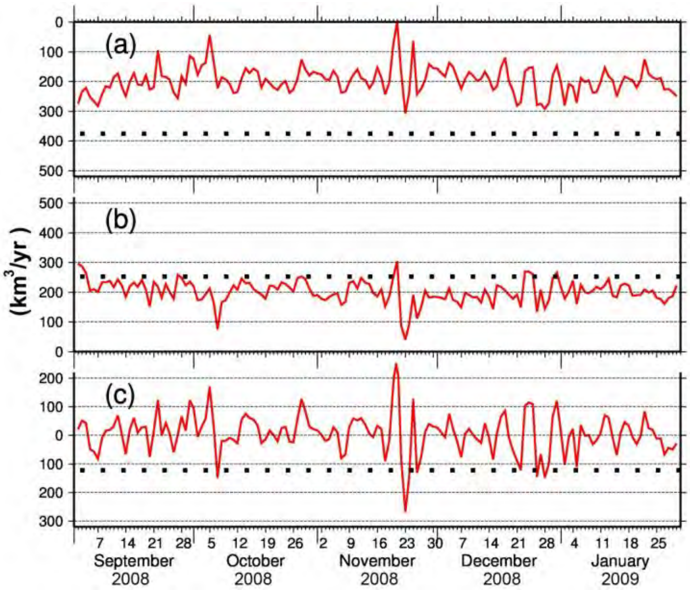


**Figure 4.** (a) Upper-layer (b) lower-layer (c) net daily water transport (km$^3$/yr ) in the southern Bosphorus Strait from September 2008 to January 2009. The mean water fluxes calculated from the ADCP observation (Jarosz *et al.* 2011a) is shown as dotted line.

The salinity transect along the main axis of the Bosphorus Strait in Figure 5 a corresponds to the case of upper layer blocking in response to a storm with leading southwesterly winds. In Figure 5 b an example is given for the normal, two-layer flow regime in which both layers are active. Figure 5 c shows the salinity transect during a lower layer blocking period.

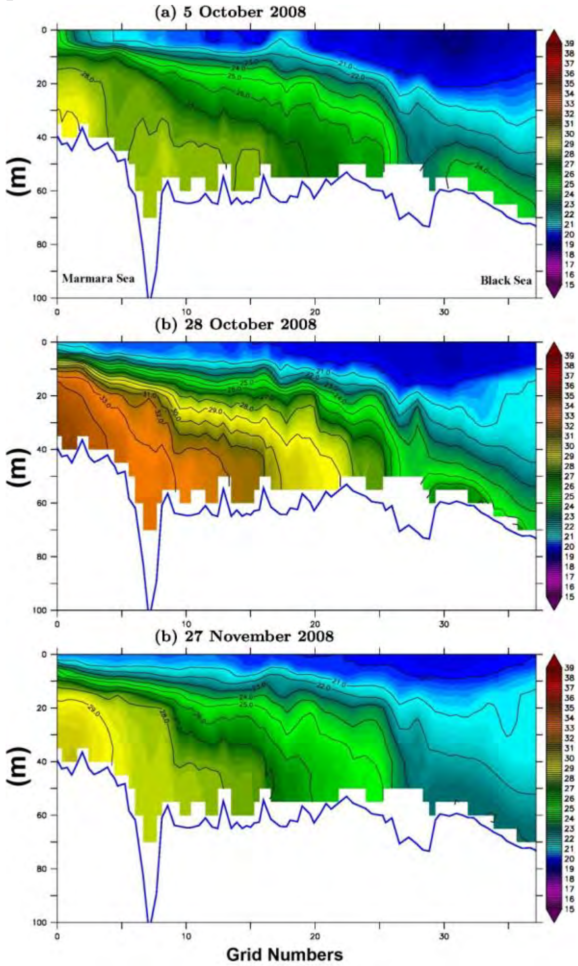


**Figure 5.** Salinity transect along the main axis of the Bosphorus Strait (a) Upper layer blocked (b) Normal conditions (c) Lower layer blocked. Left side is the Marmara Sea and the right side is the Black Sea.

The upper layer blocking events are evident in the model time-series of meridional velocity near the southern exit of the Bosphorus in Figure 6, when the upper layer currents are reversed (positive) and later followed by increased southward (negative) currents with increased depth for the next couple of days. Comparison of the model generated water transport with ADCP observations (Figure 2 in Jarosz *et al.*

2011) seems to indicate similarities in terms of the time dependence of events. For example, two cases of upper layer blocking events as shown in Figure 5a were also observed by Jarosz *et al.* (2011).

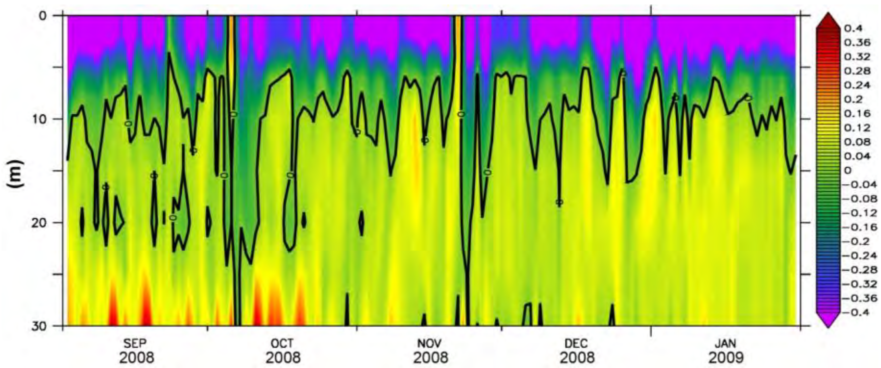

**Figure 6.** Along strait velocity (m/s) at the station located at the southern exit of the Bosphorus Strait. The black line is zero contours. The two upper layer blocking events happened; one in beginning of October and the other at 19-23 November 2008.

The atmospheric influence on the blocking events is further evaluated by analyzing the time series of the P+R-E (precipitation plus river inflow minus evaporation), wind speed, mean sea level pressure averaged over the Black Sea, and the sea level difference between the two ends of the Bosphorus Strait shown in Figure 7 a,b,c,d. During the blocking events (shaded), the drops in the barometric pressure indicate passing storms, the latter one in November being extensively studied by Book *et al.* (2014). The dominant wind directions (not shown) during the blocking events are southwesterly. Since the HYCOM does not incorporate the effects of the atmospheric pressure, we conjecture that the strong winds reflect these effects. It is less straightforward to establish direct correspondence of upper layer blocking with P+R-E (Figure 7 a). The sea level difference between the two ends of the Strait appears negatively correlated with the water transport (Figure 7 d).

Model experiments (EXP1 to EXP4) have been run in addition to the control experiment, doubling the river inflow in EXP1, doubling the wind stress in EXP2 in comparison to the control run, relaxing the mass conservation option of HYCOM in EXP3. In this set-up surface water fluxes are not required to conserve mass in the model anymore. This option allows the model lose or gain volume during the model integration period at the open boundaries. In EXP4, the river inflow was doubled relative to EXP3. By doubling the wind stress over whole model surface grid points and river discharge in the Black Sea, it is expected that the Strait will response to the changes in forcing fields.

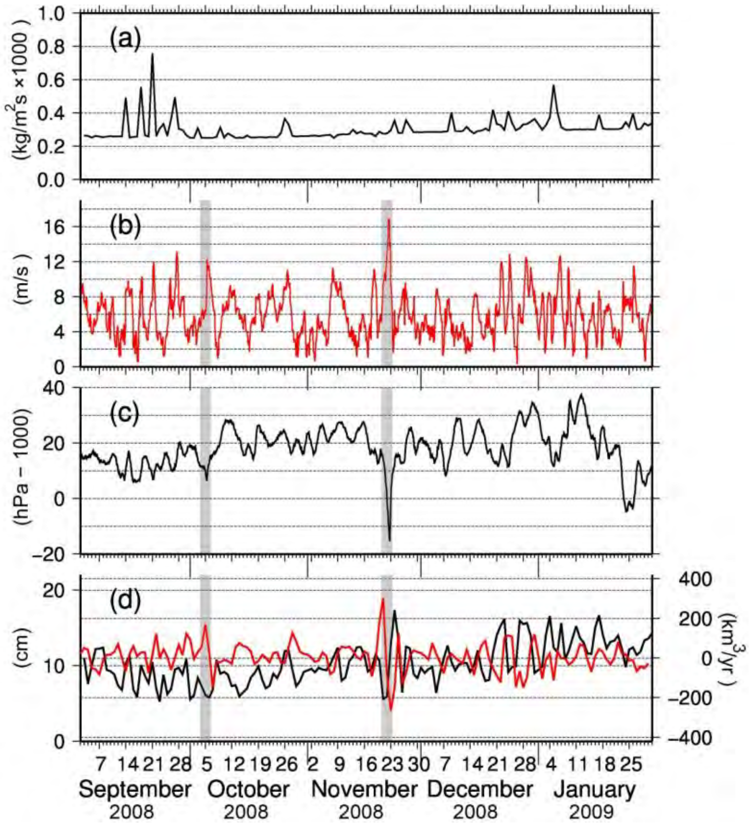


**Figure 7.** Time series of daily averaged over the Black Sea (a) precipitation minus evaporation (kg/m$^2$s ×1000 ) (b) wind speed (m/s ) (c) mean sea level pressure (hPa − 1000) (d) sea level difference (cm ) (black line, left axis) between the southern and nothern ends of the Bosphorus Strait and the net water transport (km$^3$/yr ) (red line, right axis) from the control experiment.

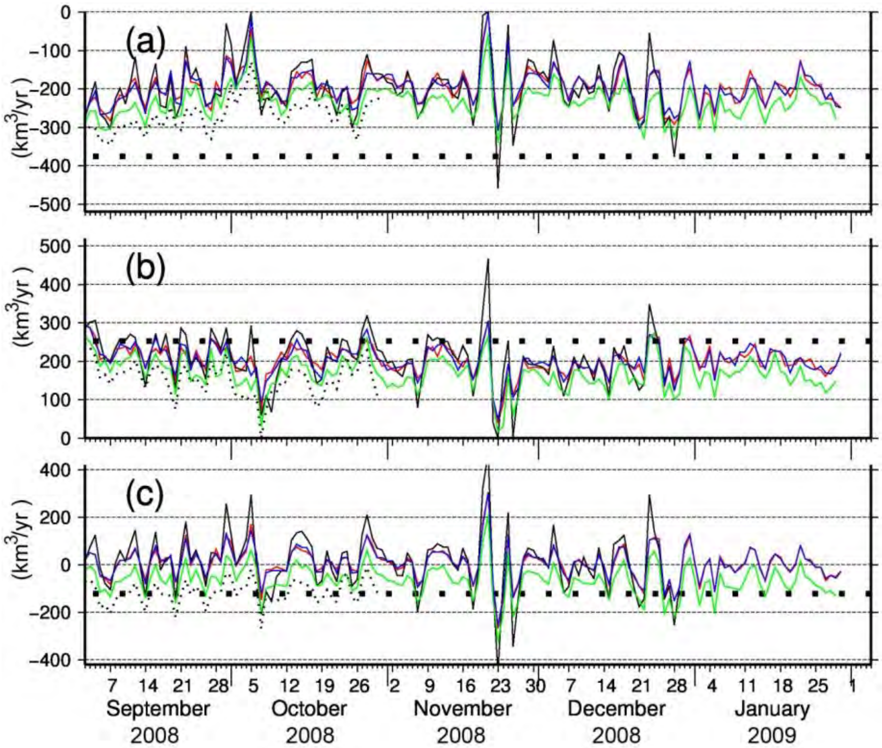


**Figure 8.** Time series of daily water transport ($km^3/yr$) at the Bosphorus Strait. Red line is control run, blue line is EXP1, black line is EXP2, green line is EXP3 and the dotted line is EXP4. (a) Upper layer (b) Lower layer (c) Net Flux. The bold dot line shows the averaged transport calculated by Jarosz *et al.* (2011a). EXP4 could not be integrated until the end of the experiment time due to the instability of the model.

The experiments investigated sensitivity with respect to forcing, displaying the time series of water transport in Figure 8. With doubled river influx (EXP1, blue line), or wind stress (EXP2, black line) the results are very similar to the control experiment, since the requirement of mass conservation essentially results in weak or zero net barotropic flux across the TSS in all three experiments. In EXP3 when the mass conservation is relaxed in the model, the upper layer transport is increased due to increased net flux, while the highest increase occurs when river inflow is doubled in combination with the relaxed mass conservation (EXP4). EXP4 could not be integrated until end of the integration period due to the instability of the model generating strong currents along the OBs. Increasing the sponge layer or nudging factor did not work to stabilize the model at the open boundaries. In a further study, the model boundaries would be forced by the real-time temperature, salinity and SSH fields to better represent the open boundaries. Since the model responds quickly (in a couple of days) to the changing forcing fields, the relatively short model integration is enough to see the effects of the relaxation on the water transport.

In summary, a numerical simulation of the Marmara Sea was conducted with a new set-up of the HYCOM. The water transport through the Bosphorus Strait predicted by the model is in agreement with the available observations. The numerical model experiments reveal the importance of the wind stress and rivers on the transport and circulation in the TSS. Upper layer blocking occurs during southwesterly winds of approaching storms indicated by depressions in barometric pressure. Increase in river inflow results in increased transport only when mass conservation is relaxed in the model, while doubling of the river inflow or the wind stress results increased fluctuated response in water transport.

The current model, although of a moderate horizontal resolution of about 400 m, produces encouraging results for investigating the exchange flow and circulation dynamics of the TSS. The relatively coarse resolution 1.125° of atmospheric forcing utilized does not allow surface fluxes to be represented at sufficient resolution. However, due to the optimal vertical coordinate choice of the model, it is a rather important quality of the model that the pycnocline could be preserved against excessive diffusive effects during the model integration.

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**THE BOSPHORUS JET**

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## 1. Introduction

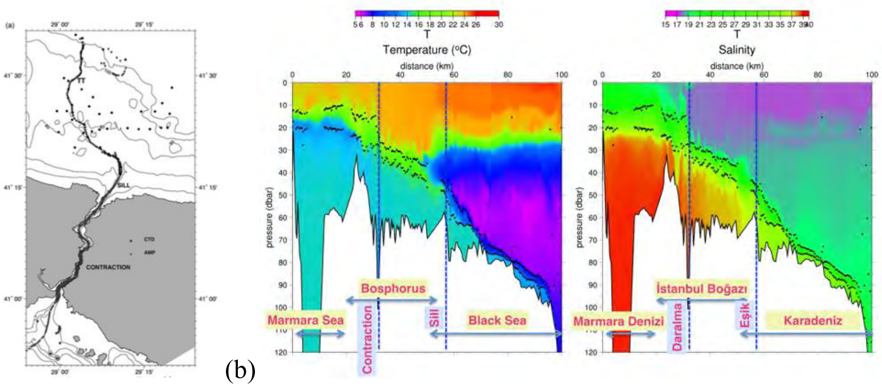
The Turkish Straits System (TSS) provides the only mechanism of communication between the Black and the Mediterranean Seas, allowing material transport between these two seas by the two-layer exchange flows. The exchange has great influence on the water mass characteristics and transport of materials with potential to alter the environmental states of the TSS and the neighbouring basins of the Mediterranean and the Black Seas.

**Figure 1.** MODIS aqua image of Emiliana huxleyi bloom on June 23, 2003 (http://disc.sci.gsfc.nasa.gov/oceancolor/additional/science-focus/ocean-color/marmara.shtml).

The counter flowing waters of the Black Sea and Mediterranean Sea are mixed by turbulent entrainment processes along their course through the TSS (Özsoy *et al.* 2001) and issue into the adjacent basins (Figure 1) either as surface buoyant jets (at the Bosphorus exit to the Marmara Sea and Dardanelles exit to the Aegean Sea) or bottom dense water plumes that generate gravity currents and plumes cascading into the interiors of these seas (at the Dardanelles exit to the Marmara Sea and Bosphorus exit to the Black Sea).

## 2. The Functioning of the Bosphorus Strait

In order to visualize the unique processes of mixing and transport within the Bosphorus Strait we provide interpretation of a unique data set that has been collected in the 1994 study of Gregg *et al.* (1999) and Gregg and Özsoy (1999, 2002). A continuous set of measurements were obtained from a free fall AMP instrument connected to the R/V BİLİM with a signal transmitting optical fiber cable. A total of 178 temperature and salinity profiles were collected along the complete path of consecutive stations (Figure 2a) extending from the Marmara Sea to the Black Sea, following the Bosphorus channel, for which the temperature and salinity are respectively displayed in Figures 2b and 2c. Details of the measurements and their interpretation can be found in Özsoy *et al.* (2001).




(a) (b)

**Figure 2.** (a) Locations of the dense profiling network and the continuous distribution of (b) temperature and (c) salinity along the Bosphorus, from Marmara Sea to the Black Sea obtained from 178 profiles. Black dots separate the upper, interfacial and lower layers estimated from salinity profiles (Özsoy *et al.* 2001).

## 3. The functioning of the Bosphorus Jet

Unique opportunities to visualize the detailed structure of the flows through the TSS and in the adjacent basins is also offered by space photographs, notably during the recent International Space Station observations by astronauts. Examples are provided below.

The two images in Figure 3 show features of the Bosphorus Jet. In the color image of Figure 3a, the water surface has high reflectance, showing the flow along the Bosphorus and the jet issuing to the Marmara Sea, with dark lines showing multiple small fronts and boat wakes. In the thermal image of Figure 3b colder waters are displayed in darker blue and warmer areas in light blue. The light blue of the Black Sea and Marmara waters excluding the jet area have warmer temperatures, while the dark blue area covered by the Bosphorus Jet demonstrates the turbulent mixing and entrainment process that results in the cold waters. The surface waters south of the main contraction of the Bosphorus and in the core of the Bosphorus Jet exiting to the Marmara Sea derive their cold temperatures from increased mixing and turbulent entrainment of cold water from below.

(a) (b)

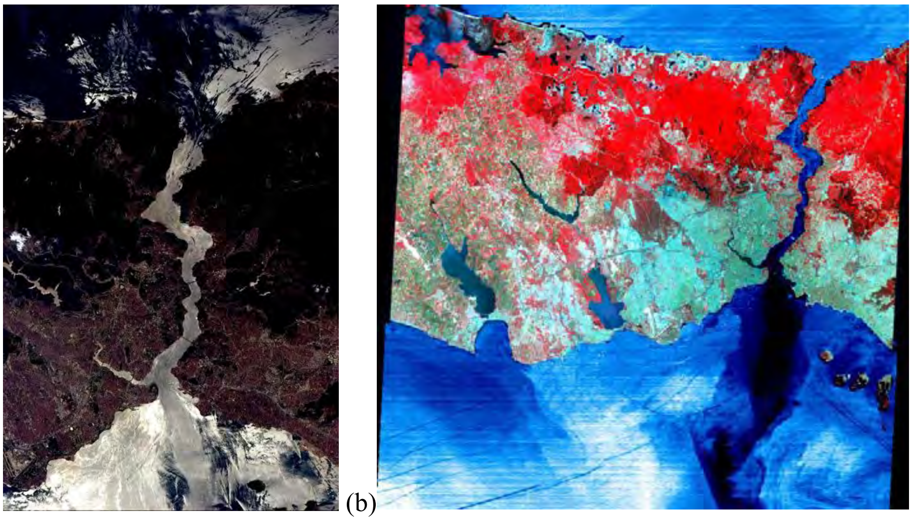


**Figure 3.** The Bosphorus Jet as seen on the (a) 7 July 2013 high reflectance image obtained by astronaut Chris Hadfield aboard the International Space Station (https://twitter.com/Cmdr_Hadfield/status/350012636345270272/photo) and (b) 16 June 2000 ASTER image (https://asterweb.jpl.nasa.gov/gallery-detail.asp?name=Istanbul). On land, the green color shows the city area, while the remaining forested areas are shown in red false color, in this image from the beginning of the millennium.

In the Marmara Sea, a strong upper layer circulation (Beşiktepe *et al.* 1994) with a large anti-cyclonic loop with occasional smaller scale eddies is joined by the Bosphorus Jet. The Bosphorus Jet, as well as the other jets and plumes exiting on different sides of straits function to enhance vertical and horizontal mixing through turbulent entrainment processes and by the mesoscale processes of jets, jet fragments and eddies, and thereby are the main agents of basin-wide mixing processes. Their contribution to total entrainment exchanges between layers and to the total basin averaged mixing and entrainment processes have to be quantified. The local response of the jets to changes in forcing, and the further influence of eddy and jet breakdown processes on mixing are also important elements of the overall mixing. However, from the above example of the Bosphorus Jet, it is clear that the jets can play a primary role on basin-wide mixing. These fine scale processes in the end determine tracer distributions and their residence times in the respective basins.

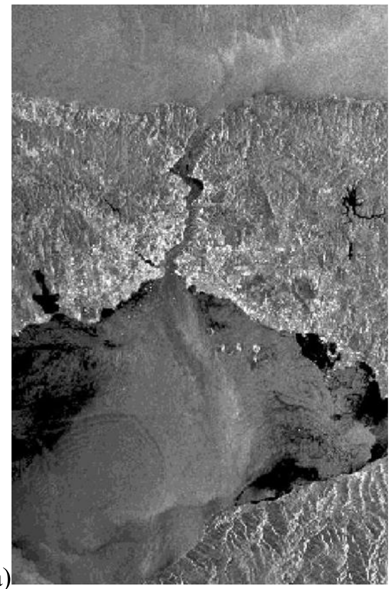
(a)  (b) 

Figure 4. The Bosphorus Jet in the (a) ERS-1 SAR image of the Bosphorus Strait and the adjoining Marmara and Black Sea regions (after Özsoy *et al.* 2001) and (b) April 16, 2004 International Space Station image showing turbid coastal waters from the Black Sea transported by strong currents and later carried through the Strait into the Sea of Marmara (https://eol.jsc.nasa.gov/SearchPhotos/photo.pl?mission=ISS008&roll=E&frame=2175).

In the Synthetic Aperture Radar (SAR) image of Figure 4a, the Bosphorus Jet is made visible by the surface roughness effects detected by the satellite sensors. The Jet reaches and strikes the Bozburun Peninsula on the opposite side, where a series of internal waves have been created at the area of impingement, seen to be spreading towards the Marmara Sea, in the image.In the ISS colour image of Figure 4b, the surface flow converges toward the Black Sea mouth of the Bosphorus, superposed on the predominantly easterly currents along the Black Sea coast, then flows south through the Bosphorus Strait and exits into the Marmara Sea in the form of a jet. The transported material is shadowed past the small island on the path of the Jet.

The remarkable picture in Figure 5 shows flows of material originating from the Black Sea coast (near the planned new site of the 3rd airport of İstanbul) entering the Bosphorus and reaching the Marmara Sea in the form of a surface jet, which once more curves toward the west after striking the cape of Bozburun. In Figure 5, we recognize that the Bosphorus Jet touching the southern coast effectively isolates the polluted Gulf of

İzmit area from the rest of the circulation of the Marmara Sea, thereby limiting its flushing and adversely affecting the environmental status of the Gulf.

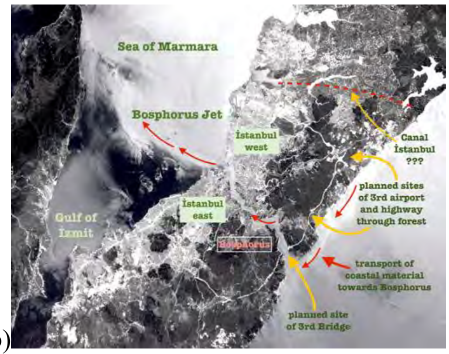
(a)(b)


**Figure 5.** Turkish Straits captured by ISS astronaut Samantha Cristoforetti on June 9, 2015 (a) color image showing transport of coastal materials first eastwards by currents in the Black Sea, later into the TSS through the Bosphorus and spread into the Marmara Sea by the Bosphorus Jet, (b) paths of currents and locations of planned “development” in the region (https://twitter.com/astrosamantha /status/608197918395400192).

## 4. Significance of the Bosphorus Jet for the TSS Ecosystem

The nutrient transport across the TSS (Polat and Tuğrul 1995) fuels the interactions between ecosystems of the neighboring seas. In the example of Figure 1, presented earlier, a typical phytoplankton bloom coccolith Emiliana huxleyi, well known for its turquoise blue colour illustrates a condition found in the spring season in the Marmara Sea. The observed event is part of the Marmara local primary production process and the dark colour of the current flowing in from the Bosporus into the Marmara Sea is the Black Sea water devoid of the same plankton species because its bloom in the Black Sea is a little later. Finally, the bloom locally formed in the Sea of Marmara reaches the Aegean Sea with a jet flow exiting the Dardanelles Strait.

Significant mixing occurs inside the Straits and further by surface buoyant jets upon exit to the wider sea regions from the two Straits. The surface plumes carrying relatively fresh water and chemical / biological signatures from their sources affect material cycling in the target basins not only through transport, but also as a result of efficient turbulent mixing and entrainment in the exit regions. Interfacial mixing at the straits and jet mixing near their exit regions yield the highest horizontal rates of change in properties within the TSS and largely determine the cycling of matter and biological productivity of the confined waters of the Marmara Sea; a fact emphasized earlier by Ünlüata et al. (1990) and Beşiktepe et al. (1994).

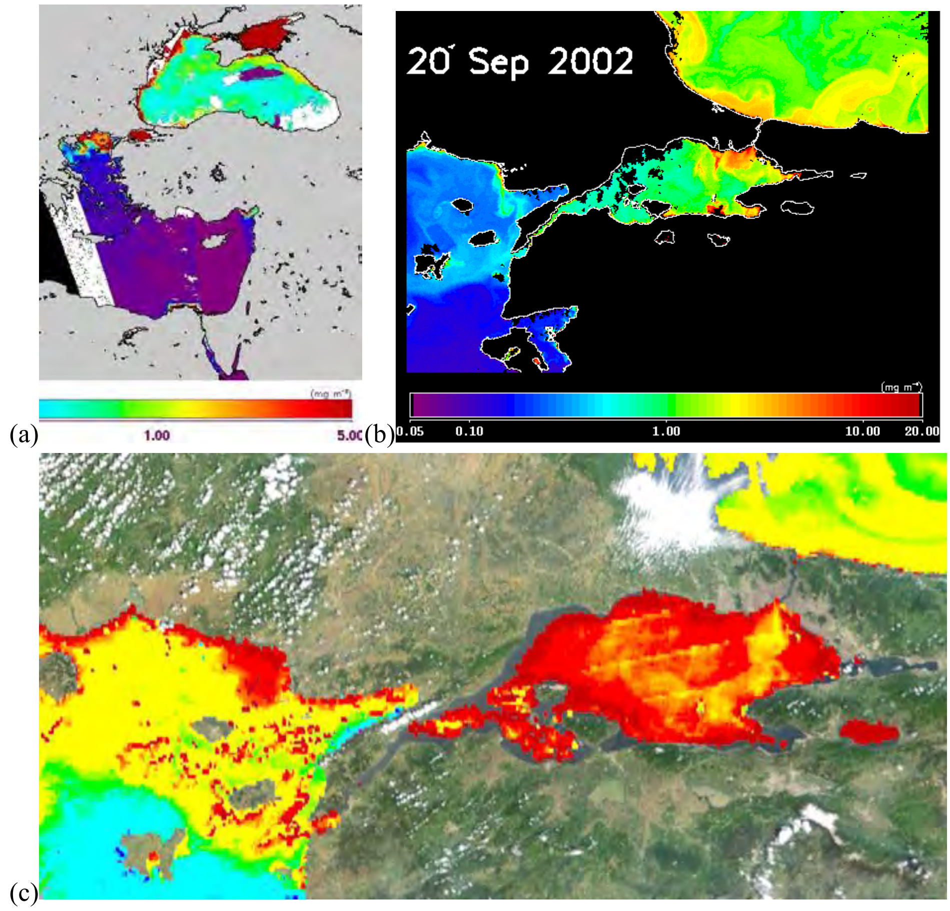



**Figure 6.** Satellite images showing the interaction of the Turkish Straits System with the neighboring seas: (a) chlorophyll distribution in ten Eastern Mediterranean and Black Sea with hot areas (red) in the Marmara Sea and Azov Sea, medium areas downstream of the Danube River along the western Black Sea shelf and in the northern Aegean downstream of the TSS, (b) chlorophyll distribution on 20 September 2002, (c) 12 May 2015 MODIS Aqua chlorophyll image showing phytoplankton blooms in Marmara Sea and the Bosphorus Jet enhancing the production by transporting nutrients to the Marmara Sea from the Black Sea.

The efficient jet induced local recycling makes this small basin a region of high productivity often far exceeding the Black Sea (Figure 6a), and incomparable to the “blue desert” of the eastern Mediterranean Sea. A similar picture of chlorophyll distribution in Figure 6b emphasizes the gradients and transport of chlorophyll from the Black Sea to the Aegean Sea in the autumn season. Finally the Bosphorus Jet transporting nutrients to the Marmara Sea buffer zone where the isolated and polluted waters of the TSS create continuous blooms as shown in Figure 6c.

High concentrations of chlorophyll were found in the TSS region in the "Ünlüata Cruises" of the SESAME European project, in continuous sampling of surface waters fed through a Turner fluorometer (Figure 7). In fact the situation was the same on cruises repeated in April and September 2008, extending from the Eastern Mediterranean to the mid-sections of the Black Sea, which showed that the highest chlorophyll concentrations of up to 3 mg/l were always found in the TSS, while the concentrations were much lower in the other regions. It seems that the Sea of Marmara is in a state of eutrophication with continuous blooms saturated with high levels of primary production and detrital material that is depriving it from being the precious marine heritage of rich marine life that it was only less than half a century ago.

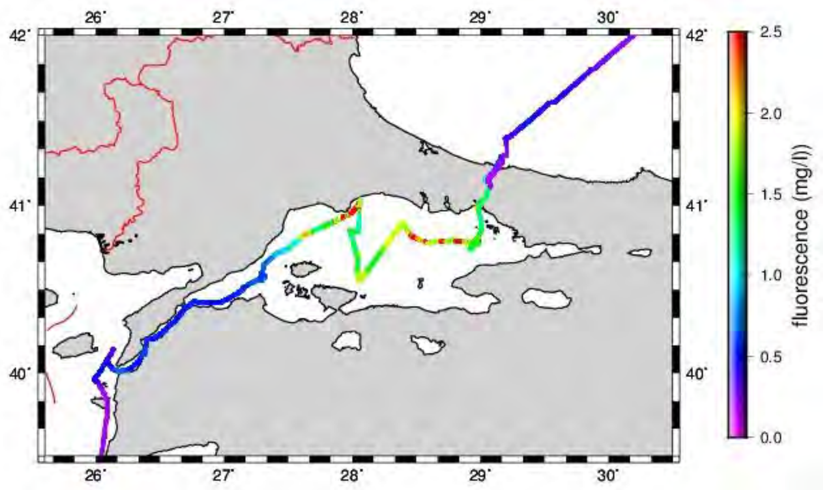



**Figure 7.** Chlorophyll concentration on the cruise path of the R/V BİLİM during April 2008.

Significant changes have occurred in our lifetime in the ecological status of the TSS, and mainly after the 1960's industrialization and population expansion. The eutrophic Marmara Sea waters fed by Black Sea nutrients (Polat and Tuğrul, 2005), as well as the efficient jet induced local recycling makes this small basin a region of high productivity often far exceeding the Black Sea, with increasing occurrences of mucus and harmful algae blooms (Figure 8-12). The plans for what is often inappropriately called as 'development' pose increasing risks of ecosystem crises and failures in the TSS, with implied effects on adjacent basins, as many signs of deterioration are already easily discernible.

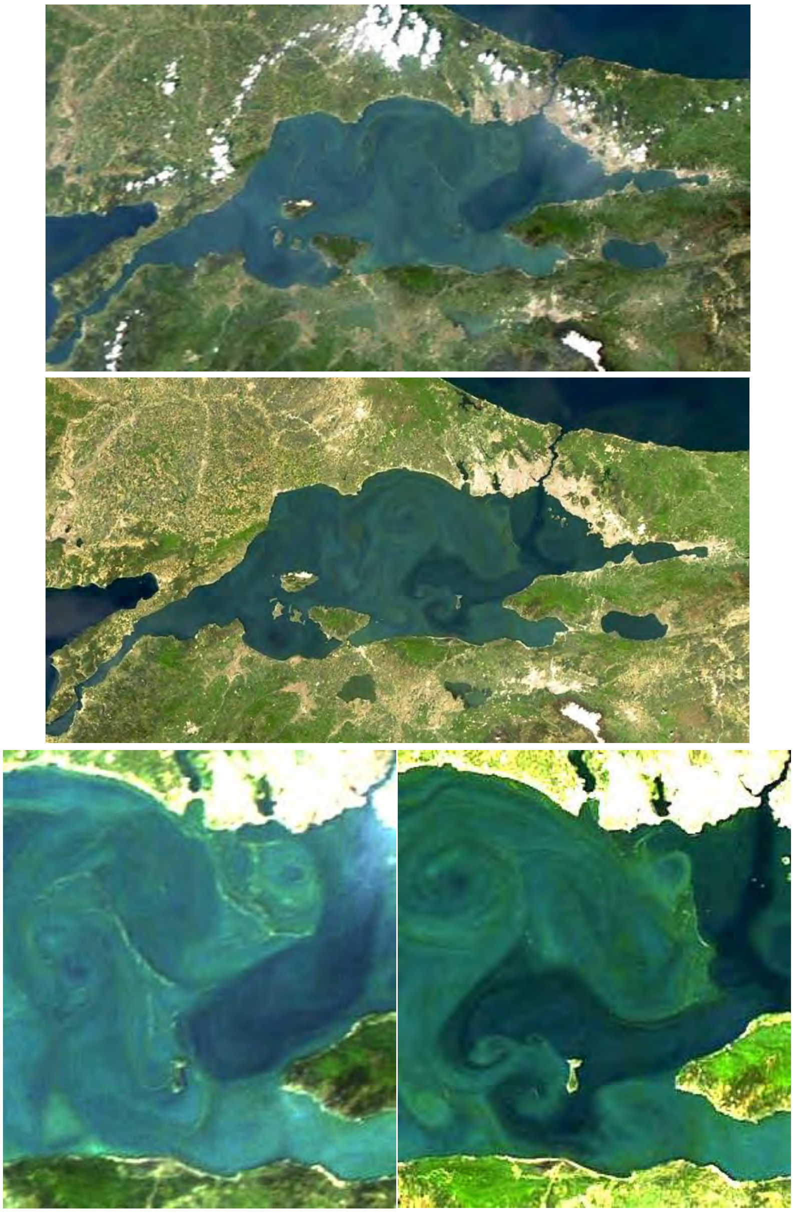


**Figure 8.** MODIS ocean colour images on 26-27 April 2013, showing the Bosphorus Jet (dark colour) surrounded by what looks like coccolith (green) and toxic plankton (orange) blooms. The upper two panels are the images covering the entire TSS, while the lowest panel shows enlarged images showing the Bosphorus Jet for the consecutive days of 26-27 April 2013.

MODIS Aqua images in Figure 8 show the Bosphorus Jet advancing inside the Marmara Sea, where the flow features are made visible by the ongoing coccolith bloom in the TSS. What was not immediately discerned in the satellite images is the yellowish to orange colored striations lined along circulation features such as eddies and jets, providing excellent “flow visualization”, which ominously turn out to be Harmful Algae Blooms (HABs). Such blooms, indicative of the decline in the ecological status of the Marmara Sea are now increasingly observed since the last ten years. The aerial images in Figure 9 provide further evidence during exactly the same dates displayed in Figure 8, showing the actual toxic blooms that were identified for the first time in this period.

**Figure 9.** (a) Possible toxic plankton bloom near Tekirdağ; Milliyet, 24 April 2013 (b) from a jet flight over the Marmara Sea on 28 April 2013 (Photo: Dr. Bettina Fach, IMS-METU).

A similar event in full bloom is observed in Figure 10a, by the beautiful artwork of a visible satellite image created by the circulation of the Marmara Sea supporting a Harmful Algal Bloom, which was reported to include toxic dinoflagellates such as Prorocentrum micans and Noctiluca scintillans, made visible once again by the numerous lines aligned with the flow demonstrating the existence of numerous eddies and jet segments created by the surface flow. The image used in Figure 10a has been displayed at the 14$^{th}$ İstanbul Biennial entitled “Salt Water” as a piece of artwork of nature, at the same time calling attention to the very urgent state of matters regarding the marine environment of the TSS. In this figure the Bosphorus Jet is made up of various segments making up the familiar S-curve of meandering currents first advancing south from the Bosphorus, then turning east and north towards the northern coast, later to turn southwest. In between this current pattern are dispersed many small fronts and eddies where the yellowish-orange colored HAB species help to visualize the complex flow pattern. The aerial picture in Figure 10b during the same dates near the southern exit of the Bosphorus Strait on the Anatolian side shows the actual blooms in the process.

**Figure 10.** (a) Spiral eddies, jets and dinoflagellate blooms (red tide) in the Marmara Sea, 17 May 2015, based on an image of the NASA Earth Observatory, (http://earthobservatory.nasa.gov/IOTD/view.php?id=85947&eocn=image&eoci=related_image), (b) local aerial picture of the coastal area of the Marmara Sea south of İstanbul, showing the same bloom published in the daily journal Milliyet on 20 May 2015. (http://www.milliyet.com.tr/marmara-iste-boyle-oluyor-gundem-2061522/).

Fish migration between the Mediterranean and Black Seas and the local production in the Marmara Sea traditionally have been positive assets of the TSS that support intense fishing activity. The excessive and uncontrolled fishing activity together with the increased pressures of pollution by the highly populated and industrialized coastal environment and intense shipping through the TSS have caused the marine life to be adversely affected. The intense phytoplankton blooms including HABs are only the symptoms of the decline in the health of the TSS by the eutrophication process that has an alarming increase in recent years.

## 5. Marine Transport and the TSS Environment

The TSS, deserving the highest level of environmental protection as a consequence of its natural reserves of high economical stand, is concurrently located at the convergence of major oil/natural gas marine transport routes and pipelines from the hinterlands of Black Sea and Caspian Seas to world markets. This region with rich energy resources is an important supplier of the world and specifically of the European energy demand. In order to ensure safe marine transport while still being watchful of environmental protection, the outcome of the planned project can contribute to knowledge serving the reduction of accidents and traffic regulation in a congested, environmentally sensitive zone. A secure route means lower transport prices positively affecting oil prices, henceforth increasing the competitiveness of European and local industry. The risks in the TSS have become increasingly evident by frequent cases of grounding, ramming and collisions leading to fires and spread of pollution in recent years. The danger of heavy accidents is a nightmare for the tens of millions of people living in the region.

Linking three continents, the TSS is four times busier than the Panama Canal and three times busier than Suez Canal, surpassing 150 ships/day, with about 15 ships/day carrying dangerous cargo. Some of today's vessels are up to 400,000 gross tons in size and 400 m in length, while the narrowest point the Bosphorus is only 700m wide and its navigable channels in each direction are only 200 m across. Maneuvering under currents reaching 2-3 m/s locally in the strait and exit regions can often be hazardous.

The ship traffic passing through the TSS have increased by about 10 times by numbers and by about 20 times by weight in the last 80 years since the Montreux Treaty (1936) regulating it under current international policy and law (Plant, 2000). The congested traffic makes the Turkish Straits extremely predisposed to accidents (Figure 11), mostly resulting from poor visibility, strong currents and winds. Accidents involving collisions, grounding, fires and explosions often result in oil spills severely threatening this very delicate environment and the very safety of the maritime transport itself (Tan and Otay, 1999; Örs and Yılmaz, 2003; Ulusçu *et al.* 2009; Birpınar *et al.* 2009). It is estimated that 175,000 tons of oil spilled into the TSS from major accidents during 1979-2003. Turkey has unilaterally adopted marine traffic regulations including a sensors based system of Vessel Traffic Services in 1994, for increased security of shipping in the TSS, leading to a dramatic reduction of accidents since then.

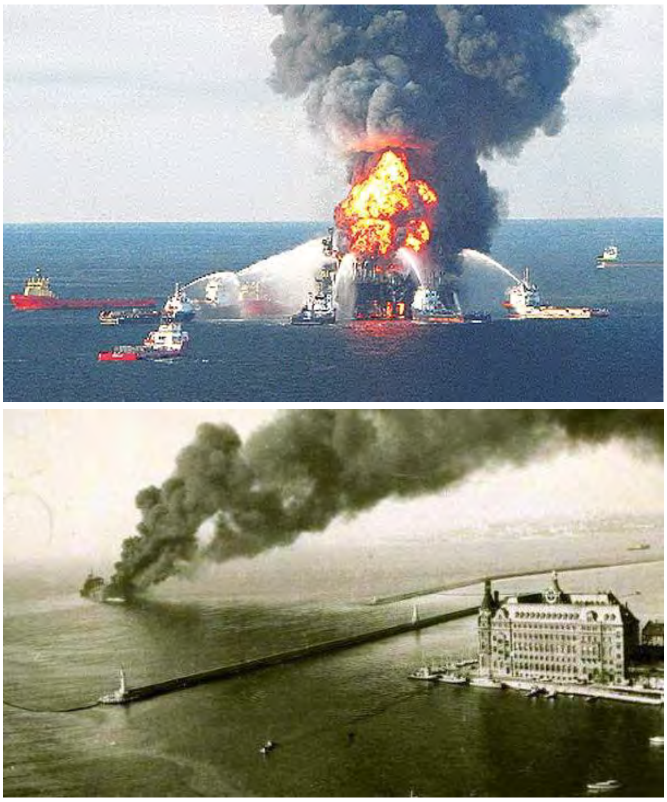


**Figure 11.** The Independenta (1979) tanker fire and explosion near the Marmara exit of the Bosphorus on the jet exit region, resulting in 43 deaths, with 95,000 tons of oil spilled to the marine environment and spread to the TSS.

### 6. Modeling Needs

The nonlinear, turbulent, strongly stratified hydrodynamics of the flow through the narrow straits has made the modeling of the TSS a grand challenge. The coupling of the adjacent basins of highly contrasting properties, in a region of extreme hydro-climatic variability can only be achieved if the entire TSS is modeled as a finely resolved integral system, accounting for steep topography, nonlinear hydraulic controls and turbulent mixing processes, as well as an active free-surface. The challenge has been taken in a number of steps, using models of increasing complexity, of the Bosphorus Strait based on ROMS (Sözer, 2013, Sözer and Özsoy, 2016), as well as those covering the entire TSS while fully resolving the narrow Bosphorus: a curvilinear grid MITgcm (Sannino *et al.* 2016) and an unstructured grid FEOM, the results of which are shown in Figure 12 (Gürses et al, 2016; this volume) currently continued to be developed.

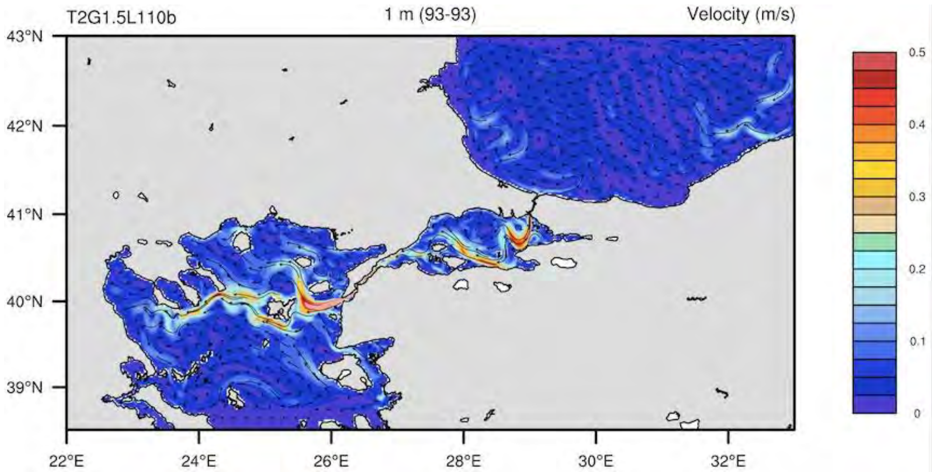



**Figure 12.** Surface currents generated by uniform northeasterly wind of 14 m/s in FEOM based TSS model.

The meso-scale dynamics of the two Straits and the Marmara Sea appear successfully captured by these models. The response to net barotropic volume flux, The efficient jet induced local recycling makes this small basin a region of high productivity often far exceeding the Black Sea (Figure 6a), and incomparable to the "blue desert" of the eastern Mediterranean Sea. A similar picture of chlorophyll distribution in Figure 6b emphasizes the gradients and transport of chlorophyll from the Black Sea to the Aegean Sea in the autumn season. Finally the Bosphorus Jet transporting nutrients to the Marmara Sea buffer zone where the isolated and polluted waters of the TSS create continuous blooms as shown in Figure 6c.guided by past field experiments, indicates adjustment to net flux and atmospheric conditions. The flow under mild to strong net flow evolves from an anti-cyclonic cell to an S-shaped current with a smaller anticyclone withdrawn closer to the Bosphorus. In extreme cases the lower and upper layers get blocked at the Bosphorus. The circulation pattern appears analogous to buoyancy driven flow adjacent to a river mouth.

An example of the various modeling results only sampled in Figure12 replicates the main known features of the surface currents, such as the jets issuing from the Bosphorus and Dardanelles Straits, and a number of cyclonic / anticyclonic eddies in the Marmara Sea. The most essential element to capture in the integrated modelling of the TSS circulation is the Bosphorus Jet, which as an internal forcing of the Marmara Sea determines the circulation developed by the forcing of the coupled system of adjoining seas imposed on the whole system by the flows developing out of Bosphorus Strait.

## 7. The Use of HF-radars

Besides being a fundamental component of ocean monitoring systems, HF radars have a broad range of applications they can provide valuable inputs by providing data on ocean surface currents, such as search and rescue operations for people and objects lost at sea, oil spill accidents, water quality monitoring, marine protected areas, marine navigation and ocean energy production. The United States has developed a HF radar network consisting of 185 coastal radars providing real-time ocean currents data to the public along its continental coasts (http://cordc.ucsd.edu/projects/mapping/maps/). In Europe, a working group consisting of Spanish and Portuguese institutions (http://www.iberoredhf.es/en/home) aims to improve the exploitation and visibility of data generated by HF radars on the coasts of the Iberian Peninsula coast. Other efforts in Europe are aiming to make the HF radar data available, as shown in a recent meeting in Lisbon (http://www.emodnet-physics.eu/hfradar/Home). Besides these, there is an international effort to build a global HF radar network of over 400 HF radar systems deployed in the worldwide (http://www.ioos.noaa.gov/globalhfr/welcome.html).

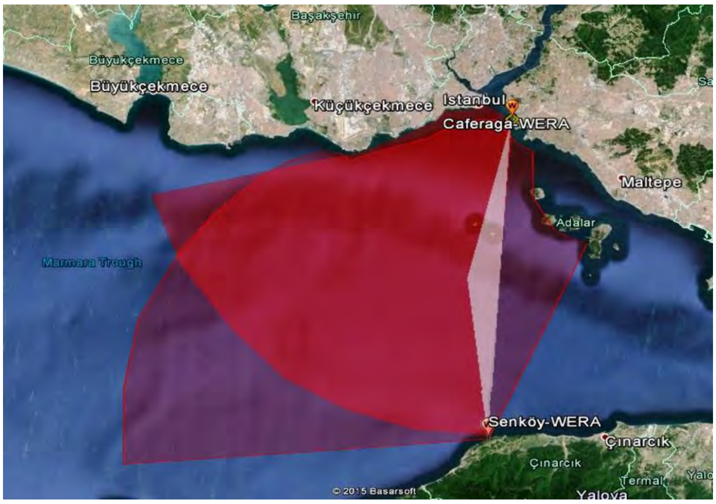



**Figure 13.** Proposed HF-radar deployment to cover Bosphorus outflow (red patch is where full current vectors can be recovered).

The accurate prediction of the strength orientation and three-dimensional properties of the Bosphorus Jet is of critical importance for the prediction of the Marmara Sea circulation, which develops from the jet providing the initial conditions south of the Bosphorus Strait. It is well known from experiences using integral TSS models (Sözer, 2013; Sözer and Özsoy, 2016; Sannino *et al.* 2016; Gürses *et al.* 2016) that the response times of the straits are much shorter than the basin response time, encompassing also the most unstable features of the turbulent Bosphorus Jet turbulent patches and eddies (Figures 8 and 10). Detailed information obtained by an HF Radar System on the surface currents of the Bosphorus Jet would serve as the most important element of a coastal marine observatory to be developed in the most congested traffic route of the region. Real-time and archived observations are the best assets for model validation and possible data assimilation for improved predictions. Our efforts proposing to build such an observatory for the TSS so far have not been appreciated and irresponsibly turned down by non-scientist functionaries of the establishment, leaving us the option of anticipation for the future.

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**A REVIEW OF HIGH RESOLUTION MODELING STUDIES OF THE EXCHANGE FLOWS OF THE TURKISH STRAITS SYSTEM**

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## 1. Introduction

Constructing a model of the entire TSS uniformly representing the rich diversity of observed hydrodynamic processes including strong topographic control, non-linear hydrodynamics, strong stratified turbulence, hydraulic controls, separated flows, multi-scale interactions, turbulent mixing and entrainment has been a *grand challenge* in oceanography that we have approached in small steps. In the past, the problem has only been addressed by a series of simplified models of the individual elements of the system (e.g. Oğuz *et al.* 1990; Ilıcak *et al.* 2009; Oğuz and Sur; 1989; Staschuk and Hutter, 2001). In this paper, we review the earlier work (Sözer, 2013; Sannino *et al.* 2015) carried out with three-dimensional models of the individual Bosphorus Strait or the coupled dynamics of the TSS, momentarily skipping some details and updates already submitted for publication (Sözer and Özsoy, 2016; Sannino *et al.* 2016). We will only review some salient features and partial results that have not been discussed in those journal papers.

## 2. Model Development

### 2.1 ROMS Model for the Bosphorus Strait

The modeling of the Bosphorus Strait hydrodynamics is based on the ROMS, a well-documented and tested community model (Hedström, 1997; Haidvogel *et al.* 2000; Shchepetkin and McWilliams, 2005). Models with both idealized and realistic geometry versions have been used to study the Bosphorus Strait (Sözer 2013).

The idealized geometry of the Bosphorus Strait (Figure 1a) is a straight channel ~34 km in length, 70m in depth and 1300 m in width, with a contraction of 700 m width located at one-third of its length and a sill of 500 m length and 57 m depth at the crest located near the lower density end of the strai represented on a 55x512x35 rectilinear grid of $\mathbf{\Delta x} = \mathbf{\Delta y} = 100$ m with variable vertical spacing of $\mathbf{\Delta z} = 1.42 - 2.0$ m in generalized s-coordinates. For simplicity, only salinity effects are included. Constant horizontal and vertical diffusivity values of 15 m/s$^2$ and $10^{-4}$ m/s$^2$ are respectively used for momentum and tracers. For the realistic geometry model (Figure 1b), high resolution bathymetric data of Gökaşan (2005) have been first resampled and interpolated to a variable resolution rectilinear grid of 163x716 nodes with **Δx** = 50 - 200 m, **Δy** = 50 - 325 m and 35 s-levels with vertical spacing of 0.7 - 2.85 m. The Generic Length-Scale (GLS) turbulence scheme with the k-epsilon formulation and radiation boundary conditions were used for flow variables at the north and south open boundaries. High order advection schemes, volume-conservation at open boundaries, non-linear equation of stat, and Smagorinsky formulation of lateral diffusive effects on constant geopotential surfaces have been used. In both models, 2d velocity has been prescribed at the southern boundary to force the net flow. No-slip boundary conditions and quadratic bottom friction (RDRG2 = 0.005) and recursive advection scheme to minimize effects of sharp gradients have been used.

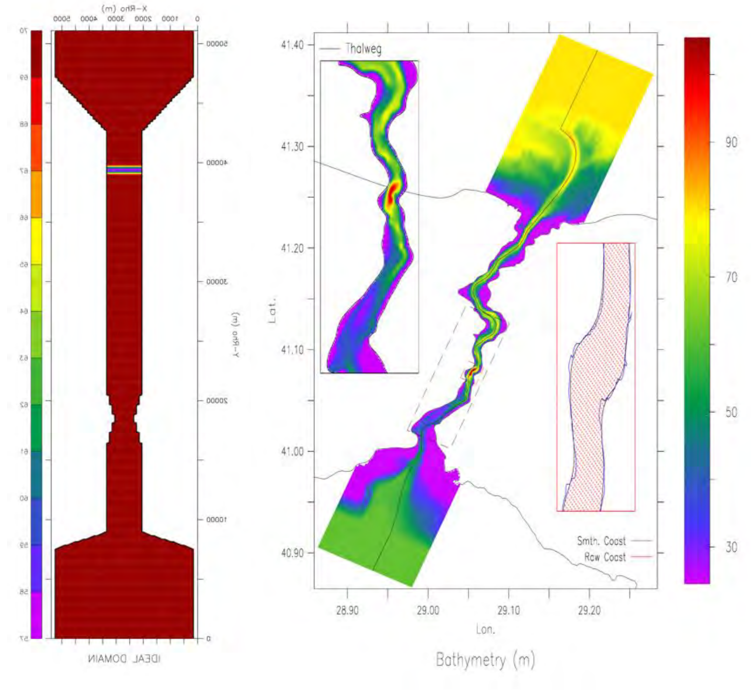


**Figure 1.** ROMS model configuration for (a) idealized and (b) realistic geometry models of the Bosphorus.

### 2.2 MITgcm Model for the Turkish Straits System

The Massachusetts Institute of Technology general circulation model (MITgcm) is used to study the entire TSS, including adjacent areas of the northeast Aegean Sea and the Black Sea. A non-uniform curvilinear orthogonal grid (1728 × 648), tilted and stretched at the Bosphorus and Dardanelles Straits covers the domain at variable resolution of 50 m at Straits to about 1 km in the Marmara Sea, with 100 vertical z-level steps in the range of 1.2 m - 80 m. (Figure 2).

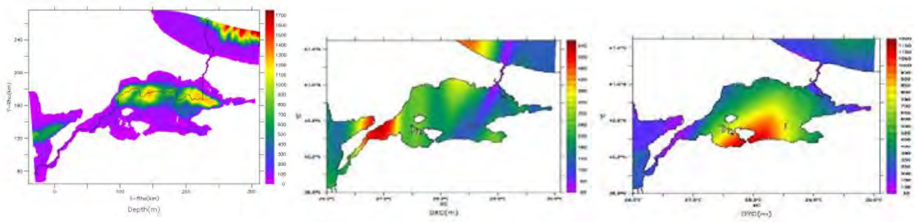

**Figure 2.** (a) Model topography (depth in m, solid line is the thalweg), and step size of model horizontal discretization (m) in (b) lengthwise and (c) transverse directions.

The model is initialized with lock exchange initial conditions represented by three vertical profiles of properties obtained during June-July 2013. No-slip conditions, high order tracer advection and turbulent closure parametrization scheme of Pacanowski and Philander [1981], with horizontal diffusivity of $10^{-2}$ $m^2s^{-1}$, and variable horizontal viscosity following Leith [1968] have been used.

## 3. Model Results

### 3.1 Bosphorus Model - Exchange Flows

With the model started from non-uniform, stratified boundary conditions at the two ends of the strait approximating September 1994 observations of Gregg and Özsoy (2002), a steady solution is reached after several cycles of adjustment oscillations, as shown in Figure 3. The Cold Intermediate Water (CIW) of the Black Sea entering below the warm mixed layer (Figure 3a) comes in contact with the warmer waters of the undercurrent at the interface, modifying the turbulence properties of the flow, while the salinity stratification also contributes to these properties (Figure 3b). The vertical viscosity computed from the turbulence closure scheme (Figure 3c) indicates turbulent patches in the upper and lower layers of the flow with greatly reduced values at the interfacial layer, where the turbulence is suppressed by the density stratification.

The model solutions qualitatively reproduce many features reported in the earlier observations (e.g. Özsoy *et al.* 2001; Gregg and Özsoy, 2002), such as the wedge shape of the upper and lower layers of rather uniform properties, the thickness and depth of the mixing interfacial layer between them, the apparent hydraulic controls at the contraction and sill, the thin surface layer outflow into the Marmara Sea, the sill overflow and subsequent adjustment on the Black Sea shelf. Boundary conditions are able to establish and preserve the intended stratification in the neighboring Seas.

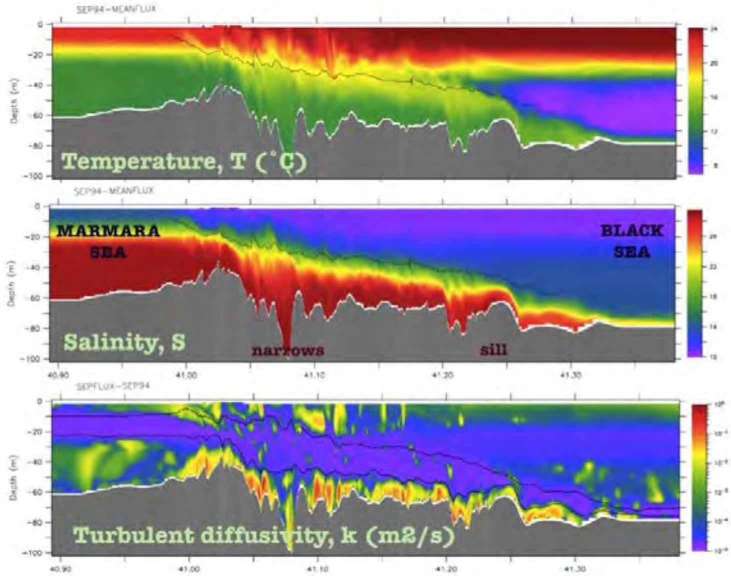


**Figure 3.** An example of a lock-exchange solution with stratified initial conditions at the two end reservoirs of the Bosphorus: (a) temperature, (b) salinity and (c) turbulent diffusivity along the Strait, following the thalweg.

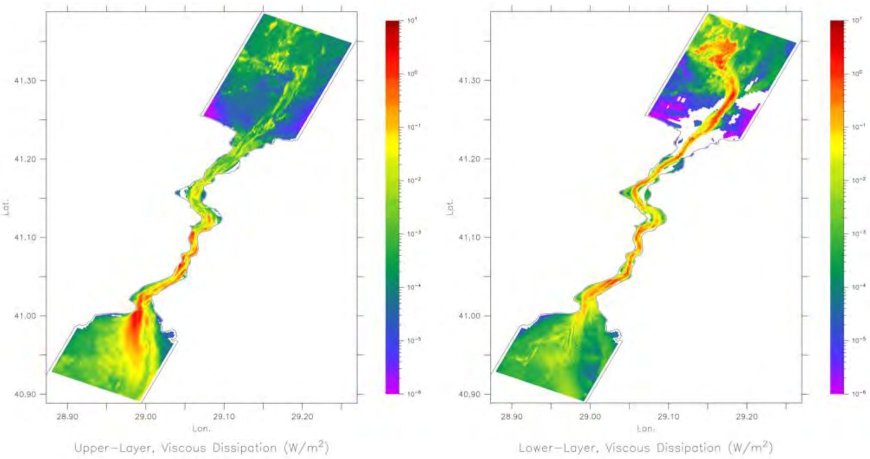


**Figure 4.** Horizontal distribution of the mechanical energy dissipation by turbulence in the (a) upper layer and (b) lower layer.

The horizontal distribution of the upper and lower layer mechanical energy dissipation rates shown in Figure 4 confirm dissipation at the various bends and along the bottom by friction, at the surface jet issuing into the Marmara Sea, past the northern sill and along the bottom plume on the Black Sea shelf. Total dissipation values of ~10.1Mw and ~7.3Mw were found for the upper and the lower layers respectively, for the entire model domain.

### 3.2 Hydraulic Control

Because the hydraulic control issue deserves extensive discussion expounded upon in the relevant papers (Sözer and Özsoy, 2016; Sannino *et al.* 2016) we only provide a very brief description of the horizontal distributions of the two-layer composite densimetric Froude number $\mathbf{G^2} = \mathbf{F_{1w}}^2 + \mathbf{F_{2w}}^2$ where $\mathbf{F_{iw}}^2 = \mathbf{u_i}^2/\mathbf{g'h_i}$ are the local layer Froude numbers ford lower layers $\mathbf{i}$=1,2 respectively, where $\mathbf{u_i}$ is the layer average current speed and $\mathbf{h_i}$ the depth, $\mathbf{g' = g\ \Delta\rho/\rho}$ is the reduced gravity with density ratio $\mathbf{\Delta\rho/\rho}$.

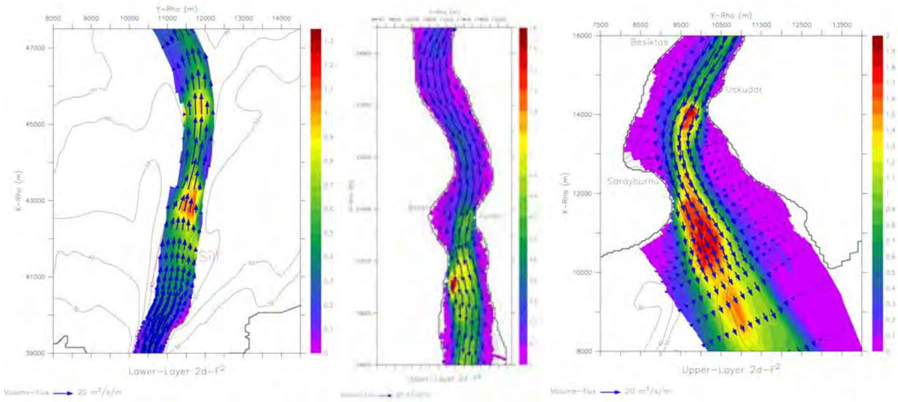

**Figure 5**. Froude number in the (a) lower-layer past the northern sill, (b) upper layer in the contraction region and (c) upper layer at the Marmara Sea exit of Bosphorus.

We leave the details of the Froude number discussion to the respective papers quoted above. We only note that the demonstration of hydraulic controls at the relevant sections of the straits is a very delicate matter that requires successive levels of approximations.

### 3.3 Response to barotropic forcing

Either a velocity based two-layer decomposition assigning upper / lower layer volume fluxes to oppositely directed components $\mathbf{Q_1}$ and $\mathbf{Q_2}$ is used, or a three-layer decomposition assigning the top, interfacial and bottom layers $\mathbf{Q_T}$, $\mathbf{Q_I}$ and $\mathbf{Q_B}$ respectively using salinity to separate layers is preferred, where layer limits are defined by 10% difference from the top and bottom values.

In Figures 5 and 6 we display the changes that occur continuously in the Boshorus exchange flow as the net flux is changed. These simulations are performed by successive initializations of the model starting from the stratified central run with a barotropic flux of $\mathbf{Q} = 9.5 \times 10^3\ \mathrm{m^3/s}$, and in each case running at least for about 7 days to reach steady state solutions. The top, interfacial and bottom layer volume fluxes $\mathbf{Q_T}$, $\mathbf{Q_I}$, and $\mathbf{Q_B}$

respectively calculated at the mid-strait section and identified by local salinity limits are shown with the heavy arrows in Figure 5 and 6.

Increasing the flow to take on positive values of the net flux (towards the Marmara Sea) in Figure 5, the upper layer flow becomes increasingly dominant to both the interfacial and lower layers, finally leading to the case where the lower layer becomes blocked, as observed in the measurements, e.g. Latif *et al.* (1991). The zero-velocity line for low negative fluxes coincide with the center of the interfacial layer and rises above it in the north, while with increasing positive flux, the isotach becomes deeper and aligned with the lower demarcation of the interface layer. It is noteworthy, however, that the switch to the blocking situation occurs very suddenly as the barotropic forcing is increased, for instance from the unblocked case just before the last one in Figure 6. The zero velocity isotach is depressed below the salinity interfacial layer for the stronger levels of barotropic forcing.

We start in Figure 6 with the case in which the upper layer completely blocked by an extreme negative net flux (towards the Black Sea). In this case, because the upper layer is blocked in the form of a wedge and pushed all the way up north past the contraction region, the flow is configured with three-layer stratification in the Strait, where the upper layer Marmara waters flowing north and forming the thick interface layer are pushed under the wedge of former upper layer waters originally invading the Strait from the Black Sea. The zero-velocity isotach for this extreme flux is much separated from the salinity interface and has lifted closer to the surface in the northern part of the strait. The three-layer structure in which the interfacial and bottom layers are co-flowing against the retreating top layer flow in this extreme case is similar to what has been noted in earlier measurements, e.g. Latif *et al.* (1991). As the positive flux is gradually decreased first the blocked wedge of the original Black Sea upper layer retreats until the southern exit when the interfacial layer of Marmara Sea water becomes thinner and carries less transport, till after that the upper layer flow starts to build up at the cost of the interfacial layer which gets thinner and starts to get an equal share of flux with the lower layer when the net flux approaches zero. In most positive flux experiments excluding the upper layer blocked cases the zero velocity isotach is above the interfacial layer, meaning that the interfacial and lower layers act in unison.

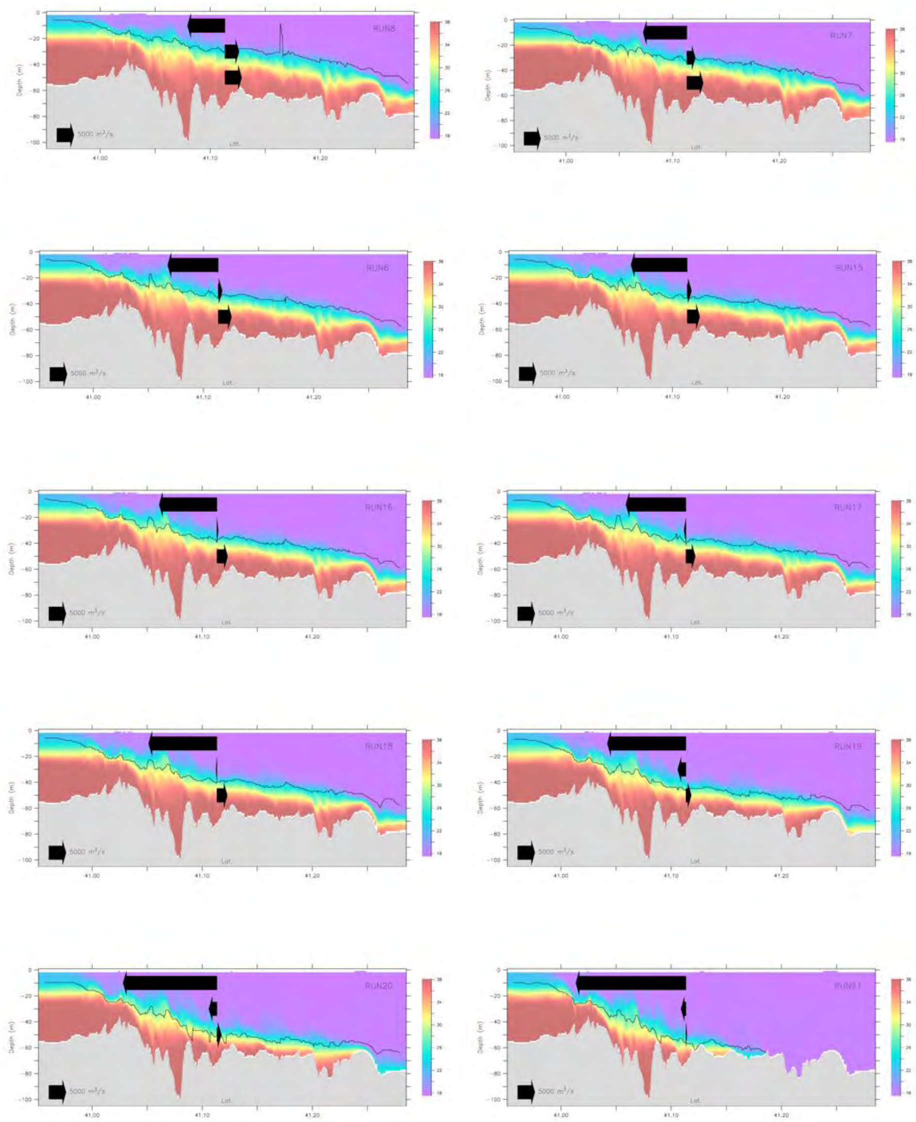

**Figure 6.** The salinity distribution, the zero velocity isotach, and arrows showing the relative magnitudes of the top, interfacial and bottom layer fluxes for increasing positive net flux values of **Q**= 1900, 5700, 9500, 11400, 13300, 15200, 17000, 23700, 28400, 33200 $m^3/s$ (towards the Marmara Sea). The layer fluxes are compared to a scale arrow of 5000 $m^3/s$ at the bottom of each plot.

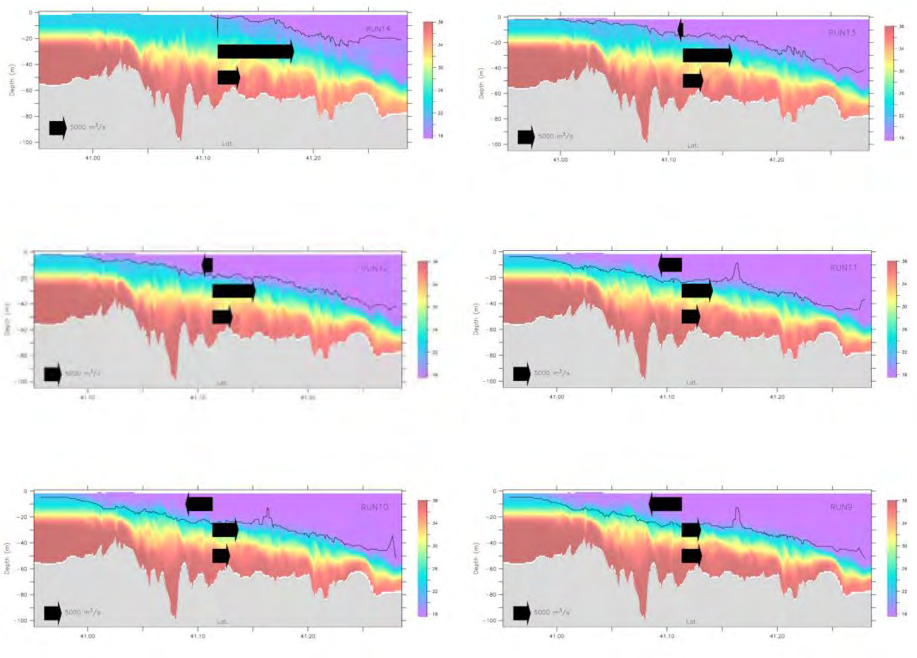

**Figure 7.** The salinity distribution, the zero velocity isotach, and arrows showing the relative magnitudes of the top, interfacial and bottom layer fluxes for decreasing negative net flux values of **Q**= -28500, -19000, -15200, -7600, -4700, -1900 $m^3/s$ (towards the Black Sea). The layer fluxes are compared to a scale arrow of 5000 $m^3/s$ at the bottom of each plot.

### 3.4 Bosphorus sea level difference and exchange fluxes

Historical and modern measurements seem to agree on sea-level differences of 30-60 cm across the entire TSS, and 20-60 cm across the Bosphorus (Marsili 1681; Möller 1928; Smith 1942; Gunnerson and Özturgut 1986; De Filippi *et al.* 1986; Büyükay 1989; Alpar and Yüce 1998; Özsoy *et al.* 1998; Gregg and Özsoy, 1999; Yüksel *et al.* 2008). Gregg *et al.* (1999) found rapid, nonlinear changes of sea level near the contraction of the Bosphorus in parallel to the changes in the depth of the density interface. Similar behavior is discovered in our model simulations (Figure 7), with the largest changes in free-surface height occurring at the Marmara Sea junction and at the contraction region, in consequence of the hydraulic control at these locations. The final elevation difference between the two ends of the strait is about 26-40 cm in various runs with stratified boundary conditions amounting to the smaller density difference between the two seas, comparable with the values measured by Gregg and Özsoy (2002) during the moderate flow conditions of September 1994.

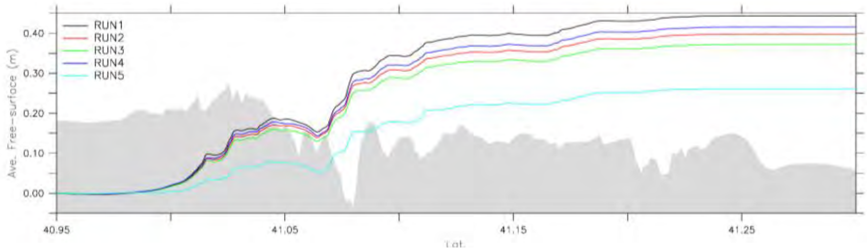


**Figure 8.** Sea level changes along the Bosphorus for various runs in Sözer (2013) (bathymetry in the background).

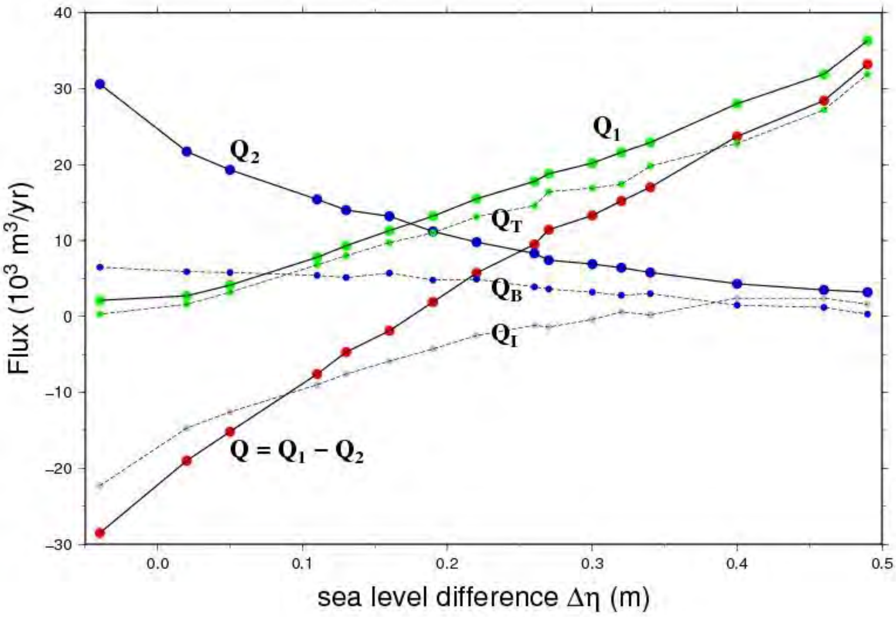


**Figure 9.** The variation of the net barotropic flux **Q** (red, solid line), and two-layer fluxes in the upper layer, $\mathbf{Q_1}$ (green, solid), lower layer, $\mathbf{Q_2}$ (blue, solid), three-layer fluxes in the top layer, $\mathbf{Q_T}$ (green, dashed), bottom layer, $\mathbf{Q_B}$ (blue, dashed) and interfacial layer, $\mathbf{Q_I}$ (gray, dashed), with sea level difference **Δη**. ($\mathbf{Q_T}$, $\mathbf{Q_T}$ and $\mathbf{Q_I}$ are positive southward, $\mathbf{Q_2}$ and $\mathbf{Q_B}$ are positive northward, and **Δη** is the sea level difference north-south).

The relationships between the sea level differential **Δη** across the Bosphorus and the net barotropic flux **Q**, together with the two and three layer fluxes are provided in Figure 8, based on the model runs summarized in Figure 6. Blocking of the lower layer occurs for a net flux of **Q** = 33200 m$^3$/s out of the Black Sea resulting in a sea level difference of **Δη** = 0.49m, and for the upper layer blocked case of **Q** = -28500 m$^3$/s the sea level difference is negative, **Δη** = -0.04 m, i.e. close to zero. The relationship between net flow **Q** and the sea level difference **Δη** is close to a linear one except close to blocking. The variations of the two-layer fluxes $\mathbf{Q_1}$, and $\mathbf{Q_2}$, and the three layer fluxes $\mathbf{Q_T}$, $\mathbf{Q_1}$, and $\mathbf{Q_I}$ are sketched in Figure 7, with $\mathbf{Q = Q_2 - Q_1 = Q_T + Q_I - Q_B}$ by definition. The bottom layer flux is not much sensitive to changes in sea level.

Upper layer fluxes estimated from current measurements from a bottom mounted cabled ADCP at Baltalimanı in the Bosphorus and sea level monitored at coastal stations at Şile on the Black Sea and Yalova on the Marmara Sea coasts during the years 2008-2012 (Tutsak, 2013) low-pass filtered at 30h are compared in Figure 9. Despite deviations between measurements and model results, a rough comparison is made between the ibndependent estimates. It is also interesting to note that monthly average sea level differences of Tutsak (2013) varied in the range of 15-30 cm for Şile-Yalova stations with respect to the Bosphorus, and 30-40 cm for Yalova-Gökçeada stations with respect to the Dardanelles Straits.

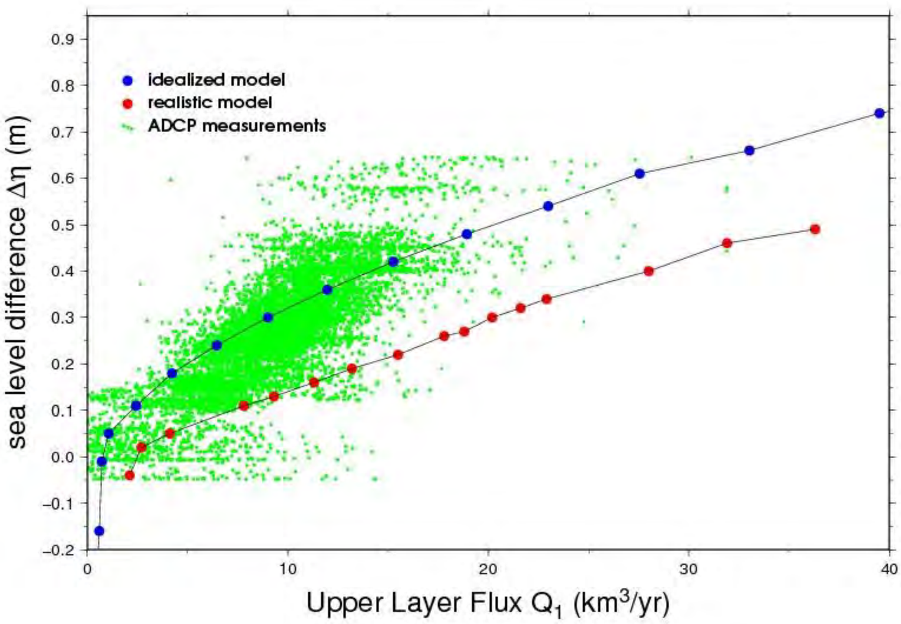


**Figure 10.** The relationship between upper layer flux $\mathbf{Q_1}$ and sea level difference **Δη** based on idealized (blue) and realistic (red) geometry Bosphorus model results and measurements of ADCP current profiles integrated across the flow area at Baltalimanı versus the sea level difference Şile – Yalova (green) during 2008-2012.

### 3.5 MITgcm Model of the Turkish Straits System

The non-uniform curvilinear orthogonal grid and the vertical resolution implemented in the MITgcm model have demonstrated to be sufficient to capture the fine scales within the two Straits and also to well represent mesoscale in the Marmara Sea. We only review basic results here and leave the rest to Sannino *et al.* (2016). The response of the currents and density structure over the water column to different net flow is also examined through the setup of experiments with varying net barotropic volume flux values of Q = -9600, 0, 5600, 9600, 18000 and 50000 $m^3/s$ respectively (positive values represent flow from the Black Sea towards the Mediterranean).

For the studied flows driven solely by the net flux, an S-shaped current first moving south from the Bosphorus, later turning northwest and finally exiting from the Dardanelles Strait appears to be the basic character of the circulation. With a negative flux of Q=-9600 $m^3/s$ towards the Black Sea, the upper layer flow is still positive, and sufficient to generate an anticyclonic net circulation in the midst of the Marmara Sea, as shown in Figure 10. For zero net flux, the same structure is preserved and as the positive values of the barotropic flux is increased further the size of the central gyre is reduced and the flow becomes increasingly more attached to the northern coast of the Marmara Sea. As the flux is increased to 9600 $m^3/s$, the central anticyclonic circulation cell takes an elongated form. For the extreme flux values of Q=18000 $m^3/s$ and Q=50000 $m^3/s$, the lower layer flow in the Bosphorus becomes blocked, and qualitative changes occur in the circulation of the Marmara Sea, with a smaller anticyclone near the Bosphorus exit, a jet attached to the northern coast, and a secondary anticyclone further west, and a cyclonic circulation emerging in the south. For these cases, the circulation pattern looks more like the buoyancy driven flow along the coast adjacent to the mouth of a river.

The generation of a basic anticyclonic circulation in the Marmara Sea for lower net fluxes, evolving towards a more balanced circulation of cyclonic-anticyclonic eddies appears to be a result of the vorticity balance of the basin. As shown by Spall and Price (1998), and studied by Morrison (2011), the net basin circulation is sensitively determined by the potential vorticity (PV) imports and exports of the basin. From this point of view, the reduction of interface depth (or upper layer thickness) from the Black Sea to the Marmara Sea implies a decrease in fluid vorticity, or anticyclonic circulation assuming the input to have zero vorticity.

The behaviour of the buoyant plume entering the Marmara Sea, initially shooting south and hitting the opposite coast is displayed in all cases in Figure 10, although the later turning of the flow to the west is typical of buoyant plumes at this scale. Buoyant flows entering the sea are typically attached to the right hand coast (looking out from the exit in the northern hemisphere, especially for initial vorticity zero below a critical limit (e.g. Nof, 1978, Stern *et al.* 1982). Often a bulge of the buoyant fluid is formed, as the flow turns right to follow the coast, as often observed at river mouths (e.g. Huq, 2013).

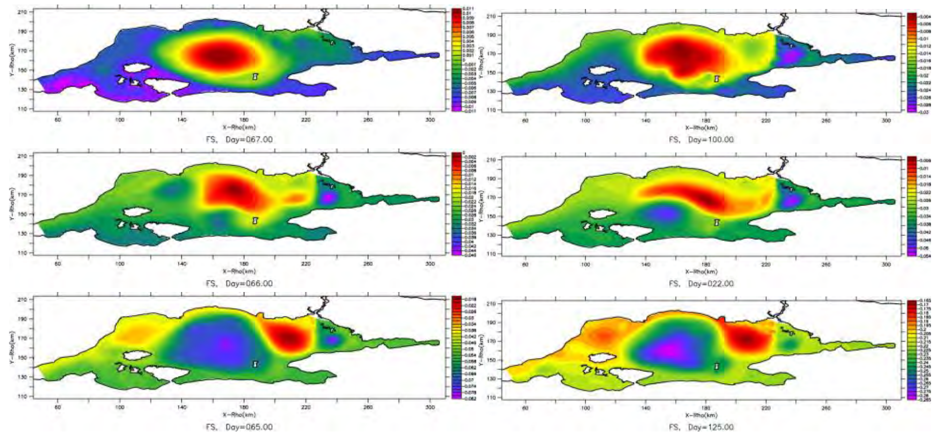

**Figure 11.** The free surface variations in the Marmara Sea for varying net barotropic volume flux values and total days of run for Q = -9600 (day=67), 0 $m^3/s$ (day 66), 5600 $m^3/s$ (day 100), 9600 $m^3/s$ (day 22), 18000 $m^3/s$ (day 65) and 50000 $m^3/s$ (day125).

In a two-layer system with variable bottom topography and dynamically active layers, the circulation may develop differently, with topography influencing the lower layer flow, and the resultant interface topography influencing the upper layer flow (Beardsley and Hart, 1978). As the net flux is increased in Figure 10, the changes in the circulation pattern may be a result of this kind of interactive adjustment of the flow layers to bottom and interface topography.

The qualitative change in the circulation towards a series of anticyclonic and cyclonic eddies following the meander of the currents, when the flux is increased to 18000 $m^3/s$ and 50000 $m^3/s$ is reminiscent of the Alboran Sea, where similar gyres filling the basin develop under high fluxes (Spall and Price, 1998; Riha and Peliz, 2013).

The sea level differences that develop at the two straits, Bosphorus and Dardanelles are given in Table 1, in relation to the net barotropic fluxes and the values obtained from the TSS model are compared with the ROMS model results for the Bosphorus (Sözer, 2013). While the total range of sea level in the Marmara Sea between cyclonic and anticyclonic areas varies between 2-12 cm (Figure 10), the net sea level differences across straits are much larger, varying between 2-85 cm in the Bosphorus and 1-32 cm in the Dardanelles, while the results for the Bosphorus compare well between the two models. These results would imply sea level differences of about 0-120 cm between the Black Sea and the Aegean Sea, for the range of net transport tested.

**Table 1.** Sea Level Difference at Straits as a Function of Net Flux

| Net flux Q ($m^3/s$) | Bosphorus (TSS) Sea level difference $\Delta\eta$ (cm) | Dardanelles (TSS) sea level difference $\Delta\eta$ (cm) | Bosphorus (ROMS) sea level difference $\Delta\eta$ (cm) |
|---|---|---|---|
| -9600 | 2 | 1.5 | - |
| 0 | 8 | 5 | 14 |
| 5600 | 10 | 7 | 18 |
| 9600 | 14 | 11 | 22 |
| 18000 | 22 | 16 | 30 |
| 50000 | 85 | 32 | - |

The salinity cross-sections throughout the TSS are shown in Figure 11, following the thalweg line of Figure 2a, for selected net barotropic flux values. The upper layer thickness remains around 25 m for fluxes up to 9600 $m^3/s$, and increases to 35 m at the maximum flux value of 50000 $m^3/s$. The upper layer reflects modified Black Sea characteristics while the lower layer reflects Mediterranean characteristics all along the transect, while the most rapid changes in salinity occur in the Bosphorus and Dardanelles straits, by mixing between the two water masses, as also indicated by observational results (Beşiktepe *et al.* 1993). The interface depth also varies strongly in the two straits, where fast exchange currents subject to hydraulic controls at transition areas (Gregg *et al.* 1999; Gregg and Özsoy 1999, 2002; Özsoy *et al.* 2001; Ilıcak *et al.* 2009; Sözer 2013).

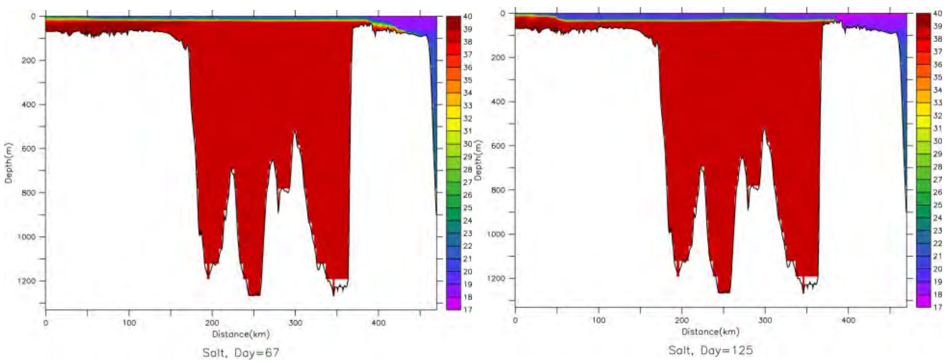


**Figure 12.** Salinity cross-sections along the thalweg line of Figure 2a in the Marmara Sea for selected net barotropic volume flux values of Q = -9600 and 50000 $m^3/s$.

Below the sharp pycnocline of the Marmara Sea, properties are rather uniform, except very near the interface where an injection of more saline water from the Dardanelles spreads below the halocline. The spread below the halocline is typical for the summer season of June 2013 for which the model has been initialized. However, the appearance of denser waters at winter time would change this pattern as the dense water sinks to the westernmost depression of the Marmara Sea and spreads along the bottom (Beşiktepe *et al.* 1993, 1994; Hüsrevoğlu 1999).

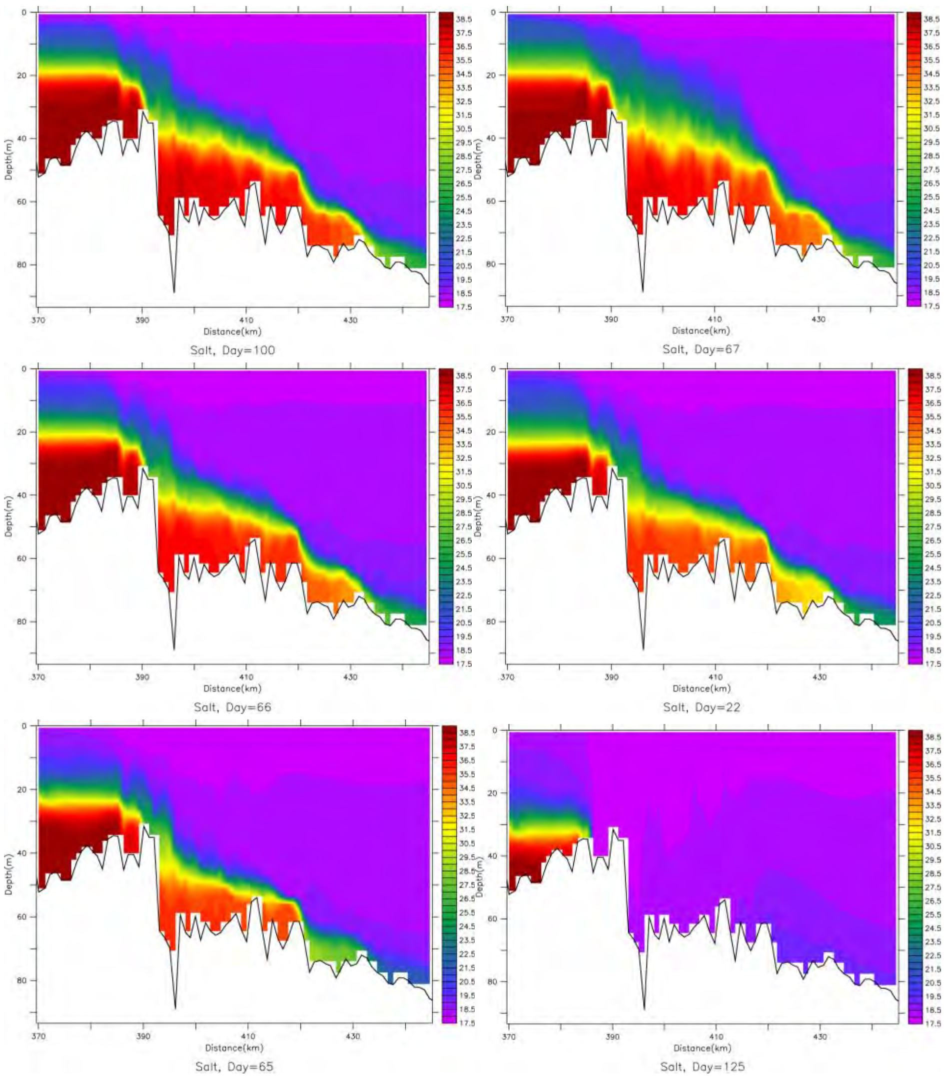


**Figure 13.** Salinity cross-sections across the Bosphorus along the thalweg in Figure 2a, for varying net barotropic volume flux values of Q = -9600, 0, 5600, 9600, 18000 and 50000 $m^3/s$.

The expanded views of salinity cross-sections for the Bosphorus and Dardanelles are respectively shown in Figures 12 and 13. The cross sections in Figures 12 and 13 confirm the existence of hydraulic transitions at expected hydraulic control sections based on past observations, also better resolved by higher resolution local models of the straits

(Gregg *et al.* 1999; Gregg and Özsoy, 1999, 2002; Özsoy *et al.* 2001; Ilıcak *et al.* 2009; Sözer 2013).

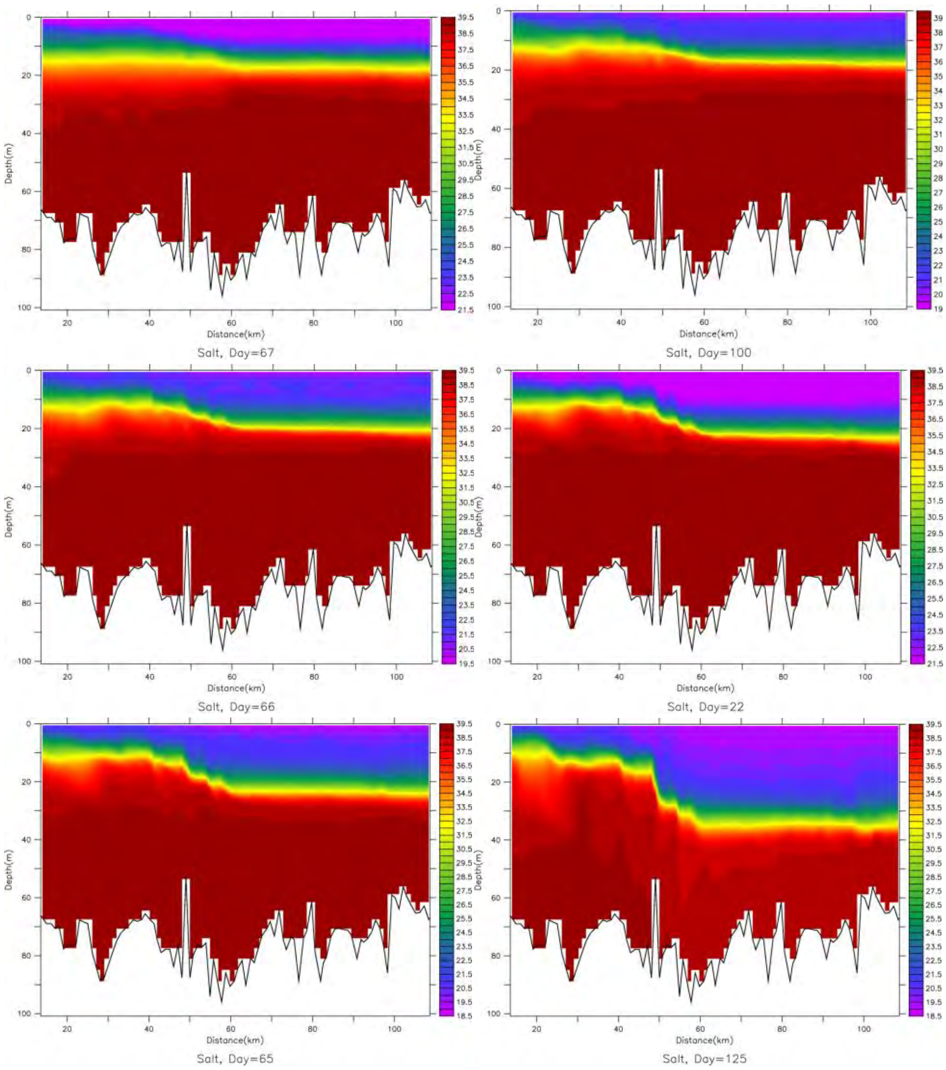


**Figure 14.** Salinity cross-sections across the Dardanelles along the thalweg in Figure 2a, for varying net barotropic volume flux values of Q = -9600, 0, 5600, 9600, 18000 and 50000 $m^3/s$.

Because the TSS has distinct regions of varied geometrical properties with a wide range of dynamical processes active in these regions, the physical response is different in each region. The evolution of kinetic energy is shown in Figure 14 for different regions. It is observed that the approach to a steady state is very fast in the two straits, while the wider areas of the three adjacent basins respond much slower.

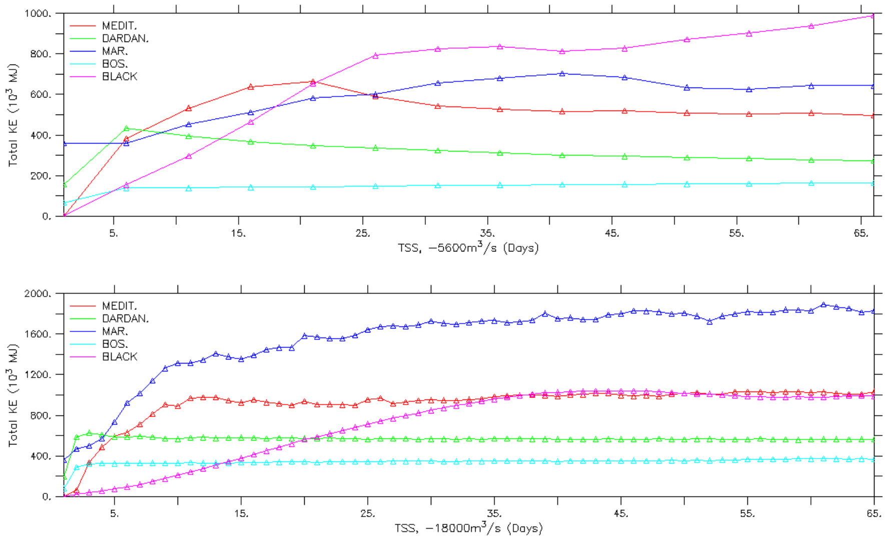


**Figure 15.** Evolution of kinetic energy for different regions of the TSS for selected values of net transport, Q=5600 and 18000 m$^3$/s.

Finally in Figure 15, a comparison is made of the upper-layer ($Q_1$) and lower-layer ($Q_2$) volume fluxes through the Bosphorus, based on observational data and the results from the Bosphorus model (ROMS) of Sözer (2013) and the TSS (MITgcm) models. Although the Bosphorus model is more specific to the Strait and has better resolution, the TSS model results perform even better in comparison with observations.

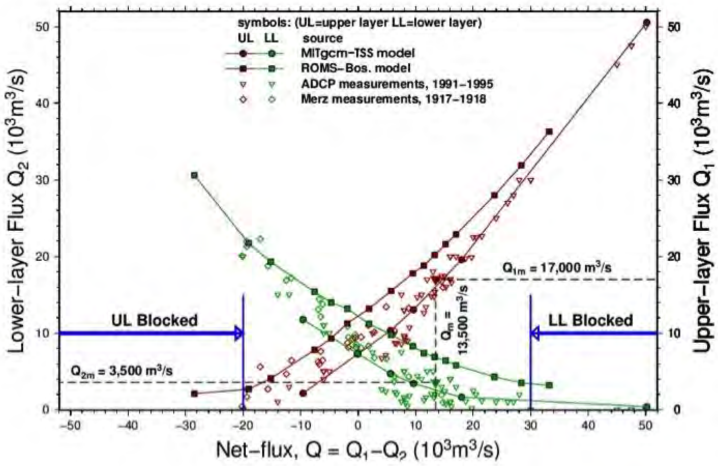


**Figure 16.** Upper-layer ($Q_1$) and lower-layer ($Q_2$) volume fluxes through the Boshorus as a function of the and net flux ($Q=Q_1-Q_2$), based on observational data and compared with the results from the Bosphorus model (ROMS) of Sözer (2013) and the TSS (MITgcm) models.

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# A FINITE ELEMENT MODELING STUDY OF THE TURKISH STRAITS SYSTEM

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## 1. Introduction

The Turkish Strait System (TSS) connects the Black Sea with the Aegean Sea through the Bosphorus and Dardanelles Straits and the Sea of Marmara (Figure 1). The outflow of dense water of Mediterranean characteristics from the Bosphorus influences the long-term evolution of the Black Sea and outflow of low salinity waters from the Dardanelles Strait alters the North Aegean Sea. The TSS circulation is characterized by a two-layer exchange flow system associated with a sharp two-layer stratification. The annual freshwater flux into the Black Sea by rivers and rainfall is greater than the loss by evaporation and thus accounts for a positive freshwater balance. Ünlüata *et al.* (1990) estimated net freshwater flux (P+R-E) of 300 $km^3\ yr^{-1}$ exiting the Black Sea through the Bosphorus. The water surplus of the Black Sea drives a net barotropic flow through the TSS, superposed on top of a baroclinic exchange flow governed by hydrostatic pressure (density) differences between the two seas.

An extensive review of literature related to the currents and circulation developing in the TSS, fluxes through the Bosphorus and Dardanelles Straits and past efforts to model the TSS are presented by Gürses (2016). The modeling of the TSS has been prohibited by the requirements of fine horizontal grid size to represent straits, the need to adequately represent the complex domain geometry and the lack of available data sets. These rather stringent requirements have only permitted the system to be partially investigated. The applications have been restricted by their very nature, depending on imposed boundary conditions at their limits which are not independent of the adjoining active regions (Sözer and Özsoy, 2016). Therefore, the results are far from being fully representative of the dynamics of the entire TSS. Quasi-regular meshes have been used in the majority of earlier studies, despite the fact that mesh regularity dictates refinement in the entire domain.

The method used in the present study, presented by Gürses (2016), is to employ an unstructured mesh Finite Element Sea Ice-Ocean Model (FESOM) which already has been successfully applied to other similar cases, including the flow through the narrow straits of the Canadian Arctic Archipelago (Wekerle *et al.* 2013). The choice of the finite element discretization permits us to employ local refinement where necessary, so as to explicitly resolve the TSS at required details to address its complex dynamics in an integrated way. We extend originally closed boundaries at the external regions in adjacent seas far enough from the TSS interior to accept reservoir conditions to represent adjacent basins. In particular, we aim to answer the following questions: How significant are the improvements obtained by the model when the original relatively isolated configuration is additionally forced by surface atmospheric fluxes? How successful is the model in predicting volume transport through the Bosphorus and its variability, under the present approximations and in comparison with previous modeling efforts or measurements?

## 2. Study domain and bathymetry

The geometric properties of the Marmara Sea, the Bosphorus and the Dardanelles Straits with their prominent geometric features are presented in detail by various studies (Ünlüata *et al.* 1990; Gregg and Özsoy, 2002, Beşiktepe *et al.* 1994). Taking these studies into account, the model bottom topography is produced by carefully matching and combining bathymetric data from different sources, as standard datasets proved to be unsuitable for our area of interest. Gürses (2016) gives detailed information about the data sources and how they have been merged, filtered and interpolated onto the high resolution model grid.

## 3. Model Setup

FESOM is developed at the Alfred Wegener Institute (Danilov *et al.* 2004; Wang *et al.* 2014). It is a general ocean circulation model which solves the standard set of hydrostatic primitive equations in the Boussinesq approximation using the finite element method on an unstructured triangular surface mesh with tetrahedral volume elements. Piecewise linear basis functions are employed for velocity and tracers (in three dimensions) and sea surface elevation (in two dimensions), the so called P1-P1 scheme.

Vertical mixing is parameterized with the scheme of Pacanowski and Philander (1981) (PP), with a background vertical diffusion of $10^{-5}$ $m^2/s$ for momentum and $10^{-6}$ $m^2/s$ for tracers and the maximum value set to 0.005 $m^2/s$ for either of them. Although this simple scheme suits the need of the TSS, we conducted a test simulation with the K-Profile Parameterization (KPP, Large *et al.* 1994). It is found that the results are very similar compared with the PP simulation considering the mean circulation and the stratification in the Marmara Sea. Horizontal eddy viscosity is parameterized by a biharmonic operator with a coefficient of 2.7 $x10^{13}$ $m^4/s$ scaled with the element size cubed while horizontal eddy diffusivity is parameterized by a Laplacian operator with a coefficient of 2000 $m^2/s$ scaled with the element (Griffies and Hallberg 2000). These values are selected based on the convergence study for second order finite difference Laplacian diffusion by Wallcraft *et al.* (2005) and set for the reference resolution of 1 degree in the model. A biharmonic operator is preferred since it involves scale selective filtering, suppressing finer scales. Laplacian is the only available scheme in FESOM for the eddy diffusion. Typical value for harmonic diffusivity of the Bosphorus, Dardanelles and Marmara Sea are calculated to be on the order of 40, 150 and 600 $cm^2/s$, respectively.

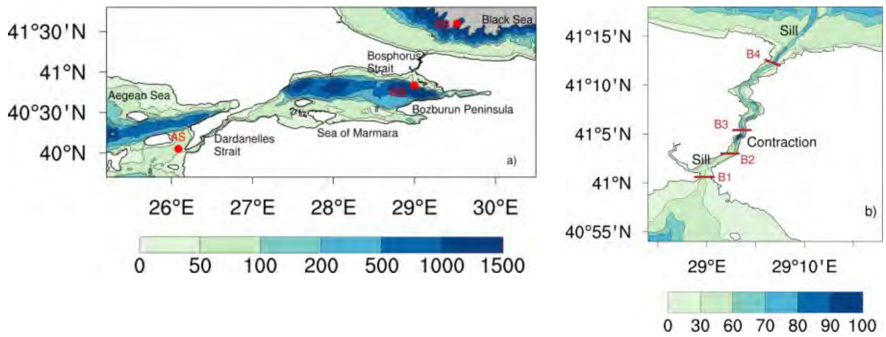


**Figure 1.** Location and bathymetry (in m) of a) the Turkish Strait System, b) the Bosphorus.

The model domain extends from 22.5°E to 33°E in zonal direction and 38.7°N to 43°N in meridional direction. The minimum horizontal mesh resolution in the Bosphorus and Dardanelles Straits is ~65 m and ~150 m, respectively and the maximum resolution in the Marmara Sea is set to ~1.6 km. In the adjacent regions of the Aegean and Black Seas, a resolution of ~5 km is used except for the exit and shelf areas which are better resolved. The model uses 110 z levels. The strong stratification and steep continental shelf in our implementation demands high vertical resolution in order to resolve the nonlinear hydraulic transitions, the stratified turbulent exchange flows between the upper and lower layers in the straits as well as to prevent excessive pycnocline erosion in the Marmara Sea. The minimum vertical grid spacing is set to 1 m within the first 50 m. The maximum layer thickness is not greater than 65 m in the deeper part. The time step has to be adjusted according to the minimum horizontal mesh resolution and is set to 10 s during the initialization and increased 30 s as total integration time increases.

As a first step, a lock-exchange experiment was performed (simulation BASIC), initialized with temperature and salinity data collected during the SESAME Project[1] in October 2008 (Table 1). A deep CTD cast is selected from each basin and the vertical profiles of temperature and salinity are assigned uniformly to the respective domain, are separated by a sharp discontinuity close to the mid-strait position, thereby producing a so called a lock-exchange configuration. The locations of the selected CTD stations are

[1] *Southern European Seas: Assessing and Modeling Ecosystem changes*

indicated by red dots in Figure 1. For the BASIC simulation, surface atmospheric forcing is not taken into account, setting momentum, water and heat fluxes to zero. The model is initialized from a state of rest and integrated for three months in order to assess its general behavior. No-slip boundary conditions are applied and normal velocities are to zero at all solid boundaries including those replacing the normally open boundaries the extremities of the model domain in the adjacent Black and Aegean Seas. The adjusted state of the BASIC experiment at the end of three months is used to set the initial conditions in the further simulations. In order to further evaluate model performance a one-year long hindcast simulation was performed for the year 2008 (Experiment BBExc).

**Table 1.** Summary of the CTD Stations selected for the lock-exchange experiment

| Station ID | Latitude | Longitude | Maximum sampling depth (m) | Total station depth (m) |
|---|---|---|---|---|
| AS | 40°02.996'N | 26°04.831'E | 67 | 72 |
| MS | 40°46.919'N | 28°59.971'E | 1191 | 1219 |
| BS | 41°36.033'N | 29°31.519'E | 1203 | 1271 |

BBExc is forced by realistic atmospheric data, but ignores net water mass fluxes from the Black Sea. The atmospheric data which drives the system are obtained from ECMWF at 6 hourly temporal and 0.125° spatial resolution for the year 2008. Bulk formulae which formerly extensively tested and utilized by the Mediterranean Forecasting System are implemented following Pettenuzzo *et al.* (2010). More details can be found in Gürses (2016). Atmospheric forcing fields are corrected against contamination by land points if they are accessed during the spatial interpolation onto the sea nodal points. The 'creeping algorithm' (also called 'sea over land') procedure is used to circumvent this problem (Kara *et al.* 2007).

## 4. Results

### 4.1. The idealized lock-exchange experiment

#### 4.1.1. Temporal evolution of the flow in the straits

In the BASIC simulation case started from lock-exchange initial conditions, the basic gravity-driven flow through the TSS is studied without the influence of the net barotropic flow or the influence of atmospheric forcing. Time series of daily averaged kinetic energy in the Marmara Sea and volume transports respectively passing through the southern sections of the Bosphorus and Dardanelles Straits (not shown here) are shows that the net volume transport initially responds very rapidly in both shooting up in a few days and finally reaching a stable in two weeks, indicating a fast adjustment period. A slower settling time of about 30 days is observed for kinetic energy in the Marmara Sea, due to the adjustment of the larger basin.

When the model starts the barriers between the water masses located at the mid-strait positions are literally released in lock-exchange style, the density difference across the front creates a horizontal pressure gradient between basins, which is initially peaked up at the front and later spreads out as the exchange flow is initiated. Initially stagnant heavier waters start moving in the direction of the low density basin near the bottom of the Strait, while the lighter waters at the surface move in the opposite direction in compensation, as required by mass conservation. The following adjustment process establishes the sharply stratified two-layer exchange flow regime throughout the system. In the Bosphorus the along-strait bottom layer flow evolves and passes over the northern sill within the first day of integration before the Black Sea waters enter the contraction zone (Figure 2, left panel). The velocity and density fields adjust themselves to the topography. After 15 days of integration, the upper and lower layer flows are fully established in a quasi-steady state in the Bosphorus. This period is even quicker in the much wider Dardanelles Strait as a result of the lower initial density gradient between the Aegean and the Marmara Sea (Figure 2, right panel).

In close correspondence to the hydraulically controlled regime of straits, the model results clearly show the roles of strait geometry primarily determining the exchange flows through the entire TSS, by adjusting to the initial perturbation in a very short time as compared to the response of the system as a whole. The flow in the Straits adjusts indeed within less than a day or two, as a result of the suggested main hydraulic controls at the contraction and sill of the Bosphorus (roughly at 24 and 48 km, Figure 2, left panel) and the narrows at Nara Passage of the Dardanelles Strait (at about 30 km, Figure 2, right panel). Once these hydraulic controls are established, the system evolves further by density adjustments in the larger domain including the basin of the Marmara Sea. Results obtained by Sannino *et al.* (2016) from a modelling exercise using different methodology confirms the same behavior, with the hydraulic controls at the Bosphorus and Dardanelles primarily establishing the stable response of the TSS, and therefore also setting up the basic circulation regime in the Marmara Sea.

#### 4.1.2. Marmara Sea circulation

The simulated surface circulation of the Marmara Sea averaged over the third month of integration shows a well-defined strong jet leaving the Bosphorus with core velocities of ~1.0 ms$^{-1}$ (not shown here). This jet sets the main flow in motion and continues to the southern coast, moving parallel to the Bozburun peninsula, turning towards the northwest over the shelf region, and meandering before funneling into the Dardanelles Strait. As a result, a basin scale anticyclonic gyre is established with an average speed of 0.2 ms$^{-1}$ and a series of small eddies (~20 km in diameter) scattered around the pathway of the main flow and at coastal embayments, with different signs of vorticity. They are separated from the main flow due to natural obstacles like islands, coastlines or rapid changes in depth. Some of the resolved eddies are identified and reported in earlier studies. These include for example the ones reported in the vicinity of the Bosphorus-Marmara Junction (BMJ, Ünlüata *et al.* 1990), a cyclonic eddy located in the southeast coast (Chiggiato *et al.* 2012) and a coastal cyclonic eddy in the north (Demyshev and Dovgaya, 2007). Besides, they are consistent with earlier observations (Beşiktepe *et al.* 1994; Gerin *et al.* 2013) and concurrent findings of Sannino *et al.* (2016). The BASIC simulation reveals that surface eddy activities are concentrated around the BMJ, namely the region of inflow into the Marmara Sea.

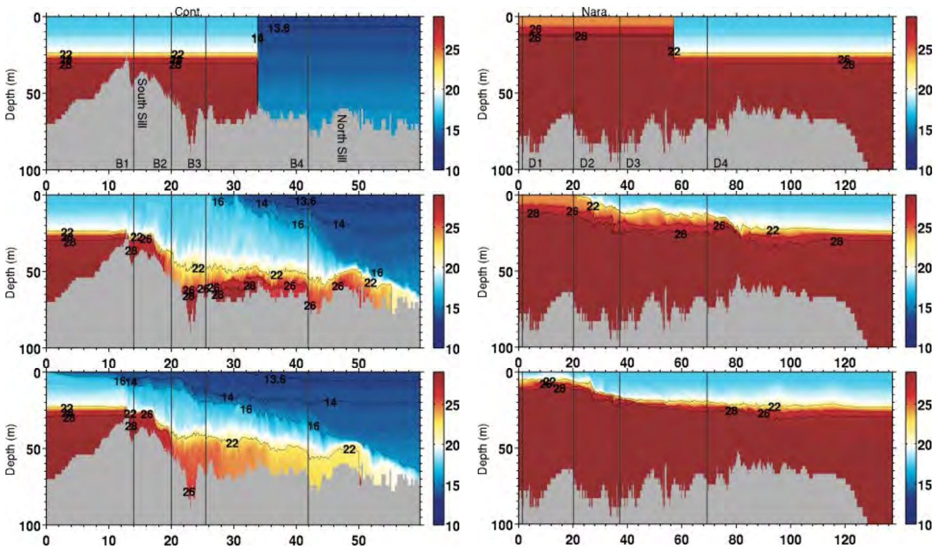


**Figure 2**: Snapshots of potential density along the Thalweg of the Bosphorus (from south to north, left panel) and Dardanelles (from south to north, right panel) at the initial state and after 1 and 7 days (from top to bottom). The x-axis denotes the distance in km.

The current plot at 20 m depth shows that the interfacial waters are transported with the Aegean inflow following the main channel, entering into the Marmara Sea (not shown here). In the entrance region, the flow meanders and forms two quasi-persistent eddies with a reversing sense of rotation (~15 km in diameter). At 50 m depth, the circulation pattern changes notably. The Dardanelles effluent entering the Marmara Sea follows the deep channel on the southern side of the widening section and continues straight until it hits the Marmara Island. The current at this stage bifurcates, leaving the northward branch to recirculate back into the Dardanelles along the northern half of the widening section of the Dardanelles Strait while the weaker southern branch flows around the Marmara Island before sinking deeper in the westernmost depression. There is a series of eddies moving slowly with different signs of vorticity extending down to 100 m depth (not shown here).

The simulated mid-basin pycnocline is located at 20 m on the average and does not oscillate much due to the lack of atmospheric or barotropic forcing in the BASIC experiment. Nevertheless, the 10 m circulation map shows that the flow enters the Bosphorus at this level. This indicates that the pycnocline is tilted upwards towards the Bosphorus and the jet leaving it is confined to the upper 10 m.

### 4.2. Simulations with realistic atmospheric forcing

The main driving forces in the Turkish Strait System are the atmospheric forcing and the Black Sea freshwater input (Gregg and Özsoy, 2002). The response of the Marmara Sea to both of these factors has been previously taken up by Chiggiato *et al.* (2012) and Demyshev and Dovgaya (2007), although the influence of strait dynamics has been completely ignored and only represented as inflow / outflow in their work. In recognition of the importance of these external factors we take solely the atmospheric forcing into consideration in this section and leaving the Black Sea freshwater forcing aside for further studies. Our model open boundaries are closed in the Aegean and the Black Seas, we take into account the effects of neighboring basins by attempting to include the atmospheric forcing as described earlier.

The surface circulation and salinity fields simulated by BBExc averaged for the months of April and October 2008 are shown in Figure 3. The circulation in April is characterized by eastward flow in the northern part of the Marmara Sea, and a westward flow in the southern part of the basin, and very little eddy activity. In contrast, observations show a strong anticyclonic gyre dominating the eastern part of the Marmara Sea driven by the Bosphorus jet. The difference in the circulation pattern in April between the simulation and the observations is due to missing Black Sea freshwater forcing. This clearly demonstrates that substantial changes in the surface circulation of the Marmara Sea by energizing the Bosphorus jet is expected to be driven by the freshwater excess of the Black Sea. In other words, the Bosphorus throughflow is indicated to be a significant driver of the seasonal circulation of the Marmara Sea. In October, BBExc simulation shows strong westward surface flow associated with cyclonic eastern and anticyclonic western eddies. As a result, the main flow diverted on to the southern shelf and passes through the island groups located in the vicinity of the Dardanelles entrance.

Regarding surface salinity fields, the BBExc simulation shows differences in the studied months of April and October 2008. Waters exiting the Bosphorus fills almost the entire eastern Marmara basin under the calm wind conditions in April. In October, fresher Bosphorus originated waters are mostly trapped in the vicinity of the northern coast. This shows that the circulation reacts faster to the changes in atmospheric conditions transmitted by the Bosphorus jet, whereas the adjustment of the salinity field depends on a multiplicity of other factors on the longer term.

The adjustment in the average position of the simulated $\sigma_t = 25$ surface in the Marmara Sea (not shown here) reveals the role of winds on interface depth. The correlation between the BBExc simulation and the measurements reveals that atmospheric forcing is responsible for high frequency variability in both simulations. In particular, the storm activities are responsible for the changes of up to 2 m in the interface depth within a few days. The absence of barotropic forcing results in a shallower interface position compared with the observations. Additionally, a weaker seasonality of the pycnocline is observed showing that the position of the interface is probably controlled by the freshwater balance in the Black Sea.

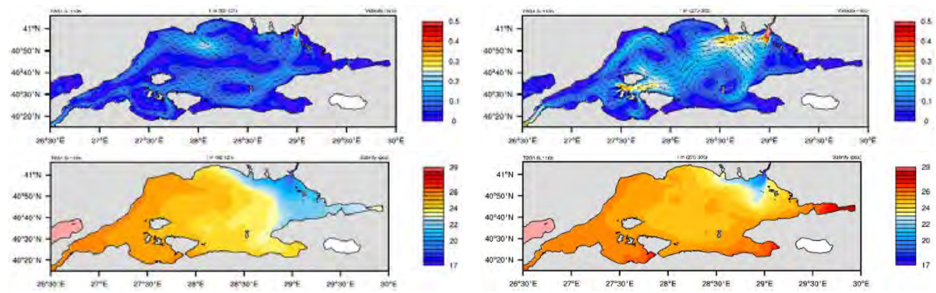

**Figure 3.** Simulated surface circulation in ms-1 (upper panel) and salinity in psu (lower panel) in the Marmara Sea averaged over April 2008 (left) and October 2008 (right) for experiment BBExc.

The observations were obtained during the SESAME Marmara Sea cruise separated into two legs of 4 days duration each. The first leg was carried out from 11 to 14 April 2008, and the second leg from 1 to 4 October 2008. T-S diagrams of water masses in the Marmara Sea are presented in Figure 4. The observed salinity and temperature profiles averaged over all CTD stations in the Marmara Sea are compared with the model results obtained from the BBExc simulations. The comparison is carried out for the upper 50 m of the water column, where most seasonal changes occur. Comparison of water properties below this depth requires longer simulations since the associated time scales are longer, based upon mean residence time estimates of 6-7 years, Ünlüata *et al.* (1990). The observations (dashed lines) show that the halocline and thermocline are positioned deeper in spring than autumn, evidently due to the increased freshwater input into the Black Sea in spring. The thermocline and halocline estimated from both simulations are in agreement with their observed structure in the Marmara Sea.

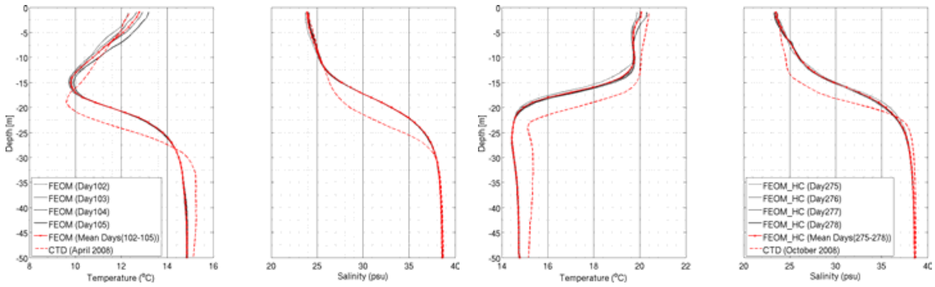


**Figure 4.** Vertical profiles of temperature and salinity in the surface layers of the Marmara Sea averaged over all stations. Model results are interpolated onto the position of the CTD stations for simulation BBExc. Red dashed lines represent the observations. Black and red solid lines indicate daily and cruise time averaged simulations, respectively. Left panel: April 2008, Right panel: October 2008.

Figure 4 compares the observed and the average simulated temperature and salinity fields in vertical water column. The simulated profiles during the measurement period are also depicted. The surface temperature discrepancy between simulation and observation does not exceed 0.5°C. The temperature minimum ~ 4 m above the thermocline in April 2008 is captured in the simulation. Below the thermocline, on the average across the Marmara Sea, the model predicts slightly colder water (by ~15°C) compared to the observations, due to the influences propagated from the horizontally uniform initial temperature profile imposed in the small external domain in the Aegean Sea. The salinity in the surface and deeper layers are simulate well comparing to the measurements. Lack of barotropic forcing due to Black Sea inflow possibly reveal such kind of uniform surface salinity which in reality may not be too uniform and because the Black Sea not physically well represented in the present model. This reveals that the model is capable of ensuring high skill in representing the gradients of temperature and salinity fields in vertical. However, there is a bias in the positioning of the aforementioned fields. This is linked to the missing freshwater forcing from the Black Sea which leads the rise of the interface in the Marmara Sea.

The model performance is further assessed by means of root-mean-square error (RMSE) comparison of properties between the model and the observations, computing errors over each CTD profile in the depth range 0 - 50 m (Figure 4). Despite the initialization with simple profiles, BBExc results are in agreement with the observation for both measurement periods (Figure 5). The source of the error is the misplacement of the halocline and thermocline which are too close to the surface. The error field is independent from the representation of hydrological properties of the Black Sea water influencing surface layers of the Marmara Sea. Temperature errors for both hindcast experiments do not differ much for each measurement periods.

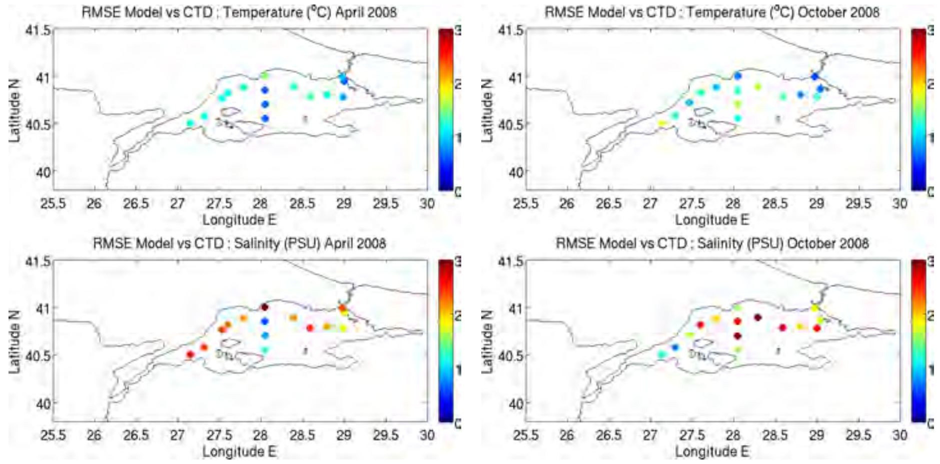


**Figure 5.** Accumulated root-mean-square errors between simulated and observed temperature (upper panel) and salinity profiles (lower panel) in the Marmara Sea for April 2008 (left) and October 2008 (right).

### 4.2.1. Model assessment with focus on the Bosphorus Strait

In the following we concentrate on the more realistic simulation, BBInc, and further investigate the ability of the model to simulate flow features and transports in the Bosphorus Strait. We compare time series of modeled and observed velocities in the southern Bosphorus, based on observations obtained from Jarosz *et al.* (2011). Observations indicate that the along-strait velocity component of the southern Bosphorus (at the middle of Section B1) varies considerably throughout the year 2008. In the simulation, the mean depth of the zero-velocity isotach is 8.75 m, shallower than the observed depth of 13.5 m reported by Jarosz *et al.* (2011). The maximum simulated along-strait current speed in the upper layer (1.31 $ms^{-1}$) is considerably lower than the observed value of 2.3 $ms^{-1}$ (Jarosz *et al.* 2011).

Measurements of volume transports through the Bosphorus and Dardanelles straits were conducted from September 2008 to February 2009 during the experiments reported by (Jarosz *et al.* 2011). A comparison of these observations with the simulated transport time series is presented in Figure 7. The correlation coefficients between model and observations for the upper and lower layer and net daily mean volume transports through the northern Bosphorus respectively are $r_{upper}$=0.75, $r_{lowe}$r=0.68 and $r_{ne}$t=0.74. These results reveal that the model is consistent with the measurements and able to capture the variability of the transport.

During the same period, the simulated net mean transport (49.7 $km^3\ yr^{-1}$) into the Marmara Sea compares relatively well with the observed net flux (86.3 $km^3\ yr^{-1}$) reported by Jarosz *et al.* (2011). However, simulated upper layer and lower layer transports (240.1

km$^3$ yr$^{-1}$ and 190.4 km$^3$ yr$^{-1}$, respectively) are much lower that the observed transports (359.9 km$^3$ yr$^{-1}$ and 273.6 km$^3$ yr$^{-1}$, respectively) for the period Sep-Dec 2008. The amplitude of the fluctuating components of transport in the model results is lower compared to that in the measurements. This is due to missing Black Sea freshwater contribution, the relatively coarse resolution of the atmospheric forcing and limited model domain in the Black and Aegean Seas.

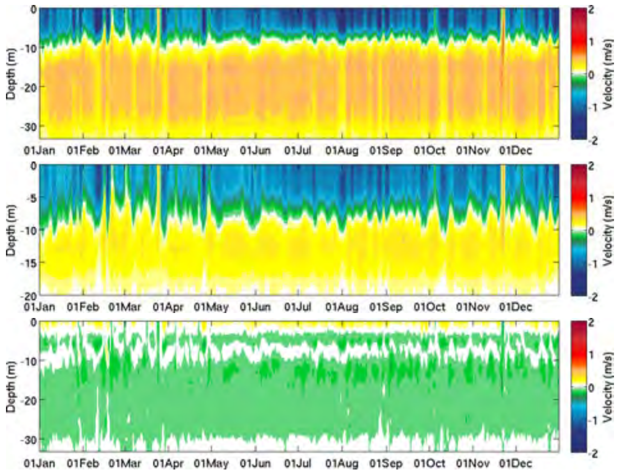


**Figure 6.** Time series of the simulated along-strait velocity profiles (ms$^{-1}$) in the middle of the Section B1 (top) and close to the Asian coast on Section B1 (middle) and cross-strait velocity profiles in the middle of the Section B1 (bottom) for the year 2008.

### 4.2.2. Blocking events

Under normal conditions, a progressive decrease occurs in the thickness of the upper layer starting from the northern end of the Bosphorus (45 - 50 m over the northern sill) until the Dardanelles-Aegean Sea Junction (~10m). The upper layer thickness in the Marmara Sea is typically around 25 m. Strong northerly winds combined with higher sea level difference between the Aegean and the Black Sea may deepen the interface position in the northern exit of the Bosphorus, leading to blocking of the lower layer flow which can last a few days (termed "lower layer flow reversals", LLR). Conversely, strong southerly wind in combination with a decrease in sea level difference can arrest the surface layers and even reverse it for several days (termed "upper layer flow reversals", ULR, Latif *et al.* (1991); Jarosz *et al.* (2011)).

An upper layer blocking event occurring on the dates of November 21 and 22, 2008 in the model (Figure 6). The blocking event has created a pulse of northward owing net currents through the Dardanelles and Bosphorus, evident from surface currents displayed on the left hand side panels of Figure 8. For comparison, the simulated monthly mean surface currents in November 2008 are shown in the right hand side panels of Figure 21, indicating the average situation which is only disturbed during the blocking event.

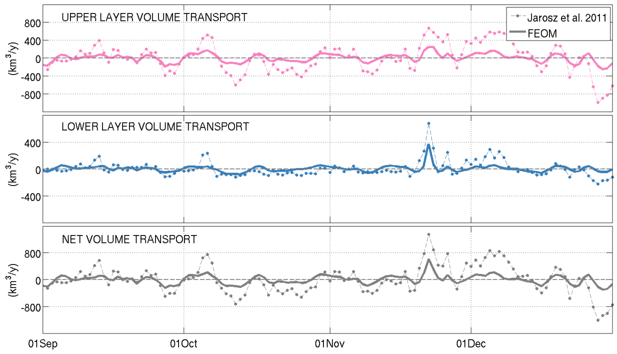


**Figure 7.** Time series of detrended simulated (solid line) and observed (dotted line) volume transport through section B4 (Northern Bosphorus). Observations are taken from Jarosz *et al.* (2011).

In fact, the currents on November 21, 2008 correspond to an explosive cyclone passing over the region characterized by strong southwesterly winds. The effects of this storm on the TSS and its dynamic response to the atmospheric forcing has been analyzed in some detail by Book *et al.* (2014)), based on the measurements campaign of Jarosz *et al.* (2011)). Both the observations and the model results indicate a complete change in the flow direction as the upper layer is blocked and pushed backwards. In the Bosphorus, the simulated currents exceed 1 ms$^{-1}$ starting from the southern sill until north of the contraction. The flow reversal reaches as far as the Bosphorus-Black Sea Junction. A similar flow reversal is observed in the Dardanelles (Figure 8) with a one-day time lag after the Bosphorus. The circulation in the Dardanelles displays a channel-wide cyclonic recirculation cell near its southern exit.

During the year 2008, the ECMWF atmospheric data reveals that there were several strong storms (lasting 3 - 5 days) passing over the TSS region. Observations indicate several upper layer blocking events from September to December 2008, Jarosz *et al.* (2011)). The upper layer flow reversals observed during the periods 1 - 7 October 2008 and 20 - 22 November 2008 are clearly represented in the simulation (Figure 6). It should be noted that lower layer blocking has not been observed during the time period September to December 2008, neither in observations nor in our simulation.

## 5. Conclusions

We have set up and tested the multi-resolution ocean model FESOM for the limited but complex domain of the TSS, using a particularly enhanced resolution in the Bosphorus and Dardanelles Straits in order to adequately represent the energetic processes in these regions in the overall dynamics of the coupled system. Based upon an initial adjustment of the lock-exchange configuration to quasi-steady state in the BASIC experiment, BBExc simulation dwells upon the impacts of realistic atmospheric forcing (BBExc) excluding the Black Sea freshwater budget on the dynamics of the TSS.

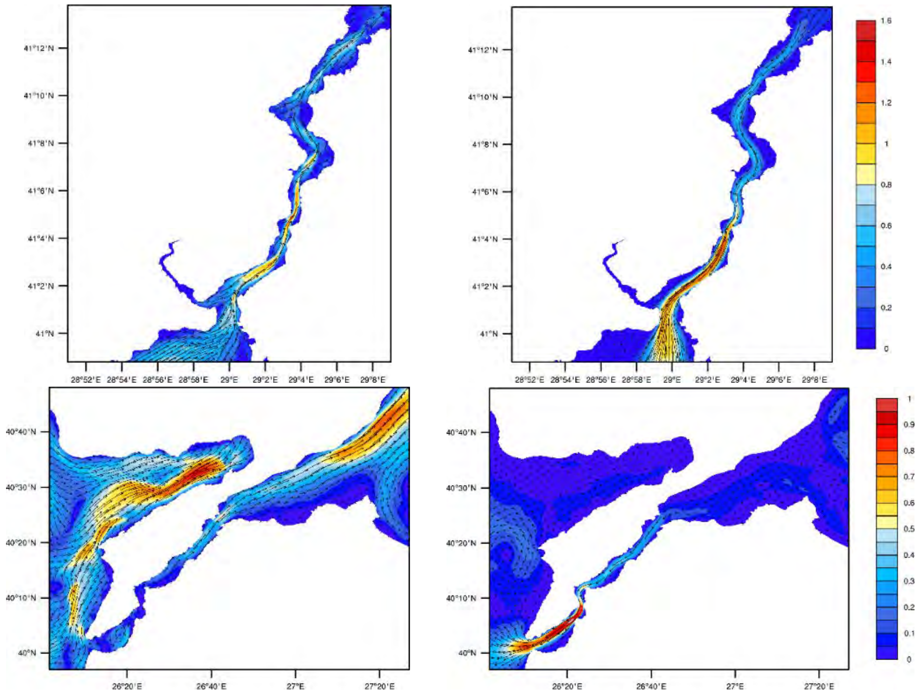

**Figure 8.** Simulated surface currents (in $ms^{-1}$) on November 21, 2008 in the Bosphorus (top left) and on November 20, 2008 in the Dardanelles (bottom left) and surface currents averaged over November 2008 (right).

Our BASIC simulation produced a general circulation and a stable stratification in the Marmara Sea consistent with previous measurements. Sensitivity experiments showed a reasonable compromise between resolution and computational cost, which the selected model configuration seemed to satisfy. The pycnocline depth in the Marmara Sea in BBExc showed a rising trend towards the surface in the absence of net volume transport through the Bosphorus. This trend is probably controlled by the Black Sea freshwater budget. Comparing the simulated surface circulation in the Marmara Sea in both experiments showed the circulation to be dominated by the Bosphorus inflow and modulated by atmospheric forcing. The results were compared with respect to observed salinity and temperature CTD profiles in the Marmara Sea and transport measurements in the Bosphorus. The comparison with transport measurements in the Bosphorus revealed very strong model skill in representing the variability despite low the upper layer and lower layer mean transport and standard deviation were lower compared to the observed values.

To conclude, the novelty in this work is the ability to uniformly represent the integral behavior of the TSS, which demonstrates the advantage of the multi-resolution approach. We proved that one key forcing functions is the atmospheric forcing and it is essential to provide realistic fluctuations of the pycnocline depth in the Marmara Sea.

The model can be improved in several ways. (1) An improved variability and a stable pycnocline depth with the correct seasonal cycle and net transport through the Bosphorus is only possible by including the freshwater budget. (2) The comparison of transports revealed the significance of the atmospheric forcing on the high frequency variability. In our simulations, we applied a correction to the sea points along the shore line to hinder the contamination of the land based points in the ECMWF wind field. Higher resolution atmospheric forcing both in spatial and temporal sense would be more justifiably needed to accurately represent forcing in this small and complex region on the passageway of atmospheric cyclones. (3) So far, the choice for the initial and boundary conditions were idealized. The model setup is now ready to perform multi-year simulations with realistic initial conditions. (4) The current model setup revealed a significant correlation between the sea level difference between Black and Aegean Seas and transport through the southern Bosphorus ($r = -0.87$), and this should be explored further. (5) More realistic surface water, heat and salinity boundary conditions and the incorporation of nonlinear free surface approach recently developed for the FESOM are all too relevant for the TSS and its inter-basin coupling, and are expected to improve results in the future. (6) Given the importance of the sea level difference on the TSS transports, the model domain should be extended to include the entire Black and Mediterranean Seas. We expect that a more realistic simulation of SSH in the two basins should improve the simulated transports.

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# CHALLENGES FOR COUPLED MODELING OF INTER-BASIN EXCHANGE APPLIED TO TURKISH STRAIT SYSTEM

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## 1. Introduction

Many years after the first development by Kirk Bryan and his colleagues at GFDL (Geophysical Fluid Dynamic Laboratory) in the late 60s, ocean modelling today is still a very demanding research area utilizing modern science and technology. Despite great technological advances in high-performance computing and earth observation systems, the current understanding of the oceans fails to fully recognize complex multiple scale interactions characterizing these regions. Computationally demanding state-of-art modelling systems in use today either represent a limited spectrum appropriate for the particular geometry and grid, or parameterize corresponding processes. The development of fully coupled multi-component earth system models (ESMs) is a solid example of the promising new era in model development aiming to construct more complete, complex and robust modelling systems able to represent interactions among individual components of the often inhomogeneous and delicately coupled earth systems. It is clear that the next-generation ocean modelling systems will require new computational methods and advanced modelling to account for complex processes and data assimilated from new observation systems. In addition to the limited capability of current ocean models to resolve all too important smaller scales, the ocean is still vastly under-sampled to validate model results and produce better short-term forecasts. Models of basins interconnected by straits have to resolve small scale processes of hydraulic controls, turbulence and mixing in deep basins, straits, fjords etc., and have to consider their direct influences on the neighboring domains of the coupled basins. Likewise, mass budgets of coupled basins and their nonlinear free surface variations influence strait response, in return. Narrow straits such as the Bosphorus, Dardanelles, Messina and Gibraltar Straits provide ample evidence for all the complexity that arises as a result of coupling between straits and the adjacent ocean domains.

The multi-scale nature of systems of multiple basins interconnected through straits, coastal systems with a mosaic of fjords, estuaries, continental shelf and canyon geometries, regions of fresh-water influence or upwelling systems with inherently coupled elements make them individually challenging to study and understand, and even more so when such systems are coupled with each other. The short-term forecasting of these complex systems being already problematic, their multi-decadal and climate predictability yet needs greater care to preserve the capability to resolve the all too important smaller scales. In the end, the demands for accurate representation of physics quickly become counterweighed by computational demands, only to be partially relieved by innovation. Amongst such coastal systems, sea straits providing communication between sea basins have special ranking in complexity. Models of basins interconnected by straits have to resolve exchange flows influenced by hydraulic controls, turbulence, interfacial mixing, free surface variations and internal waves and possible tidal effects at the strait, as well as linked processes in the adjacent seas such as the full nonlinear variations of the free surface, realistic lateral and surface water and mass fluxes, intrusions of surface jets and bottom plumes issued from straits, continental shelf and internal mixing processes, surface and internal sloshing and the response of coupled systems to extreme weather conditions/events. Narrow straits such as the Bosphorus, Dardanelles, Messina and Gibraltar Straits provide ample evidence for all the complexity that could be envisioned, with also a series of closely connected actions in the adjacent seas.

## 2. Challenges in modelling of interconnected basins

The multi-scale ocean modelling of interconnected basins mainly involves coupling of hydrostatic, non-hydrostatic, turbulent and sea surface processes, further influenced by air-sea interaction, wind-wave dissipation and tidal effects (Lermusiaux *et al.* 2013). The diverse multi-component nature of the problem makes it challenging to study nonlinear interactions and feedback mechanisms among system components. The combined effects of processes at various temporal and spatial scales often presents a setback to investigate the dynamic response of the entire system as a whole, preventing a total understanding of the system. To that end, ocean models developed for interconnected basins must target to resolve the multi-scale dynamics of the ocean environment, from small scale turbulence in straits or passages to large scale circulation and gyres/eddies in the adjacent sea/s or semi-closed water bodies. Despite recent developments in ocean modelling in terms of dynamics, physical parameterizations and the numerical techniques (spatial discretization techniques, high-order schemes, adaptive unstructured meshing, nesting, grid generation and data assimilation), the multi-scale ocean modelling of interconnected basins coupled with straits, fjords and steep topographic features is still a very active and demanding research area that requires innovative state-of-art modelling tools to allow the entire system to be simulated, preferably based upon an easy to use, portable, efficient modelling framework. Modern developments in numerical ocean modeling and the increasing availability of computing resources have led to increasingly sophisticated models decreasing the number of simplifying approximations needed in the past and the need to couple non-hydrostatic and hydrostatic models to resolve multi-scale processes demands challenging new and full interpretations of the Navier-Stokes equations (Blayo and Rousseau, 2015).

One of the techniques to overcome difficulties in resolving details of processes in complicated ocean domains has been to devise methods allowing variable resolution where it is most needed inside the model domain. Over the last decade, the surge of interest in unstructured mesh methods resolving complex domains (i.e. straits, overflows and the continental break) have led to improved new ocean models such as ADCIRC (Westering *et al.* 1992), FVCOM (Chen *et al.* 2003) and FESOM (Danilov et al, 2004; Wang *et al.* 2008) allowing to refine the computational grid in desired sub-regions (Danilov, 2013). Often, spurious modes maintained in unstructured-mesh models have made them computationally more demanding compared to structured-mesh models (Danilov, 2013). Additionally, the multi-resolution functionality provided by the unstructured meshes are 2 to 4 times more expensive per degree of freedom than the structured-mesh models (Danilov, 2013). The difficulties in implementation of numerical methods (i.e. data assimilation systems and open boundary conditions) still prevent or limit the usage of the unstructured mesh ocean models to represent complex regional systems. The design of data assimilation systems in adaptive or multi-resolution mesh is more difficult than building a forward model, while using an adaptive mesh for the adjoint calculation has its own numerical requirements and difficulties (Weller *et al.* 2010). The implementation of conservation of the mass and energy in adaptive type meshes is also crucial problem because spurious waves can be generated in the adaptation phase of the mesh that eventually dominate the solution.

On the other hand, the well-known finite-difference methods in ocean modelling are based on structured meshes. When compared with unstructured mesh models, these models have poor representation of the coastlines especially for coarse resolution cases and it is often difficult to enhance the resolution of the underlying grid in a particular region even when curvilinear coordinates and nesting strategies are employed. These problems also prevent realistic use of structured grid ocean models in applications involving interconnected basins, where excessive local refinement of the model grid to fine-scale components (i.e. straits) is needed. To overcome difficulties in designing structured grids in complicated domains, the composite or multi grid approach was developed and applied in the 90s. For example, Eby and Holloway (1994) investigated the grid transformation approach to couple separate model domains of the Artic region and the global ocean. In their design, the information along common boundaries were passed between the two model components in each iteration of the solver. Similarly, Dietrich *et al.* (2008) designed a multiple-grid ocean model to study the effects of the Mediterranean Overflow Water (MOW) in the North Atlantic Ocean, where a seamless integration between grids of different spatial resolution were achieved by using the method of upwind boundary fluxes developed by Dietrich *et al.* (2004). A similar composite grid approach has been used to study residence time in a partially mixed estuary (Warner *et al.* 2010), making sure that the numerical solution in each grid would not be different from the solution in a single grid including the entire domain. To simplify the coupling between multiple grids, the overlap regions are often forced to be coincident (all grid properties are identical in overlapping grid cells). In this case the domains could actually be merged into a single grid alleviating the need for composite grids of different resolution, such as needed in the case of interconnected basins. Coupling of models with different dynamical cores (e.g. hydrostatic and non-hydrostatic) and physical parameterizations often required in multi-scale ocean modelling (e.g. interconnected basins) is not possible in this approach.

In addition to the possible use of a single monolithic grid to represent various scales, the nesting approach is often used in ocean modeling to bridge across coarse and fine scales. For time-dependent problems, adaptive mesh refinement (AMR) allows dynamically adjusted resolution, such as in the AGRIF (Adaptive Grid Refinement in Fortran; Debreu *et al.* 2008) package, discretized on a structured grid. Successful application of the nesting approach by Sannino *et al.* (2009) demonstrated the influence of the Strait of Gibraltar on the water column stratification and convection in Mediterranean Sea, allowing better representation of hydraulic control in the strait for improved estimates of volume transport and Mediterranean Outflow Water (MOW; Dietrich *et al.* 2008). Although the nesting approach is quite common in ocean modeling, the representation of interconnected basins like the TSS still poses a challenging problem. Moreover, the two-way data exchange among the nested models is also problematic and might create mass conservation problems due to the interpolation, numerical errors and spurious mixing along the boundaries.

In essence, the behavior is reflected in the definition of a “system”- a set of interacting or interdependent components forming a complex whole. The Turkish Strait System (TSS) is a perfect example of the complex ocean modelling problem that can be posed for such systems. It is a unique environment to study exchange flows, hydraulic controls, turbulence, internal waves, subject to externally imposed net water flux variability, extreme weather events, storm surges, internal sloshing and tidal effects. The combined effects of these processes are essential to determine the overall system response, which actually is a demanding problem of coupled ocean modelling.

## 3. Challenges in modelling of Turkish Strait System

The oceanographic conditions of the TSS has been extensively well investigated in the last thirty years. The variability of currents and other physical properties are well established, although the much needed coastal observatories are lacking. The basic dynamics creating the two-way exchange flows of the TSS are the density and pressure differences between the Black and the Aegean Seas, first revealed by Marsili (1681) studying the Bosphorus three centuries ago (Defant, 1961; Soffientino and Pilson, 2005; Pinardi, 2009; Pinardi *et al.* 2016). The TSS is very sensitive to climatic changes, and potentially can induce such changes in the adjacent basins (Özsoy, 1999). Acting as the limiting element of the TSS, the Bosphorus Strait controls the exchange of mass and materials between the Black and the Mediterranean Seas (Ünlüata *et al.* 1990; Özsoy *et al.* 1995; Polat and Tuğrul, 1995), thereby influencing the stratification, water and mass budgets (Özsoy *et al.* 1993; Özsoy and Ünlüata, 1997, 1998; Delfanti *et al.* 2014; Falina *et al.* 2016; Jordà *et al.* 2016). The mass budget dictates the upper layer flux to be about two times larger than that of the lower layer, yielding a net flux of about 300 $km^3$/yr from the Black Sea to the Sea of Marmara (Latif *et al.* 1991; Ünlüata *et al.* 1990). Geometrical features of the Bosphorus (Oğuz *et al.* 1990; Özsoy *et al.* 1998) imply 'maximal exchange', as proposed by Farmer and Armi (1986) influenced by local topographic features. The exchange flows respond dynamically to time-dependent hydro-meteorological forcing in the adjacent basins (Özsoy *et al.* 1995a, 1996, 1998; Gregg and Özsoy, 1999). Observations suggest increased entrainment past the hydraulic controls at the southern contraction and the northern sill in the Black Sea (Gregg *et al.* 1999, 2002; Özsoy *et al.* 2002).

The Sea of Marmara possesses a two-layer stratification and associated flow system, in which an approximately 25 m layer of relatively less saline (salinity ~25) water mass of the Black Sea origin is separated from the rest of the water body by a sharp permanent pycnocline. The two-layer structure is preserved even in the winter season when abrupt cooling of surface waters increases the density of the upper layer by about 1-2 $kg/m^3$. The corresponding flow system in the sea reveals a stronger circulation in the upper layer with a preferential direction towards the Aegean Sea. The upper layer circulation inferred from the existing hydrographic data (Beşiktepe *et al.* 1995) suggests the presence of a large anti-cyclonic loop of the surface flow upon issuing from the Bosphorus. As this larger scale flow system is generally controlled by seasonal wind forcing, evolution of the surface buoyant jet of the Bosphorus surface outflow by horizontal and vertical entrainment processes near the Bosphorus-Marmara junction region adds further complexity to the regional circulation. The currents in the lower layer is much weaker, and the time scale of their transit across the sea towards the Bosphorus is approximately an order of magnitude longer than that of the surface layer. The exchange flows respond dynamically to forcing on time scales from several days to years by wind setup, water budgets and atmospheric pressure differences. Three dimensional hydrodynamic models have been used to investigate exchange flows under ideal conditions of the Bosphorus Strait and need to be further developed for application to the Bosphorus and Dardanelles Straits. The conditions in the Marmara Sea connected to the outlying seas by the Bosphorus and Dardanelles Straits are also relatively well known, although its complex nature with a wide shelf and deep basins, and severe winter weather conditions often create complex currents and meteorology that justifies further careful consideration of risks concerning navigation and the environment.

The strategy of recent studies aiming to understand the TSS necessarily has been a divide-and-conquer approach to decompose/isolate individual components and very few modelling studies have attempted to study the integral behavior of TSS considering contrasting properties and nonlinear interactions of its sub-components. In this case, the existing modelling studies have passed through a series of successive developments, starting from two and three dimensional models with idealized geometry and extending to realistic three-dimensional ocean models applied to individual elements of the system.

Idealized two-layer, one-dimensional or two-dimensional models solving horizontally or vertically integrated hydrodynamic equations have been developed for the Dardanelles Strait (Oğuz and Sur, 1989; Staschuk and Hutter, 2001) as well as the Bosphorus Strait (Oğuz *et al.* 1990; Ilıcak *et al.* 2009). Three-dimensional models solving full set of primitive equations have later been developed for the Dardanelles Strait (Kanarska and Maderich, 2008) and for the Bosphorus Strait (Sözer and Özsoy, 2002a and 2002b; Oğuz, 2005; Sözer, 2013; Sözer and Özsoy, 2016). In addition to these models developed for straits, some earlier studies have aimed to treat Marmara Sea as an isolated marine basin, with the addition of artificial inflow and outflow sources at the Bosphorus and Dardanelles Straits, thereby decoupling the dynamics of the straits from the basin (Demyshev and Dovgaya, 2007; Demyshev, 2012 and Chiggiato *et al.* 2011). The main problem of all these approaches rest in ignoring the interactions among various components, by imposing inappropriate boundary and initial conditions to subsystems of the TSS. Although models representing the individual components of the entire system are definitely valuable tools for analyzing the hydrodynamic behavior of those components, recent studies using integrated modelling of the TSS by Gürses *et al.* (2016) and Sannino *et al.* (2016) showed that the TSS hydrodynamics cannot be adequately understood or even resolved, unless the details of the very substantial dynamics of the straits are included in full detail in the essentially coupled system. The nonlinear, strongly stratified hydrodynamics of the flow through the narrow straits has made the modelling of TSS a grand challenge because of the need to resolve the straits in fine detail, which typically are not elaborated in modelling applications concerning open oceans and coastal regions (Sannino *et al.* 2016).

Specifically, in the case of the Turkish Straits System (TSS), surface water jets and bottom plumes generated in the Black, Marmara and Aegean Seas and the intrusion of water masses into the adjacent seas have to be accounted for, essential for driving the Marmara Sea circulation and with particular effects on the double diffusive instability regime of the Black Sea. Representing these fine scale features, at the same time insisting on conservation of mass and energy among the components of interconnected system are essential for models. There is an obvious need for current state-of-art modelling tools to be developed using model coupling frameworks/libraries at the required level of sophistication (in terms of both physics and computational methods) to facilitate the construction of innovative modelling systems and their applications.

## 4. Towards multi-instance and multi-component ocean models for interconnected basins

As briefly mentioned in the previous sections, the development of methods for systematic coupling of multiple marine basins and straits has never been formally attempted in the past. The intended novel design is based on coupling multiple realizations of high resolution ocean model components, surpassing the earlier concepts of trying to fit the entire system in a single model application, destined to fail in the accurate representation of temporal and spatial characteristics of each sub-system. The multi-instance ocean modeling (MIOM) system aims to create specialized coupling tools linking separate components of the system irrespective of size and structure, thus enabling to study multi-scale processes in the interconnected system. The higher-level modelling system basically acts to orchestrate simultaneous operation of individual marine components by allowing two-way interactions among them and also with the active atmosphere model. The TSS is a perfect example to test and develop such modeling system, given its complex internal dynamics coupled with the near-field and remote effects of two large basins.

The design of such a complex modelling system (MIOM) presents a set of difficulties in employing independently developed model components for different parts of the domain. Each model component could have different horizontal and vertical grid structure and spatial resolution. In this case, specialized tools such as model coupling libraries and frameworks are used to couple different model components. The Earth System Modeling Framework (ESMF; Hill et. al., 2004a and 2004b; Collins et. al., 2005), Model Coupling Toolkit (MCT, Jacob *et al.* 2005, Larson et. al., 2005), Model Coupling Environmental Library (MCEL, Bettencourt, 2002), OASIS (Redler *et al.* 2010, Valcke, 2013) and C-Coupler (Liu *et al.* 2014) can be given as examples of methods simplifying the regular tasks in creating a coupled modelling system. To tackle the problem, the MIOM will use driver based model coupling approach based on the ESMF coupling framework. The ESMF framework is selected because of its unique online three-dimensional re-gridding capability, which allows the driver to readily perform interpolation over the exchanged fields (i.e. temperature, salinity, heat and momentum fluxes) using the National Unified Operational Prediction Capability (NUOPC) layer. The NUOPC layer basically simplifies common tasks of model coupling, component synchronization and run sequence (i.e. implicit, semi-implicit and explicit type of coupling) by providing an additional wrapper layer between coupled model components and the ESMF framework (Figure 1).

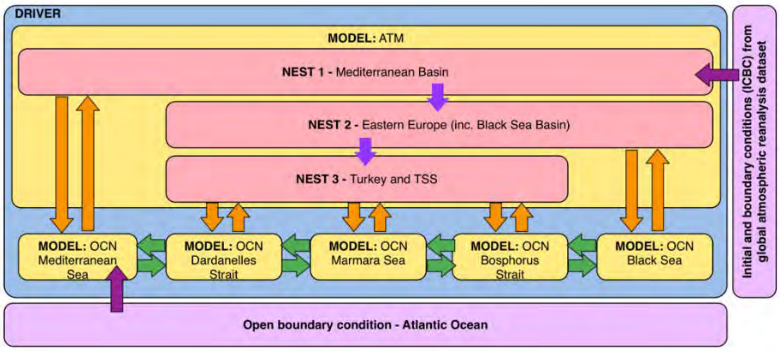


**Figure 1** Design of multi-instance ocean model (MIOM) and coupling with active atmosphere component for TSS.

In the proposed ocean modelling system of MIOM, individual ocean model components exchange information (i.e. water fluxes, tracers) along their overlapped regions that are called buffer zones or dynamic interfaces. In this case, the seamless integration of model components requires mapping of exchange fields (i.e. temperature, salt, velocity components) among different instances of the modelling system using conservative methods of interpolation to prevent addition of artificial heat, momentum and mass fluxes by exchanging fields. A possible disadvantage of this method is that the model instances do not constrain the interior of the counterpart model instance directly, and there is nothing to prevent unrealistic drift of the model instances and/or sharp gradients of fluxes between the model components. A method to solve this problem is to apply flux balancing algorithm such as a revised version of the smoothed semi-prognostic (SSP; Greatbatch *et al.* 2004) method used in two-way nesting of ocean models (Sheng *et al.* 2005) to balance fluxes between adjacent model instances.

As it is mentioned before, the developed models of TSS uses relatively low-resolution offline atmospheric forcing to drive the individual components of the TSS model and it neglects the two-way interaction and feedback mechanisms in the air-sea interface that might have a vital importance in the response of the overall system to the atmospheric conditions especially for the blocking problems in the straits and water mass exchanges through the straits by modifying evaporation from the Mediterranean and Black Seas surfaces. Additionally, the previous study of Turunçoğlu and Sannino (2016) showed that the coupled atmosphere-ocean model tends to modify the heat fluxes in the air-sea interface of the Mediterranean Sea by reducing the latent heat loss from the sea surface and the rate of change of latent heat flux might reach up to %10 especially in Eastern Mediterranean. The decrease of evaporation over the sea also affects the precipitation over the sea due to the reduction of moisture content of the lower atmosphere. It is clear that the nonlinear air-sea interaction should play an important role in the dynamics of the TSS system and mass transport through the straits. The coupling of MIOM system with a fully active atmosphere component is expected to reduce biases by improved representation of the air-sea interface. The coupling of MIOM system with an active atmospheric component will be the first attempt to design and test a novel modeling approach to integrate the different earth system model components to represent the entire TSS.

The earlier studies investigating the hydrodynamic behavior of the TSS have focused on individual components of the system either coupled with or in the absence of complicating atmospheric effects. The previous study of Chiggiato *et al.* (2011) only included the two Straits as open boundaries (inflow and outflow sections) and used atmospheric forcing at 7 km spatial resolution to simulate the mainly wind-driven circulation superposed on the basic flow imposed through the straits. It is clear that the horizontal resolution used by Chiggiato *et al.* (2011) is still insufficient to study the detailed response of the very narrow straits to atmospheric conditions. Due to the multi-scale nature of the region of interest, the horizontal resolution of required atmospheric forcing for modelling entire TSS and the bordering seas are not uniform. While the required horizontal resolution of atmospheric forcing for Marmara Sea is around 5-10 km (internal Rossby radius of deformation is estimated to be around 17 km by Chiggiato *et al.* 2011), higher resolution atmospheric forcing of 1-3 km is required to study water transport and circulation in very narrow straits. The various horizontal resolution requirements of the study lead the usage of nesting strategy to perform atmospheric simulations. Accompanying the nested domain configuration with desired horizontal resolution, a non-hydrostatic regional atmosphere model will provide high-resolution atmospheric forcing for the entire modeling system (MIOM). The use of a non-hydrostatic model allows to add additional inner-most nests over straits with enhanced horizontal resolution for better representation of local effects such as complex coastlines and steep topography.

The methodology developed will provide the much needed tools to examine seemingly hidden details in a functional prototype and open up new opportunities to understand the complex feedback mechanisms and interactions which are crucial in the development of forecasting capabilities. The approach also employs a development strategy that would allow addition of other components as needed in the future, using the same methodology: for instance hydrological models of river catchments can be added as land components supplying riverine and overland flow components, or biochemical model components representing marine ecosystems.

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**ACOUSTICAL PROPERTIES AND AMBIENT NOISE MEASUREMENTS IN THE SEA OF MARMARA**

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## 1. Introduction

Scientific studies about the acoustical properties of the Sea of Marmara and connecting straits (TSS, Turkish Straits System) are very limited in scope and all are related to ambient noise measurements. In general, this inland sea is characterized by higher underwater ambient noise levels if compared to the other Turkish seas; Mediterranean, Aegean and Black Sea. The scope of this chapter is to review the available studies along the TSS, possible sources of the noise, their distributions and to provide an opportunity to discuss current and future work requirements.

European Union (EU) Marine Strategy Framework Directive (MSFD), came into force on 15 June 2008, aims to protect the marine environment across Europe more effectively. In 2010 a set of criteria and also indicators produced for Member States to easily implement the MSFD. Descriptor 11 is about underwater noise and other forms of energy. It is clearly declared that “the Marine Directive aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend”. Commission Decision 2010/477/EU published two indicators for Descriptor 11 of the MSFD on criteria and methodological standards on good environmental status (GES) of marine waters. These indicators are: a) Indicator 11.1.1 on low and mid frequency impulsive sounds, b) Indicator 11.2.1 on continuous low frequency sound (ambient noise) (Van der Graaf *et al.* 2012). Indicator 11.1.1 requires to monitor impulsive sounds at 10 Hz -100 kHz frequency band which are higher than the defined threshold levels. Indicator 11.2.1 requires to monitor ambient noise which is continuous low frequency sound at 63 Hz and 125 Hz center frequencies using 1/3 octave band. These frequencies are compatible with ISO 266:1975. Trends are monitored in this measurements.

## 2. Acoustical properties of the region

Sound propagates at a certain speed that depends on the medium, and other factors such as salinity, temperature and pressure. For example, it travels faster in denser media such as more saline waters. In the Sea of Marmara, the surface salinity is between 21-30 parts per thousand and at the bottom the salinity increases to 38.5 parts per thousand similar to the Mediterranean (see also physical oceanography division, this volume). The surface waters are mostly mixing with the Black Sea while the deep water is coming from the Mediterranean. This behavior of the Sea of Marmara is playing a big role on acoustic propagation.

The surface temperature of Sea of Marmara is between 6 and 24.5°C and at the bottom the temperature is approximately 14.5°C (see physical oceanography division, this volume). The variability of these temperature and salinity profiles have important roles in the definition of the sound speed profiles. At near-surface depths some characteristic negative sound gradients are observed in summer against the positive ones in winter. Depending on the vertical sound profiles, acoustical waves can be trapped and effectively carried very long distances in the sea.

The temperature and salinity values are almost constant below -40 m in the Sea of Marmara; about 14.5°C and 38.5 parts per thousand, respectively. So the pressure is the dominant factor of sound speed change. In other words, sound speed in the Sea of Marmara increases with pressure below -40 m.

## 3. Ambient noise measurements in the Sea of Marmara

Ambient noise contains a significant amount of anthropogenic component (Dahl *et al.* 2007). Therefore, it is important to describe underwater ambient noise in terms of its spectrum, or frequency content. Measurements at the Turkish seas have shown that the Sea of Marmara is 4 dB (decibel) noisier than the Black Sea and Mediterranean Sea (Mutlu 2005). However, such a suggestion needs more comprehensive acoustical monitoring at sea.

Turkish Naval Research Center (TNRC) has been conducting Total Radiated Noise (TRN) and LOFAR (Low Frequency Analysis and Ranging) measurements for the naval ships at Erdek, SW part of the Sea of Marmara, for more than 15 years. Ambient noise is the first measurement taken before the ship noise measurements. In case of historical data needed, those measurements could be a good source to ask from the Turkish Navy.

There are important observations and acoustic monitoring of odontocetes in the İstanbul Strait. Between the years of 2009 and 2010 acoustic monitoring was conducted using two-band spectrum intensity ratio at 130 and 70 kHz. This ratio *helped* to identify Phocoenidae out of Delphinidae (Akamatsu *et al.* 2013). Fixed passive acoustic monitoring is the method used for two years to identify porpoises and delphinids in the middle of the İstanbul Strait (Kameyama *et al.* 2015). Two delphinid species, *Tursiops truncatus* and *Delphinus delphis*, as well as harbor porpoise *Phocoena phocoena* were monitored between 2010 and 2012. Delphinids have short inter-click intervals (ICIs) (20-40 ms) at night. This is possible because of their feeding. Delphinids used long range (100-160 ms) sonar at daytime (Dede *et al.* 2014). These ICIs are used to detect and classify the cetaceans.

One of the most significant acoustical data sets was given by Ülüğ *et al*. (2008) and Ülüğ (2009). The results represent some ambient noise levels measured along the İstanbul Strait (stations 1 and 6), its southern outlet (stations 7 and 8) and offshore Tuzla (station 9) (Figure 1). As a comparison, maxima, minima and averages of the measurement levels at the stations 3 and 7 were given in Figure 2.

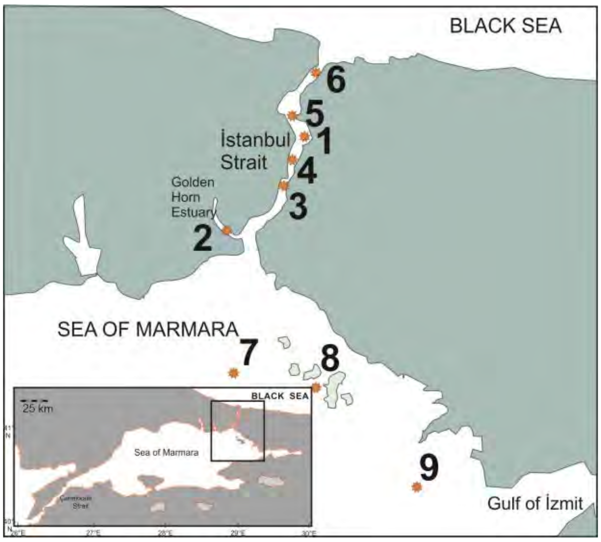


**Figure 1.** Ambient noise measurement stations along the İstanbul Strait and its southern outlet (modified from Ülüğ 2009).

The noise levels along the station 3 at the İstanbul Strait were much variable and 20-30 dB higher at maximum levels if compared to the stations in the Sea of Marmara (Figure 2). The difference at ambient noise levels increases toward higher frequencies. The spectrum levels for both stations decrease after 500 Hz which is close to the upper limit for shipping traffic noise. İstanbul Strait has its own unique noise characteristics as composed from its high current speeds and turbulence noise due to current reversals at certain depths. Secondary main effect of the high noise is the high intensity of local shipping. The cargo and container ships have almost 150-170 dB Source Level (SL). On the other hand, Sea of Marmara is much silent than the İstanbul Strait even at the maximum levels. The effects of the oceanographic conditions in the İstanbul Strait give rise to spatial and temporal inhomogeneities of the sound speed in the water column. Along its narrow passages Transmission Loss (TL) is low due to distance.

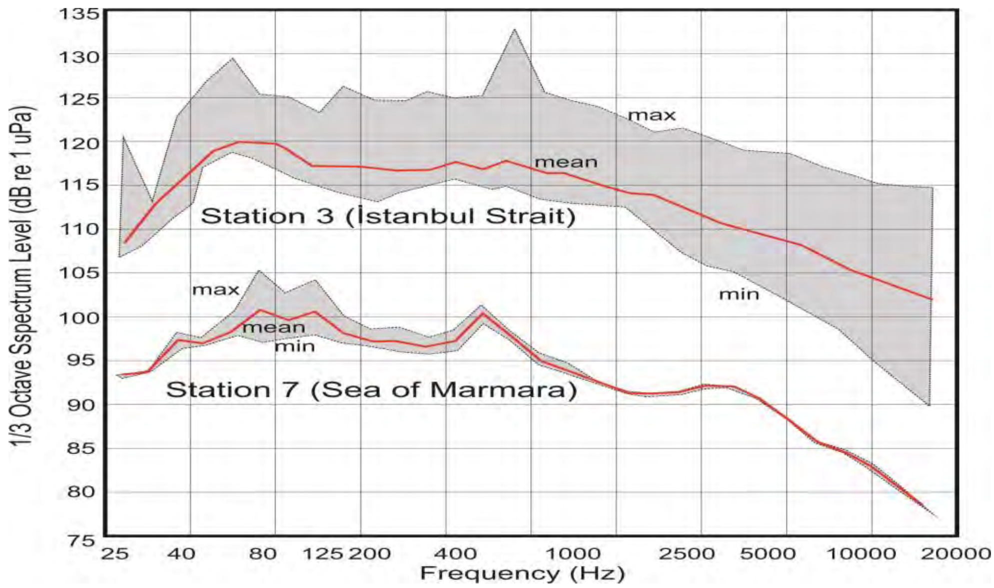


**Figure 2.**1/3 octave band ambient noise levels at station 3 and station 7 (modified from Ülüğ 2009).

Transmission Loss (TL) is 40 dB at 100 m, 60 dB at 1000 m, and 80 dB at 10.000 m using the basic TL=20*log (r) formula, where r is the distance in meters. A cargo or container ship with almost 170 dB source level passes through the İstanbul Strait for every hour. The noise from such a ship will be heard as a 130 dB noise at a distance of about 100 meters from the ship, which is a basic explanation for the very high noise level observed at the station 3 (Figure 1). We should also consider the actual TL would be less than the result of TL=20*log (r) formula. This fact is also another reason for high ambient noise.

When we look at a much different location (at station 7) than the narrow strait which is approximately 15 km far from the southern outlet of the İstanbul Strait, we expect a higher Transmission Loss and lower Received Level of noise at the measurement point. For example, for 10.000 m distance from ship there could be a 80 dB TL resulting a very low received level. Using the same example of a 170 dB source level the received level would drop to 170-80=90 dB which is close to the average ambient noise level in the Sea of Marmara.

We understand that the narrow geography of the Strait and close passing of heavy traffic creates a 20-30 dB higher Noise Level in the İstanbul Strait comparing to that in the Sea of Marmara. Figure 2 is only representing two points with about one-hour measurement data. For a better understanding of acoustical properties in this area there should be much more detailed measurements.

Around 50,000 ships are passing through the Turkish Straits and the Sea of Marmara every year. Shipping noise is dominant at low frequencies. The main shipping routes among the coasts are displayed in Figure 3. Coastwise shipping is also an important noise contribution to the Sea of Marmara.

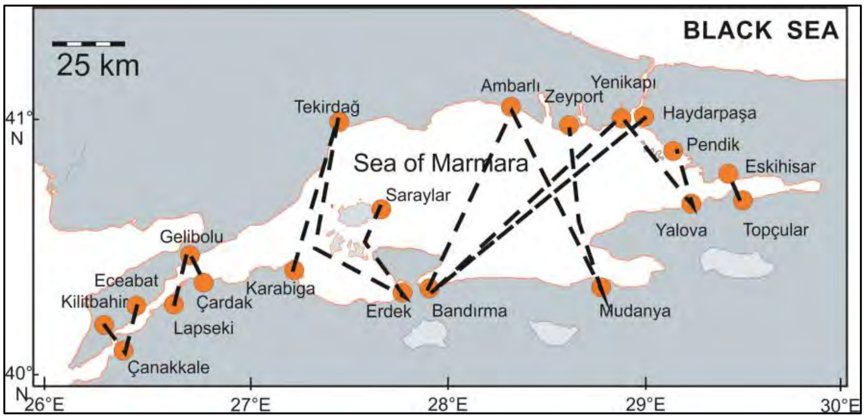


**Figure 3.** Main coastwise shipping routes in the Sea of Marmara. Data modified from the Turkish Ministry of Transportation, Maritime and Communication; UDHB (2016).

Vessel speed is one of the main factors controlling the shipping noise. This is also defined as acoustic cavitation noise which can be used in underwater applications as one of the ships noise signatures. Fast ferries create very high noises disturbing the habitat. Moreover, shipping noise is also related to the weight of the ship. As the weight and size of the ships gets bigger the noise also gets higher. Shallow water noise levels are approximately 5 dB greater than deep water levels at the same frequency and wind speed (Wenz 1962). This is also coherent with the measurements at the İstanbul Strait and surroundings.

Measurements of ambient noise waveforms (or spectra) in South Norwegian Sea indicated that the underwater ambient noise increase of 5 dB in winter reference to summer ambient noise (Walkinshaw 2005). Unfortunately, no measurement data is available for the Sea of Marmara to verify this situation. Around the İstanbul Strait, the highest winds in winter is about 10 m/s while in summer it is about 2 m/s. Wind noise is one factor at the winter time. Another factor is the sound channels generated due to sound speed profile. These sound channels let the sound to travel far distances in winter. In summer negative gradient sound speed profiles do not let the sound travel so far.

Turbulence is more effective in the southern part of the İstanbul Strait where there has been a 10 m thickness was observed. On the other hand, at the northern part of the İstanbul Strait turbulence thickness is about 2 m (Güler 2006). Rain falling on the sea makes a loud and distinctive sound and creates ambient noise across a broad range of frequencies with a peak around 15 kHz. Heavy rain can increase noise levels by up to 35 dB above the background noise level (Ma *et al.* 2005). Underwater sound attenuation changes depending on the frequency. Attenuation increases at higher frequencies. At 100 Hz the attenuation of underwater sound is 0.02 dB per km. At 1000 Hz attenuation of underwater sound is 0.06 dB per km (NRC, 2003). Industrial areas, ports and shipyards are other important actors of the underwater noise. The highest maritime traffic is mostly limited to coastal areas at the megacity of İstanbul with a population more the 14 million. Many ports, marinas and shipyards are scattered through the Gulf of Izmit. Therefore, these localities are expected to be noisiest areas in the Sea of Marmara. The northern and central strands of the North Anatolian Fault in the Sea of Marmara (see geologic oceanography division, this volume) are the main sources of moderate and destructive earthquakes and minor seismic activities with noise frequency less than 100 Hz.

Noise maps for different frequencies (100, 1000 and 10000 Hz) have been produced for the İstanbul Strait which partly cover the south outlet of the İstanbul Strait (Figures 4a, b, c) (Ülüğ 2009). Third-octave filtering is the preferred method for the underwater sound analysis in the İstanbul Strait and also for the MSFD. Figure 4a is representing the low frequency noise map of the İstanbul Strait and surroundings obtained from 9 stations and using 1/3 octave band at 100 Hz. Colors are from dark blue to red which is displaying lower noise with dark blue and higher noise with red. Measured ambient noise in this area is between 93-123 dB on average. The area between Beşiktaş and Üsküdar is the most noisy area with over 120 dB noise level. Figure 4b is representing the medium frequency noise map of the İstanbul Strait and surroundings using 1/3 octave band at 1000 Hz. The noise level at 1000 Hz is similar to 100 Hz. which is between 95-125 dB. Finally, Figure 4c displays the high frequency noise map for the same region using 1/3 octave band at 10000 Hz. Noise level is between 80 and 95 dB at 10000 Hz. Shipping noise is less effective at higher frequencies and attenuation gets more important at high frequencies.

Combining three ambient noise maps obtained from different frequencies (Figure 4), the red color areas, which are over 120 dB, are the most important areas to be taken into consideration. Reducing the shipping speeds or reducing the local shipping noise with controlling the local passenger ships in this area would reduce the noise.

New measurements and more detailed noise maps are needed, covering all of the Sea of Marmara after relevant studies according to MSFD.

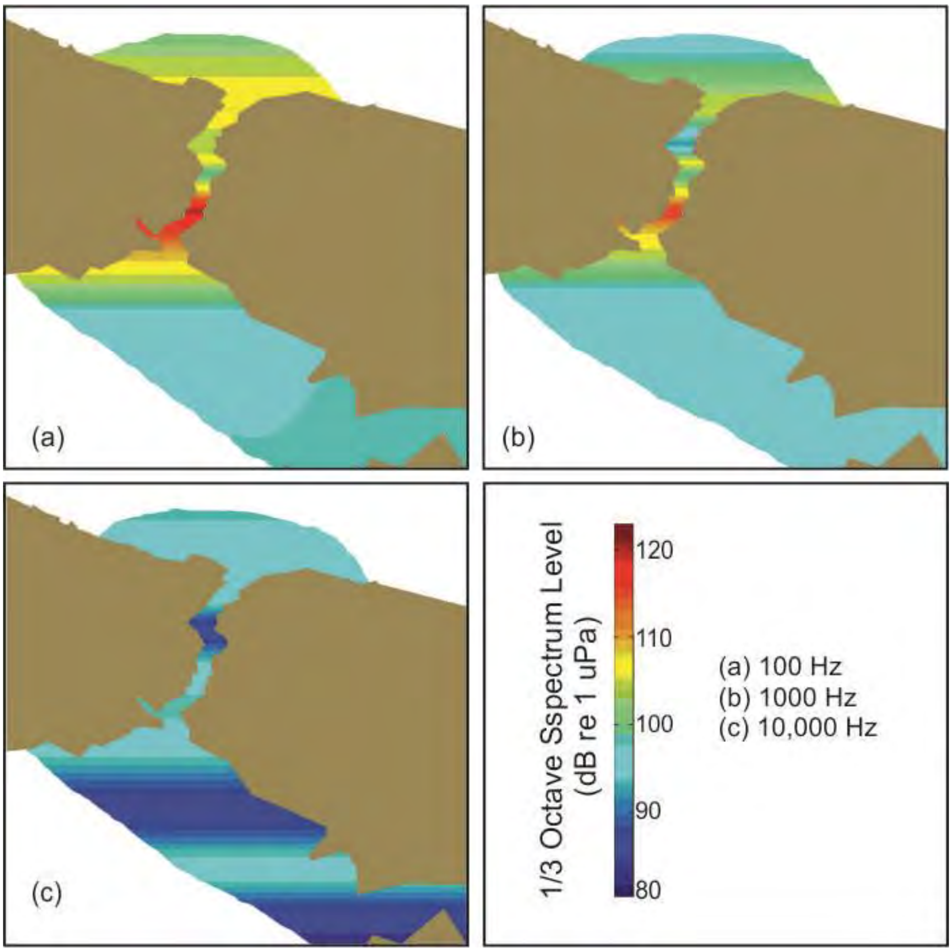


**Figure 4.** a) Low frequency (100 Hz), b) mid frequency (1000 Hz) and, c) high frequency (10000 Hz) noise maps (modified from Ülüğ 2009).

## 4. Discussion and conclusion

Very few studies about underwater ambient noise at the Sea of Marmara has been conducted and published till 2016. Acoustic properties of the Sea of Marmara have been achieved from various CTD, XBT and XSV measurements providing the sound speed profile. The Office of Navigation, Hydrography and Oceanography (ONHO) has the national database for all these measurements.

Ambient noise contains the noise from surface agitation, precipitation, biological activities, shipping, seabed saltation and seismic signals in the absence of transient signals from earthquakes. There are also localized noise sources in the ocean which are producing noise limited to a frequency band. These are seismic air-guns, low frequency active sonar and other type of sonars, drilling, shipping, echo sounders, undersea earthquakes, volcanic eruptions and sound of cetaceans. The cetaceans use the same frequency band with the anthropogenic noises. The chaotic underwater noise limits the ability of ceteceans to communicate and adds a stress factor to underwater environment. Underwater noise pollution is harming cetaceans resulting injuries and even death.

All sound sources and their noise levels were summarized in a logarithmic plot of acoustic power-flux density against frequency by Coates (2002). The dB scale show that acoustic intensity is normalized by comparison with a reference plane wave (Figure 5). Contrary to the localized noise sources, the ambient noise at the bottom of the graph is range independent as it may emanate from many sources, near or far to the measurement station.

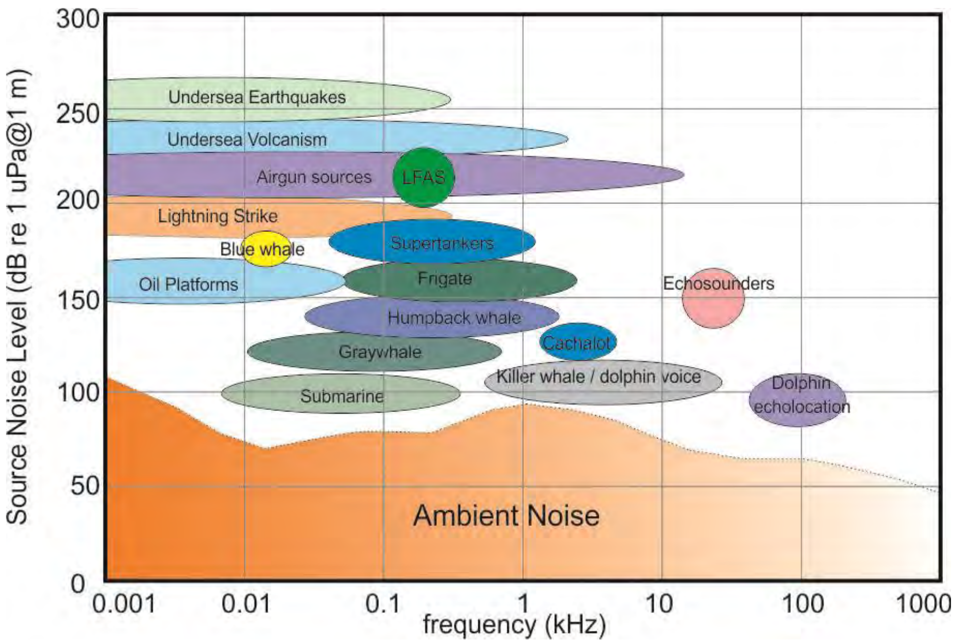


**Figure 5.** Spectra of ambient noise (composition of seismic, shipping, heavy rain, surface waves, fish choruses, snapping shrimp and thermal noise from low to high frequency) and some of the localized noise sources in the oceans (modified from Coates 2002). LFAS: Low frequency active sonar.

Heavy shipping is a major anthropogenic noise source in the Sea of Marmara. The suspended bridges along the İstanbul Strait are adding noise into sea as well. Two new bridges were inaugurated in 2016; the Yavuz Sultan Selim Bridge at the northern sector of the İstanbul Strait and the Osmangazi Bridge across the Gulf of Izmit. Their noise contributions into the marine environment should be monitored.

Low Frequency Active Sonars, which operate at 100-1000 Hz frequency band and can travel great distances, are not used in the Sea of Marmara since Turkish Navy does not use them at present, and no other navies or companies conducted such kind of sonar tests in the Sea of Marmara. The "*Kanal İstanbul*" project, an artificial sea-level waterway between the Black Sea and the Sea of Marmara, will evidently be a major candidate for future source of noise pollution which will dramatically change the underwater noise structure of the Sea of Marmara.

The recent acoustical data showed that the noisiest area is located between Beşiktaş and Üsküdar in the southern part of the İstanbul Strait, where the noise levels are about 125 dB at low and mid frequencies. This is due to heavy local shipping, turbulence and the noise from the nearby suspended bridge. Another key point is that nearby shipping noise is the main source in the low frequency band. A comparison of the noise in the İstanbul Strait with those in the ocean or deep water open seas would not be fair. The İstanbul Strait is a shallow and narrow water passage which could only be compared with similar geographical places. For example, an 18-month study at the Haro Strait between the United States and Canada provides a longer-term data at a strait where the noise levels reach to 130 dB at maximum (Veirs and Veirs 2006). The ambient noise in the Sea of Marmara is around 95 dB; much lower if compared to the İstanbul Strait. However, one should never forget that these levels are only supported with very short period of measurements, and open to variations due to many factors explained in this chapter.

A recent study using real time shipping data (AIS data), sound propagation model, environmental data and numerical methods also gives similar results to the actual measurements close to 100 dB noise in the Sea of Marmara at 40 m depth. This level increases to 120 dB at the main shipping routes (Skarsoulis *et al.* 2016). Their prediction model is also showing a decrease of noise by depth, according to the results obtained at 100 and 200 m water depths. Therefore, it is important that ambient noise levels along the İstanbul Strait should be monitored in long-term and, if higher, they should be reduced under 120 dB level. In that respect, it is important to bear in mind MSFD is an important guidance for us to start new projects to monitor our seas. Although few data available till now they are still very precious to give us an insight of the past and the trends of the noise. We should start monitoring the ambient noise of our seas as soon as possible.

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## 1. Introduction

The Sea of Marmara is a 280-km long and 80-km wide intracontinental sea on a waterway between the Mediterranean and the Black Seas (Figure 1). The surface area, water volume and the greatest depth of the sea is about 11,470 km$^2$, 3380 km$^3$ and 1370 m, respectively. It is connected to the saline Aegean Sea (S=38.5‰) via the Çanakkale Strait and to the less saline Black Sea (S=18‰) via the Istanbul Strait. The present sill depths of these straits are -65 and -35 m, respectively.

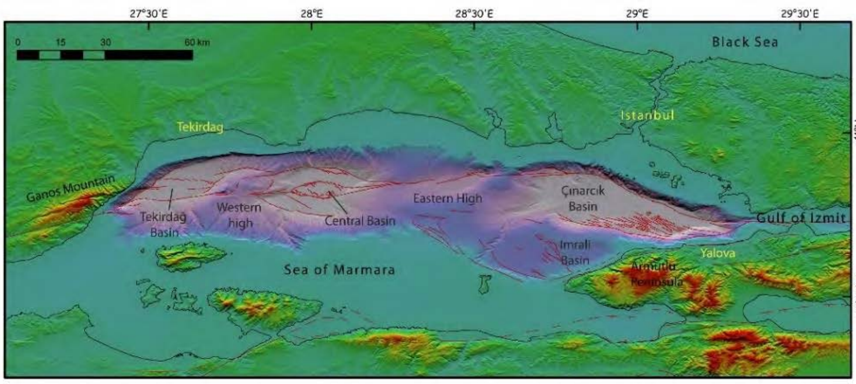


**Figure 1.** Shaded elevation topography and bathymetric map of the Sea of Marmara showing the main morphological elements (deep basins, highs, gulfs, bays, canyons) and fault system modified after Armijo *et al.* (2005). Tekirdağ Basin (-1190 m, 200 km$^2$), Central Basin (-1280 m, 330 km$^2$), Kumburgaz Basin (-850 m, 140 km$^2$), Çınarcık Basin (-1370 m, 575 km$^2$); İmralı Basin (-400 m, 590 km$^2$), Western High (-840 m, >50 km$^2$), Central High (-640 m, >145 km$^2$).

The Sea of Marmara consists of shelf areas, three deep basins (>1100 m), ~850 m-deep Kumburgaz Basin, NE-trending highs separating the deep basins, E-W oriented 100-200 m deep gulfs or bays, and the ~400 m deep İmralı Basin (Figure 1). It is located on the North Anatolian Fault (NAF), a continental transform-fault plate boundary between the Eurasian and Anatolian-Aegean plates (Figure 1). In this chapter, we first discuss the geological setting and describe the main morphologic elements and the fault geometry, and then review briefly the morphotectonic evolution of the Sea of Marmara.

## 2. Geological setting

The Sea of Marmara is situated on a very complex basement that consists of various paleotectonic units and their cover rocks and the Palaeocene-Miocene rocks of the Thrace basin (Figure 2; Görür *et al.* 1997; Şengör *et al.* 2005, 2014). The paleotectonic units are the İstanbul Zone (Palaeozoic), Sakarya Continent (Late Palaeozoic), Karakaya Complex (Triassic) and Intra-Pontide ophiolitic mélange. The Thrace basin sequence consists mainly of turbidites, deltaic sandstones and shales, and reefal carbonates. The basin evolved as a fore-arc basin on the northern margin of the Intra-Pontide Ocean during the Palaeocene-Oligocene and closed by collision of the Sakarya and Rhodope-Pontide continents during the Oligocene-Miocene (Görür and Okay 1996).

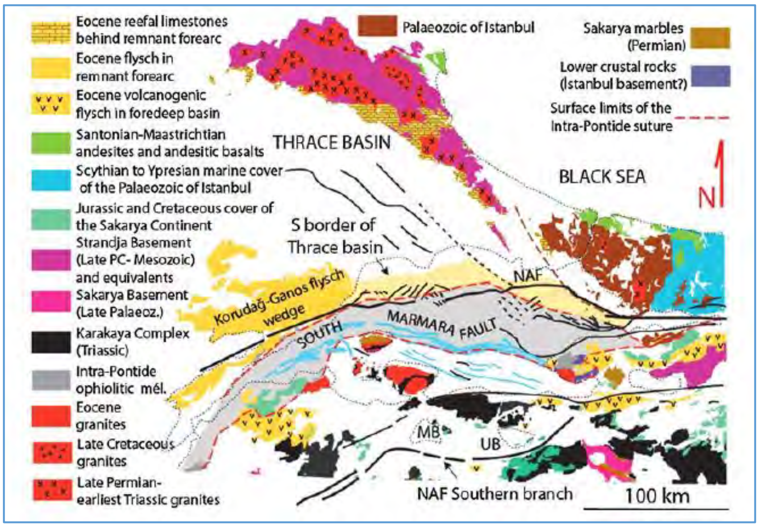


**Figure 2.** Schematic map of Le Pichon *et al.* (2014) showing the geologic setting of the Sea of Marmara and the basement rocks, older than Miocene, and the branches of the NAF. Black lines are Middle Miocene to younger right-lateral strike-slip faults belonging to the north Anatolian shear zone.

The Sea of Marmara is located on the dextral NAF zone, which a 1200 km long intracontinental plate boundary connecting East Anatolian convergent zone with the Hellenic subduction zone (Şengör *et al.* 2014; Le Pichon *et al.* 2015). The NAF splays into branches east of the Marmara region, forming a westward widening deformation zone under the influence of the N-S extensional Aegean regime (McKenzie 1972, Dewey and Şengör 1979; Taymaz *et al.* 1991; Şengör *et al.* 1985, 2005, 2014; Le Pichon *et al.*

2015). The most active northern branch of the NAF is the Main Marmara Fault (MMF) (Le Pichon *et al.* 2001), entering the sea in the Gulf of İzmit in the east and connecting with the Ganos-Saros fault in the west. According to recent GPS measurements, the branch accommodates ~75% of 25 mm/yr total dextral displacement between the Eurasian and Anatolian-Aegean plates (Flerit *et al.* 2003; Reilinger *et al.* 2006).

The Sea of Marmara is considered to have been a gateway between the Mediterranean Sea and the Black Sea (and its pre-Quaternary ancestor, Parathethys). Its geological evolution has therefore controlled the paleogeography and paleoceanography of its neighboring basins by its connection with or isolation from these basins having contrasting water chemistries (Görür *et al.* 1997; Çağatay *et al.* 2000, 2006).

## 3. Morphology of the Sea of Marmara

### 3.1. Shelf areas

The shelf areas occur above a shelf break at -90-100 m, and can be geographically divided in to the Southern and the Northern shelves. The Southern shelf is relatively broad and large (up to ~35 km wide; ~4200 km$^2$) compared to the Northern shelf (up to ~20 km wide and ~1890 km$^2$) (Figure 1; Gazioğlu *et al.* 2002). The southern shelf, 170-km long between the Şarköy and İzmit canyons, includes 110 m-deep Gulf of Gemlik and 50-60 m-deep Erdek and Bandırma bays. It receives high amount (annually 2.2x10$^6$ tons, EİE 1993) of sediment load carried by Kocaçay, Gönen and Biga rivers and trap these sediments in its half grabens. The shelf is characterized by E-W to ESE-WNW striking and N-dipping normal faults (Smith *et al.* 1995); at the northern coast of Kapıdağ Peninsula and İmralı Island, and between Bandırma and Gemlik.

The northern shelf is relatively narrow, with higher slopes (16-29°). The narrowest part of the shelf is located offshore the Ganos Mountain, while the maximum widths (~15 km) are off the two main embayments, Silivri and Tekirdağ Bays. The Prince Islands are located at the eastern part of the shelf (Figure 1). The shelf is wide at the outlet of the İstanbul Strait and around the Prince Islands (~15-20 km) and becomes narrow towards the Tuzla peninsula (~7 km). The overall shelf dips gently towards the shelf break at about -90 m (Çağatay *et al.* 2009). The shelf displays irregular bottom topography with some tectonic, constructional and erosional features, such as wave-cut notches, channels, terraces, platforms, escarpments and amphitheater-like landslide scarps forming submarine canyon heads (Eriş *et al.* 2007). Paleoshorelines were defined in the form berms, wave-cut notches and terraces at -64, -85, and -93 m below present sea level (Çağatay *et al.* 2009). The WNW–ESE trending scarps and steps at the outlet of the İstanbul Strait and around the Prince Islands shelf area are related with the strike-slip faults with dip-slip components. The largest one is 6.1 km-long and 12 m-high fault scarp south of Büyükada, representing the uplift of the Paleozoic basement (Çağatay *et al.*

2009). The shelf edge west of the İstanbul Strait is characterized by sediment wedges consisting of prograding Quaternary units.

### 3.2. Deep basins and slopes

The deep basins Tekirdağ, Central and Çınarcık have rhomboidal or wedge shapes (Figure 1). The Tekirdağ Basin (1190m deep) is a rhomb-shaped depression with an area of ~200 km$^2$. It is bounded by a 1.1km high prominent bathymetric escarpment (northern boundary fault) dipping south at 11- 23° (Okay *et al.* 1999). The southern slope of the basin is less steep (6-7°) than the northern one. In the southwest, the basin is partly covered by the Ganos landslide and marked by the Şarköy Canyon (Figure 1).

The Central Basin is a 1280-m-deep, rhomb-shaped depression with an area of about ~330 km$^2$ (Figure 1). In its central part, there is an 8 km-wide and 40-m-deep, rhomb-shaped young bassinette. Considering vertical offset of the 16 ka old mega turbidite-homogenite unit (Beck *et al.* 2007), the subsidence rate in this small basin is 6 mm/yr. It has a similar structure to that in the Tekirdağ Basin, with a transtensional segment of the MMF and the two boundary faults in the north and south.

The Çınarcık Basin is a wedge-shaped basin with a maximum depth of -1370 m and an abyssal area of about 575 km$^2$ (Figure 1). It is bounded by the WNW-trending (N120°) Prince Islands fault, that appears eroded and drained by submarine valleys, and by an oblique strike-slip fault, north of the Armutlu Peninsula. This basin is bordered by the transpressive Central High in the west and by the İzmit Canyon in the east, forming a deep furrow extending eastward into the Gulf of İzmit. At the base of slope of the northern boundary of the Çınarcık Basin there is bench between the cliff and the fault scarp (Grall *et al.* 2014). The bench is characterized by transtensional right-lateral deformation, inferred from the en-échelon N100°-N130° striking fault scarp. The southern flank of the Çınarcık Basin is marked by WNW-trending discontinuous faults.

The deep basins are filled with up to 6 km of sediments according to PSDM reflection and OBS refraction data (Laigle *et al.* 2008; Bécel *et al.* 2010). Seismic stratigraphy of the upper part of the basin fill sedimentary successions is interpreted to consist of onlapping sequences deposited with 100 ka glacial/interglacial cyclicity (Sorlien *et al.* 2012; Grall *et al.* 2012, 2013; Şengör *et al.* 2014). These sequences dip towards the active fault in each basin (i.e. northwards towards the Prince Islands fault in the Çınarcık Basin and to the south in the Tekirdağ Basin). Core studies suggest that at least the uppermost ~30 m of the basinal sedimentary sequence consists of 75% turbidite-homogenite and 25% hemipelagic sediments (Beck *et al.* 2007). The sedimentation rate in the deep basins ranges from 1 to 3.5 mm/year, with the rate during the glacial periods being 2-3 times that of the interglacials (Çağatay *et al.* 2000, 2015; Beck *et al.* 2007).

The continental slopes connecting the shelf with the deep basins have slope angles ranging between 6° and 29°, and are incised by a number of submarine canyons with different morphological and tectonic features and submarine landslides (see Altınok *et al.* this volume). Another feature of the slopes are the folds formed by downslope creep of sediments (Shillington *et al.* 2012). The major canyons include the İzmit Canyon (Gasperini *et al.* 2011), the North İmralı Canyon and several canyons located on the southern slope of Tekirdağ Basin including the Şarköy Canyon (Zitter *et al.* 2012; Çağatay *et al.* 2014). The major landslides are observed south of Tuzla and north of Yalova in the east of the Çınarcık Basin (Özeren *et al.* 2010) and the Ganos landslide complex in the southwest of the Tekirdağ Basin (Figure 1; Zitter *et al.* 2012).

The northern continental slope extends between Gaziköy and the Istanbul Strait with a characteristic multi-cuspate shape and then makes a sharp turn to the southeast (Figure 1). The northern slope ranges in width from 4 to 9 km, including many submarine canyons and landslides, with different slope angles even greater than 18°. Canyons appear to be more common on the northern slope of the Çınarcık and Central basins than those of the Tekirdağ Basin (Görür and Çağatay 2010). The length of these canyons, which branch at the shelf edge, are slightly shorter at the Western and Central highs. At slopes with high dips (20-29°), landslides are also common (see Altınok *et al.* this volume).

The southern slope is less steep with slope angles commonly varying between 6° and 16°. In particular, the southern slopes of the Tekirdağ and Central Basins with low slope angles have the longest, widest (1-3 km) and deepest (up to 400 m) submarine canyons (Zitter *et al.* 2012, Çağatay *et al.* 2014). The sinuous North İmralı Canyon, located on the southern slope of the Çınarcık Basin and Şarköy Canyon on the southwestern slope of the Tekirdağ Basin are the most important canyons on the southern slope (Çağatay *et al.* 2014 and references therein). The Şarköy Canyon is located on a fault and associated with a submarine landslide (Altınok *et al.* 2003).

### 3.3. Highs

The NE-trending Central and Western Highs separate the Çınarcık, Central and Tekirdağ Basins and rise about 600 m above their surroundings (Figure 1). They both have anticlinal structures. The Central High has a rather rugged relief and rises up to –440 m. It has transpressive structures such as folds and thrusts, and hosts the Kumburgaz Basin (Wong *et al.* 1995; Şengör *et al.* 2014). The Kumburgaz Basin is a 35 km-long, 11 km-wide and ~850 m-deep, ENE-trending depression (Figure 1). It is connected with the Büyükçekmece Canyon at its eastern tip. The basin is characterized by high sedimentation rate (2-2.5 mm/yr) for Holocene period according to core studies (Beck *et al.* 2007). The sedimentation rate in the basin might have been two to three times higher during the lacustrine stage prior to 12.6 ka BP. The sedimentation rate elsewhere on the Central High is a low (0.2-0.5 mm/yr) compared to the Kumburgaz Basin. The Kumburgaz Basin is bound to the north and south by active faults, the former being a segment of the MMF (Figure 1).

The Western High between the Central and the Tekirdağ basins is ~28 km wide and has a folded structure trending northeast (Figure 1). Its surface morphology is rather irregular with NE-trending folds, small basins and soft sediment deformation and mud diapiric structures. Its thick sediments (at least 6 km; Bayrakçı *et al.* 2013) have been cut by the MMF in the south, and boundary faults at other sides. The eastern flank has accretionary stacks of sedimentary lobes and the western flank sediment collapse structures along the west-bounding listric fault (Grall *et al.* submitted).

### 3.4. İmralı Basin

İmralı basin is a 400 deep roughly oval-shaped depression with a width of 18 km and length of 50 km (590 km$^2$), located between the Çınarcık Basin and Southern Shelf. It is a transtentional basin bounded along its northern and southern boundaries by dextral faults with a normal component. It has accumulated 2-3 km thick sediments since probably 4 Ma (Şengör *et al.* 2014). The sedimentation rate during the last 24 ka varies from 1-1.5 mm/yr in the central part of the basin to 0.15 mm/yr on the edges, based on core studies (Çağatay *et al.* 2000; McHugh *et al.* 2008; unpublished data from the Marsite cores recovered in 2014).

### 3.5. Gulfs of İzmit and Gemlik

The Gulf of İzmit is an elongated 2–10 km wide inlet located on the MMF in the east. It has three subbasins; Darıca, Karamürsel and Gölcük, from west to east (Figure 1b; Çağatay *et al.* 2012). The central one constitutes the largest (165 km$^2$) and deepest (210 m) part of the gulf. The Hersek and Gölcük openings to the Darıca and Gölcük basins have sill depths of -55 and -38 m, respectively (Çağatay *et al.* 2003; Kurt and Yücesoy 2009). The Çatalburun and Hersek are two delta fan complexes in the gulf (Figure 1).

The Gulf of Gemlik is an E-W elongated inlet located on the NAF's middle strand which extends towards Lake İznik in the east (Figure 1). The gulf is 36 km long and 11 km wide and has a maximum depth of -113 m in the central depression, Burgaz Basin. It covers an area of 350 km$^2$ and is connected to the rest of the southern shelf in the west with -50 m sill (Yaltırak and Alpar 2002; Gasperini *et al.* 2011; Vardar *et al.* 2014). The main freshwater input into the gulf is via the Gençali and Karsak creeks. The main morphological elements are a WNW-ESE trending, oval shaped depression in the central part, Gençali delta in the east, the uplift structures offshore Kapaklı in the north, Gemlik rise between Gençali and Kurşunlu in the southeast, and numerous transtentional fault scarps (Figure 3.6; Babayev 2015). On a smaller scale, there are prograding shelf-edge deltas in the north that are sourced from small creeks in the Armutlu Peninsula. The slopes connecting the deep Burgaz Basin with the northern and southern nearshore areas are steeper compared with the slope towards the sill in the west, where the change is more gradual. The steep slopes in the north and south of the gulf are characterized by 20-30 m high cliffs and 70-80 m deep N-S trending deep submarine valleys on both margins.

## 4. Faults and fault scarps

The NAF's northern branch follows the boundary between the Sakarya Continent and the Istanbul Zone in the east and the northern boundary of the Intra-Pontide suture in the west (Şengör *et al.* 2005; Le Pichon *et al.* 2014). It enters the Sea of Marmara in the Gulf of İzmit, extends westward via different segments and connects with the Ganos-Saros Fault (Le Pichon *et al.* 2001; Armijo *et al.* 2002). The fault segments include the WNW-trending Prince Islands segment, the Central High segment, and the Central Basin –Western High segment, the Central High-South Tekirdağ segment, and the transpressive Ganos segment (Figures 1 and 2).

The ENE trending Prince Island segment is ~45 km long and connects with the E-W striking Central High segment. This fault forms the steep northern escarpment of Çınarcık Basin which are marked by landslides and arcuate faults. At the base of the escarpment there are en-échelon faults offsetting a 10 m high bench (Figure 3). On the other hand, the southern slope of this basin has several short, strike-slip faults with a normal component (Armijo *et al.* 2002) and a major extensional fault system delimiting the southern boundary of the İmralı Basin (Figures 1 and 3). This boundary fault extends parallel to northern shoreline of the Armutlu Peninsula, and connects with the MMF in the Gulf of İzmit (Armijo *et al.* 2002). There are also several active normal faults within the İmralı Basin (Şengör *et al.* 2014).

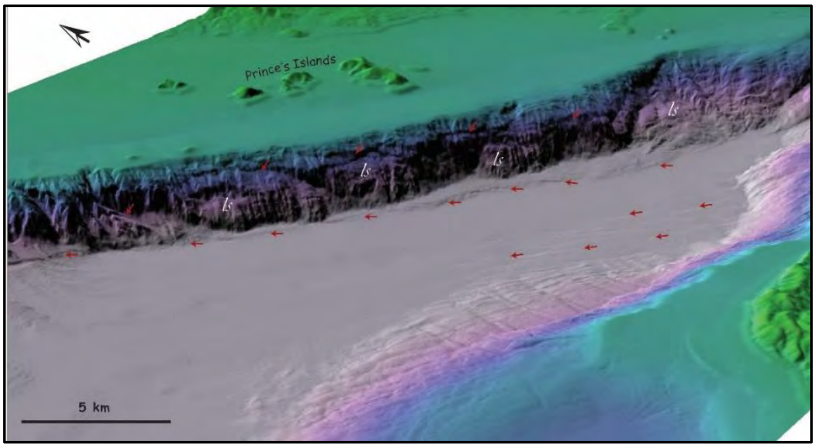


**Figure 3.** 3D NE oblique view of Çınarcık Basin showing escarpment of Prince Island fault sliced by landslides and arcuate faults, and en-échelon faults at its base (ls: landslide, red arrows indicate fault traces).

The Central High segment extends westward forming a transtentional bend in the north of the Kumburgaz Basin and a right step over in the central part (Figure 1). Micro-bathymetric mapping and seafloor dive observations indicate that the fault scarps of this segment is covered by sediments and that its seafloor expression is less pronounced than that of the other segments of the MMF, suggesting lack of recent activity (Armijo *et al.* 2005; Henry *et al.* 2008). Some morphological features offset by the Central High segment indicate its active character in the last few ka (Figure 5). This segment splits into three branches west of the Central High (Figure 1); the NW-striking northern boundary fault of the Central Basin and the two faults forming the boundary of the rhomb-shaped bassinette in the center of the Central Basin. In detail, the two faults bounding the bassinette consist of small en-échelon faults representing Riedel structures (Demirbağ *et al.* 2003). Considering vertical offset of the 16 ka old the mega turbidite-homogenite unit (Beck *et al.* 2007), the small basin is subsiding at a rate of 6 mm/yr.

NW-SE striking faults mark the outer boundary of the Central Basin at the base of a 1-km-high escarpment (Figure 1). These boundary faults embrace the flat floor of the Central Basin where sediments accumulate. They are oblique-extensional faults and present an arcuate trace in map view. Some distinguishable en-échelon fault scarps enclose a pull-apart basin in the middle of the Central Basin with a characteristic rhomb-shape. The inner pull-apart basin between eastern and western strike-slip segments is bounded by sharp normal fault scarps that offset the flat bottom of the basin (Figure 1). Between these two segments, the extensional step-over is about 4 km.

The MMF extend westwards cutting through the Western High with a deep furrow and fresh scarps (Armijo *et al.* 2005) (Figure 1). This segment on the Western High forms a right step over with the formation of a 1 km-wide and 5 km-long, E-W elongated pull-apart basin. The MMF extends westward and forms the southern boundary of the Tekirdağ Basin. It is partly covered by the Ganos landslide and connects with the N-70° striking Ganos segment which occupies a submarine valley on the western slope of the Tekirdağ Basin (Okay *et al.* 1999). It forms a 1 km-wide small pull apart basin on the upper slope, 5 km off the coast at Şarköy. On land, northeast of the Gelibolu Peninsula the 45-km-long transpressive Ganos segment has resulted in the prominent topographic high, the Ganos Mountain (924 m) (Okay *et al.* 1999) (Figure 4).

In the Tekirdağ Basin, the boundary faults are connected at depth forming a detachment plane below the sole of the Plio-Quaternary sediment infill (Okay *et al.* 1999) (Figure 4b). The transtensional, sub-vertical segment of MMF and the northern boundary fault form a negative flower structure in this basin. The Tekirdağ Basin appears as an oblique half-graben structure filled with sediments tilted southwards towards the active fault. Progressive tilting of syn-tectonic sediments implies that the MMF is the primary structure controlling the evolution of the Tekirdağ Basin. Even this basin is highly asymmetric, its remarkably consistent sedimentary sequence suggests a uniform pattern of growth (Seeber *et al.* 2004). Seismic reflection profile MTA 05 (Parke *et al.* 2003) indicates clearly a steep dip in the upper reach of the fault (Figure 4b). Antithetic normal faults cross the basin floor in the northern side. These faults are 1-3 km long and extend in a left stepping en-échelon arrangement with their south side down. They create relatively minor vertical offsets in the syn-kinematic sedimentary deposits.

The southern shelf is characterized by N-dipping normal faults and associated half grabens (Smith *et al.* 1995). The most important normal faults extend E-W along the northern coast of the Kapıdağ Peninsula, north of the İmralı Island and onshore area (Akbaş *et al.* 2002). Recently, Le Pichon *et al.* (2014) defined a 10 km-wide, curvilinear, south concave deformation zone on the southern shelf that extended from the Gulf of Gemlik to north of the Marmara Island and the Çanakkale Strait, and called it the South Marmara Fault (SMF) (Figure 2). This zone was active during the Lower Pliocene from 4 Ma to 3.5 Ma and was associated with an anticline. Only its eastern branch from the Gulf of Gemlik to the İmralı Island is still active today. The SMF zone appears to follow the boundary between the Sakarya Continent and the Intra-Pontide suture (Figure 2). According to the geodetic measurements, the faults in the NAF's southern branch accommodate only 4-5 mm of the total 20-24 mm dextral motion between the European and Anatolian-Aegean plates (Meade *et al.* 2002; Le Pichon and Kreemer 2010; Reilinger *et al.* 2006).

On the northern shelf around south of the Prince Islands, some minor SE- and ESE-trending extensional faults have been mapped by Çağatay et al. (2009) and Akkargan and Alpar (2000). The ESE trend of these faults suggests that they are reactivated Hercynian structures (Özeren et al. 2010).

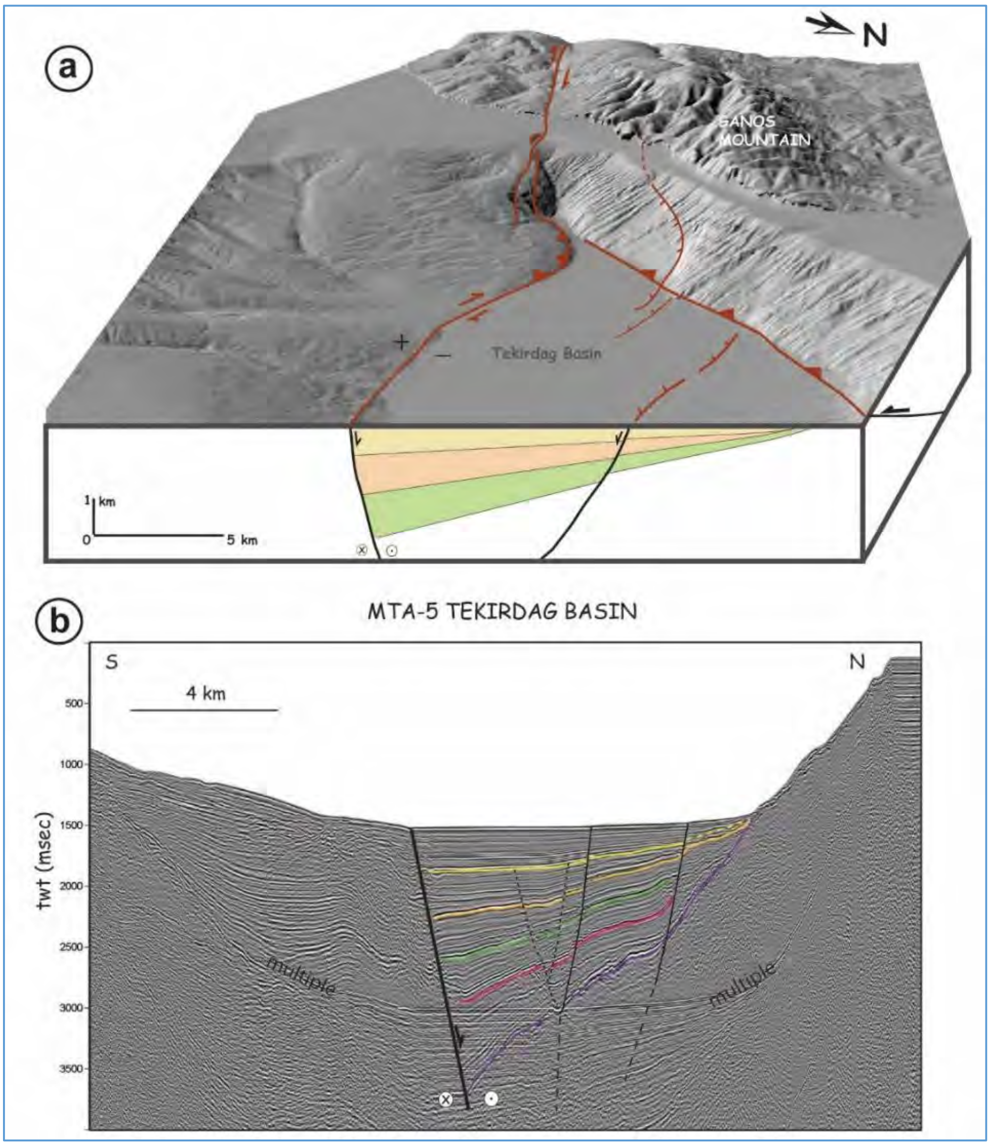


**Figure 4.** (a) Perspective view looking southwest of the western end of the Tekirdağ Basin with combined onland topography and multibeam bathymetry; (b) Seismic-reflection profile MTA 05 (Parke *et al.* 2003; Uçarkuş 2010) reflects asymmetry of the basin. The fastest subsidence is along the Main Marmara Fault forming the southern boundary of the Tekirdağ Basin (Uçarkuş 2010).

## 5. Morphotectonic evolution of the Sea of Marmara

As explained in Section 2, the Sea of Marmara evolved on a very complex basement that consists of various paleotectonic units and their cover rocks and the Paleocene to Miocene rocks of the Thrace Basin (Görür *et al.* 1997; Şengör *et al.* 2005, 2014; Le Pichon *et al.* 2015) (Figure 1).

The first phase in the opening of the Sea of Marmara was the development of a shear zone as the incipient NAF in the Sea of Marmara region during late middle Miocene (12-11 Ma ago; Şengör *et al.* 1985, 2005, and 2014). This was also the time when the Mediterranean waters briefly invaded the future Sea of Marmara along this shear zone (Görür *et al.* 1997; Çağatay *et al.* 1998; 2006). The Intra-Pontide ophiolitic mélange within the Marmara trough and Karakaya complex forming Izmir-Ankara suture zone rocks in the south appear to have been important in localization of the shear zone along which 100 km-wide NAF zone in the Marmara region subsequently developed, and hence in the evolution of the Marmara basins (Şengör *et al.* 2005, 2014). However, the intensified marine geological-geophysical surveys in the Sea of Marmara after the 1999 İzmit and Düzce earthquakes indicate that the present morphology of the Sea of Marmara with its 1250 m-deep basins is younger than the Neogene. Considering the rate of subsidence (up to 6-7 mm/yr; Beck *et al.* 2007; Grall *et al.* 2012), sedimentation rate (1-3.5 mm/yr; Çağatay *et al.* 2000; Beck *et al.* 2007; Grall *et al.* 2014) and the thickness of sediments in the deep basins (up to 6 km; Laigle *et al.* 2008; Bécel *et al.* 2010), the ages of the deep Marmara basins do not extend beyond the early Pleistocene (i.e. ~2.5 Ma BP).

The interaction of the NAF strike-slip tectonics and the N-S extensional Aegean regime prevailing in northwest Anatolia played a decisive role in the formation the three deep strike-slip basins between the splays of the NAF and the intervening bathymetric highs. Using recent GPS measurements, the total dextral displacement along the NAF zone in the Marmara region is about 25 mm/yr, with 18-20 mm of this motion being accommodated along the most active branch of the NAF (i.e., the MMF) (Straub and Kahle 1997; Flerit *et al.* 2003). However, the geological slip estimates are smaller ranging from 10 mm/yr to 20 mm/yr over the last 3 ka to 500 ka; but mostly averaging 18.5 mm/yr (Hubert-Ferrari *et al.* 2002; Polonia *et al.* 2004; Kozacı *et al.* 2009, Aksoy *et al.* 2009; Kurt *et al.* 2013; Grall *et al.* 2013). The difference between geodetic and geologic slip rates is probably due to the possibility that part of the dextral motion is accommodated by faults in the south.

Considering the overall geological setting, different mechanisms have been proposed for the basin formation in the Sea of Marmara. Some researchers propose an evolutionary model consisting of different stages ending a thorough-going fault (Şengör *et al.* 2014; Le Pichon *et al.* 2015). Others suggest pull-apart fault geometries and strain partitioning for the crustal thinning and basin subsidence (Armijo *et al.* 1999; 2002) or oblique slip on non-vertical through-going master faults for the formation of the Marmara basins (Okay *et al.* 2000; Seeber *et al.* 2004, 2006, 2010; Kurt *et al.* 2013).

According to Şengör *et al.* (2014) and Le Pichon *et al.* (2015) the following stages are involved in the evolution of the Sea of Marmara, following the development of the wide shear zone 12-11 Ma ago within the structurally complex basement: (1) initial purely extensional stage during 4.5 Ma and 3.5 Ma with the entrance of the NAF through the Gulf of Gemlik extending to the palaeo-Ganos Fault and the formation of the SMF and two left-laterally offset paleo-Central and paleo-İmralı basins in front of the westward propagating NAF, as supported by the 3D deep seismic mapping of basement and the sediment fill by Bayrakçı *et al.* (2013), and (2) formation of the through-going MMF and the Marmara deep basins 2.5 Ma ago. This evolutionary model is compatible with the geological observations based on seismic studies, geological and geodetic slip rates and subsidence rates in the Sea of Marmara, as well as heat-flow modelling (Grall *et al.* 2012), as discussed extensively by the above cited authors (in particular, see Le Pichon *et al.* 2015 for discussion).

The formation of the deep strike-slip basins along the northern Marmara trough are further elaborated by different authors (Wong *et al.* 1995; Okay *et al.* 1999, 2000; Seeber *et al.* 2004, 2006; Uçarkuş 2010; Sorlien 2012; Kurt *et al.* 2013). The formation of the Tekirdağ and Çınarcık basins are explained by a model involving extension and subsidence by oblique slip on the transform fault. Using this model, Seeber *et al.* (2004) obtained a maximum age of 1.4 Ma for the Tekirdağ Basin and later Kurt *et al.* (2013) 1.4 Ma for the Çınarcık Basin, with the age increasing from 1 Ma in the easternmost Çınarcık and 1.4 Ma in the central part. Meanwhile, Uçarkuş (2010) proposes a fault wedge model for the formation of the Çınarcık Basin.

The NE-SW orientation and anticlinal structures of the Western and Central highs suggest that they are transpressional structures formed penecontemporaneously with the MMF and the deep basins. However, Şengör *et al.* (2014) suggests that the highs might have their origins in the outer arc of the Thrace Basin, and that with the shearing they attained their present orientation, with shortening into s-structures and elongation in an ENE orientation, without almost no rotation.

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# EARTHQUAKES AND EARTHQUAKE-RELATED GEOHAZARDS AND THEIR IMPACTS IN THE SEA OF MARMARA REGION

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## 1. Introduction

Numerous damaging earthquakes, underwater mass failures and moderate tsunamis took place in the Sea of Marmara region throughout its geological history (Figure 1). The most important earthquake sources with capability to generate large magnitude earthquakes in this tectonically active region are the segments of most active northern branch of the North Anatolian transform fault (the Main Marmara Fault; Le Pichon *et al.* 2001), which has a dextral motion of 23–25 mm/year (Reilinger *et al.* 2010). The right-lateral motion along the North Anatolian Fault (NAF), together with N-S extension, resulted in the formation of the deep transtensional and subsiding Plio-Pleistocene basins at a lateral rate of 5-10 mm/year (Seeber *et al.* 2006). The recurrence period of earthquakes on the branched segments in the western part of the Sea of Marmara region (~150-420 yr) is substantially longer than those along the İzmit Bay segment (~150 yr) (Rockwell *et al.* 2009). There are other fault branches of the NAF along the southern slope at the north of İmralı Island and further south on the southern shelf, which together accommodate about 5 mm/year of dextral motion today (Figure 1). These branches are still capable of generating magnitude 7 earthquakes with approximately 500 years repeat time (Le Pichon *et al.* 2014). The earthquakes occur on the shallow normal ($h<10$ km) and strike-slip ($10<h$) faults. Therefore, $M_s>6$ earthquakes may create tsunamis in the Sea of Marmara. Another tsunami source is the sudden mass failures along the steep continental slopes, usually triggered by the earthquakes.

As it is seen above the Sea of Marmara region is characterized by moderate to high seismicity, moderate tsunamis and submarine mass failures. Therefore, the seismic design of any coastal and offshore infrastructures should aim to eliminate the probability of occurrence of potential accidents and their devastating consequences. The scope of this chapter is to review the most notable historical earthquakes and earthquake-related events, i.e. submarine mass failures and tsunamis, and to present the distribution of potential geohazard areas in the Sea of Marmara.

## 2. Important earthquakes and their impacts

The estimation of earthquake-related geohazards in the Sea of Marmara and their effects on the shores could be made more reliable with the development of the reliable historical information and determination of the potential sources in the sea. The latter requires availability of the detailed multi-beam bathymetric and seismic data. The final step in the risk assessment is the execution of comprehensive modeling.

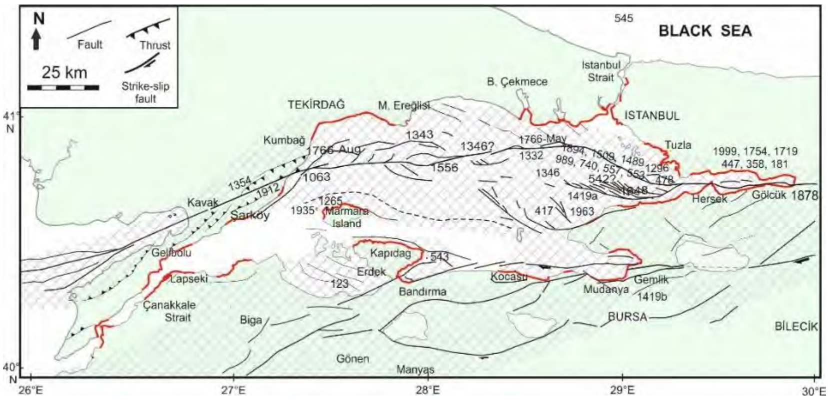


**Figure 1.** Main earthquakes and tectonic elements in the Sea of Marmara region (fault system after Armijo *et al.* 2005). Fenced areas indicate high level of earthquake hazard. The red shorelines stand for the places where tsunamis have been observed or reported in the historical documents.

About 400 known historical earthquakes have taken place in the Marmara region from 427 BCE to 1900 (Ambraseys 2009). In the period between 1900 and 1988, 10 large magnitude earthquakes (Ms>5) occurred, just two of them being disastrous (Ms>7) (Eyidoğan *et al.* 1991). In 1999, two massive earthquakes (Kocaeli Mw 7.4 and Düzce Mw 7.2) confirmed once again the migration of fault ruptures along the NAF (Şengör *et al.* 2005). Some of these historical and instrumental events are associated with tsunamis (Figure 1). The most important and well known events are given below.

**123, October 10:** The earthquake hit the Kapıdağ Peninsula, İznik (Nicaea) and İzmit and tsunami waves were observed at the Orhaneli River and İzmit (Altınok *et al.* 2011).

**181, May 3:** A relatively large earthquake occurred on May 3 and caused destruction in Izmit and Sakarya (Sangarius) (Ambraseys 2009). The year of the event is between 180 and 192, but dated to 181 according to Malalas, a sixth century writer (Papazachos and Papazachou 1997). This earthquake is not associated with a tsunami.

**358, August 24:** A series of earthquakes at the eastern part of Marmara region (the biggest Ms 7.4, Ambrasyes 2002a) affected from Macedonia to Trabzon (Downey 1955; Foss 1991). Tsunami waves were observed in İzmit with the earthquake (Ambraseys and Finkel 1991; Guidoboni *et al.* 1994).

**417, April 20:** On the basis of Ottoman Achieves, many ships sunk along the coast of İstanbul due to a co-seismic tsunami (BOA YEE 91/19).

**447, January 26:** Many towns in Bithynia, Phyrygiae and Hellespont were ruined (Ms 7.2, Ambraseys 2002a). In addition to ordinary houses many public buildings collapsed in İstanbul (Ambraseys 2009). The event was associated with high sea waves attacking the shores. The land slipped away in Bithynia, sea waves flooded throwing up fishes on land, ships grounded and some islands submerged (Bidez and Parmentier 1898; Guidoboni *et al.* 1994; Ambraseys and Finkel 1991; Ambraseys 2002b).

**478, September 24:** A destructive earthquake (Ms 7.3) at the eastern part of the Sea of Marmara devastated İzmit for the sixth time and caused damage in Istanbul for the second time (Ambraseys 2002a). Co-seismic sea waves inundated some unknown shorelines, destroying several houses (Guidoboni *et al.* 1994; Ambraseys 2009).

**542, August 16:** A severe earthquake, with questionable tsunami, caused loss of lives in İstanbul, with considerable damage and a number of free-standing monuments overturned (Ambraseys and Finkel 1991).

**543, September 06:** The earthquake caused serious damage in Erdek (Artaki) and seismic waves were observed (Dindorf 1831; Soysal *et al.* 1981; Demirkent 2001; Guidoboni *et al.* 1994).

**545 August:** This earthquake occurred in the Black Sea region. The tsunami waves swept the lowlands of Varna and Balchik, entering almost 6 km inland, and drowning many people in Odesa and Balchik (Dindorf 1831; Teophanes 1883). The tsunami entered into the İstanbul Strait too and many people died from drowning (BOA YEE 91/19).

**549 January:** Huge waves hit the shores of İstanbul during this strong earthquake. The fish hunters found a big dead fish, 20 m long, on the shore, believing it was a cursed one (BOA YEE 91/19).

**553/4, August 15/16:** This event was most severe in the regions of Istanbul and İzmit (Soysal *et al.* 1981). In İzmit Bay, the sea waves inundated low-lying coastal areas about 3 km, especially at the subsided parts (Soysal 1985; Ambraseys 2009).

**557, December 14:** After long lasting foreshock series a strong earthquake (Ms 6.9, Ambraseys 2002a) to the north of Sea of Marmara completely destroyed the western side of the Küçükçekmece (Rhegium) region, with damage extending to İstanbul and inland of Thrace (Ambraseys 1960; Soysal *et al.* 1981). The porphyry column, which stood in front of the Sekoundianos place in Bakırköy (Hebdomon), was lifted into the air by the shock, rotated and thrust eight feet into the ground (Ambraseys 2009; Ozansoy 1996). The sea invaded the land by around 3 miles in Thrace, (Migne 1866; Soysal 1985), possible outside the city walls of Constantinople.

**740, October 26:** The earthquake was most devastating in its scale (Ms 7.1, Ambraseys 2002a) and was destructive in the eastern part of the Sea of Marmara, ruined Kocaeli (Bithynia), Karamürsel and İznik (Mallet 1853; Downey 1955). Many churches, monasteries, public buildings and private houses in Bithynia were destroyed or ruined, with a great loss of life. Only one church was left standing in İznik (Ambraseys 2009). The sea drew back at some places changing the coastline permanently (Theophanes 1883; Heck 1947; Ambraseys and Finkel 1991; Kılıç 2001; Demirkent 2001). It is not clear whether this was the result of the uplift of the coast (Ambraseys 2009).

**989, October 26:** The earthquake (Ms 7.2) caused extensive damage in İstanbul and İzmit, destroying many churches and even the Saint Sophia (Ambraseys 2002a). Seismic sea waves flooded the coast in many parts of İstanbul, causing damage. The waves destroyed the Maiden's Tower (Eutropius) built on a small islet located at the southern entrance of the İstanbul Strait, killing a monk living there (Demirkent 2001; Ambraseys 2009).

**1063, September 23:** A rather large earthquake (Ms=7.4, Ambraseys 2002a) in the Sea of Marmara caused considerable damage in the regions of Tekirdağ, Erdek and Çanakkale (Guidoboni and Comastri 2005). The Handrian temple in Erdek (Cyzcus) collapsed. A flood of seawater was observed Hasluck (1910).

**1265, August 10–12**: A strong event (Ms 6.6 Marmara Island earthquake, Altınok and Alpar 2006; 40.7°N, 27.4°E, h=n, M (6.6), Papazachos and Papazachou 1997), occurred at midnight causing subaerial landslides near Çınarlı, NW part of the Marmara Island. This landslide created small-scale sea waves (Ambraseys 2002a).

**1296, June 1:** The earthquake occurred on Adalar fault (Guidoboni and Comastri 2005), and caused considerable damage in Istanbul (Ambraseys 2002a). This earthquake is not associated with a tsunami.

**1332, February 12/16:** This event (Ms 6.8; Papazachos and Papacahou 1997; Soloviev 2000) occurred in a stormy day. Violent thunderstorm and heavy seas caused damage to the sea walls and buildings in Istanbul (Ozansoy 2001; BOA YEE 91/19).

**1343, October 18:** The main shock ($M_S$ 7.0, Ambraseys 2002b) hit the Ganos region, Bolayır, Gelibolu and Thrace, causing extensive damage on the northern coast. Many parts of the city walls in İstanbul collapsed. The aftershock was equally damaging to Marmara Ereğlisi (Heraclea) (Ambraseys 2002a). The seawater flooded the coast, throw the harbored ships forcefully onto the land. In the Veliefendi region, Bakırköy, the sea invaded the land by 2 to 2.2 km, dragging many people, farm animals and ships (Ozansoy 2001). When the sea retreated back, the land was littered with mud and dead fishes. The sea rose against the sea walls of İstanbul and flooded up as far as the Beylerbeyi (Stauros) in the İstanbul Strait, damaging boats.

**1346, May 19:** The eastern part of Hagia Sophia church in İstanbul was collapsed and its dome suffered partial collapse, closed to pray for 11 years. The epicentral area of this earthquake, even not associated with a tsunami, may be in the central Marmara region.

**1354, March 1:** The earthquake (Ms 7.4) hit Tekirdağ (Redestos), Eceabad (Madytos), Gelibolu, Çanakkale and Thrace regions (Ambraseys 2002a). Some villages sank into the ground. The epicenter is located by the Ganos fault (Altınok and Alpar 2006).

**1419, March, 15:** A Ms 7.2 (Ambraseys 2002a) earthquake hit the southern part of the Sea of Marmara (Ambraseys 2009), with small to moderate damage in İstanbul. Some places were flooded by sea. According to Al-Maqrizi (1364-1442), two earthquakes occurred on May 25 and December 18; the first one caused tsunami, which caused casualties in the İzmit Bay (Ozansoy 2001), while the latter hit the regions of Bursa and İstanbul (Taher 1979).

**1489, January, 16:** A damaging earthquake affected İstanbul and surroundings. Many buildings and minarets were destroyed and Sultan Beyazıt abandoned the city for several days (Ürekli 1999). Note that an explosion caused by a thunderbolt on 1490, April, 23 was not associated with an earthquake (Ambraseys 2009). No tsunami occurred.

**1509, September 10:** This earthquake ($M_S$ 7.2) was one of the largest seismic events in the Sea of Marmara region during the Ottoman period, and even felt from Mt. Athos (Ambraseys 2002b). In the İzmit region, castles, quay walls and almost all mosques were demolished (Ambraseys and Finkel 1995), the waves flooded the dockyards and lower districts (Öztin and Bayülke 1991; Kuran and Yalçıner 1993). In İstanbul (estimated population and houses are 160,000 and 35,000, respectively), more than 1000 houses were ruined, 5000 people were killed and 10,000 injured. Sand liquefaction occurred particularly along the sea flooded coastal areas. The waves hit the city walls around the Golden Horn estuary. The tsunami runup height was about 6.0 m, as high as the city walls (Heck 1947; Ambraseys 1960; Soysal 1985; Papazachos *et al.* 1986). The sea invaded the dried valley of Bayrampaşa river in Aksaray and some other low lying areas (Lycosthenes 1557; Knolles 1603; Orgun 1941; Danişmend 1971). The numerically simulated run-up elevations indicated that the highest tsunami amplitudes near the shore can exceed 3 m, even reaching the 5.5 m level along the 26 km long Asian coasts of İstanbul (Yalçıner *et al.* 2002). In addition, increased sea levels due to storms or surges may cause higher tsunami run-up elevations as much as ± 1-1.5 m (Alpar *et al.* 2003).

**1556, May 10:** This earthquake occurred in the central part of the Sea of Marmara and hit its northern coasts (Ambraseys and Finkel 1995). Even it was not one of the strongest events in the region many free-standing structures and city walls in İstanbul were heavily damaged. This earthquake is not associated with a tsunami.

**1648, June 28/21:** The earthquake (M 6.4; Papazachos and Papacahou 1997) began with a terrible roar after the sunset and most of the large structures damaged in İstanbul (Heck 1947; Antonopoulos 1978; Soysal *et al.* 1981; Papadopoulos and Chalkis 1984). The waves attacking onto the land destroyed 136 ships (Cezar 1963; Soysal 1985; Altınok *et al.* 2011). No documentation exists stating that the quake was felt in other places than Istanbul (Ambraseys 2009).

**1719, May, 25:** A major earthquake (Ms 7.4, Ambraseys 2002a) hit the eastern part of the Sea of Marmara, destroyed İzmit, Karamürsel, Yalova, Sapanca and Düzce, and took about 6000 lives. City walls, towers on the seaside, 40 mosques and 27 towers have been ruined in İstanbul and partly in Thrace (Ambraseys and Finkel 1995).

**1754, September 2:** A Ms 6.8 earthquake at the eastern part of the Sea of Marmara caused great damage in İzmit, partly in Geyve, and took about 2000 lives, 60 in Istanbul (Ambraseys 2002a). The sea receded from shore, of İstanbul presumably, but not caused any damage (Ambraseys and Finkel 1995; Ambraseys 2009).

**1766, May 22:** A Ms 7.1 earthquake occurred to the east of the Sea of Marmara and was felt thoroughly in the northern Aegean region, from Selanik (Thessaloniki) to Izmir (Ambraseys 2002a). A large area from İzmit Bay to Tekirdağ was damaged, with over 4,000 deaths (Ambraseys 2002b). All types of public buildings and private houses collapsed in İstanbul, mostly at the eastern side, with at least 850 deaths and many injured. Some uninhabited islands sunk half way down into the sea (Ambraseys and Finkel 1995). To the east buildings were heavily damaged in İzmit and Karamürsel. The tsunami devastated the dockyards in the İzmit Bay (Ambraseys 1962; Öztüre 1969), observed at the Prince Islands (Hakim 1770), in the İstanbul Strait (Çeşmizade 1766–1768), at the submerged quays of Galata (Castilhon 1771) and in Mudanya (Ambraseys and Finkel 1995). The magnitude of tsunami in Istanbul was II (Antonopoulos 1980).

**1766, August 5:** Another big earthquake (Ms 7.4, Ambraseys 2002a) in 1766 occurred at the western part of the earthquake of May 22. Western parts of Tekirdağ, Ganos region and Gelibolu were affected with loss of life. Damage extended to the cities of Bursa, Istanbul, Edirne and Biga. This earthquake is more serious than the earlier shock of May 22, affecting a much larger area (Ambraseys and Finkel 1995). No tsunamis reported.

**1878, April 19:** A damaging earthquake (Ms 5.9, Ambraseys 2002b) hit west side of Sapanca Lake, İzmit, Istanbul and Bursa (Altınok *et al.* 2011). In İzmit, stone-masonry houses were damaged and some collapsed, together with four mosques. The fleet of British Royal Navy at anchor in the İzmit Bay experienced a series of powerful shocks, then the sea became agitated. The shock set up a sea wave at the western side of the İzmit Bay, propagated into the Sea of Marmara (Ambraseys 2009).

**1894, July 10:** The epicenter of the earthquake (≤7.0, Öztin and Bayülke 1991; $M_S$ 7.3 Ambraseys 2000; 2002b) was 8 km far from Yeşilköy (Sezer 1997). It was felt from Bucharest, Greece, Crete and Konya (Öztin 1994), with 474 deaths, 482 injured and 1773 homeless only in Istanbul (Ürekli 1999). The sea water was like boiling in many places (Eginitis 1894). The sea retracted outward by about 50 m from the shore, flowed back gradually, moved onto the shore by 200 m and returned back to the normal (Mihailovic 1927). The transportation ship *Eser-i Cedid* owned by the boat company İdare-i Mahsusa grounded in the coastal sands near Büyükada Island (Öztin and Bayülke 1991; Çalık 2004), possibly due to the withdrawal of the sea. Two small uninhabited islands close to the Kınalıada (Pronti) Island submerged (Dzağig 14 July 1894). The sea retracted completely and came back rapidly sinking most of the boats in the Çam inlet of Heybeliada Island (Rendelmann, 1895). Tsunami was effective between Büyükçekmece and Kartal (Öztin and Bayülke 1991). The rushing waves threaten people passing through the Galata Bridge on the Golden Horn estuary (Batur 1994). This old bridge was 1.60 to 2.4 m above the mean sea level depending on the distance from the coasts (Altınok *et al.* 2011). In Yeşilköy (Ayastefanos), the sea retracted 200 m outward from the shore about 10 minutes before the shock. After the shock, huge sea waves stroke the shore like a rock, passed over the piers and three apartment blocks by carrying many sea vessels and debris of the first block together (Öztin 1994; Batur 1999; Çalık 2004).

**1912, August 09:** The earthquake (Ms 7.3, Mw 7.4) ruptured the Ganos restraining bend to the west of the Sea of Marmara, affected an area of 400 km in radius with 2800 and 7000 loss of lives and injures (Altınok *et al.* 2003). The earthquake or associated underwater slumps created tsunami which affected the Çanakkale Strait, Şarköy, Mürefte, Avdim (Abdimi), Eriklice, Tekirdağ and İstanbul (Mihailovic 1927; Ambraseys and Finkel 1987; Altınok *et al.* 2003). Sea vessels and barges at the piers of Şarköy and Mürefte (Myriophyto) were destroyed. The tsunami damaged the boats in Yeşilköy (St.

Stefano), runup height of 2.7 m, and also the Mahrussa, a yacht of Hidiv Pasha anchored in the Paşabahçe Bay of the İstanbul Strait (Altınok *et al.* 2003).

**1935, January 04:** The Ms 6.4 earthquake (Ambraseys 1988) affected Istanbul, Tekirdağ, Edirne, Izmir and Bursa regions and destroyed severely the city center and villages of the Marmara and Paşalimanı Islands (Ayhan *et al.* 2000; Altınok and Alpar 2006). Water wells in the Marmara Island, Kapıdağ Peninsula, Lapseki and Çanakkale Strait dried up before and after the event (Pınar and Lahn 1952). Some local and abnormal sea waves at the Hayırsız Island were related with possible submarine failures (Altınok and Alpar 2006).

**1963, September 18:** The M 6.1 earthquake hit the Çınarcık and Yalova regions. The sea waves observed in the Bandırma Bay were 1 m in height and swept some benthic fauna on the Mudanya shores (Kuran and Yalçıner 1993; Özçiçek 1996-1997).

**1999, 17 August (Kocaeli):** The earthquake affected the Marmara region thoroughly and destroyed the Kocaeli area leaving behind many casualties (18,500 deaths, 25,000 injured and 75,000 damaged buildings). The earthquake mechanism caused a rapid withdraw of sea water about 150 meters just before the shock (Altınok *et al.* 1999). Tsunami arrived to the northern coasts in a few minutes after the shock, but to the southern coasts in a minute (Yalçıner *et al.* 2000). The average height of tsunami runup along the İzmit Bay was 2.5 meters (Altınok *et al.* 2001). The highest runup was 4.37 m in Değirmendere (Rothaus *et al.* 2004) where the ropes of the passenger ship "Atatürk" tied up to the Değirmendere pier, collapsed with earthquake, snapped. The ship was thrown 10-15 m upward and then onto the shore. A fishing boat tied into the pier was thrown against the oak trees at shore. Outside of the İzmit Bay; abnormal sea surface variations were reported at Heybeliada Island and in the İstanbul Strait (Altınok *et al.* 2003).

## 3. Submarine slides and related tsunami hazards

Beyond ground shaking, surface faulting and liquefaction, other earthquake-induced hazards in the region are landslides, subaqueous mass failures and tsunamis. Landslides, mass flows and creep are the most common mass wasting processes throughout the basin slopes of the Sea of Marmara (Zitter *et al.* 2012). The unstable slopes include the northern slopes of the Çınarcık, Central and Tekirdağ basins where the slope angles are up to 30°. In these areas, the potential submarine landslide areas include the slopes south the Prince Islands, south of Tuzla peninsula and north of Yalova at the entrance of the İzmit Gulf (Figure 2). In addition the western slope of the Tekirdağ basin forming the Ganos escarpment and the southwestern slope on the Şarköy canyon are potential sliding areas (Altınok *et al.* 2003). All these areas are mainly fault controlled and some, such as those south of Tuzla, north of Yalova and Şarköy Canyon have previously failed and/or are still active (Görür and Çağatay 2010; Özeren *et al.* 2010; Zitter *et al.* 2012).

Faulting and associated canyon development along the Sea of Marmara slopes appear to have contributed to occurrence of slope instabilities, large submarine failures and debris flows. Many submarine canyons, such as İzmit and Şarköy, are developed along active faults, associated with submarine landslides and act conduits of mass-flow deposits (Çağatay *et al.* 2015). These canyons formed when the main Marmara basins were uplifted or subsided mainly during the Plio-Quaternary. In early Holocene during the rivers were carrying their load till the shelf break or mid shelf, the occurrence of submarine failures and debris flows were more frequent (Zitter *et al.* 2012).

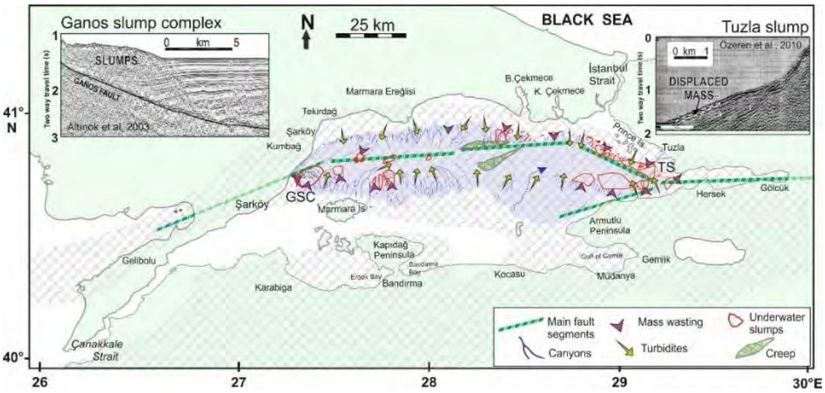

**Figure 2.** Major fault segments along the NAF zone, underwater slumps, submarine canyons, turbidites and possible creeps due to shear deformation.

The important underwater sliding structure associated with the Şarköy Canyon cover an area of 80 km$^2$ (Altınok *et al.* 2003), may have formed by successive small-scale slumps piled upon each other or a slow downslope sediment sliding. Such dip-slip motions and other mass failure activities along the main canyons, e.g. those at the extensions of the Turkish straits where large water masses pass between the seas, may trigger tsunamis as well. Gassy sediments at the base may also destabilize the slope sediments (Görür and Çağatay 2010). The historical documents and numerical modeling studies, however, show that slump originated tsunamis could only be effective along the near shore areas, especially if they are close to the coast, e.g. the northern shelf and the northern part of the Marmara Islands (Altınok and Alpar 2006). Such kind of small localized events are mostly believed to occur during the big earthquakes. Even though, major catastrophic landslides may produce local tsunamis which may be devastating in near-field, the wave amplitudes observed during such kind of local abnormal events were not extreme in the Sea of Marmara. A reasonable explanation may be the limited fault segments and the water depth which is not that great (Hébert *et al.* 2005). Research of near-field scenario tsunamis with numerical models will be beneficial.

## 4. Discussion and conclusion

Numerous cyclic sequences of large-magnitude earthquakes have taken place in the Sea of Marmara region throughout the geological history (Yaltırak 2009). The recurrence period of the earthquakes that occurred on the western margin is substantially longer than those that occurred on the eastern margin (Figure 1).

Turbidites and homogenite units, are usually the most common stratigraphic evidences of great earthquakes and tsunamis. These units are usually well preserved in the starved basins of the Sea of Marmara due to rapid subsidence and distal sedimentation, and have been differentiated on the basis of their textural, micropaleontological, geochemical and mineralogical signatures (Sarı and Çağatay 2006; McHugh *et al.* 2006, 2014; Çağatay *et al.* 2012; Beck *et al.* 2015). They usually show strong segregation and a sharp boundary between a coarse lower part and a suspended-load upper part (Beck *et al.* 2007; Çağatay *et al.* 2012). These units might have been deposited during these major earthquakes that are supposed to induce tsunamis and many types of sedimentary disturbances. The earthquake disturbances in the deep basins of the Sea of Marmara are represented by thin and laminated slightly coarser beds (Beck *et al.* 2007), with sharp basal contacts and gradational upper contacts (Sarı and Çağatay 2006) within the upper marine sequence. Some of these earthquakes are 181 (McHugh *et al.* 2006), 553, 740, 989 (instead of 986 as given by Sarı and Çağatay 2006), 1063, 1343, 1509, 1766, 1894 and 1912 (McHugh *et al.* 2006).

The latest (Ms>7) events in the Sea of Marmara region are the 1912 Ganos and 1999 Kocaeli earthquakes. The seismic gap between the seafloor rupture terminations of these events, where tectonic structure prevents rupture propagation of respective faults, will define the seismic risk remained under the Sea of Marmara. It is therefore critical to understand the historical earthquakes and tsunamis occurred in the region and to provide as much geological information as possible.

Even though tsunami events in the past are often difficult to validate, more than 30 tsunamis were documented in the Sea of Marmara between 123 and 1999 AD. Most of the tsunami hazards have been reported in the İzmit and Gemlik bays, and along the shores of Kapıdağ Peninsula, Istanbul and Gelibolu (Figure 1). In general they have been triggered by tectonic processes occurring during major earthquakes and especially along the steep western and eastern slopes which lay alongside of the fault segments as deep as 1100 m (Altınok *et al.* 2011). The earthquakes nucleated in the western Marmara region, for example, produce tsunamis occasionally, causing local and small damages along the Çanakkale, Marmara Island, Kapıdağ and Tekirdağ Bay shores (e.g. those in 543, 1063 and 1912). Tsunami waves may also be observed along the shores of the İstanbul Strait. The earthquakes in the central Marmara region may trigger moderate tsunamis in the İzmit Bay, İstanbul Strait, Gemlik Bay, Mudanya Bay and Marmara Islands (e.g. 542 and

1343). The potential of tsunami generation at the eastern Marmara region is higher, as the earthquakes triggered at this part (e.g. 478, 553, 557, 740, 989, 1332, 1509, 1648, 1766 May and 1894) have usually higher magnitudes with a triggering potential of underwater mass failures. Tsunami waves may exceed 4-5 meters at some localities along the İstanbul shores. The earthquakes occurring on the negative flower structure opening the İzmit Bay's sub-basins usually produce characteristic water movements inside this gulf only (e.g. 358, 447, 1754, 1878 and 1999). As it is seen, the regions of İzmit and Gemlik bays, shores of Kapıdağ Peninsula, Istanbul and Gelibolu are the most vulnerable coastal areas where probable tsunami waves can grow by being focused and steered by underwater topography, although the places and magnitudes of future earthquakes are debatable.

Tsunamis are destructive at shallow waters (<20 m) and low-lying coastal areas; not only from their high runup heights but also due to the generation of very strong currents. Therefore scenario tsunami modelling to understand their attributes will be beneficial. In the Sea of Marmara, a tsunami wave could reach to the nearest shores in a short time like 5 to 10 minutes (Tappin *et al.* 2002; Yalçıner *et al.* 2002). Since its effect could be seen as strong currents, a serious damage to life, property and ports may be expected if the tsunami run up height exceeds 2m, especially under the extreme wave conditions or high water due to wind set up. Therefore, the potential threats of the Sea of Marmara, which is a densely constructed inland sea and used by large level of population, tsunamis should always be considered for the proper mitigation against marine hazards, which may result from co-seismic seafloor motion, as well as occasional underwater landslides and submarine slumps.

Mitigation measures against the earthquakes and earthquake-related geohazards need to be adapted for different parts of the world, especially for coastal zones. There is a constant worldwide trend to occupy and exploit the coastal zones and their resources. Extreme hazardous events as tsunamis and coastal landslides directly affect these rich zones which are getting more and more important in the modern world from the economic and social points of view.

The most important mitigation measures in the Sea of Marmara region are good construction management and planning of escape routes and safe places. Other protection measures can broadly be classified as specific tasks for efficient early warning systems, land use planning for undeveloped regions, community master plans for preparedness and awareness.

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# GRAVITY AND MAGNETIC STUDIES OF THE SEA OF MARMARA


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## 1. Introduction

The Sea of Marmara is an inland sea of Turkey as well as being intercontinental sea between Eurasia and Anatolia. It connects the Black Sea and Mediterranean Sea through the İstanbul (Bosphorus) and Çanakkale (Dardanelles) straits.

Insufficient gravity and magnetic studies have been carried out in the Sea of Marmara and immediate surroundings. The reason for this is the high costs of marine studies and lack of geophysical survey equipment. Another reason for the lack of studies are that both gravity and magnetic maps are considered as "confidential information". Most of the studies were intended to reveal the tectonic structure of the region, and in particular to determine the nature of the North Anatolian Fault Zone (NAFZ) in the Sea of Marmara and to reveal its relationship with existing faults in the region. In this paper we summarize the results of previous gravity and magnetic studies, with a view to promote future studies in the Sea of Marmara and its surroundings.

## 2. Previous studies

Kavlakoğlu and Özakçay (1973) identified the magneto-tectonic trends and the gravity tectonic lines in Manyas-Karacabey region from the aeromagnetic maps (Figure 1). They also evaluated the results of the 1964 Manyas-Karacabey Earthquake.

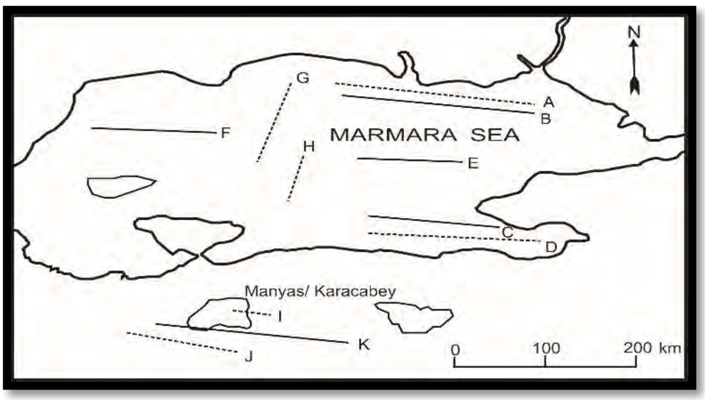


**Figure 1.** Map showing the magneto-tectonic lines in the Sea of Marmara. (G, L, H indicate tension lines; A, D, I, J indicate possible fault zones and B, C, E, F, K show structural ascending axis) (Kavlakoğlu and Özakçay 1973).

They emphasized that the similarity of magneto-tectonic lines in the Sea of Marmara and with those in the Manyas-Karacabey region. This result suggests that both regions are under the influence of the same tectonic forces. The results also reveal that the system forming the magneto-tectonic trends in the Sea of Marmara and its immediate surroundings is significantly different from North Anatolian Fault system which has a predominantly strike-slip character; and that the faults in the Manyas-Karacabey region are generally showing vertical displacement character.

Dedehayır (1976) made comments about the tectonics of the Marmara region using the magnetic vertical component map (1/100.000). As an overall evaluation, it was indicated that the southern parts of the Sea of Marmara are active concerning the distribution of magnetic parameters.

It was also emphasized that the magnetic trends for all the region were approximately east-west directional and the region has a uniform magnetic structure. Zero contour, situated at the south of Sakarya, is considered as a continuation of NAFZ in this region. The areas where magnetic intrusions penetrated under the graben structures were interpreted as extensional areas.

Hökelekli (1981) stated that magnetic anomalies of the Sea of Marmara are east-west directional at north but they are mostly situated above massifs in the south. Also, in accordance with the anomaly map, the author considered the northern boundary of the massif masses at southern area were suddenly cut off by the western extension of NAFZ.

It was indicated that among the anomalies which appear in the southern part of the Sea of Marmara, the ones situated on the İmralı Island are derived from batholiths in the area; whereas in Kapıdağ Peninsula they are derived from dykes. Hökelekli (1981) determined southward dipping slopes for the magnetic structures with mass depths of 2.5 to 2.68 km.

Kolçak (1982) determined the Moho discontinuity map for Marmara region utilizing Bouguer gravity anomaly maps. In this map it was stated that the crustal thickness decreases towards the sea and increases towards the land areas. In addition, the gravity information was compared with earthquake activity and it is stated that active areas are more coherent in regions where there is sudden change of crustal thickness than in regions where crust is considered weak (thinner).

Canıtez and Karaman (1986) observed changes on vertical gradient of gravity field in the Marmara region and came to conclusion about region's isostatic equilibrium. They mapped the differences between the calculated gravity-height relationship by least squares method and the observed values (Figure 2). The map clearly indicated the graben structure of the Sea of Marmara.

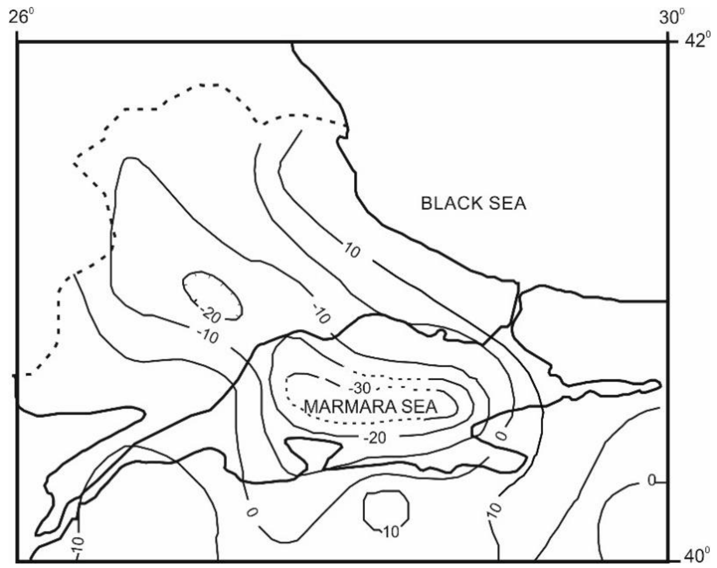


**Figure 2.** The distribution of the differences of observed average Bouguer gravity values and the expected values of gravity in the Sea of Marmara and surrounding area (Canıtez and Karaman, 1986).

Akgün and Ergün (1987) applied inversion method to Bouguer gravity anomalies and to magnetic anomalies and evaluated the obtained data. According to the results achieved from magnetic anomalies, the Sea of Marmara was seen as an extension of the Thrace Basin located at its north.

The results obtained from Bouguer anomalies show that the stripe-shaped submerged basins were formed in northern part of the Sea of Marmara are in the NAFZ's continuation towards west and that also Gulf of İzmit was considered as a tectonic basin in this zone.

Oral and Canıtez (1987) examined surface and deep structures by using Bouguer gravity data in western Anatolia. They concluded that there was a close relationship between the Bouguer gravity data and the surface geology and especially neotectonics. They explained low gravity anomalies of Western Anatolia with regional warming by evaluating in a very large area. The authors applied Hilbert Transform to characterize the effects of gravity of lateral discontinuities. Surface depth of the anomaly forming masses were tried to be estimated with spectral analysis method. Also inversion techniques were applied to examine the changes in the thickness of the crust.

Adatepe (1988, 1991) applied one and two-dimensional Fourier analysis and power spectrum to gravity and magnetic maps and then determined the average depths of the masses causing the anomaly with structure models. Also, considering the depth values acquired from gravity and magnetic data and coordinate information, three-dimensional structure models of the anomalous near surface masses were obtained.

Ergün and Özel (1995) and Ergün *et al.* (1995) interpreted the structural relationship between the Sea of Marmara and the NAFZ with the help of gravity and magnetic data. As a result of gravity data analysis, it was propounded that positive gravity anomalies correspond to uplifted blocks and negative anomalies correspond to basinal areas and crustal thinning (Figure 3).

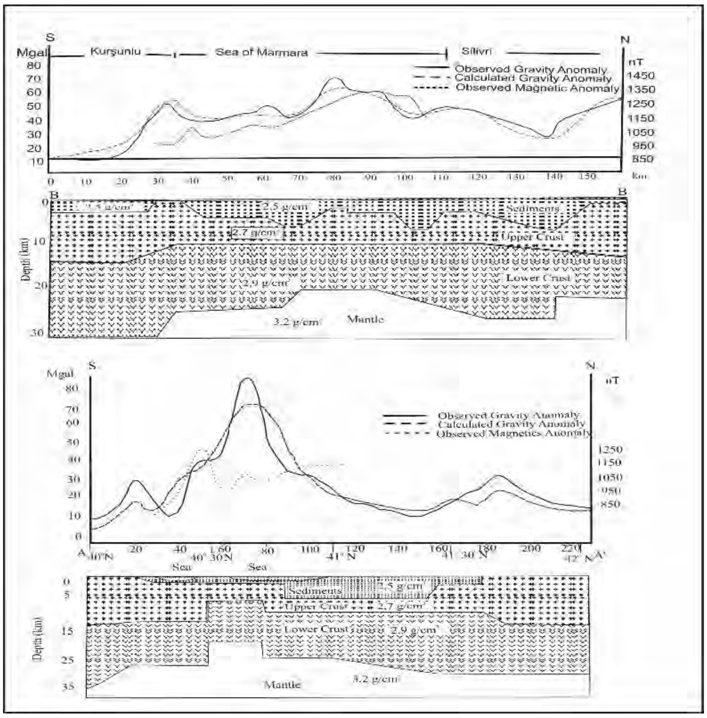


**Figure 3.** Bouguer gravity and magnetic anomaly profiles and their interpretations (Ergün *et al.* 1995).

In addition, it was indicated from magnetic data that the east-west trending anomalies were offset by segments belonging to the northern branch of NAFZ. It was asserted that; short-wavelength anomalies that were determined in the southern shelf of the Sea of Marmara could be granitic and volcanic rock originated and on these anomalies there might be an impact of the ophiolite units of Intra-Pontide suture zone.

Genç *et al.* (1996) made various analyses in the context of project "Examination of Aegean Sea and its Surrounding Using Gravity and Magnetic Methods". The results showed relatively high anomaly values in the Sea of Marmara and in the surrounding land areas (around Thrace region). The crust in this area was interpreted to be thinner or to have a higher density. The higher magnetic anomaly values on the Basins of the Sea of Marmara were explained by the presence of magma intrusions at these points. Also, the existence of these anomalies strengthened the possibility that here the strata are parallel. In addition, the researchers prepared a Moho depth map from the gravity data (Figure 4).

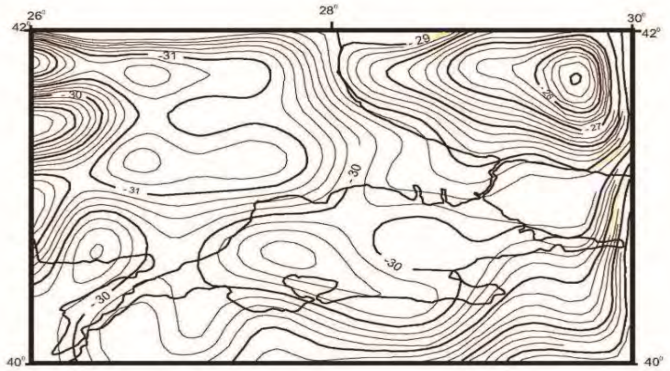


**Figure 4.** Moho depth map calculated from gravity data (contour interval: 0.25 km) (Genç *et al.* 1996)

Klingele and Medici (1997) determined the mean Moho depth of 30 km, for the Sea of Marmara and surrounding area.

Aygül and Genç (1998a, 1998b) tried to merge the gravity data that were collected in different periods at sea and on land by reducing artificial noise. In addition, they determined the depths of interfaces by analyzing gravity data and reached an average crustal thickness value of 30±3 km for the region.

Adatepe and Demirel (1999) applied one dimensional Fourier analysis and Talwani modeling along the profiles determined from the gravity map. They showed the possible fault lines of the region (Figure 5) using the results. The study therefore made an important contribution to the tectonic model of the region.

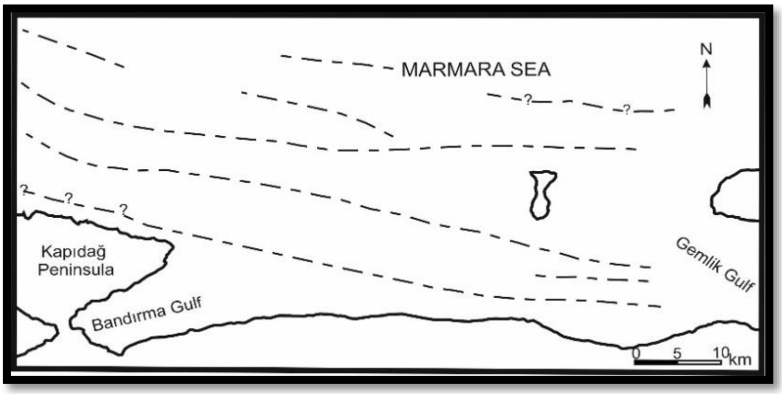


**Figure 5.** Fault map of the southern part of the Sea of Marmara proposed by Adatepe and Demirel (1999).

Hisarlı *et al.* (2000) eliminated isostatic sourced components to get a better view of the impact of anomalies. They also interpreted the model structures obtained by taking gravity and magnetic profiles from sea area and by evaluating them together. These studies determined that the Sea of Marmara was not uniform in terms of gravity and magnetic anomalies.

Adatepe *et al.* (2000) analyzed gravity and magnetic data in the Çanakkale Strait. Considering structure models obtained from drilling data and average depths obtained from all the profiles, they obtained a map showing the boundaries of magnetic structure. It was stated that these boundaries might correspond to Intra-Pontide suture zone.

Adatepe *et al.* (2002) carried out spectrum analysis and modeling studies by taking sections from Bouguer gravity map of the Sea of Marmara, and detected an average depth of 3.5 - 2.2 km from spectrum analysis for the Sea of Marmara. Using the results of the modeling studies and considering seismic data, they suggested a comprehensive tectonic model for the southern Marmara region. (Figure 6)

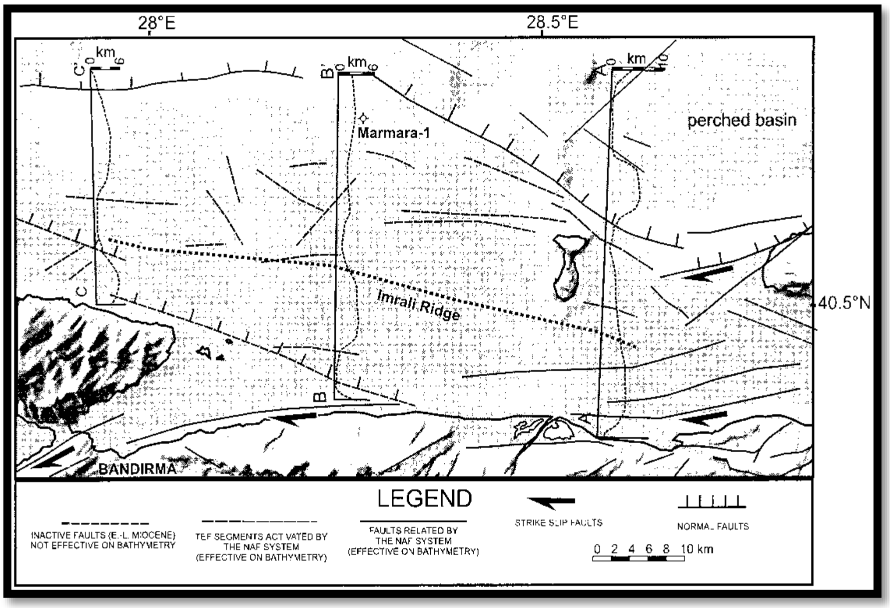


**Figure 6.** Map showing the proposed tectonic setting based on the structural gravity models given by Adatepe *et al.* (2002).

Ateş *et al.* (2003) extended North Anatolian Fault and its branches, which were well defined on land, into the Sea of Marmara using aeromagnetic anomalies, seismic and gravity profiles. Employing spectral analysis, the authors determined a Shallow Curie isotherm in the region which indicates a thinner crust in the northern Marmara trough area when compared with the land areas.

Sincer *et al.* (2005) aimed to enlighten the part of the NAFZ that extends under the Sea of Marmara by using seismic, gravity and magnetic data. Distribution of the relatively deep units were identified with tertiary base mapping. They had also designated the Curie Isotherm by the help of spectral method and determined the Curie Isotherm level to be 6-8 km shallower when compared to the land area.

It was then concluded that the crust in the northern part of the Sea of Marmara is thinner compared to the land areas. According to the power spectrum analysis, presence of magmatic rocks with depths of up to 6.5 km were identified and explained by the presence of east-west directional magnetic rocks under the Cenozoic cover units. With the common interpretation of the geophysical data collected in the Sea of Marmara, it is suggested that; there is an existence of an isostatic equilibrium formation in consequence of the subsidence in this basin. Fault distribution map obtained in the study using seismic, gravity, magnetic and observation data is given in Figure 7.

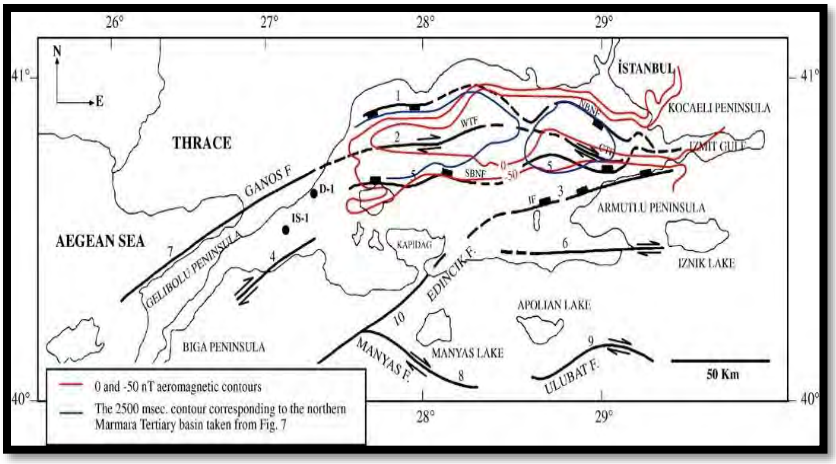


**Figure 7.** Fault distribution map obtained from seismic, gravity, magnetic and observational data (Sincer *et al.* 2005).

Ateş *et al.* (2008) constructed simple two-dimensional magnetic and gravity models. Presence of a horst in the region was determined in gravity models. Magnetic structures were suggested to be associated with the faults in the region. From the magnetic anomalies, big anticlockwise block rotations were seen in the eastern boundary of the Sea of Marmara, but on the other hand in Çınarcık and Tekirdağ basins, small anticlockwise rotations were observed.

According to the geophysical data and results of the models, it was suggested that the origin and evolution of the Sea of Marmara had started probably during the Paleozoic or even earlier with horst-like structures such as the Central High, and was followed by block rotations, magnetic material intrusion to upper crust, sedimentation and faulting.

Ateş *et al.* (2009) utilized the spatial correlation between the aeromagnetic anomalies and the faults of the Marmara region, using advanced processing methods of the reduction to the pole transformation (RTP) and second vertical derivative (SVD). In particular, SVD map shows alignments which can be correlated with the faults having high-potentials for strong earthquake generation in these areas.

Hisarlı *et al.* (2012) generated band-pass filtered anomalies using power spectra and reduced to pole (RTP) to examine the subsurface regional thermal structure of the area. Aeromagnetic data in Northwestern Turkey was analyzed with the same objective. There are few anomalies in the aeromagnetic values in the southwestern and northeastern part of the study area but apart from that, throughout the region the values are relatively uniform. According to the aeromagnetic data interpretation, it was propounded that the thickness of the magnetized crust (Curie Point Depth, CPD) lies between 9.7 and 20.3 km in the area.

Kafadar *et al.* (2013) used Gabor filter to define the discontinuity boundaries of the source bodies that cause magnetic anomalies in the Sea of Marmara. The effect of the Gabor filter on the magnetic data was tested by using theoretical total magnetic anomaly of three prism bodies with various depths and different orientations. The authors also applied Gabor filter on the reduced to pole aeromagnetic field data of the study area. Afterwards, they compared the obtained results with the fault distribution map of the region prepared in previous studies, which were found to be very conformable. These results also showed that Gabor Filter was a suitable method for mapping subsurface lineaments using magnetic data and that the technique reduces the noise in magnetic anomalies when revealing the boundaries of geological masses (Figure 8).

Albora (2014) applied Markov Random Field (MRF) approach to separate regional and residual anomalies and to determine structure boundaries. The author used gravity anomaly map of Marmara region for the field study and tried to detect the tectonic lines of the region with the obtained map by using MRF method. While forming the tectonic lines of Marmara region, a comparison was made with the previous topographic, bathymetric and seismic data.

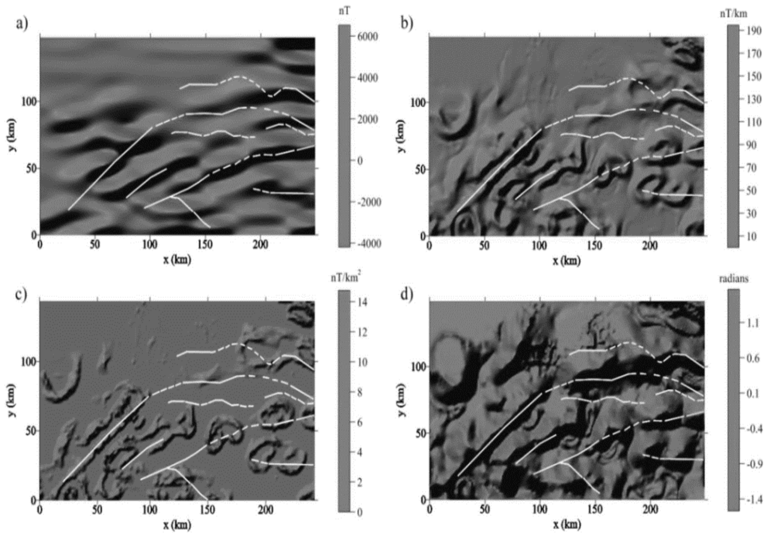


**Figure 8.** a) Response of Gabor filter for θ =0º; b) total horizontal derivative of reduced to pole (RTP) magnetic field anomaly; c) first order vertical derivative of total horizontal derivative of RTP magnetic field anomaly; d) tilt map of RTP magnetic field anomaly. White lines show the linearity in field of study while the dotted lines show the presumed faults according to aeromagnetic, seismic results and surface observations (Kafadar *et al.* 2013).

Ekinci and Yiğitbaş (2015) delineated the shallow subsurface geology and some of the structural features of Biga and Gelibolu peninsulas and surroundings by analyzing Bouguer gravity anomalies in a detailed manner. Advanced data processing methods were applied to gravity anomalies to understand the subtle details about surface geology of this tectonically important area. Residual data-set was produced by using a finite element method to reflect short-wavelength anomalies that arise from shallow geological structures.

After that, some derivative-based algorithms were performed to analyze the residual data. The acquired general anomaly patterns of the region in this study were compared with well-known surface geology map and were seen corresponding. As a result of derivative-based anomaly maps, presence of an old caldera structure in Western Biga Peninsula was detected.

As it can be seen from the studies presented above, both the quality of the maps and the analysis techniques that have been used in recent years, showed progress. This situation has allowed us to reach some important conclusions about the deep and shallow structures of the Sea of Marmara. However, it is obvious that the applications of the studies using gravity and magnetic methods should be developed further with better resolution.

## 3. Summary and conclusions

Evaluating all the studies presented above, the following conclusions can be reached (Adatepe 2000):

1. It is clearly known that the northern branch of the NAFZ continues into the Sea of Marmara through the tectonic units in the Gulf of İzmit. The most important characteristics of the magnetic maps is the east – west trending anomalies. In the analytical studies done, the inclusions of magnetic anomalies being uniform in northern part of the Sea of Marmara, indicate a high possibility of formation of a parallel layered structure. This important inclusion which continues westwards covering three deep basins in the Sea of Marmara and extending southwards to the middle of the sea. The similarities between the anomalies in the Sea of Marmara and the anomalies in Thrace Basin deserves further assessment.

   The magnetic anomalies in the southern part of the Sea of Marmara are determined to be short-wavelength and more complex. It is interpreted that the magnetic anomaly diffusion and inclusions in this region are caused by volcanic rocks. In addition, the high magnetic density seen in some parts of Marmara Island and the Çanakkale Strait is interpreted to be due to the possible presence of the Intra-Pontide suture zone.

2. Between above mentioned two zones in north and south that are having different features, there is another zone with uniform characteristics. It is possible to say

that this zone is shaped by the northern branch of the NAFZ. However, in some studies it is determined that this correlation finds different aspects and interpretations, which are mainly due to changes in the character of faults between pure the strike-slip faulting and normal faulting disrupting the uniformity magnetic anomalies. Hence, the magnetic anomalies, also show offsets along NAFZ in the Sea of Marmara, which includes various systems.

3. There are similarities among the gravity maps of the Sea of Marmara. From the relation between the Bouguer gravity values and the average heights, it is understood that the isostatic equilibrium of the region is highly achieved. Bouguer gravity values decrease when going deeper into the land from the marine environment. Those are the areas where the crust is thickened. According to results of various studies, the Moho depth calculated for the region is approximately 30±3 km. As a general feature, the area is observed to have the characteristic of a basin. Sedimentary loading resulted in subsidence and then thinning of the underlying crust in the Sea of Marmara. According to the gravity data; the existence of a ridge in the south of Istanbul can be discussed and magnetic data supports that this ridge is thinning due to intrusions of magmatic origin.
4. The results of the gravity and magnetic studies show that the Marmara basin is a deformation zone where horizontal and vertical movements merge. The results further strongly suggest that the formation, shape and size of structure lineaments are primarily controlled by faults and the region is continuing its evolution under a shearing regime.
5. The results of the various studies conducted to determine the average depths of near-surface masses causing gravity and magnetic anomalies are compatible with each other and the value is determined on average 3 – 3.5 km.
6. Gravity and magnetic studies carried out in the Sea of Marmara and its surroundings in recent years are verified with seismic data that in general contributed to a better understanding of the region’s geological characteristics (e.g., Le Pichon *et al.* 2001). On the other hand; the low data quality of the gravity and magnetic maps generated until today, restricted the possibility of local and higher resolution studies to be conducted.
7. There is a need for high-resolution gravity and magnetic maps which will be regenerated using the modern advanced technology. It is important that they are regenerated by merging the measurements made at both sea and land. This insufficiency affects the precision of the studies. Regeneration of purposive new gravity and magnetic maps and their interpretation together with the deep seismic data acquired especially done after 1999 earthquake will undoubtedly make it possible to obtain more precise results (Carton *et al.* 2007; Laigle *et al.* 2008)

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## LATE QUATERNARY PALEOCEANOGRAPHIC AND PALOCLIMATIC EVOLUTION OF THE SEA OF MARMARA

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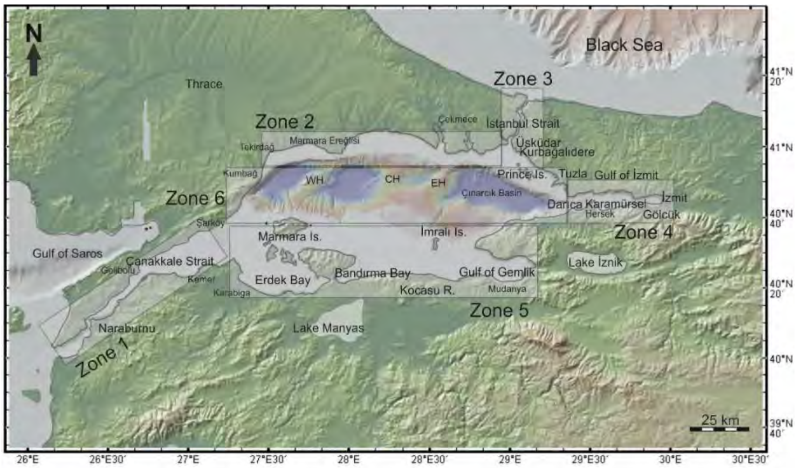
### 1. Introduction

Late Quaternary sedimentary evolution of the Sea of Marmara has been determined primarily by its geomorphology, sediment transport, global glacial-interglacial cycles and water exchange between the Black Sea and the Mediterranean Sea (e.g., Aksu *et al.* 1999). The water exchange through this inland sea was controlled by global sea-level changes and presumably changing sill depths of the connecting straits. When the Sea of Marmara was disconnected from the Mediterranean Sea it became lacustrine (e.g., Stanley and Blanpied 1980). It was a fresh to brackish water lake from early MIS-4 to early MIS-1, and experienced a serious regression during MIS 2 (Çağatay *et al.* 2009, 2015). After the marine disconnection during MIS-4, the bottom waters of the Marmara Lake became slowly brackish by fresh water input from the Black Sea via the İstanbul Strait (Çağatay *et al.* 2009; Aloisi *et al.* 2015). This lacustrine phase ended with the influx of Mediterranean Sea waters via the Çanakkale Strait sometime between 14.7 cal ka BP (Vidal *et al.* 2010) and 12.55±0.35 cal ka BP (Çağatay *et al.* 2015). Such a hydrologic modification lasted for 1000-2000 years, and represented by colonization of the shelf areas by euryhaline Mediterranean organisms which can be observed in sediment cores and high resolution reflection records (Çağatay *et al.* 2000, 2003, 2009; Aksu *et al.* 2002; McHugh *et al.* 2008; Vidal *et al.* 2010; Eriş *et al.* 2011; Vardar *et al.* 2014; Köprülü *et al.* 2016). Thereafter, the present two-layer water exchange and stratification was established during MIS-1 in the Istanbul and Çanakkale straits and the Sea of Marmara, collectively known as the Turkish Straits System. This exchange is driven by the density and sea-level differences between the Black Sea and the Mediterranean Sea.

In this chapter, a state-of-the-art review of the late Quaternary paleoceanographic and paleoclimatic evolution of the Sea of Marmara will be presented, based upon the critical analyses of the published seismic stratigraphic, sedimentological, geochemical and faunal-floral data from the late Quaternary successions of the basin.

## 2. Seismic stratigraphic characterization of the Sea of Marmara

Numerous data sets of reflection seismic profiles, from conventional to very-high resolution, were acquired from many parts of the Sea of Marmara in order to explore the sea-level history and Late Quaternary evolution of the region. The most relevant seismic stratigraphic studies from different geographic zones (Figure 1) are reviewed below.




| STAGES/ZONE 1 | | Yaltırak et al. 2000 | Gökaşan et al. 2008 | Gökaşan et al. 2010 |
|---|---|---|---|---|
| Holocene | M<br>F/L | 3 | 1/2<br>11.7 ka<br>2/3 | 1/2a<br>11.7 ka<br>2b/c/3 |
| | | 12-24 ka | 27.8 ka | 27.8 ka |
| Pleistocene | | 2b<br>130-150 ka<br>2a | 3 | 3 |

| STAGES/ZONE 4 | | Alpar and Güneysu 1999 | Alpar and Yaltırak 2002 | Kuşçu et al. 2002 | Çağatay et al. 2003 | Dolu et al. 2007 |
|---|---|---|---|---|---|---|
| Holocene | M<br>F/L | A / B | 3 | Holocene<br>12.2 ka<br>Pre-Holocene | S4 7 ka S3<br>10.3 ka<br>S2 | BU1<br>12 ka<br>BU2 |
| | | 12-24 ka | 12-24 ka | | 35.8 ka | 24.8 ka |
| Pleistocene | | C<br>30 ka<br>D/E | 2a<br>130-150 ka<br>2b | | S1 | BU3, 4, 5 |

| STAGES/ZONE 2 | | Smith et al. 1995 | Çağatay et al. 2009 | Karakılçık et al. 2015 |
|---|---|---|---|---|
| Holocene | M<br>F/L | A<br>13 Kyr<br>B | C1<br>12 Kyr<br>C2 | SU IV<br>SU III |
| | | 25 Kyr | 23 Kyr | |
| Pleistocene | | C | C3/C4/<br>C5/C6 | SU II/SU I |

| STAGES/ZONE 5 | | Aksu et al. 1999 | Yaltırak and Alpar 2002 | Hiscott and Aksu 2002 | Kuşçu et al. 2009 | Vardar et al. 2014 |
|---|---|---|---|---|---|---|
| Holocene | M<br>F/L | 1<br>2 | 3D1<br>9.7 ka<br>3D2 | SU A1<br>9.9 ka<br>SU A2 | 3<br>2 | C3<br>11.3-11 ka<br>C2 |
| | | | 29 ka | 23 ka | | 30 ka |
| Pleistocene | | 3 | 2b | B | 1 | C1 |

| STAGES/ZONE 3 | | Hiscott et al. 2002 | Koray et al. 2004 | Gökaşan et al. 2005 | Eriş et al. 2007 | Köprülü et al. 2016 |
|---|---|---|---|---|---|---|
| Holocene | M<br>F/L | 1,2,3<br>(0-9) (9-10) (10-12) ka<br>4 | 1/2<br>5.3 ka<br>2/3 | PS 1, 2, 3<br>11 ka | 1, 2, 3<br>4,5,6,<br>7 | 1a, b, c<br>7.8, (7.8-9.0), (9-12.5) ka<br>2a, b |
| | | 12-23.5 ka | 26.1 ka | | (0-3.8) (3.8-6.2)<br>(6.2-8.0) (8.0-8.8)<br>(8.8-10.5)<br>(10.5-11.5)<br>(11.5-12.2) ka | 45-35 ka |
| Pleistocene | | 5 | 3 | | | 3 |

| STAGES/ZONE 6 | | Wong et al. 1995 | Hiscott and Aksu 2002 | Eriş et al. 2012 |
|---|---|---|---|---|
| Holocene | M<br>F/L | 4 | Allounit A<br>12 ka<br>Allounit B | 1<br>12.3 ka<br>2 |
| | | | 23 ka | |
| Pleistocene | | 3a, b, c | Allounit C<br>30 ka | |

**Figure 1.** Main seismic units identified in the straits, shelves, slopes and the deep basins of the Sea of Marmara. Multibeam bathymetry data from Rangin *et al.* (2001).

### 2.1. Zone 1 (Çanakkale Strait)

The topographical restrictions along the Turkish Straits played important roles in controlling water exchange during the Late Quaternary sea level changes. The most important topographical restriction at present is the Çanakkale sill at Naraburnu with a depth of -65 m, although its location and depth was different in the past due to sediment deposition, erosion and tectonic movements (Yaltırak *et al.* 2000; Gökaşan *et al.* 2005, 2008, 2010; Çağatay *et al.* 2015). Therefore, timings, water passage modes and extents of the marine connections in the past have always been an ongoing controversy (e.g. Stanley and Blanpied, 1980; Ryan *et al.* 1997; Çağatay *et al.* 2000, 2015; Görür *et al.* 2001; Hiscott and Aksu 2002; Hiscott *et al.* 2002, 2007a,b, 2008; Kaminski *et al.* 2002; Mudie *et al.* 2004). Yaltırak *et al.* (2000) described three basic seismic units separated by unconformities above the Miocene basement with the unconformities corresponding to three major lowstands (-130/-150 m) during the last 600 ka and implying at least two disconnections between the neighbouring seas (Figure 1). Later Gökaşan *et al.* (2008) distinguished three main seismic units and several subunits (Figure 1). The channel fill deposits of their Unit 2 were eroded or non-deposited during the sea-level lowstands of 135–150 ka BP and 17–18 ka BP. Considering an erosional event associated with the latest Mediterranean intrusion, Gökaşan *et al.* (2010) revised their earlier model and suggested the development of a regionally widespread ravinement surface during MIS-2. The late-lowstand subunits 2a and 2b and highstand systems tracts (Units 2c and Unit 1) overlie the ravinement surface.

### 2.2. Zone 2 (Northern shelf)

The shelves in the Sea of Marmara extend up to -100m water depth. The northern shelf is relatively narrow, varying between 2 and 13 km in width (see also Çağatay *et al.* this volume). First characterization of the depositional environments along the shelves was initiated by Smith *et al.* (1995). The prograding clinoforms (Unit B) were defined as lowstand shelf edge deltas accumulated under lacustrine conditions during 25–13 ka BP (Figure 1). Observing 1-2 m high bioherm mounds, N-S trending ridges, and paleo-channels below the topmost marine unit, Çağatay *et al.* (2009) proposed that the Sea of Marmara evolved into a lake during the marine isotope stages MIS-2, 3, 4 and 6, whilst it was marine during MIS-1, 5 and 7, except for two brief lacustrine episodes during MIS-5. The sapropelic layers formed shortly after the Mediterranean marine transgressions. Salinification of the Sea of Marmara and blossoming of bioherms evolved rapidly after the latest connection with the Mediterranean. Karakılçık *et al.* (2014) identified that pre-Holocene deposits were observed only in deep waters (>100 m), due to sub-aerial erosional processes during the Late Glacial Maximum (LGM).

### 2.3. Zone 3 (İstanbul Strait)

The latest Quaternary succession at the southern outlet offers a complex geological setting due to rapidly changing hydrodynamic conditions, high rate of sediment input, and the depth of the sill in the İstanbul Strait (Figure 1). Hiscott *et al.* (2002) defined five seismic units above the prominent reflection Q1 truncating the underlying units (older than 160 ka, MIS 6) sharply. They depicted two lobate deltas (their Units 2 and 5) accumulated by vigorous outflow from the Black Sea; the younger one 10 and 9 ka BP. The seismic units of Kerey *et al.* (2004) correspond to the Holocene and Late Pleistocene sediments above the Palaeozoic basement rocks in the strait. In the İstanbul Strait, between Beykoz and Tarabya, the oldest radiocarbon age of marine sediments, overlying well-sorted sands with bivalve fauna (~26 ka BP), was ~6 ka BP (Çağatay *et al.* (2000); Algan *et al.* (2001). Gökaşan *et al.* (2005) claimed that the parasequence sets at the southern outlet were sourced from the Kurbağalıdere stream during the early Holocene. Hiscott *et al.* (2002, 2008) assigned this delta to a persistent Black Sea outflow during the early Holocene (~11.1–10.2 cal ka). Eriş *et al.* (2007, 2008) identified seven seismic units, overlaying Q1 lowstand erosional surface, accumulated since the latest connection with the Mediterranean (12.6 ka BP; Çağatay *et al.* 2015). They concluded that the radial delta lobe (Unit 2 of Hiscott *et al.* 2002) was of a middle-Holocene (6.65–3.75 cal ka) age, originating from the Kurbağalıdere stream. These conclusions were challenged by Hiscott *et al.* (2007), Köprülü *et al.* (2016) and Aksu *et al.* (2016).

### 2.4. Zone 4 (Gulf of İzmit)

The Gulf of İzmit is a tectonically active depositional environment. Using sparker data, Alpar and Güneysu (1999) and Alpar and Yaltırak (2002) identified shore facies of late Pleistocene deposits, middle Pleistocene marine sediments, partially eroded in the gulf during sea-level lowstand, and fluvial and alluvial fans at the bottom (Figure 1). Kuşçu *et al.* (2002) interpreted that the flat-lying upper unit over the folded and faulted chaotic reflections was deposited under low-energy conditions. Çağatay *et al.* (2003) indicated that the Gulf of İzmit was a lacustrine environment as part of the Sea of Marmara “lake” during the late glaciation and early deglaciation until it was inundated by the Mediterranean waters (12.6 ka BP; Çağatay *et al.* 2015). Therefore, the latest marine flooding of the Gulf was controlled by the bedrock sill depth of the Çanakkale Strait, which was -85 m below the present sea level. A -65 m paleoshoreline at the Darıca and Karamürsel basins was probably formed during the Younger Dryas sea-level stillstand. Due to a local shallow sill at -35 m, the eastern (Gölcük) basin was probably not invaded by marine waters until 9 ka BP. Dolu *et al.* (2007) correlated the oldest unit (SU4) with the fine grained early-middle Pleistocene sediments (Figure 1).

### 2.5. Zone 5 (Southern shelf)

Aksu *et al.* (1999) identified several stacked delta successions in the SW part of the Sea of Marmara, separated from one another by major shelf-crossing unconformities (Figure 1). These deltaic successions, from the modern delta of Kocasu River (delta 1) to the oldest (240 ka BP, delta 10), were developed due to the subsidence of the southern Marmara shelf (at a rate of 20 cm/ka) together with the Quaternary glacio-isostatic sea-level variations. Assuming a stable sedimentation rate and sediment input for each glacial cycle and the marine/lacustrine transitions being in conformity with the global sea level, Sorlien *et al.* (2012) claimed that they were lowstand deltas and their deposition were inferred to have been controlled by 100 ka glacial/interglacial cyclicity over the last 450–540 ka. Yaltırak and Alpar (2002) proposed a paleogeographic evolution model for the southern Marmara shelf and Gulf of Gemlik, using the age of deltas given by Aksu *et al.* (1999), and depth of the sill at the gulf's outlet. Hiscott and Aksu (2002) defined three basin-wide allostratigraphic units (A, B and C) within the late Quaternary successions. Allounit A extends from the seafloor downward to a 12-11 ka sequence boundary, which is a major shelf-crossing unconformity in water depths less than -100 m. On the shelf, subunit A2 (upper part of A) consists of back-stepping delta lobes and early-transgressive barrier islands and sand sheets, whilst subunit A2 (lower part of A) is a laminated sapropel in the deep basins. Allounit B accumulated along the present-day shelf edge and therefore can only be observed in the cores collected at water depths greater than 90 m. It represents basinal or prodeltaic deposits of late Pleistocene (23-12 ka) lowstand. Allounit C is a laminated sapropel in basinal cores (M2). However, the presence of such a sapropel 30-23 ka BP was strongly disputed by Çağatay *et al.* (2015). Kuşçu *et al.* (2009) investigated the prominent morphological structures in the Gulf of Gemlik, and their relations with the seismic units using the ages given by Yaltırak and Alpar (2002). Vardar *et al.* (2014) proposed that the seismic unit C2 with parallel/subparallel and occasionally sigmoid/oblique reflections was deposited under lacustrine conditions from 30 ka BP to 11–11.3 ka BP when the sea level was below the southern Marmara sill.

### 2.6. Zone 6 (Deep basins)

Using air-gun profiles Wong *et al.* (1995) defined four seismic sequences in the deep basins (Figure 1). The basement (sequence 1) is mainly observed on the shallow parts and highs between the basins. The folded and steeply dipping reflectors beyond the boundary faults (sequence 2) is the sedimentary succession deposited before the NAF became active in the Late Miocene. The sequence 3 has three different facies depending on their depositional environment, relative position to the main strike-slip faults and mass wasting activities. These Plio-Pleistocene basins subside along the steeply dipping transtensional faults at rates of 5-10 mm/year (Seeber *et al.* 2006). The sequence 4 is a thin sediment blanket throughout most of the strike-slip zone. Hiscott and Aksu (2002) claimed to have cored up to MIS-3 with a ~2.5 m long basinal core and recovered a 30-23 ka old sapropel (M2 sapropel; Allounit C) that was accumulated during a period of increased brackish-water input mainly from the Black Sea. Its upward transition to Allounit B is characterized by increment in marine microfauna and macroflora. However, it is likely that the M2 sapropel of Aksu *et al.* (2002) is the Holocene sapropel rather than belonging to an earlier period (Çağatay *et al.* 2015, see Section 3). The marine sediments in the Çınarcık Basin (younger than 12.3 cal ka BP) are represented by moderately continuous internal parallel reflectors, while underlying lacustrine sediments contain transparent lenticular homogenite layers, which are thicker and more frequent during sea-level lowstands (Eriş *et al.* 2012). In fact, the sedimentation rate in the deep basins dropped suddenly from >20 mm during the lacustrine periods to <5 mm during the marine periods (Seeber *et al.* 2006).

## 3. Chronostratigraphy and Lithostratigraphy

In recent decades, detailed sedimentological, geochemical and faunal-floral investigations were carried out in sediment cores in the Sea of Marmara. Radiometric and tephochronologic data from the Marmara cores allow us to constitute a chrono-lithostratigraphic framework for the paleoceanographic and paleoclimatic records. The records from the Sea of Marmara based on continuous stratigraphy extends dates back to about 70 ka (MIS-1 to MIS-4) (Çağatay *et al.* 2015) and discontinuous records from staggered coring on the shelf and shelf edge back to MIS-7 (Çağatay *et al.* 2009).

The Late Glacial-Holocene sediments of the Sea of Marmara were subdivided into two main units representing the marine and lacustrine conditions (Çağatay *et al.* 2000). The boundary between the units is dated at about 12 ka (uncalib.) BP. A mixed layer sediment unit containing both marine and freshwater fauna occurs between Unit 1 and Unit 2 on the outer shelf. The marine unit includes two sapropel layers deposited between 4.75 and 3.2 ka BP and 10.6-6.4 ka BP (Çağatay *et al.* 1999; 2000; Tolun *et al.* 2002). The upper mid-Holocene sapropel is found in shallow basins (e.g., Gulf of Gemlik) and shelf areas. The main Holocene sapropel (MSAP-1 of Çağatay *et al.* 2009) was studied later also by other workers (Aksu *et al.* 2002; Sperling *et al.* 2003; Kırcı-Elmas *et al.* 2008; Vidal *et al.* 2010). This sapropel is commonly recorded in the deep basin sediments of the Sea of Marmara and hence allows a correlation in basin-wide scale (Figure 2). Aksu *et al.* (2002) identified an older sapropel layer (M2: Allounit C) deposited between 29.5 and 23.5 ka BP. However, studying a 29 m long (~67 ka BP) RV Marion Dufresne core from the Central High, Çağatay *et al.* (2015) showed that the Sea of Marmara was lacustrine prior to 12.6 ka BP and that the sequence contained no other sapropel than the MSAP-1 and overlying mid-Holocene sapropel (Figure 2). The researchers stated that the M2 sapropel of Aksu *et al.* (2002) most likely represented the Holocene sapropel, and that the old radiocarbon dates from their core were likely due to partly reworked foraminifera shells picked in the sand levels.

Çağatay *et al.* (2009) reported two more sapropel units (MSAP-2 and MSAP-3) from the cores MD04-2745 and PIC-40 on the northern Marmara shelf (Figure 2). These units were deposited during the MIS-5a (81–86 ka BP) and MIS-5c (95–103 ka BP), and are so far the oldest sapropels reported from the Sea of Marmara. They were deposited shortly after every marine reconnection of the Sea of Marmara that resulted in water column stratification and increased organic productivity (Çağatay *et al.* 2009).

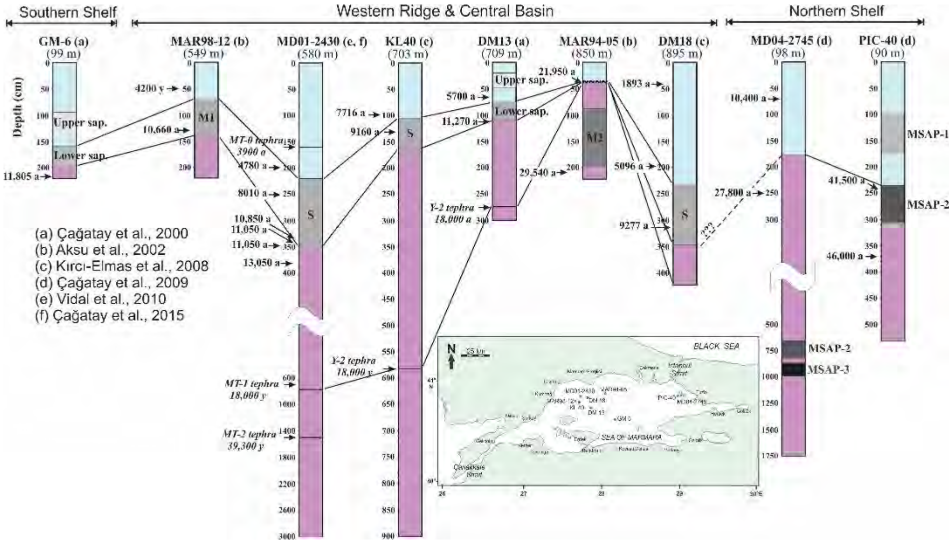


**Figure 2**. Correlation of sapropel and tephra layers in the cores from the Sea of Marmara. The radiocarbon dates are uncalibrated for comparison with previously published uncalib. ages, except for the MT-0 and MT-2 tephra, which are calibrated to calendar years.

Other important chronostratigraphic time markers in cores located in deep basins and highs are tephra layers, which include the Avellino cryptotephra from Sea of Marmarama-Vesuvius (MT-0, 3.945±0.010 ka BP, Çağatay *et al.* 2015, and references therein), Cape Riva (Y-2) tephra from Thera/Santorini (MT-1; 22±0.9 ka BP; Çağatay 2000; Wulf *et al.* 2002), and the Campanian Ignimbrite (MT-2, 39.28±0.11 ka BP) (Figure 2; Çağatay *et al.* 2015). These tephra layers are described in some detail below.

## 4. Geochemistry

### 4.1. Total organic carbon content and inorganic geochemistry

Detailed geochemical studies of cores from the Central High and Gulf of Gemlik were provided by Çağatay *et al.* (2015). The 28.88 m long core MD01-2430 from the Western High contains two units extending back to 67 ka BP. The top 3.80 m thick marine unit includes a 1.38 m thick dark olive green sapropel (MSAP-1 of Çağatay *et al.* 2009) in the lower part, which contain TOC contents of up to 2.8 wt%. The sapropel MSAP-1, together with the MIS-5a and MIS-5c sapropels (i.e., MSAP-2 and MSAP-3), occur also up to shallow depths of -70 m on the shelf. On the northern shelf and shelf edge, the MIS-5 sapropels MSAP-2 and MSAP-3 contain up to 3.3% and 5.2% organic carbon, respectively (Çağatay *et al.* 2009). The lacustrine/marine transition is marked by very high carbonate (Ca) contents of aragonitic composition, which is due to authigenic carbonate deposition (Reichel and Halbach 2007; Çağatay *et al.* 2015).

The lacustrine unit below the marine unit contains dark grey to black iron monosulphide spots and bands that are marked by high Fe and S contents. Core MD01-2430 includes three tephra layers, as already stated in the previous section (Figure 2). The topmost tephra MT-0 is a cryptotephra characterized by high contents of K, Zr, and Nb in the sediments. It belongs to the 3.9 ka BP Avellino eruption of Somma-Vesuvius. Tephra MT-1 occurs as a 7 cm thick layer, and was formed by the Cape Riva eruption of Thera Volcano in Santorini Island 22 ka BP (18 uncalib ka BP; Pichler and Friedrich, 1976; Eriksen *et al.* 1990; Druitt *et al.* 1999). The 14 cm thick oldest tephra MT-2 is equivalent of Campanian Ignimbrite eruption from the Campi Flegrei caldera west of Naples 39.3 ka BP (De Vivo *et al.* 2001).

The Ca-concentrations of core MD01-2430 display a high variability throughout the entire lacustrine unit (Çağatay *et al.* 2015). The Ca profile shows a close similarity with the $\delta^{18}O$ record of the NGRIP Greenland ice core, the Ca-record of the south-eastern Black Sea (Kwiecien *et al.* 2008; Nowaczyk *et al.* 2012), and the pollen record of Tenaghi Philippon (Greece; Müller *et al.* 2011). The positive Ca excursions in the Sea of Marmara core correlates with Greenland interstadials GI-1 to GI-18, except for GIs 3, 4 and 7 of late MIS-3 which are less distinct in the Sea of Marmara proxy records. The high Ca and organic carbon values during the GIs are accompanied by low concentrations of lithophile elements such as K, Ti, and Al. Throughout the lacustrine succession the U and Mo (redox sensitive elements) concentrations are low, being close to crustal values, but increases sharply within the sapropel and marine unit in general.

The cores from Gulf of Gemlik (MNTKS-34 and ML-01) comprise only part of the upper marine unit, which includes upper sapropel and part of MSAP-1. The TOC contents of the sapropels range from 1.5 to 2.5 wt%. The tephra MT-0 in these cores is a 6-8 mm thick cryptotephra within the upper sapropel, characterized by high μ-XRF elemental counts of K and Zr (Çağatay *et al.* 2015). The cores also include some reddish mass flow mud units, rich in Ti and Fe.

### 4.2. Stable isotope geochemistry

#### 4.2.1. Bivalves

Oxygen and carbon isotope analysis of bivalves were carried out in different units intercepted in staggered cores from the northern shelf (Çağatay *et al.* 2009). The sedimentary sequence in core C-1 from Büyükçekmece shelf represents a Holocene bioherm structure containing eurhaline bivalve fauna. In this sequence, isotope ratios were measured mostly in *Corbula gibba*. $\delta^{18}O$ values rise from the base of the core by almost 2‰ in the span of a thousand years and then more gradually to attain the modern value of 2.5‰ at the core top. In the same marine unit in Core C-17, near the Çekmece shelf edge positive values between 2.2 and 3.2‰ are observed. The $\delta^{13}C$ measurements in core C-1 show a similar initial rapid increase to positive values, but display two negative excursions at 8 and 4 ka BP.

In core Tsu02-1 from the Prince Island shelf the $\delta^{18}O$ measurements made on *C. gibba* in the uppermost marine vary from −2.2% at its base to 2.9‰ at the top unit (Çağatay *et al.* 2009). In the lacustrine unit 3 (MIS-4), the $\delta^{18}O$ values of *Dresisena rostriformis* shells show a gradual upward increase from −3.5‰ its base to −2.8‰ at its top. The strongly negative $\delta^{18}O$ values of *D. rostriformis* shells in the underlying unit L5 (MIS-6) show an upward lightening trend. In this lacustrine deposit the $\delta^{13}C$ drift to more positive values is the opposite to that of the $\delta^{18}O$ trend. The $\delta^{18}O$ values are less positive in Unit L6 (MIS-7) then those in Unit L1 (the latest marine unit) (Çağatay *et al.* 2009). Marine units (L1, L7) typically display parallel trends of $\delta^{18}O$ and $\delta^{13}C$, whereas the lacustrine units (L3, L5) species show upwards convergent and divergent trends, respectively.

#### 4.2.2. Foraminifera

The first stable isotope analysis of foraminiferal tests in the Sea of Marmara were made by Yanko *et al.* (1999) in a short core recovered from the Çınarcık Basin. This core yielded the sedimentary records of the last 3 ka. The oxygen and carbon ($\delta^{18}O$ and $\delta^{13}C$) isotopic compositions of planktic foraminifera *Globigerina quinqueloba* Natland (=*Turborotalita quinqueloba*) and benthic foraminifera *Brizalina spathulata* (Reuss) clearly indicated a strong vertical water mass stratification during the last 3 ka. The measurements in older sedimentary records were also conducted on *Turborotalita quinqueloba* (Natland), due to low planktic foraminiferal diversity and lack of sufficient quantity in available species (Aksu *et al.* 2002; Sperling *et al.* 2003; Kırcı-Elmas *et al.* 2008; Vidal *et al.* 2010). Depleted $\delta^{18}O$ of *T. quinqueloba* and Mediterranean-based planktic foraminiferal transfer function were shown to be reflecting significantly reduced sea surface temperature (SST) and salinity (SSS) during the sapropel MSAP-1 deposition (Aksu *et al.* 2002). Sperling *et al.* (2003) used the alkenone abundances (Uk'37 values) and foraminiferal oxygen isotope ratios to estimate past SST and SSS. Although the same planktic foraminiferal species used in the two studies, the latter authors found the completely opposite trend of $\delta^{18}O$ and SSS within the sapropel MSAP-1 interval. Later stable isotope measurements on planktic foraminifera *Turborotalita quinqueloba* (Hemleben *et al.* 1989) by Kırcı-Elmas *et al.* (2008) and Vidal *et al.* (2010) support the results of Sperling *et al.* (2003).

## 5. Micropaleontology

### 5.1. Foraminifera

Benthic foraminifers found in two short cores sequences from the basins represented the present two-layered oceanographic conditions (Alavi 1988). The faunal composition from several cores at the northern continental shelf areas and İstanbul Strait were used as indicators of changing environmental conditions in the coastal area (Meriç and Sakınç 1990; Meriç *et al.* 1995; Meriç and Algan 2007; Sakınç 2008). Foraminiferal fauna of the sapropelic sediments were first introduced by Çağatay *et al.* (1999, 2000), reflecting reduced oxygen conditions and high organic flux to the sea floor. Later Kaminski *et al.* (2002) denote that the bottom conditions must have been close to anoxia during the Holocene sapropel (MSAP-1) deposition, due to the paucity of benthic foraminifers. Kırcı-Elmas *et al.* (2008) suggested that the same sapropel started depositing under near anoxic bottom water conditions and continued with dysoxic-suboxic conditions. Occurrence of similar benthic foraminiferal assemblages in cores recovered from the northern and southern shelves was reported by McHugh *et al.* (2008). Only a limited number of studies were carried out on the planktic foraminifera of Late Quaternary sediments, which reported low faunal diversity (Aksu *et al.* 2002; Sperling *et al.* 2003; Kırcı-Elmas *et al.* 2008).

### 5.1.1. Benthic foraminiferal fauna

Benthic foraminifers in the Sea of Marmara display high diversity compared to planktic fauna. The cores collected from the shallow shelf area are mainly represented by genera *Ammonia*, *Elphidium*, *Aubignyna*, *Porosononion*, *Haynesina*, *Nonionella*, *Bulimina*, *Brizalina* and *Cassidulina* (Kaminski *et al.* 2002; Mc Hugh 2008). The number of species displays increasing trend towards the modern sediments (Kaminski *et al.* 2002).

The most common benthic foraminiferal species in basinal sediments are *Sigmoilinita tenuis* (Czjzek), *Brizalina alata* (Seguenza), *Brizalina dilatata* (Reuss), *Bulimina costata* d'Orbigny, *Bulimina marginata* d'Orbigny, *Hyalinea balthica* (Schröter) and *Chilostomella ovoidea* Reuss (Kırcı-Elmas *et al.* 2008). The distribution of the benthic foraminiferal assemblages shows distinct patterns within, above and below the Holocene (M1) sapropel deposited during 10.3 and 6.2 uncalib. ka BP (Figure 2) Pre-sapropel sediments deposited during ~11-10.3 uncalib. ka BP are either totally barren of benthic foraminifera ("lake stage") or include several specimens such as, *Bulimina aculeata* d'Orbigny, *Bulimina elongata* d'Orbigny, *Bulimina marginata* d'Orbigny and *Turborotalita quinqueloba* (Natland). These assemblages denote the starting of marine conditions with the saline Mediterranean Sea water inflowing through the Çanakkale Strait, just before the sapropel deposition. The lower parts of the sapropel M1 contain only few benthic species, indicating that the first stage of the sapropel deposition started under "anoxic-near anoxic" bottom water conditions. Upper parts of the sapropel are mainly dominated by infaunal life-style-taxa such as *Brizalina alata*, *Brizalina dilatata*, *Bulimina marginata*, *Bulimina costata*, *Hyalinea balthica* and *Chilostomella ovoidea*. These assemblages show that the change from "anoxic-near anoxic" bottom water conditions in the initial stage of the sapropel deposition to "dysoxic-suboxic" conditions. Near the top of the sapropel layer, the maximum abundance of suboxic *Gyroidinoides* spp. is observed. The transition from the sapropel to the post-sapropel sediments is characterized by a sharp decrease in the total benthic foraminifera (TBF). The common species found in the sapropel MSAP-1 also occur within the post-sapropel sediments. However, the post-sapropel sediments are marked by high occurrences of *Sigmoilinita tenuis* and *Bulimina costata*. The species diversity increases towards the upper parts of the post-sapropel sediments, and is represented mostly by *Sigmoilinita tenuis*, *Brizalina alata*, *Brizalina dilatata*, *Bulimina costata*, *Uvigerina mediterranea* Hofker and to a lesser extent *Bigenerina nodosaria* d'Orbigny, *Siphotextularia* sp., *Pseudoclavulina crostata* Cushman, *Spiroloculina excavata* d'Orbigny, *Quinqueloculina* spp., *Miliolinella subrotunda* (Montagu), *Sigmoilina distorta* Phleger & Parker, *Sigmoilopsis schlumbergeri* (Silvestri), *Articulina tubulosa* (Seguenza), *Lenticulina* spp., *Neolenticulina peregrina* (Schwager), *Amphicoryna scalaris* (Batsch), *Bulimina marginata*, *Hyalinea balthica*, *Melonis* spp. and *Chilostomella ovoidea*. These assemblages show the continuing suboxic conditions from the last stage of the MSAP-1 deposition to present.

Sapropel MSAP-3 has no benthic foraminifera and MSAP-2 only a sparse assemblage (Çağatay *et al.* 2009). In MSAP-2 benthic foraminifera consist predominantly of *B. spathulata*, *B. marginata* and *H. balthica* with a few brackish water species of *Ammonia infilata* and *E. crispum.*

### 5.1.2. Planktic foraminiferal fauna

Planktic foraminifers observed in the cores display low diversity in spite of high abundance, consisting of *Neogloboquadrina pachyderma* (Ehrenberg) (dextral and sinistral), *Globigerinita glutinata* (Egger), *Beella digitata* (Brady), *Beella praedigitata* (Parker), *Globigerina bulloides* d'Orbigny, *Globigerinella calida* (Parker), *Globigerinoides ruber* (d'Orbigny), *Globoturborotalita rubescens* (Hofker), *Globoturborotalita tenella* (Parker), *Turborotalita quinqueloba* (Natland) and *Orcadia riedeli* (Rögl and Bolli). The number of *Neogloboquadrina pachyderma*, *Globigerina bulloides*, *Globigerinoides ruber* and *Turborotalita quinqueloba* show significant abundances, whereas the other species are represented by sporadic occurrences throughout the cores (Aksu *et al.* 2002; Sperling *et al.* 2003; Kırcı-Elmas *et al.* 2008). Planktic foraminifers are totally absent within the pre-sapropel M1 sediments (Kırcı-Elmas *et al.* 2008). The first appearance of the planktic foraminifers begins at the base of sapropel MSAP-1, which are characterized by cold-water assemblages, including abundance of shallow dwellers *Turborotalita quinqueloba*, *Globigerina bulloides* and to a lesser extent *Neogloboquadrina pachyderma*. *Turborotalita quinqueloba* overwhelmingly dominates through the fossiliferous parts of the cores, except for levels of the MSAP-1 where *Globigerina bulloides* displays maximal abundance. The highest abundance of *Globigerina bulloides* and *Neogloboquadrina pachyderma* is observed in MSAP-1, whereas *Globigerinoides ruber* indicating warm water is restricted to the post-sapropel sediments (Sperling *et al.* 2003; Kırcı-Elmas *et al.* 2008). The distribution of *Globigerina bulloides* in the cores displays several maxima within the MSAP-1. As previously shown (Rohling *et al.* 1997; Sperling *et al.* 2003), the mere occurrence of *Globigerina bulloides* in the sapropel interval can be considered as the sign of enhanced productivity in the surface water of the Sea of Marmara during sapropel deposition. Its absence and/or presence of low specimen numbers in sediments above the sapropel section indicate that the primary production has never reached to that level after the termination of MSAP-1.

### 5.2. Palynology

The palynological records in the Sea of Marmara covers the period from MIS-2 to MIS-1. Previous palynological investigations prior to 1990s in this marine basin were locally carried out in sediments from the Golden Horn estuary (Ediger 1990; Kutluk 1994; Caner 1994) and İzmit Bay (Akgün 1995). New studies carried out after the 1999 İzmit earthquake showed slightly different pollen assemblages in the eastern and western part of the Sea of Marmara (Caner and Algan 2002; Mudie *et al.* 2002; Valsecchi *et al.* 2012). Pollen records of the last 31 ka from the Lake Iznik (Miebach *et al.* 2016) and Holocene pollen records from Lake Manyas (Leroy *et al.* 2002) are also available for paleoclimate reconstructions. Pollen records from the Çınarcık Basin include sagebrush *Artemisia* and the moisture-demanding mountain tree, *Picea*, which are absent from the western Marmara pollen records. Moreover, pollen records from the eastern Sea of Marmara have a greater diversity in typical Mediterranean temperate AP plants (e.g., *Fraxinus*, *Taxus*, *Similax*, *Juglans* and *Ostrya*) compared to those from western part.

#### 5.2.1. Late Pleniglacial– Last Glacial Maximum (LGM) interval

The end of the middle Pleniglacial and the start of the late Pleniglacial intervals from the Sea of Marmara show that the tree pollen (Arboreal Pollen) assemblage are represented by *Pinus* and deciduous *Quercus* species. Both species decline towards the Last Glacial Maximum (LGM), while *Pistacia* and evergreen *Quercus* increase. *Picea orientalis* is a drought tolerant spruce tree suggesting the start of much colder and drier conditions in the two millennia prior to the LGM from 22 to 18 ka BP (Mudie *et al.* 2007). Similar to these findings, Miebach *et al.* (2016) identified a very harsh cold and dry climate between ca. 28.4 and 18.4 ka cal BP (MIS 2) in the high resolution pollen records of Lake İznik. The late Pleniglacial interval is also marked by the arrival of *Picea* pollen, when *Artemisia* pollen influx decreases and Tubuliflorae grains dominate the herb pollen (NAP). *Abies* pollen are dominated only during the mid-Pleniglacial interval while other deciduous forest tree pollen (mostly *Ulmus, Tilia, Acer*) are present with the *Quercus* spp. *Abies* pollen is notably present throughout most of this pre-LGM-Pleniglacial section, and *Ephedra* which indicated dry step is rare or absent (Caner and Algan, 2002; Mudie *et al.* 2002). As reported by Caner and Algan (2002) and Filipova-Marinova and Angelova

(2006), Picea orientalis at the western part of the Sea of Marmara indicated cold and dry condition similar to that in the LGM that occurred around 18 ka BP.

### 5.2.2. Late Glacial–Holocene interval

Deciduous *Quercus* and *Fagus* appear in the younger parts of the Marmara cores than 13 ka BP (Mudie *et al.* 2002, 2007; Caner and Algan, 2002). Besides, *Artemisia* shows peak during the Younger Dryas (~12.7-11.5 ka BP). Evidence of cold and/or dry climatic conditions during the Younger Dry is observed also in the pollen record of Lake İznik with a setback in the spread of forests (Miebach *et al.* 2016).

### 5.2.3. Holocene interval

Presence of temperate climate forest trees such as *Tilia, Castanea* and *Ulmus* indicates warm and moist climate conditions during the Early Holocene in the peri-Marmara basin (Mudie *et al.* 2007). Similar results were reported by Valsecchi *et al.* (2012) in the high-resolution pollen record of core MD01-2430 from the Western High; these authors found an increase in moisture and temperature starting ~11 cal ka BP. During the mid-Holocene, after 7 ka BP, however, an increase in *Carpinus* and *Ostrya* indicates relatively warm and dry climate conditions (Caner and Algan 2002, Mudie *et al.* 2007). From 4 to 1.5 ka BP, anthropogenic impacts can be seen on the vegetation. According to pollen records from the lakes Manyas and İznik, vegetation changes characteristic of the Beyşehir Occupation Phase are evident during 4- 1.5 ka BP (Leroy *et al.* 2002; Miebach *et al.* 2016). This period is a cultural interval seen in palynological records of sites in southern Turkey from about 4.5 to 1.2 ka BP, and marked by rich arboriculture, including olives (*Olea*), manna ash (*Fraxinus cornus*), sweet chestnut (*Castanea*), and vines (*Vitis)* in addition to cereals (*Cerealia*) and pasture herbs, including Tubuliflorae (Leroy *et al.* 2002, Mudie *et al.* 2007).

## 6. Discussion

### 6.1. Paleoceanographic evolution

The multi-disciplinary data from core MD01-2430 from the Western High, as well as several other cores from various parts of the Sea of Marmara allow us to reconstruct the paleoceanographic evolution of the basin for the last ~150 ka BP. Moreover, a chronostratigraphic framework can be established for seismic stratigraphic units, and lake/sea level changes can be discussed based on paleoshorelines and onlap and other seismic-stratigraphic relations.

### 6.1.1 Water level changes, depositional conditions and origin of sapropels

Direct stratigraphic evidence from core MD-01-2430 indicates that the Sea of Marmara was lacustrine from beginning of MIS-4 to the early MIS-1 (Çağatay *et al.* 2015). During these periods, water level of Sea of Marmara "lake" was controlled by the Çanakkale Strait's sill depth as well as the climate oscillations. Definitive paleoshoreline features observed in the seismic lines, such as berms, wave-cut notches, wave-abraded platforms, in some cases with onlapping sediments, provide evidence of lake/sea level changes. Such features are observed at ~ -64 m, -85 m, -93 m, -105 m on the erosional unconformity delimiting the base of the marine unit reported from the northern and southern shelves as well as the Gulf of İzmit. These features were respectively attributed to the Younger Dryas, the lake level just before the latest marine transgression at 12.6 ka BP, a brief lake level stillstand during 14-12 ka BP, and the LGM, respectively (Aksu *et al.* 1999; Çağatay *et al.* 2003, 2009; Polonia *et al.* 2004; Cormier *et al.* 2006; McHugh *et al.* 2008; Eriş *et al.* 2011). In some parts of the shelf, bioherms are also observed in seismic profiles as 1-2 m high mounds and shoreward extending ridges below the Holocene marine mud drape (Aksu *et al.* 1999; Çağatay *et al.* 2003, 2009; Köprülü *et al.* 2016).

In addition to the palaeoshorelines, geometry of the seismic units on the shelf and shelf edge provides important information on the lake/sea level changes (e.g., see Aksu *et al.* 1999; Çağatay *et al.* 2009; Vardar *et al.* 2014). The seismic units on the shelf are delimited by conformable flooding surfaces at their bases and erosion surfaces at their tops. The shelf sequences therefore include unconformities and breaks in sedimentation. The lacustrine sediments are best preserved near and below the shelf break while the marine sediments are thickest on the shelf because of accommodation space created during the transgressions. The reflector below the topmost marine unit reaches to depths below −105 m (McHugh *et al.* 2008; Çağatay *et al.* 2009; Eriş *et al.* 2009). This unconformity was also in the Gulf of İzmit (Çağatay *et al.* 2003) and the southern entrance of the Istanbul Strait (Eriş *et al.* 2007), and has been attributed to the LGM lowstand.

On the northern shelf, various seismic units have been cored and analyzed. The upward-coarsening facies of Unit L2 observed near the shelf edge in Core MD04-2745 (Figure 2) corresponds to the LGM lowstand and can be interpreted as a forced-regression deposit (Çağatay *et al.* 2009). Unit L3 containing Dreissena continues to depths shallower than -70 m, and is assigned to MIS-4 indicating either the Sea of Marmara lake expanded to a mid-shelf shoreline above the -70 m. MIS-5 on the northern shelf is represented by transparent unit above flooding surface (Figure 9 of Çağatay *et al.* 2009). The upper part of this unit is intercepted in cores MD04-2745 and PIC-40 (Figure 2). This this unit is almost entirely marine except for short interval of lacustrine facies. A shelf crossing unconformity below the flooding surface truncates the units deposited during MIS-7 and earlier, and is attributed to subaerial emergence of the shelf during the MIS-6 regression.

The unit L-5 is observed in Core C-17 on the Çekmece shelf as a 4.0 m-thick dark grey lacustrine mud. It seems that during the glacial periods, the Sea of Marmara was most probably lacustrine, disconnected from the Mediterranean, and most of its shelf areas were subaerially exposed with the development lowstand shelf edge deltas (Aksu *et al.* 1999; Sorlien *et al.* 2012).

Core MD01-2430 provides continuous records of changing palaeoceanographic conditions during the past 67 ka BP (since early MIS-4) (Figure 2). These records clearly show that the Sea of Marmara was a fresh to brackish lake disconnected from the Mediterranean Sea during late MIS-4 until early MIS-1. The robust age model of core MD01-2430, based on AMS radiocarbon datings, tephrochronology and tie points determined from correlation with the NGRIP $\delta^{18}O$ data, allows for accurate dating of the sequence of paleoceanographic events. According to the chronostratigraphic of the core, the latest lacustrine / marine transition occurred at ca. 12.55 ± 0.35 cal ka BP. This age is in good agreement with a former uncalibrated $^{14}C$ age of 12.0 ka BP obtained on bulk sedimentary organic matter (Çağatay *et al.* 2000, 2003; Aksu *et al.* 2002; McHugh *et al.* 2008), but younger than the 14.7 ka BP determined by Vidal *et al.* (2010) in core MD01-2430. The considerably older age of these authors is partly due to the ~1 ka reservoir age of the Sea of Marmara “lake” and the Black Sea “lake” just before the connection (e.g., Ryan, 2007; Soulet *et al.* 2011; Çağatay *et al.* 2015).

The Holocene lower and upper sapropel units were previously radiocarbon dated at 10.6–6.4 $^{14}C$ ka BP (ca. 11.1–6.9 cal ka BP) and 4.75–3.2 $^{14}C$ ka BP (ca. 5.0–3.1 cal ka BP), respectively (Çağatay *et al.* 1999, 2000; Tolun *et al.* 2002). According to the chronostratigraphy of core MD01-2430, the sapropel MSAP-1 was deposited between ~12.3 and ~5.7 cal ka BP, and the upper Holocene sapropel between ca. 5.4 and 2.7 cal ka BP (Çağatay *et al.* 2015).

There is a very close correlation of the Ca (carbonate)-record of the lacustrine unit (dated from MIS-4 to MIS-2) in core MD01-2430 with the NGRIP oxygen isotope and the Black Sea Ca data (Nowaczyk *et al.* 2012; Çağatay *et al.* 2015). The high carbonate observed during the warm and humid Greenland Interstadials are due to authigenic carbonate deposition triggered by high organic production (Bahr *et al.* 2005; Çağatay *et al.* 2015). There is also a Ca peak observed at the lacustrine/marine transition, which represents the authigenic carbonate deposition, resulting from mixing of lacustrine Marmara and saline Mediterranean waters during the latest marine transgression (Reichel and Halbach 2007; Çağatay *et al.* 2015).

Low detrital input during the interstadial periods of early MIS-3 is indicated by the low carbonate-free concentrations of lithophile elements (e.g., K). This was most likely the result of low erosion rates, which might have been caused by increased density of vegetation and high lake levels during the GIs. The highest detrital (and illite-clay) input occurred during the LGM and late glacial (from 22 to15 ka BP), suggesting high erosion rates and low lake levels in the catchment under cold and dry conditions, a conclusion supported by as low as -105 m shoreline terraces and wave-cut erosional features discussed above.

The low concentrations of the redox-sensitive elements (e.g., U and Mo) in the lacustrine unit suggests oxic bottom water conditions in the Marmara "Lake" during MIS-4 to MIS-2 (Çağatay *et al.* 2015). Concentrations of these elements increase sharply after the marine connection, and peak during the sapropel MSAP-1 deposition, suggesting high organic carbon burial and low redox bottom-water conditions (Çağatay *et al.* 2000, 2015; Aksu *et al.* 2002; Tolun *et al.* 2002). This conclusion is corroborated by the benthic foraminifer data (Kırcı-Elmas *et al.* 2008). Palaeo-salinity reconstructions of Sperling *et al.* (2003), as well as the planktic foraminiferal $\delta^{18}O$ values within and above the sapropel MSAP-1 (Kırcı-Elmas *et al.* 2008), show that there was a relative sea surface salinity increase, rather than a fresh water input from the Black Sea during the sapropel deposition.

The deposition of the sapropel MSAP-1 as well as the sapropels MSAP-2 and MSAP-3 of MIS-5, took place soon after the periods of each marine flooding. The inflow of dense Mediterranean water resulted in water stratification and raised nutrient-rich deep lake waters to the surface, thereby triggering high organic productivity for the sapropel formation. Deposition of MSAP-1 took place under suboxic to anoxic conditions (Çağatay *et al.* 2000; Sperling *et al.* 2003; Kırcı Elmas *et al.* 2008). Sapropels MSAP-2 and MSAP-3 were deposited under suboxic to dysoxic and anoxic conditions, respectively (Çağatay *et al.* 2009). We therefore suggest a mechanism for the formation of the Marmara sapropels similar to the one leading to the formation of the younger Holocene Black Sea sapropel, whose deposition between ~7.5 and 2.7 cal ka BP was triggered by the inflow of Mediterranean waters at ~9.3 cal ka BP (Calvert 1990; Jones and Gagnon 1994; Çağatay 1999; Arthur and Dean 1999; Ryan 2007; Soulet *et al.* 2011).

The upper Holocene sapropel was deposited under suboxic bottom water conditions only in the shallow parts during ~5.4-2.7 cal ka BP (Çağatay *et al.* 2015). Its organic matter consists mainly of marine algal origin (Tolun *et al.* 2002). These data suggest that the upper sapropel is most likely the result of increased organic productivity caused by elevated, local delivery of nutrient-rich fresh water during the Holocene climatic optimum.

### 6.1.3. Mediterranean and Black Sea connections and salinity evolution

As already explained in the previous sections, the core evidence indicates that in the Sea of Marmara, the environmental conditions alternated between marine and lacustrine during the period from MIS-1 to MIS-7. The sea was marine and in connection with the Mediterranean during the early MIS-1, MIS-5 and MIS-7, and it was disconnected (i.e., lacustrine) during MIS-2, MIS-3, MIS-4 and MIS-6. The marine sediments are characterized by the occurrence of euryhaline molluscs and foraminifera as well as by positive $\delta^{18}O$ values. The brackish to freshwater lacustrine units are defined by the presence of *D. rostriformis*, absence of foraminifera and negative $\delta^{18}O$ values.

The trends of $\delta^{18}O$ in marine and lacustrine units are opposite of each other and indicate that the salinity in the basin evolved over time with connections and disconnections. The increasing trend of $\delta^{18}O$ in the marine unit (L1) in the northern shelf cores suggests a transition from earlier fresh/brackish to significantly more saline conditions within about thousand years (see Figure 8 of Çağatay *et al.* 2009). Moreover, in the marine units the trends of $\delta^{18}O$ and $\delta^{13}C$ converge with both parameters increasing upward. Within the lacustrine unit L5 (MIS-6) the upward diverging trends of $\delta^{18}O$ and $\delta^{13}C$, with $\delta^{18}O$ decreasing and $\delta^{13}C$ increasing upward. This upward decreasing $\delta^{18}O$ and the diverging trend indicate freshening of the waters with time (Çağatay *et al.* 2009). The slowly freshening trend of $\delta^{18}O$ during MIS-6 show the progressive dilution of salt waters that entered the Sea of Marmara during MIS-7. The $\delta^{18}O$ data shows that salinification during the marine connection is much faster (~1-2 ka) than freshening (some 10s of ka) after marine disconnection. In the case of salinification, denser Mediterranean water would enter the Sea of Marmara and descend into the deep basins by gravity, displacing the less dense lake waters upwards, which would then be quickly expelled to the Aegean Sea. In contrast, freshening is energetically less favourable because it requires the removal of dense salty waters in the deep basins, which involves diffusion and eddy mixing. Consequently, we observe from the stable isotope signals a rapid (ca. 1 ka) salinification in the base of the uppermost marine unit (L1) and a much more gradual freshening in lacustrine unit L5 (MIS-6).

Modelling studies by Aloisi *et al.* (2015) using pore water isotope and salinity data, confirms the conclusions of Çağatay *et al.* (2009) based on the stable isotope results. Results of Aloisi *et al.* (2015) shows that the bottom waters of the Marmara Lake were brackish (S ∼4‰) prior to the postglacial reconnection with the Mediterranean Sea and that the freshening of the Sea of Marmara by the Black Sea spill-out started at least 50 cal ka BP and continued until the latest reconnection (~12.6 ka BP; Çağatay *et al.* 2015).

Strong freshwater discharges from the Black Sea occurred during GIs of MIS-3, as indicated by very low $\delta^{18}O$ values (-9 ‰) of bulk carbonates (Çağatay, unpublished data) and the presence of bivalve fauna of Neouxine Black Sea affinity in the shelf sediments (Çağatay *et al.* 2009). The Black Sea itself received large amounts of melt waters via the eastern European rivers (i.e., Dniester and Dnepr) and from the Caspian Sea via the Manych-Kerch spillway during at least 30 ka BP and 15-14 ka BP (Chepalyga 1995, 2007; Bahr *et al.* 2007; Çağatay *et al.* 2015). Hence, high water levels up to the Çanakkale outlet might have prevailed in the Sea of Marmara “lake” during the GIs.

The fact that the Sea of Marmara was disconnected from the Mediterranean during MIS-3 constitutes a discrepancy considering the global sea level and the Çanakkale sill depth. According to newly calibrated Red Sea level record, the sea level during MIS-3 varied between ~-60 and ~-80 m (Grant *et al.* 2012). The Sea of Marmara being lacustrine during the MIS-3 lead Çağatay *et al.* (2015) to suggest a sill depth shallower than -60 m for the Çanakkale Strait during this period. The alternative hypothesis is that strong fresh water discharges from the Black Sea during especially the MIS-3 interstadials might have prevented a significant Mediterranean inflow in the Sea of Marmara via the Çanakkale Strait (Çağatay *et al.* 2009).

### 6.2. Paleoclimatic evolution

Both low and high resolution pollen data from the Sea of Marmara reveal the existence of palynological zones related to the Last Glacial/Interglacial paleoclimatic changes (Mudie *et al.* 2002, 2007; Caner and Algan 2002; Valsecchi *et al.* 2012; Miebach *et al.* 2016). These studies show that cold and dry conditions prevailed during the LGM from 22 to 18 ka BP and the late glacial, until the Bølling-Allerød interstadial (14.7 to 12.7 ka BP). The presence of deciduous *Quercus* and *Fagus* and *Artemisia* peak in the Sea of Marmara during the Younger Dryas (12.7-11.5 ka BP) suggest cold and arid/semi-arid conditions. Warm and moist climate conditions prevailed in the early and middle Holocene. Anthropogenic effects appear in the pollen records during 4 ka BP to 1.5 ka BP, which is characteristic of the Beyşehir Occupation Phase.

The multi-proxy data from core MD01-2430 also provides important paleoclimate information for northwest Anatolia and Eastern Europe during the last ~70 ka. As explained in section 4.1, the multi-proxy records including Ca (TIC), oxygen and carbon isotopes, K (and other lithophile elements) of the Marmara core show a very good correlation with the north Greenland ice core (NGRIP), Tenaghi Philippon and Black Sea records, indicating strong teleconnections with the North Atlantic. The positive Ca and negative oxygen isotope excursions of up to -2 per mil (in excess of the temperature effect; M.N. Çağatay, unpublished data) especially during GIs 5, 8, 10, 11, 12 and 15 within the period strongly suggest warm and humid conditions in the peri-Marmara regions, as well as input of melt waters from north European ice sheets via the Black Sea. During the GIs there was relatively high vegetation density in the Sea of Marmara and the Black Sea drainage basins, as suggested by low detrital input. GIs 3, 4 and 7 are less distinct in the Sea of Marmara proxy records, suggesting progressively evolving cold and dry conditions towards the LGM, probably associated with the strengthening of the Siberian high pressure system in the region.

## 7. Conclusions

The sedimentary records from staggered cores the shelf and uppermost slope of the Sea of Marmara extend back to MIS-7 (190 ka BP). The paleontological and stable isotope data show that the Sea of Marmara was marine during MIS-1, MIS-5 and MIS-7, and lacustrine during MIS-2, MIS-3, MIS-4, MIS-6, and possibly during sub-stages MIS-5b and MIS-5d. However, these records observed on the shelf are discontinuous and includes breaks in sedimentation during the lowstands of the Marmara Lake. In contrast, core MD01-2430 provides a continuous stratigraphy for the last 67 ka and show lacustrine conditions in the Sea of Marmara during 67-12.6 ka BP (early MIS-4 to late MIS-2).

Lacustrine conditions occurred with drop of the global sea level below the Çanakkale sill depth that might have varied through time because of sediment deposition, erosion and tectonic movements. The elevation of the sill is not well known prior to latest marine reconnection of the Sea of Marmara at ~12.6 ka BP. Various lines of evidence suggest that the sill depth was higher in the past to explain the lacustrine conditions during MIS-3, MIS-5b and MIS-5d.

$\delta^{18}O$ and $\delta^{13}C$ data show that the salinification process after the marine connection is rapid reaching completion within the first 1 to 2 thousand years. On the other hand, the freshening process after the disconnections from the global ocean is more gradual, and taking place over some tens of thousands of years. The freshening might have been aided by the high input of meltwaters from the Black Sea during the GIs.

Sapropels formed after every marine reconnection of the Sea of Marmara. The rich organic carbon content in the sapropel mud results from enhanced organic productivity and preservation under low bottom-water oxygen conditions. These conditions suitable for sapropel formation are established as the consequence of the inflowing dense saltwater filling the deep basins and displacing the prior lake water with its nutrients up to the surface where it is utilized in organic production before being expelled through the Çanakkale outlet. Another important feature of post-glacial marine reconnection is the development of 1-2 m high bioherm mounds and ridges on the shelf areas.

Changing sea/lake levels in the Sea of Marmara are evidenced by paleoshoreline features that are observed as berms, wave-cut notches, wave-abraded platforms at ~-64 m, −85 m, −93 m, -105 m on the shelf and shelf edge; these features correspond to Younger Dryas, the lake level just before the latest marine transgression at 12.6 ka BP, a brief lake level stillstand sometime between 14 and 12 ka BP, and the LGM, respectively.

Erosional unconformities developed across the entire shelf in connection with regressions culminating with a lacustrine lowstand during MIS-2 and MIS-6. Flooding surfaces formed after each marine invasion and during the subsequent transgressions. The transgressions were relatively fast, because they coincide with the glacial terminations. The oscillation between sea and lake, modulated by global eustatic sea level, has resulted in thick (but incomplete) deposits of the marine sediments in seaward thickening wedges on the shelf and very minor accumulations of lacustrine sediments in forced-regressive clinoforms at the shelf edge. The vast bulk of the lacustrine sediments have accumulated at and beyond the shelf edge and resided today in seaward-dipping strata on the upper continental slope.

Evidence suggests that in the period of 14 to 12 ka BP and just prior to the most recent invasion of the Mediterranean Sea, the level of the Sea of Marmara lake fell below its outlet to produce the observed shoreline terrace at−93m as first documented by Aksu *et al.* (1999). In this case, the Mediterranean connection triggered a rapid refilling back to the sill level, followed by a more gradual transgression as the newly transformed Marmara Sea rose in tandem with the external ocean. In the course of this transgression Mytilus colonies took hold on the newly drowned hard substrate and flourished as bioherms. The molluscs took advantage of the nutrients pumped back to the surface waters by the growing volume of saline deep water. As the shoreline receded landward and more substrate submerged, the colonies grew into long rows (ridges) in the shoreward direction or became left behind as discrete mounds.

Pollen records from and around the Sea of Marmara sediments suggests teleconnections with the North Atlantic. This conclusion is supported with multi-proxy geochemical and isotope records from the Sea of Marmara sediments, which show excellent correlation of with the north Greenland ice core (NGRIP) isotope. The GIs in the Sea of Marmara are well expressed by high Ca (carbonate) concentrations, low detrital input and negative oxygen isotope excursions, strongly suggesting high organic productivity, high vegetation density in the peri-Marmara regions, and high input of melt waters from north European ice sheets via the Black Sea. Lesser intensity of GIs 3, 4 and 7 in the Sea of Marmara proxy records suggests possible teleconnections with the Siberian high pressure system during these periods.

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## COLD SEEPS AND THEIR DEPOSITS IN THE SEA OF MARMARA

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### 1. Introduction

Cold seeps are found in different oceanic and marine settings (Kennicutt *et al.* 1985; Moore *et al.* 1990; Campbell 2006; Tyler *et al.* 2003) including the Sea of Marmara (Geli *et al.* 2008; Zitter *et al.* 2008; Tryon *et al.* 2010; Dupre *et al.* 2015). Typically, they release fluids rich in methane and other hydrocarbons that are produced by microbial degradation of organic matter or thermogenic processes. Discharge of these fluids on the seafloor are usually associated with carbonate crusts and a rich chemosynthetic community of organisms.

The Sea of Marmara consists of three sub-basins (Tekirdağ, Central and Çınarcık) with up to 1270 m depth, NE-SW trending Central and Western Highs separating the sub-basins, and shelf areas with less than 100 m-depth (Figure 1). The Sea is cut by the northern and middle splays of the North Anatolian Fault (NAF) system. Cold seeps and associated carbonate crusts and chimneys occur along active faults (Cremiere *et al.* 2012, 2013). Seafloor observations and collection of gas, sediment and carbonate crust samples were made during Marnaut and Marsite cruises using Nautile manned submersible and Victor 6000 ROV dives in 2007 and 2014 (Henry *et al.* 2007; Ruffine *et al.* 2015).

In this paper we briefly discuss the environmental conditions and mechanisms of formation of the authigenic carbonate crusts and carbonate chimneys and black sulphidic sediments along the active faults in the Sea of Marmara, based on the results of mineralogical, textural and stable oxygen and carbon isotopic analyses of the authigenic carbonates (Figure 1). The analyses were carried out using binocular and thin-section microscopy, X-ray diffraction and mass spectrometry.

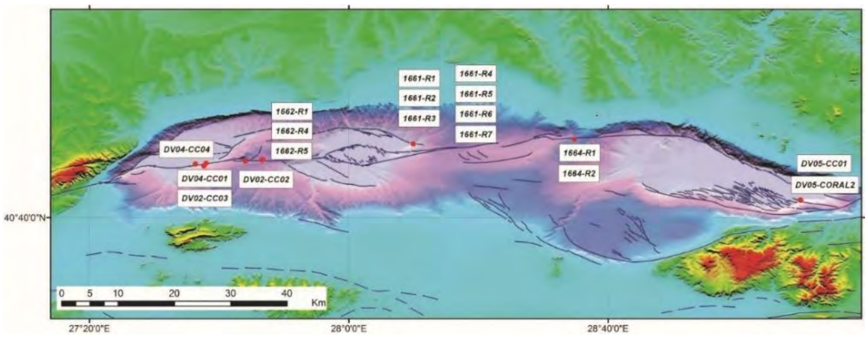


**Figure 1**. Morphotectonic map of Sea of Marmara showing locations of studied authigenic carbonate samples (bathymetric data from Le Pichon *et al.* 2001). Blue lines indicate faults (Uçarkuş *et al.* 2011).

## 2. Main Results and discussion

### 2.1. Field occurrence:

Cold seeps widely occur along the submerged North Anatolian Fault system in the Sea of Marmara, as observed during the acoustic surveys (Geli *et al.* 2008; Zitter *et al.* 2008; Dupre *et al.* 2015). The temperature of these seeps are close to the bottom water temperature of the Sea of Marmara (i.e., 14°C). The seeps commonly emit hydrocarbon gases (mainly methane) and other fluids, such as brackish water and oil (Bourry *et al.* 2009). At the base of the slope off the Ganos Mountain, mantle helium spills out through a tension gash (Burnard *et al.* 2012). Oil seepage and gas hydrates were observed from a mud volcano cut by the Main Marmara Fault on the Western High (Tryon *et al.* 2010).

The authigenic carbonate crusts occur as pavements and chimneys in the Sea of Marmara (Çağatay 2010; Crémière *et al.* 2012). The pavements range up to 10 cm in thickness and the chimneys and mounds up to 2 m high (Figure 2). The authigenic carbonates are commonly associated with patches of black sulfidic sediments that overlay or are surrounded by carbonate pavements (Figures 2B, 3A, B). The black colour is due to the presence fine-grained Fe-monosulphides. The black sulphidic sediments occur usually with bacterial mats that accommodate a rich chemosynthetic community of bivalves, sea urchins and marine annelid worms (Polychaeta) (Figure 3A, B). The bivalves show similarities to *A*, which is a mytilid species found in the Eastern Mediterranean (Ritt *et al.* 2012). The normal seafloor sediments of the Sea of Marmara are beige coloured and include widespread bioturbation (1-2 cm diameter boring holes) caused by the pink shrimp *Parapenaeus longirostris* (Lucas, 1846) (Artüz 2006; Öztürk 2009) (Figure 3B).

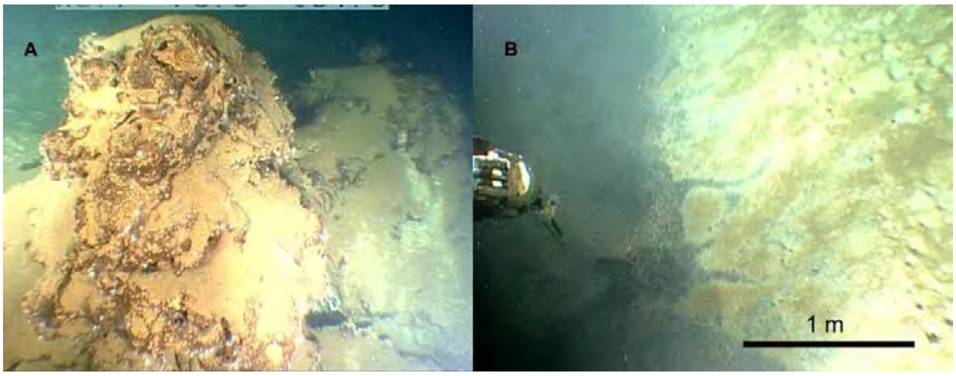


**Figure 2.** (A) A 2 m-high carbonate mound with its base fractured by faulting, Central Basin. (B) A fault scarp east of the Central Basin. Black sulphidic sediments in flat area at the base of the fault scarp and beige oxic sediments on the fault scarp bored by pink shrimp *Parapenaeus longirostris*.

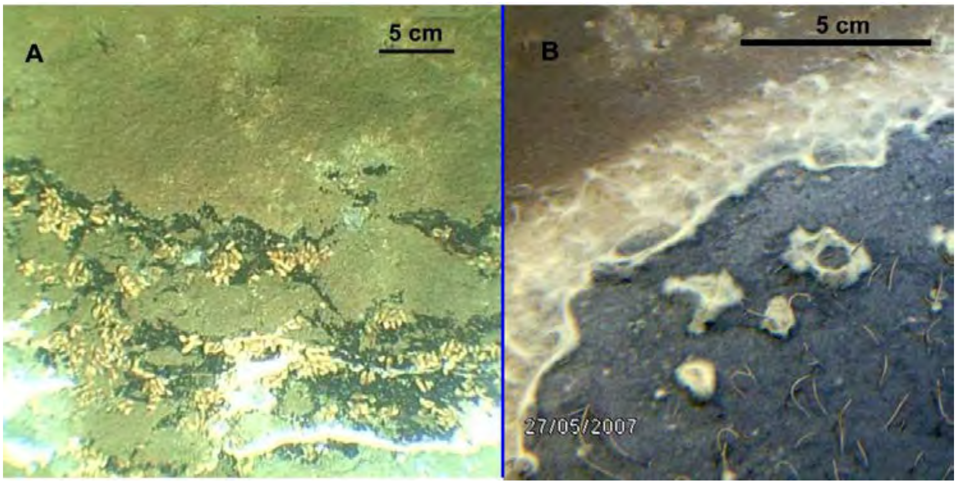


**Figure 3.** (A) Carbonate pavement fractured by faulting and fractures filled with black sulfidic sediments and colonized by scores bivalve *Idas modiolaeformis*. Central Basin, east. (B) A patch of black sulfidic sediment colonized with tube annelid worms Polychaeta and white filamentous bacterial mat. Western High.

### 2.2. Mineralogy, textures and structures

The authigenic carbonates consist mainly of aragonite with trace amounts of high Mg-calcite. A few samples contain subequal amounts of aragonite and calcite. Carbonate crusts commonly have sinter-like porous, botryoidal and sugary textures with a rich fauna of bivalves and serpulid tubes cemented by carbonates (Figures 4, 5). Some samples are coated by and contain veinlets of Fe-oxyhydroxides (Figure 4B). Binocular microscopic observations indicate carbonate veinlets and 300-200 μm in diameter ornamented tube worms. Acicular aragonite crystals occur inside the bivalve shells. Some samples contain up to 200 µm in diameter pyrite crystals. In some samples rare 0.5 mm-wide Fe-oxyhydroxide fracture filling veinlets are present.

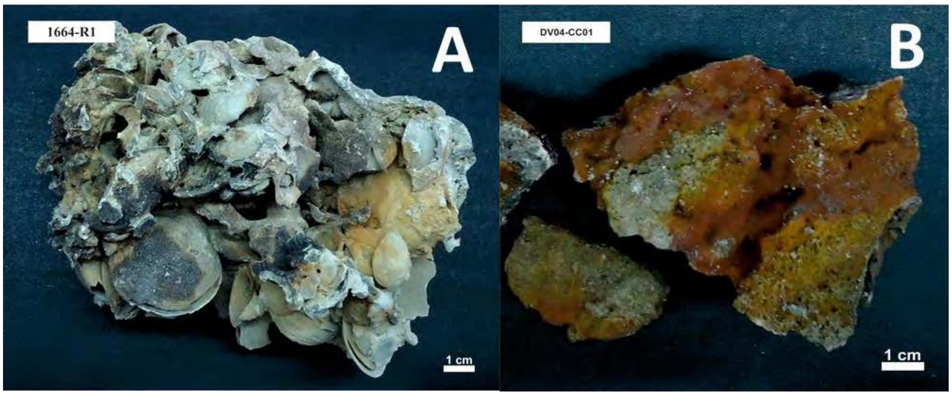


**Figure 4**. Carbonate crust samples with a colony of bivalves (A), and botryoidal structure and Fe-oxide covered surface (B)

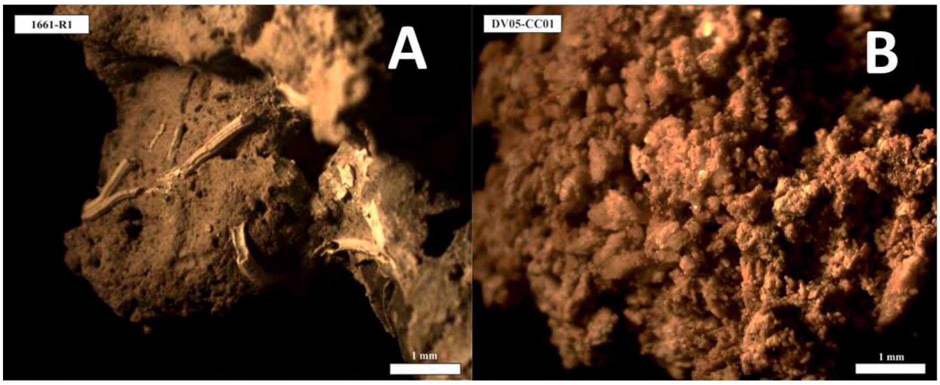


**Figure 5**. Binocular microscope pictures of carbonate crusts with serpulid worm tubes (A), and sugary texture (B).

### 2.3. Stable isotope composition

Carbon isotope values of 20 authigenic carbonate samples from the Sea of Marmara range from -47.62 to -13.65 ‰ V-PDB (Table 1). The relatively heavy carbon isotope values (-13.65 to -24.90 ‰ V-PDB) are observed on the Western and Central pressure highs. Oxygen isotope values vary between 1.32 and 3.8 ‰ V-PDB. These values are compatible with deposition of the carbonates from the Mediterranean water forming the deep water mass in the Sea of Marmara.

**Table 1**. Stable carbon isotope ($\delta^{13}C$) and oxygen isotope ($\delta^{18}O$) values of carbonate samples. Samples with relatively heavy $\delta^{13}C$ values within grey-shaded area are from pressure highs.

| Samples | δ13C ‰ | δ18O‰ |
|---|---|---|
| 1661 R1 | -47,62 | 3,07 |
| 1661 R2-A1 | -42,5 | 3,0 |
| 1661 R2-U2 | -46,3 | 2,9 |
| 1661 R3 | -29,8 | 1,8 |
| 1661 R4-1 | -44,2 | 2,2 |
| 1661 R4-2 | -40,6 | 1,8 |
| 1661 R5 | -37,5 | 2,2 |
| 1661 R6 | -43,9 | 3,8 |
| 1661 R7 | -36,56 | 1,99 |
| 1662 R1 | -13,65 | 3,27 |
| 1662 R4 | -23,16 | 3,37 |
| 1662 R5 | -24,90 | 3,12 |
| 1664 R1 | -18,10 | 2,82 |
| 1664 R2 | -20,15 | 2,88 |
| DV02 CC02 | -35,35 | 3,21 |
| DV02 CC03 | -14,83 | 3,22 |
| DV04 CC01 | -42,10 | 1,32 |
| DV04 CC04 | -36,31 | 1,63 |
| DV05 CC01 | -43,79 | 3,07 |
| DV05 CRL2 | -4,58 | 1,22 |

### 2.4. Formation of authigenic carbonate and black sulphidic sediments

In the active methane emission zones in the Sea of Marmara, the sulphate/methane boundary occurs at or close to the seafloor, whereas elsewhere in the sea, the same boundary is located at 2-5 m below the seafloor (Çağatay *et al.* 2004). This, together with commonly very light stable carbon isotope values (13C=-29.8 to – 47.6, indicates that the anaerobic oxidation of high methane flux emitted from the active faults is the major process (Boetius *et al.* 2000; Valentine and Reeburg 2000; Orphan *et al.* 2001; Niemann *et al.* 2006) that provides the necessary $HS^-$ and $HCO_3^-$ ions for the formation of Fe-sulphides in the black reduced sediments and the carbonates in the authigenic crusts, chimneys and mounds at or close to the seafloor. Furthermore, the anaerobic methane oxidation reaction provides food and energy for the rich chemosynthetic life.

The origin of methane is either biogenic or thermogenic in the Sea of Marmara. The hydrocarbon gases sampled on the pressure highs are of thermogenic origin and have similar carbon isotopic composition with those of the Thrace basin (Bourry *et al.* 2009; Gürgey *et al.* 2005). Heavy $\delta^{13}C$ values (-13.65 to -24.90 ‰ V-PDB) observed in the authigenic carbonates on the pressure high indicate the derivation of carbon from the oxidation of organic matter or degradation of oil.

## 3. Conclusions

Widespread fluid emissions occur along the North Anatolian Fault system in the Sea of Marmara. These emissions are associated with carbonate pavements, carbonate chimneys and black sulphidic sediments that are colonized with bacterial mats and a rich chemosynthetic fauna of bivalves, sea urchins and annelid worms (polychaeta). The isotope evidence, together with the close association of the carbonate and sulphidic deposits indicates that they are formed by the anaerobic oxidation of biogenic or thermogenic methane at or near the seafloor.


### Acknowledgments

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# COASTAL GEOMORPHOLOGY OF SEA OF MARMARA AND ITS ISLANDS

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## 1. Coastal Geomorphology of Sea of Marmara

Sea of Marmara, which comprises the Turkish Strait System together with Istanbul and Çanakkale Straits (Dardanelles and Bosphorus), is an inland sea with a total surface area of 11.500 $km^2$. The system controls the water exchanges between the Mediterranean Sea and the Black Sea. The Sea of Marmara extends for about 240 km in east-west and about 70 km in north-south directions. The total lenght of its coastline is 927 km (Figure 1).

Various natural agents should be considered to shed light on the development of coastal landforms. Almost none of relief forms such as those peculiar to fluvial, volcanic, karstic and semi-arid environments hing enigmatically upon such different agents and processes acting in coastal areas. Because, coastal landform development is in one sense the combination of these distinctive morphonamic processes, coastal topography and coastal forms involve a great variety of morphological forms and coastal types as the result of internal and external factors.

In consideration of the aforementioned issues, factors having importance for development of Sea of Marmara coasts as such in the world coasts (Erinç, 2001) are as follows;

1- Lithology
2- Internal factors
3- External factors
4- Time
5- Geomorphological characteristics of the coastal area

To dwell briefly on these agents, it can be stated that Sea of Marmara and its environs, along with some local differences, forms an area typical of discordantly covered reliefs. Massif rock units are covered by surficial deposits. The southern and northern parts of the Sea of Marmara have been primarily controlled by the North Anatolian fault for the last 15 Ma. Sea of Marmara coasts are at present shaped by waves and currents as the main external agents of coastal landform development. The effects of organisms, excluding reefs, pond scums and mangroves typical of tropical coasts, cannot be neglected when anthropogenic involment by constructing coastal structures (i.e. pier, harbor, fishing port, filling facility, sewage plant, fill areas etc.) are considered.

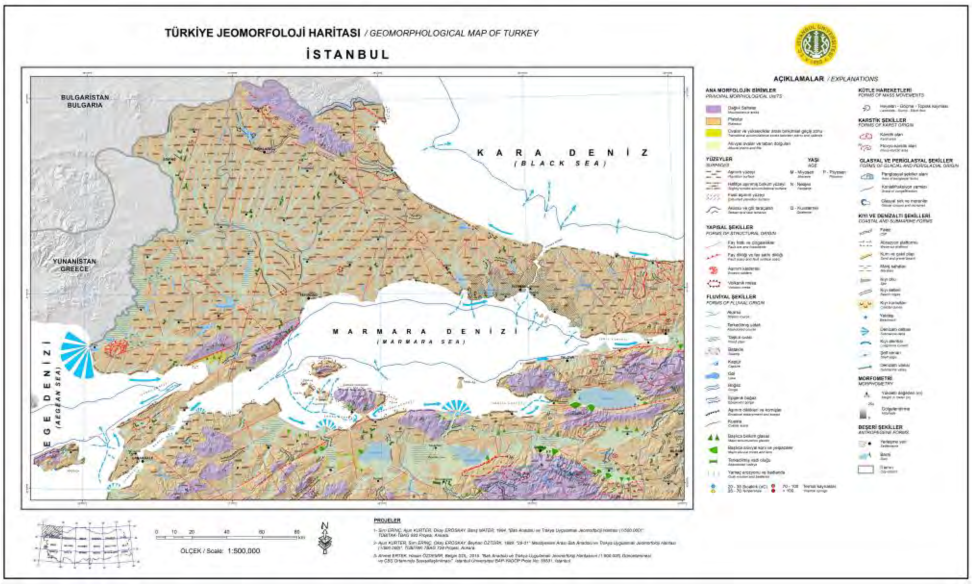


**Figure 1.** Geomorphological map of Sea of Sea of Marmara and Turkish Straits System coasts (from Erinç *et al.* 1984).

Time is of utmost importance in geomorphology. This is due to its importance in designating factors and processes that resulting landforms faced. Such as in world coasts, the coasts of the Sea of Marmara are also at youth stage due to inundation following the last glacial period. Morphological features of the coastal region is of particular importance in the east-west oriented longitidunal Sea of Marmara coasts coasts. Thus, islands in its northern and southwestern parts are raising mountain summits and hills formed by old massive rocks on the shelf areas. Typical examples are Mt. Kayışdağ, Dragos Hill and Büyüada (Great Island). These are monadnocks (erosional residues) composed of quartz sandstone emerged as result of peneplenation. On the other hand, the environs of Istanbul Islands became like islands as result of sea-level rise; as such in the Southern Marmara Arcipelago.

In general view, Apline section of the E-W aligned mountain range in the northern part of Turkey formed as consequence of tectonic movements. Thus, as is the case with the Black Sea coasts, mountains extending parallel to the sea resulted in the formation of longitidunal coasts throughout the Sea of Marmara. These coasts are considered to have been controlled by tectonic lines running parallel to the coastline. Thus, the environs of the Sea of Marmara are diversified in respect to geological structure and relief forms. By virtue of the North Anatolian Fauls in the middle of the Sea of Marmara, coastal landforms vary as well.

The coastal forms which offer local differences that are not very similar to each other draw the attention along the northern and southern Marmara shores. The shelf area extends to 2-30 km from the shore. However, it is variable. For example; it extends up to 30 kms in Karadağ offshore of northern Bandırma while it is only 2 km wide in Çınarcık. From the shelf area, a steep continental slope (chamfer) descends to the deep sea floor which extends to 1250 m. There are three basins lined in the east- west direction (Tekirdağ, Central and Çınarcık basins) and two ridges with intertwined crests between the basins (Ardel-Kurter 1973, Çağatay *et al.* this volume). The deepest point of Sea of Marmara is in Çınarcık Pit in the east and the depth is 1270 m.

Structure and relief have played an important role in determining coastal patterns. The northern part of the Marmara trough extending between the Bosphorus and the Dardanelles is the cover units leaning towards the Paleozoic massif of Istranca and Istanbul or the edges of the low plateau formed by these massifs. In the west, however, the masses of Ganos and Korudağ bring a mountainous edge rising above the Sea of Marmara. with the maximum height is 945 m (İnandık 1958). In the Samanlı Mountains, altitude is 1115 m behind Yalova; and in the south of Gölcük, it goes up to 1314 m. The highest point in the Marmara Region is the Uludağ Peak, 2543 m in the south-east.

Coastal area between Gelibolu and Marmara Ereğli: These shores are represented by high and steep cliffs as they are mostly in the group of faulted shores. However, lowland shores and beaches are encountered in the riverside outfalls and erodible dead cliff shores.

Coastal area between Marmara Ereğlisi and the Bosphorus: The Marmara Ereğlisi forms a protrusion towards the Sea of Marmara to the south. In fact, the place where it is located is a tombolo, which is later tied to the land. Apart from this, there is not much elevation in the area as it is formed from low plateau area in general; it is represented by low cliffs and the cliffs are transformed into dead cliffs, where there are erodible rocks. This part constitutes the Çatalca Plateau shores. As one heads west towards the Bosphorus from Silivri, shore takes the form of “harbour shore”. Shore-set lakes (lagoons) are formed by the closure of the fronts of the old coves with a set. K. Çekmece Lake is another shore-set lake as well as B. Çekmece Lake. In their forming, the waves and currents and submarine topography as the external factors, especially marine factors, played the important role. Gürpınar environs and Beylikdüzü shores are the examples of landslide shores. These shores usually present a mature topography since they are usually formed of Silivri clay and sand and Bakırköy limestones. In general, the plateau surfaces of about 50-100 meters behind the shore end with cliffs of 10-20 meters. Yeşilköy, Bakırköy, Zeytinburnu and Yenikapı shores of existing cliffs lost their naturalness due to coastal use and remained in urban texture. Especially due to the coastal road between Yeşilköy and Eminönü and the presence of anthropogenic fillings and recreation areas, these shores have been artificially modified (i.e., generally manmade).

The Bosphorus coasts: This strait that ties the Black Sea and the Sea of Marmara extends between Rumeli Lighthouse- Anadolu Lighthouse and Haydarpaşa Port-Ahırkapı Lighthouse (Sarayburnu). It is more indented than the Çanakkale Strait. The length of the Bosphorus; between Rumeli Lighthouse-Ahırkapı Lighthouse (Sarayburnu) on the shore of Rumeli is 55 kms. and between Anadolu Lighthouse-Haydarpaşa Port in the Anatolian side is 35 kms. The Bosphorus stretches in the form of an S in the northeast-southwest direction; its length in plan-view is 30 km. The Bosphorus, which is wide in its the northern and southern outlets, narrows in the middle parts. While the width is 3.6 km between the Rumeli Lighthouse and the Anatolian Lighthouse in the north, it is 2.5 km from Ahirkapi Lighthouse-Haydarpaşa Port in the south. The narrowest point is 700 m between Anatolian and Rumelian fortresses.

The Bosphorus was excavated in the Paleozoic Graptolitic schists (570-225 million years ago) and occasionally served as a valley and occasionally a waterway in the glacial and half-glacial periods in the Quaternary (2.5 million years). Finally, it was completely inundated with sea water about 7500 years ago (7.400 ± 1.300 years) (Göksu *et al.* 1990; see also Çağatay *et al.* this volume) and it got its appearance of today. As the archaeological researches suggest that the civilization in Fikirtepe (Kadıköy) dates back to 5000 BC and Yarımburgaz (K.Çekmece) to 4800 BC; it has been determined that environmental changes around the entrance of the Bosphorus and the Golden Horn almost paralleled the human occupation about 7000 years ago (Meriç 1990). The Bosphorus is the waterway form of the river valley buried in the Çatalca-Kocaeli Plateau by sea flooding. Looking carefully, it is understood that the steep rising behind Üsküdar-Haydarpaşa is a meander steep that developed on the slope of a river valley and formed as a result of side erosion and formed a concave input. It offers compatibility because the opposite shores of the Bosphorus are an old river valley. However, the folding of the strait shores does not sometimes resemble each other. This is the evidence of a continuation of a developed landslide under the Bosporus in the local area. Since, this compatibility deteriorates and improves in the opposite direction of compatibility. The most typical of these is "Beykoz Landscape" opposite Büyükdere Bay.

The Golden Horn, an inlet of the Bosphorus, is a river valley created by the merging of the streams of Alibey and Kağıthane, formed like itself by sea-flooding. In other words, the Golden Horn is a typical example of ria shore, just like the Istanbul and Dardanelles Straits.

Submarine Geomorphology of Istanbul (Bosphorus) Strait: The -50 m deep contour (isobath) follows the entire strait gutter in the form of a channel parallel to the shore. In general, the 50 m deep channel has elliptical depressions of up to 70 m and up to 110 m in front of Rumeli fortress. The 50 m depth contour following the Istanbul Bosphorus does not reach the Sea of Marmara in the south and closes. This is caused by a heel rising to a depth of 40 metres between Sarayburnu-Harem. A submarine valley extending 14 km on the shelf in the Sea of Marmara is the continuation of the strait gutter towards the Sea of Marmara. The strait continues in the north with a submarine valley over the Black Sea continental shelf. The sediment thickness in the middle reaches 100 m (Gökaşan 1998). In the section of in front of Büyükdere where it corresponds to a buttress of at least 65 m., the current Istanbul Bosphorus waterway is formed as a consequence of the flooding of the sea on the valley where there are rivers flowing in two different directions to the north and south after the melting of the glaciers in the last post- glacial period. At the same time, the area where the rivers settle here is actually the result of the faults passing through the NAF (North Anatolian Fault). For this reason, the Bosphorus is an old fault valley where there are inactive faults which can be active at any time (Gökaşan 1997 ve 1998). The alluvium here is rather new and the fact that the baby ashes in the cube grave of Yenikapı excavations (Kocabaş 2008) are 8500 years old or the marine sediments in the southern outfall of the Bosphorus are 7500 years old indicate that the Istanbul Bosphorus waterway is very young.

Coastal area between the Bosphorus and Tuzla: It is seen that rocks such as shale, limestone, quartzite, arkose belonging to the Paleozoic massive from Üsküdar shores are exposed in cliffs. With the erosion of the old Neogene deposits that have been stripped off the surface behind the cliff, the Istanbul Peneplain, a fossil topography, emerges. Here, the K. ve B. Camlıca hills, Aydos Mountain, Kayışdağ and Alemdağ are the monadnocks, that is, mountainous masses that have remained from the erosion. However, since these shores between Kadıköy and Tuzla are filled by humans, with the anthropogenic effect, the sea has no ties with the land. Active cliffs have also taken the form of anthropogenic (manmade) cliff. These shores offer a mature topography, since they are usually formed by the shale. In general, the plateau surface behind the shore ends with cliffs of 10-20 m. Haydarpaşa, Kalamış and Pendik coves lost their naturalness due to the coastal use and remained in urban texture. Due to the coast road and fillings made between Kadıköy-Pendik (Photo 1) as well as the establishment of Haydarpaşa Port; Haydarpaşa, Kadıköy, Moda, Bostanci, Pendik, Kartal, Tuzla ferry ports; Fenerbahçe Yacht Harbor and Pendik and Tuzla shipyards; these shores naturally lost their ties with the land and they are usually manmade arrangement. The slope of the common cliff slopes on these shores is in the range of 5-10° as it is in the Moda cliffs.

Tuzla coasts: The islands present here have emerged in the present coastal form, either by natural means or, by manmade connections. The most important role in this area is the stopping of coastal development by the partial filling of the Tuzla (Kamil Abduş) Lake (lagoon) and by its partial joining into the channel. The presence of marine terraces, marine elements and shells in the 20-40 m in Tuzla is a proof that the shore rose in the Pleistocene. Taking into account the similar uplift in the west between Şarköy and Mürefte at +140 m; and between Yalova and Karamürsel in the east at 18-20 m., we can talk clearly about the effectiveness of the NAF in the field. However, the terrestrial effect and coastal uplift differ (Ertek 2006).


**Photo 1.** Maltepe fillings along the Sea of Marmara shores in Anatolian part of İstanbul (http://www.milliyet.com.tr/gundem/dev-park-havadan-goruntulendi-1911144/son-dakikagundem/SonDakikaGaleri/13.07.2014/1911144/default.htm?PAGE=2).

Northern coasts of İzmit Gulf: They are the shores of a plateau area split by the short rivers descending from the Kocaeli peninsula. However, based on the effectiveness of the NAF, they are still young shores. For that reason, with the exception of river outfalls, they are often cliff-top and high-shore. By the development of a pond fan in the outfalls of the rivers which are energized by the influence of the NAF and eventually the fostering fans formed a mountain rug on the northern shores of the Izmit Gulf (Çuvaş 2002). Due to the settlements of the industry developing towards İzmir, the coastal form is man-made arrangement. The eastern part of the Gulf is low and it is a field of marsh and reeds with the alluvion carried by the Yuvacık brook from the south and Çuhahane brook from the south. This is a place where the NAF comes from the east and submerges into the Sea of Marmara, as will be remembered from the surface rupture of the 1999 Marmara Earthquake.

Southern coasts of İzmit Gulf: Particularly because the active North Anatolian Fault passes through the southern shore of the bay, the freshness of the morphological forms and the occasional change of the shoreline can be seen even during the historical periods. The southern shore of the Izmit Gulf is coastal with a generally straight line extending east-west. However, in the Laledere and Hersek deltas on the outfall of Laledere and Yalakdere, there are deltaic plains in the form of protrusions to the north. The coastal shape changes around here. Apart from this, beyond the shore extending between Yalova and Karamürsel, there are marine terraces consisting of old abrasion platforms extending in two different levels at 12 and 20 m (Erinç 1956).

Southern coasts of the Sea of Marmara: Shoreline in comparison with the northern shores of the Sea of Marmara is more indented due to the existence of various coastal formations such as deltas (Hersek, Laledere, Kocasu, Gönen, and Biga deltas), peninsula (Kapıdağ, Bozburun peninsulas) and gulfs (Izmit, Gemlik, Bandirma and Erdek gulfs). These shores, which extend between Lapseki and Izmit, offer considerable diversity in terms of structure and relief. In particular, rocks are older, stiff and massive. The massive Samanlı Mountains form a protrusion in the east-west direction towards the Sea of Marmara in the south of the NAF. İmralı Island in Bozburun extension is the continuation of this. From the south of the Gemlik Gulf, the second, that is, southern branch of the NAF in east-west direction passes. Along this active branch, the coastal form also offers diversity.

Coastal area between Gemlik and Bandırma: Here, the structure and relief are again in the foreground. Except for the low shore formed bu Kocasu Delta, generally high and cliffy hills are dominant until Bandırma (Yıldırım 2001).

Kapıdağ Peninsula and its coasts: Kapıdağ, an old island, is a tombolo tied to Anatolia by a double coastal arrow. The reason for the inverted triangle is that the shores are formed of faults and high cliffs (Güneysu 1999; Gazioğlu *et al.* 2014).

Biga coasts: 20 km west of the Gonen Delta, there is a beach area formed by low shorelines. This area called Denizkent or Tahirova is a developed coastal plain in front of the Sinekçi Fault. From the western part of this beach, another shoreline formed by the alluviums of Biga brook is passed. From Karabiga to west, up to Umurbey, the shores with the massive character are steep and formed of cliffs. However, because of the loosely cemented claystone, sandstone and conglomerates of Miocene between Umurbey and Lapseki, the area again gets a low plateau appearance and the cliffs usually turn into coastal plains with landslides (Bekler 2011) or marine terraces and sloping cliffs. According to various researchers, coastal terraces at various ages were identified in 164 localities and 97 different levels with elevation, age, fossil and marine material characteristics. Young tectonic movements are also effective in the Marmara Region. In addition to the 110 m harmonization of the coastal terraces on the northern and southern shores of the Sea of Marmara, such as Hoşköy, in the north (Lokalite 11) and Hamamlı (Localities 106) in the south in the Kapıdağ peninsula; due to the fossils (Yaltırak *et al.* 2000) not conforming with each other show the effectiveness of the local tectonics. For this reason, the Çavda level at Çanakkale Sarıyarlar (Lokality132), located between 180-190 m and 520.000-550.000 years old, is located at 1-2 m levels. The original Çavda level, however, is 95-110 meters. Thus, while a rise of 80 cm is relevant the first, a fall of 93-94 m should have occurred in the second. With the many new coastal zone locations and levels to be uncovered around the Sea of Marmara from now on, we think that the amplitude of the active tectonics in the field will be revealed in more details based on radiometric age determinations of all of them and that the geomorphological development of the field will take place in a healthier way (Ertek *et al.* 2001).

Coasts of Çanakkale Strait: This strait, extending between Gelibolu-Çardak and Kumkale-Seddülbahir ties the Sea of Marmara to the Aegean Sea. It is less indented than the Istanbul Bosphorus. The length of the Dardanelles Strait is 78 km between the Ilyas Burnu (Seddülbahir) and the Çankaya Burnu (Gelibolu) on the Rumeli shore and the distance between Kum Burnu (Kumkale) and the Çardak Lighthouse (Çardak) is 94 km. The Bosphorus stretches in the northeast-southwest direction and the air distance is 60 km. The north-eastern outfall between Gelibolu and Çardak Lighthouse is 3.2 km and the south-western outfall is 3.6 km wide. The narrowest part is between Kilitbahir and Çanakkale with 1.2 km. Stratigraphy of the Dardanelles is composed of lithologies such as Sarcassian-Pliocene limestone, marls and pebbles, sand and clay (MTA 2002). The streams reaching the Çanakkale Strait created small size coastal plains. Although the strait has the characteristics of a river valley buried entirely on a Pliocene age abrasion surface, it conveys sharp traces of tectonics by drawing sharp elbows, as seen in the Dardanelles-Eceabat region. The shores of Çanakkale Strait are influenced by surface currents coming from Marmara and reaching the Aegean. A shoreline arrow is located in the north of Lapseki, parallel to this stream direction (Güneysu 2000). The shores of the Çanakkale Strait show slightly concave shoreline features from the Marmara entrance to the Çanakkale-Eceabat elbow, with traces of terrestrial erosion. The southwest of Gelibolu is an example to this in the west of the strait. To the east of the strait the delta formed by Uludere preserves its properties despite the presence of surface currents. Following the Çanakkale-Eceabat elbow, the eastern shores of the strait first to the south and then to the south-west show low coastal features with deltas formed by the Koca Çay and Kabalak brooks. In the southwestward direction of the Kabalak Delta, the shoreline provides a concave view that can be called meander, bearing the trace of terrestrial erosion. In this area, developed cliffs as the result of waves are detected (according to Erinç *et al.* 1984in Güneysu 2000). In contrast, the western shores of the strait show a straight stretch. The eastern coasts of the Çanakkale strait end with a low coastal feature with the delta formed by the Küçük Menderes Stream at the exit of the strait to the Aegean Sea (Güneysu 2000).

Submarine Geomorphology of Çanakkale Strait: In the middle of Çanakkale strait there is a groove extending from north to south with a depth of 50 metres. There are oval-shaped deep pits from place to place in this groove. The depth is 102 m in Nara Burnu, 109 m between Çanakkale and Kilitbahir. With the impact of strong strait currents bottom deposits are partially seen. The Çanakkale Strait is an old river valley which is directed to the north and south, but the Gelibolu Peninsula is formed of three different islands. The Gelibolu section is partially filled with fillings as a result of sea flooding and the strait is turned into a waterway. The walla of the strait are faulted, and their primary position is a faulted valley, like the İstanbul Bosphorus. In the middle part of the strait the sediment thickness is around 40 m (Gökaşan *et al.* 2008).

### 2. Coastal Geomorphology of Sea of Marmara Islands

Geographically, compared to the island countries like Greece or the Philippines, there are not many islands, islets and rocks in the Turkish seas in general. However, in Sea of Marmara, there are more islands. Based on tectonic, eustatic, climatic and structural reasons, the Sea of Marmara is an inner sea with more islands, islets and rocks than the other Turkish seas. The islands in the Sea of Marmara are gathered in the archipelago in the south of Istanbul and in the South Marmara. Apart from a few that are individual, there are islands and rocks nearby.

It is possible to combine the Sea of Marmara islands in two major groups and the others in a dispersed third group. (1) Istanbul Islands, (2) Southern Marmara Archipelago, (3) Other Sea of Marmara Islands (Ertek 2011).

### 2.1. İstanbul Islands

Other names are Red Islands or Prince Islands. In the southeast of Istanbul, there are a total of 9 islands 5 of which are big with an average of 1 km from the shore and with inhabitants. These are;

Büyük Island (Prinkipo), 5 km²
Heybeli Island (Halki), 2.46 km²
Burgaz Island (Antigoni), 1.46 km²

Kınalı Island (Proti), 1.32 km²
Sedef Island (Androvita), 0.34 km²
Kaşık Island (Pita), 0.06 km²
Tavşan Island (Neandros) 0.11 km²
Yassı Island (Plati), 0.12 km²
Sivri Island (Ohia), 0.10 km² (Source: Mediterranean Islands, 2003).

It is seen that rocks such as shale, limestone, quartzite, arkose of Paleozoic age seen from Üsküdar shores are exposed in cliffs. With the erosion of the old Neogene depots that have been stripped off the surface behind the cliff, the Istanbul Peneplain, a fossil topography, emerges. Here, the K. ve B. Camlıca hills, Aydos Mountain, Kayışdağ and Alemdağ are the monadnocks, that is, mountainous masses that have remained from the erosion. Besides these, the Istanbul Islands, which have been flooded and splatterd in front of the mentioned shore offer the same features. They rise from the sea just like Kayışdağ and Aydos Mountain. They are the oldest rocks of Istanbul at the same time as they rise from the sea level due to the presence of quartzitic rocks (MTA, 1964 ve 2002). In the coastal area between Kadıköy and Tuzla to the 3.5-6.5 km south of the Marmara coasts are the Istanbul islands. Except for the Yassı Island and Sivri Island, the others are almost parallel to the shore. The first two are further offshore at about 6 km southwest of Burgaz Island. The total area of the Istanbul Islands is approximately 11 km² (10,772 km²) and the total length of the coasts is 46 km. There are permanent settlements in five of the islands (Büyük Island, Heybeli Island, Burgaz Island, Kinali Island and Sedef Island). The majority of houses are used as summer houses. In summer there is an intense domestic tourism activity in the islands.

Istanbul islands are the remaining monadnock hills from the abrasion caused by hard rocks like the Lower Ordovician quartzite (quartz arenite) on the Kocaeli Peneplain located in the coastal area between Kadıköy and Tuzla. Istanbul islands are formed as a result of tilting of Kocaeli peneplain in Pliocene and the sea flooding of southern part's 25000 years ago (Ertek 2008).

Büyük Island, with an area of 5.4 km² and a coastal length of 13.1 km, is the largest and located in the furthest south-eastern part. The length in the north-south direction is 4.6 km while the width in the east-west direction is 1-2 km. The central and southern parts of Büyük Island are formed of the Lower Ordovician quartzites (Aydos Formation). On these hard rocks from north to south, there are three hills named Belen Tepe (201 m), Yüce Tepe (200 m) and Avcı Tepe (171 m) which are separated by long and narrow ridges. There are unseparated detrital nodular limestones of Denizli Village Formation which are Middle-Upper Devonian-Lower Carboniferous age old and patched with quartzites by a thrust west of the quartzites. The fossil surface of 2 km long, consisting of Lower Ordovician age-old arkosic sandstones (Kurtköy Formation) extending 60 m northward from the quartzitic Belen Hill to the northernmost, is in the shape of a long tall ridge. However, the arkosic sandstones are surrounded by the Baltalımanı member shales of the Denizli Village Formation and of Middle-Upper Devonian-Lower Carboniferous age, which is softer on the shore. There are several dry valleys in this section containing the actual settlement. On the western bank of the island, Dil Burnu is located with 100 m in width and 500 m in length. To the south of this foreland is Yörükali Bay, Nizam Bay to the east of the island and Karacabey Bay to the southeast. Yörükali, Nizam, Değirmen beaches are the low shores of the island. These are the shores consisting of steep slopes extending from the Birlik Meydanı on the fossil surface to the shore. For example, the slopes of Nizam Neighborhood in the east are inclined to the southeast and 17°. Büyük Island shores are usually drowned, young and high shores (Ertek 2008).

Heybeliada is located between Burgazada and Büyükada and has an area of 2.3 km² and coastal length of 8.8 km. Its length in the north-south direction is 1, 85 km while the width in the east-west direction is 1-2.5 km. In the central part of Heybeliada there are two abrasion hills at the height of 140 m in the north and 127 m in the south bound with a narrow high which is formed of the Lower Ordovician age quartzites (Aydos Formation). There are arkosic sandstones of the Kurtköy Formation in the area, which surrounds the quartzites from the south and especially from the west and also forms an 82 m hill to the north of the island. The narrow surface area, which emerges as a fossil surface at 60 m on the western side of the 140 m hill, is forked in the south-west of the island and ends at 10 m in the forms of two different types of cliffs. To the north of the 140 m hill, it is tied to an 82 m arkosic sandstone hill with a narrow high. In the central part of the island towards the north, there are partly softer Middle-Upper Devonian-Lower Carboniferous age Baltalimani shale member of the Denizli Village Formation. In this section where the original settlement is located, there are two dry valleys developed towards the east and west direction. On the western coast of the island, there is the Değirmen Burnu which is 100 m wide and 300 m long and is formed by the turbiditic sandstone-shale succession of Trakya Formation. To the south of the island is the Çam Limanı (Cove), whose outfall is open to the south and is C-shaped. The slope between the 140 m peak and Yörükali Beach located in 500 km south-western is 16°. Degirmenburnu south and Çam Limanı are in the low-shore group and are pebbly-sandy beaches. The Heybeliada coasts are usually drowned, young and high coasts (Ertek 2008).

Burgazada has an area of 1.5 km² and a shore length of 5.6 km. and it is located between Kınalı Island and Heybeli Island of the Istanbul Islands. Its length in the north-south direction is 1 km while the width in the east-west direction varies between 1 and 1.5 km. Almost all of Burgaz Island is formed of the Lower Ordovician quartzites (Aydos Formation). The highest point is the 167 m hill. To the north of the quartzites, there is a fossil surface that has been formed from arkosic sandstones (Kurtköy Formation) extending in narrow areas with 50 m. This surface forms the Mezarlık

Burnu on the shore. There is also another quartzitic nose called Kalpazankaya Burnu in the southwest of the island. To the east of the island where the original settlement is located there are partly softer Middle-Upper Devonian-Lower Carboniferous age old Baltalimani shale member of the Denizli Village Formation. Here it is represented by a dry valley. The Sadun Boro Bay to the south of the Mezarlık Burnu enters the low-shore group and has a pebbly-sandy beach. In general, the Burgazada coasts are usually drowned, young and high coasts (Ertek 2008).

Kınalıada is the most northwestern of the Istanbul Islands with a 1.3 km² area and a coastal length of 5 km. Its length in the north-south direction is 1300 m and the width in the east-west direction varies between 850-1300 m. Nearly all of Kınalıada is formed of the Lower Ordovician quartzites (Aydos Formation). The highest points are 105 m on the west, 114 m on the east and 92 m on the south. These are tied to each other with narrow highs. To the north of the quartzites is an arkosic area with a narrow area in the main settlement in Kınalı's north and east, there are partly softer Middle-Upper Devonian-Lower Carboniferous age old Baltalimani shale member of the Denizli Village Formation. Üçpınar Cove, west of the island, also has a pebbly beach with a low coastline. In addition, the Kaya Burnu in the north-west of the island, the Ocak Burnu in the southwest and the Liman Burnu in the east are significant protrusions. Besides, Kınalıada coasts are usually drowned, young and high coasts (Ertek 2008).

Sedef Island is located to the east of Büyükada with an area of 0,157 km² and a coastal length of 3 km. Its length in the north-south direction is 1 km and the width in east-west direction is between 100-500 m. The island was completely formed by shale-sandstone-clayey limestones of Upper Silurian-Lower Devonian age of Pelitli Formation. There is a 56 m peak in the central part. From here, a ridge stretching to the north and south of the island stretches and ends at the shore. In the north and south it has noses in the shape of bulges. Sedef Island coasts are usually drowned, young and high coasts. However, it has a sandy-pebbly beach on the low coast of the south-western coast (Ertek 2008).

Tavşanadası is located to the south of Büyükada with an area of 0,010 km² and a coastal length of 3,5 km. Kaşıkadası is the smallest of the Istanbul Islands with an area of 0,008 km² and a coastal length of 1,5 km and is located between Heybeliada and Burgazada. It is 500 m long in the north-south direction and 30-225 m wide in the east-west direction. The highest point is the 23 m hill in the north of the island.

Yassıada has an area of 0,052 km² and a coastal length of 2,5 km. It is located 5,5 km further south east from Heybeliada. Sivriada (Nooz Island) has an area of 0,045 km² and a coastal length of 3 km. It is located 6,5 km further south west of Heybeli Island.

## 2.2. Southern Marmara Archipelago

When we look at the geological structure of the Southern Marmara Islands; we can see that they are formed of massive and metamorphosed rocks. Their cliffs rise from and extend over the southern Marmara shelf. After the last glacial period, they were converted to islands by marine flooding. Kapıdağ is one of the southern islands, that was later tied to the land with a double clamping set forming the Belkıs tombolo. South Marmara Archipelago, rising on the southern Marmara shelf in the south-western part of the Sea of Marmara, consists of 23 islands and islets and numerous rocks (Ertek 2011). The islands, which have a total area of about 165 km², constitute a continuation of the Kapıdağ Peninsula in morphological and structural aspects. These islands are the monadnocks rising from the southern Marmara shelf. Especially Marmara Island (117 $km^2$) which gives its name to "Sea of Marmara" and from which marble is extracted, is the main one. Others are Paşalimanı Island (21 $km^2$), Avşa Island (20 $km^2$), Ekinlik Island (2.47 $km^2$) and Sheep Island (1.71 $km^2$) (Ertek 2011). There are settlement in the first four islands. Other islands and islets are deserted. From these, a formation of beachrock 200 m long, 2 meters below the sea to the west of the Koyun Island, and in the same place, tsunami deposits extending to +2 m above the low-rise limestone were unearthed. It has been demonstrated that the level of the Sea of Marmara varies with both eustatic and tectonic and climatic processes (Ertek *et al.* 2015).

## 2.3. Other Sea of Marmara Islands

These are the other scattered islands and islets in the Sea of Marmara. These are İmralı Island, Tuzla islets, islets in the north-east of Kapıdağ Peninsula and the Biga Islands. The massive Samanlı Mountains form a protrusion in the east-west direction towards the Sea of Marmara in the south of the NAF. İmralı Island in Bozburun extension is the continuation of this protrusion. Neogene formations cover the Upper Cretaceous volcanites. The total area of these islands is 10 km².

## 3. Conclusions

As of September 2016; 26 of our 81 provincal cities have coasts to the sea. 15 city centres have been established on our 8333 km long coastline. Three of 7 regions of Turkey take their names from the position of Anatolia and 4 from the sea where the coast is located. The Sea of Marmara and therefore the "Marmara Region" are one of them. Four city centers, Istanbul, Tekirdag, Çanakkale and Yalova are located on the Sea of Marmara coasts and on the Straits.

Sea of Marmara coasts like the Black Sea and the Mediterranean Sea coasts are high, rocky, cliffy, mostly steep and young coasts. Quaternary tectonic movements and transgressions and regressions due to climate changes (sea pressure and sea ebbs), resulted in the Sea of Marmara coasts with formation of estuaries and rias. Today, their advanced forms are visible. In general, the rias corresponding to the stream outlets were partially filled with alluvial deposits and small coastal plains were formed at their locations, the estuaries with a limited number were closed with the coastal spits, and harbor coasts appeared as in the Buyukçekmece and Küçükçekmece lagoons (İnandık, 1958). There are many traces of this development (delta lobes) on this shelf area covering more than half of the basin, as well as old coastal remains are seen high in the form of marine terraces along the shores. There are some tsunami deposits preserved in some localities of the South Marmara Archipleago, some of which are formed by earthquakes (Ertek *et al.* 2015).

In brief, the coasts of the Sea of Marmara and the Islands offer a morphological character that is still in the youth phase, and marine processes continue to function. However, anthropogenic factors should not be ignored because the naturalness of the Sea of Marmara is slowly being removed by humans. For this reason, as is the case elsewhere in the world, there is a rapidly increasing tendency towards "Anthropogenic Geomorphology" in our country (Ertek 2016 a and b).

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# BACTERIOLOGICAL STUDIES OF THE SEA OF MARMARA

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## 1. Introduction

The Sea of Marmara located between Turkey's Asian and European regions, and connecting Black Sea and Mediterranean Sea via Istanbul Strait and Canakkale Strait, respectively. It is under the pressure of various anthropological factors such as urbanization and industrialization. Additionally, the Sea of Marmara receives pollution from Black Sea inflow (Tugrul and Polat 1995; Topcuoglu *et al.* 2000). Furthermore, as an important water route between the Mediterranean and the Black Sea, the Sea of Marmara is under pressure of marine transportation (Tasdemir 2002). The bacteria that come from ships' ballast water is another factor on the composition and abundance of bacteria in the Sea of Marmara (Altug *et al.* 2012).

The majority of bacteria present in domestic wastewater is composed of saprophyte bacteria of fecal or terrestrial origin and pathogenic bacteria such as *Salmonella, Shigella, Brucella, Mycobacterium, Escherichia, Leptospira, Campylobacter, Vibrio,* and *Yersinia* (Westwood 1994; Black 1996). Microbial contamination in coastal waters may change seasonally due to temperature, rainfall and other influences (Janelidze *et al.* 2011). The pathogenic bacterial inputs are undesirable situations with respect to public health, ecology and the environment.

Although the Sea of Marmara is an important basin between the Mediterranean and the Black Sea, data concerning bacterial composition for an understanding of ecological roles of the most abundant bacterial species are still scant in the area (Altug *et al.* 2009a; Altuğ 2012). Due to its peculiar hydrodynamic characteristics and the various pollution factors mentioned above, the Sea of Marmara offers unique opportunities for researching bacterial composition under different, poorly described conditions. This chapter summarizes bacteriological studies conducted in the Sea of Marmara in recent 30 years.

## 2. Fecal Pollution

Fecal pollution is a worldwide public and ecosystem health problem that affects many coastal and marine waters. Therefore, it is necessary to monitor microbiological water quality to reduce public health risk and to protect water quality (WHO 2003). The Sea of Marmara is an inland sea which is surrounded by 7 cities and under pressure of urbanization and industrialization. It is used for marine transportation, fisheries, aquaculture, tourism and recreation activities and receiving fecal contamination from both point and non-point sources. Only from Istanbul 25 and in total more than 40 marine outfalls discharging municipal and industrial wastewater into the Sea of Marmara (TUBITAK-MAM 2010; ISKI 2015).

There are many studies focusing on indicator bacteria concentrations, bacterial pathogens and source tracking of fecal pollution from water, sediment and biota in the Sea of Marmara. Altug *et al.* (2008a) were investigated indicator and some pathogen bacteria in two bivalve species (*Chamelea gallina* and *Donax trunculus*) which was collected from the northern coast (Tekirdag) of the Sea of Marmara between November 2005 and December 2006. It was indicated that the maximum concentrations of FIB (*E. coli*, total coliform and fecal coliform) were recorded in August and few samples from summer session were positive for *Salmonella* spp. in both species. Another study was done by Altug *et al.* (2012) investigated the occurrence of pathogenic bacteria in the ships' ballast water coming from different regions of the world to the Sea of Marmara between 2009 and 2010. According to study 27 pathogenic bacteria belonging to 17 familia were detected and this was indicating that the ships carry a potential risk for the Sea of Marmara. Sivri *et al.* (2014a) were assessed total coliform bacteria (TCB) concentrations and genetic heterogeneity of *E. coli* using PCR/DGGE for two years (January 2009- December 2010) in south-western coastal area of Istanbul. It was reported that mean TCB concentrations ranged from $10^1$ to $10^4$ MPN per 100 ml. Additionally there was temporal and spatial genetic homogeneity in *E. coli* marine populations. Similarly another study which was investigated *E. coli* at surface and deep waters of Kapidag Penunsula from 2010-2011 reported genetic homogeneity of studied *E.coli* populations (Sivri *et al.* 2013).

Golden Horn Estuary is one of the remarkable research area, which is located at southwest of the Strait of Istanbul. It had historically been polluted by urban pollution and has gone through a series of rehabilitation efforts. Aslan-Yilmaz *et al.* (2004) were monitoring indicator bacteria levels for five years from 1998 to 2002. Authors indicated that surface fecal coliform was above $10^6$ CFU/100 ml at the inner part in 1998 and both fecal coliform and enterococci counts gradually decreased below $10^3$ CFU/100 ml in the summer of 2002. Another study was done by Zeki (2012) assessed microbial water quality of the estuarine surface waters over a one-year period (February 2011 - January 2012) using membrane filtration and quantitative PCR (qPCR) methods to test for traditional (fecal coliform, enterococci, *E. coli*) and alternative indicators (*Bacteroides thetaiotaomicron*) of fecal pollution. It was reported that fecal coliform and *E. coli* mean concentrations were $1.84\times10^3$ CFU/100ml and $2.98\times10^4$ cell equivalent (CE) per 100ml respectively. *Enterococci* mean concentrations in the estuary were $1.24\times10^4$ CFU/100ml by membrane filtration and $4.62\times10^4$ CE/100ml by qPCR. *Bacteroides thetaiotaomicron* concentrations ranged from below the detection limit to $2.42\times10^4$ CE/100ml by qPCR. Studies indicated that despite of the rehabilitation studies and controlling all point sources, there is still sewage intrusion to the Golden Estuary and FIB concentrations significantly increase after rainfall events. Alibey and Kagithane creeks feeding the estuary were the main sources of sewage pollution (Zeki *et al.* 2013).

Currently, microbial water quality criteria are regulated under Surface Water Quality Directive (2015), Bathing Water Quality Directive (2006) and Water Pollution Control Directive (2004) in Turkey. Regulations require monitoring of fecal indicator bacteria (total coliforms, fecal coliforms, enterococci and *E. coli*), *Salmonella* and enterovirus in coastal, marine and freshwaters. Researchers reported that fecal indicator bacteria concentrations were mostly above national criteria in the studied sampling sites and various pathogenic bacteria were isolated from recreational areas of the Sea of Marmara between 1991 and 2012 (Cotuk and Kimiran 1998; Aslan-Yilmaz *et al.* 2004; Ciftci and Altug 2010a; Altug *et al.* 2010c; Sivri and Seker 2010; Zeki 2012; Sivri *et al.* 2012a; Altug *et al.* 2013; Balkıs *et al.* 2013; Gurun and Kimiran-Erdem 2013; Sivri *et al.* 2013, Sivri *et al.* 2014a).

## 3. Bacterial Diversity

Researches on marine bacterial diversity are important in order to understand the community structure and distribution patterns in marine ecosystems. Although culture-independent studies have served as common applications in detecting bacterial diversity, there are also a number of studies in which it has been shown that cultured strains of marine bacteria can represent significant fractions of the bacterial biomass in sea water (Rehnstam *et al.* 1993; Pinhassi *et al.* 1997). Based on DNA–DNA hybridization of the genomic DNAs of isolates obtained with the traditional medium against community DNA, it has been suggested that readily culturable bacteria are abundant in the marine water column (González and Moran 1997). There are several studies focusing on bacterial diversity of the Sea of Marmara using both culture and molecular methods.

Kimiran-Erdem *et al.* (2007) were isolated hundred *Enterococcus* strains from seawater samples collected from coastal areas of Istanbul and indicated that *Enterococcus faecalis* (96%) was the most abundant species. Altug *et al.* (2011b) reported 22 aerobic heterotrophic culturable bacteria species from the southern part of the Sea of Marmara between 2006 and 2007. Authors indicated that the species belonging to the *Enterobacteriacea* family were the most prevalent. Highest bacteria species were belong to the Gammaproteobacteria class followed by Actinobacteria and Bacilli classes respectively. In another study, Cardak and Altug (2014) reported 17 species belong to *Enterobacteriaceae* at three stations located north of Sea of Marmara between February 2006 and March 2007. It was indicated that the most common species was *E. coli* (27.28%) whereas the least common species were *Enterobacter gergoviae* and *Enterobacter aerogenes* (1.59%) among the total of 126 isolates. *Pseudomonas aeruginosa* was isolated by Sivri *et al.* (2014b) using rapid method from Istanbul coastal area. Gammaproteobacteria which includes pathogenic species have been reported to be the most abundant group in the Sea of Marmara water column (Altug *et al.* 2011b; Quaiser *et al.* 2011; Altug *et al.* 2012; Altug *et al.* 2013). Bacterial diversity of the Sea of Marmara which was prepared according to reviewed studies is given at Table 1.

**Table 1.** List of bacterial species from water and sediment of the Sea of Marmara (Kimiran-Erdem *et al.* 2007; Cetecioglu *et al.* 2009; Altug *et al.* 2011b; Altug *et al.* 2013; Sutcuoglu and Korun 2011; Cardak and Altug 2014; Sivri *et al.* 2014b)

| **Species** |
|---|
| **Propionibacteriaceae** |
| *Propionibacterium acnes* (sic) (Gilchrist 1900) Douglas and Gunter 1946 |
| *Propionibacterium* sp. |
| **Dermacoccaceae** |
| *Dermacoccus nishinomiyaensis* (Oda, 1935) Stackebrandt *et al.* 1995 |
| **Micrococcaceae** |
| *Micrococcus luteus* Lehmann and Neumann 1896 |
| **Flavobacteriaceae** |
| *Chryseobacterium indologenes* (Yabuuchi *et al.* 1983) Vandamme *et al.* 1994 |
| **Dehalococcoidaceae** |
| *Dehalococcoides mccartyi* Löffler *et al.* 2013 |
| **Alicyclobacillaceae** |
| *Alicyclobacillus acidoterrestris* (Deinhard *et al.* 1988) Wisotzkey *et al.* 1992 |
| **Bacillaceae** |
| *Bacillus cereus* Frankland and Frankland 1887 |
| *Bacillus mycoides* Flügge 1886 |
| *Bacillus pumilus* Meyer and Gottheil 1901 |
| *Bacillus thuringiensis* Berliner 1915 |
| *Bacillus vallismortis* Roberts *et al.* 1996 |

*Virgibacillus pantothenticus* (Proom and Knight 1950) Heyndrickx *et al.* 1998

**Staphylococcaceae**

*Staphylococcus epidermidis* (Winslow and Winslow 1908) Evans 1916

*Staphylococcus hominis* Kloos and Schleifer 1975 emend. Kloos *et al.* 1998

*Staphylococcus intermedius* Hajek 1976

*Staphylococcus lentus* (Kloos *et al.* 1976) Schleifer *et al.* 1983

**Carnobacteriaceae**

*Trichococcus pasteurii* (Schink 1985) Liu *et al.* 2002

**Enterococcaceae**

*Enterococcus faecalis* (Andrewes and Horder 1906) Schleifer and Kilpper-Balz 1984

*Enterococcus gallinarum* (Bridge and Sneath 1982) Collins *et al.* 1984

*Enterococcus solitarius* Collins *et al.* 1989

**Lactobacillaceae**

*Pediococcus pentosaceus* Mees, 1934

**Streptococcaceae**

*Lactococcus lactis* ssp. *lactis* (Lister, 1873) Schleifer *et al.* 1986

*Streptococcus pneumoniae* (Klein 1884) Chester 1901

**Clostridiaceae**

*Clostridium glycolicum* Gaston and Stadtman 1963

**Caulobacteraceae**

*Brevundimonas vesicularis* (Büsing *et al.* 1953) Segers *et al.* 1994

**Brucellaceae**

*Brucella melitensis* (Hughes 1893), Meyer and Shaw 1920

**Sphingomonadaceae**

*Sphingomonas paucimobilis* (Holmes *et al.* 1977) Yabuuchi *et al.* 1990

**Alcaligenaceae**

*Alcaligenes faecalis* ssp. *faecalis* (Castellani and Chalmers 1919) Austin *et al.* 1981

**Desulfuromonadaceae**

*Pelobacter propionicus* Schink 1984

**Geobacteraceae**

*Geobacter metallireducens* Lovley *et al.* 1995

*Geobacter uraniireducens* Shelobolina *et al.* 2008

**Enterobacteriaceae**

*Citrobacter braakii* Brenner *et al.* 1993

*Citrobacter freundii* Werkman and Gillen 1932

*Enterobacter aerogenes* Hormaeche and Edwards 1960

*Enterobacter cloacae* (Jordan 1890) Hormaeche and Edwards 1960

*Enterobacter gergoviae* Brenner *et al.* 1980
*Enterobacter sakazaki* (Farmer *et. al.* 1980)
*Escherichia coli* (T. Escherich, 1885)
*Klebsiella ornithinolytica* Sakazaki *et al.* 1989
*Klebsiella oxytoca* (Flügge 1886) Lautrop 1956
*Klebsiella pneumoniae* (Schroeter 1886) Trevisan 1887
*Klebsiella pneumoniae* ssp. *pneumoniae* (Schroeter 1886) Ørskov 1984
*Pantoea agglomerans* (Ewing and Fife 1972) Gavini *et al.* 1989
*Proteus mirabilis* Hauser 1885
*Proteus vulgaris* Hauser 1885
*Salmonella enterica* (*ex* Kauffmann and Edwards 1952) Le Minor and Popoff 1987
*Salmonella enterica* ssp. *arizonae* (Borman 1957) Le Minor and Popoff 1987
*Salmonella typhi* (Schroeter 1886) Warren and Scott 1930
*Serratia fonticola* (Gavini *et al.* 1979)
*Serratia liqefaciens* (Grimes and Hennerty 1931) Bascomb *et al.* 1971
*Serratia marcescens* Bizio, 1823
*Serratia odorifera* Grimont *et al.* 1978
*Serratia plymuthica* (Lehmann and Neumann 1896) Breed *et al.* 1948
**Vibrionaceae**
*Vibrio fluvialis* Lee *et al.* 1981
*Vibrio vulnificus* (Reichelt *et al.* 1979) Farmer 1980
*Vibrio alginolyticus* (Miyamoto *et al.* 1961) Sakazaki 1968
**Aeromonadaceae**
*Aeromonas hydrophila* (Chester, 1901) Stanier, 1943
*Aeromonas caviae* (*ex* Eddy 1962) Popoff 1984
**Shewanellaceae**
*Shewanella algae* Simidu *et al.* 1990
*Shewanella putrefaciens* (Lee *et al.* 1981) MacDonell and Colwell 1986
**Ectothiorhodospiraceae**
*Alkalilimnicola ehrlichii* Hoeft *et al.* 2007
**Lysobacteraceae**
*Stenotrophomonas maltophilia* (Hugh 1981) Palleroni and Bradbury 1993
**Pseudomonadaceae**
*Pseudomonas aeruginosa* (Schroeter 1872) Migula 1900
*Pseudomonas luteola* Kodoma *et al.* 1985
*Pseudomonas oryzihabitans* Kodama *et al.* 1985
*Pseudomonas putida* (Trevisan 1889) Migula 1895

Few studies have assessed bacterial diversity of water column and sediment of the Sea of Marmara using molecular techniques. Cetecioglu *et al.* (2009) detected 48 bacterial species in anoxic marine sediments. It was observed that bacterial communities were very similar among sampling sites at time of study. Kolukirik *et al.* (2011) and Ince *et al.* (2010) were detected 234 bacterial OTUs from 10 different most polluted locations of Sea of Marmara sediment. The bacterial communities were dominated by Proteobacteria (32-48%) as well as Marmara Bacterial Clusters (13-23%) which was unique to Sea of Marmara. Similarly, the study conducted by Quaiser *et al.* (2011) indicated that Gamma- and Alpha-proteobacteria, followed by Bacteroidetes, were dominated the bacterial communities in Marmara deep-sea water column (from 500m to 1250m), whereas Planctomycetes, Delta- and Gamma-proteobacteria were the most abundant groups in sediment.

## 4. Bacterial Heterotrophic Activity

The classification of bacteria is carried out according to common feeding types. Therefore, bacteria are divided into heterotrophic bacteria provides energy by using organic materials and autotrophic bacteria that oxidized inorganic substances and provides energy. “Heterotrophic bacteria” term covers all the bacteria that use organic nutrients for growth. These bacteria are found all kind of water supply, food, soil, air, and plants. This broad description contains a primary or secondary disease-causing bacteria and the coliforms that indicative for bacteriological contamination factor in the environments (Allen *et al.* 2004). Heterotrophic bacteria play an important role in the biological breakdown of organic material in the marine environment (bio-degradation) (Deming and Baross 1993). The structure of microbial communities is sensitive to changes in ambient environmental conditions and trophic levels (Danovaro *et al.* 2000) and it depends on nutrient inputs which is especially entering the environment from anthropogenic activities (Jensen *et al.* 1990; Hansen and Blackburn 1992). Determination of levels of heterotrophic bacteria in marine environments is important for characterized the bacteriological quality of seawater.

There are many studies on determining the bacterial abundance (Sorokin *et al.* 1995) and their activity in the Sea of Marmara (Aslan Yılmaz and Okus 2002; Altug and Bayrak 2003a, 2003b; Altug and Icoz 2004a, b; Altug *et al.* 2007a; Altug 2008b; Altug *et al.* 2009a, b, c; Altug *et al.* 2010a, b; Altug *et al.* 2011a, b; Sivri *et al.* 2011, 2013; Altug *et al.* 2012; Altug *et al.* 2013; Cardak *et al.* 2015). Aslan-Yılmaz (2008) reported that the minimum cultivable heterotrophic bacteria (HPC) value as $0.38x10^8$ cell $lt^{-1}$ and the maximum HPC level as $16.5x10^8$ cell $lt^{-1}$ at the inner part of Izmit Bay. In another study the lowest HPC value was recorded as $0.4x10^5$ CFU/100ml (2002, around Prince’s Islands) and the highest value was reported as $18x10^8$ CFU/100 ml (2010, Istanbul coastal area sampling station) (Altug and Bayrak 2003a; Altug *et al.* 2010c). In another study, total aerobic mesophilic heterotrophic bacteria level were tested in the mucilage and surrounding water during mucilage occurrences in the Sea of Marmara. While the highest HPC level reported as $2.7x10^{10}$ CFU/100 ml in mucilage samples, the lowest HPC levels reported as $1x10^{5}$ CFU/ml in reference station samples (Altug *et al.* 2010d). Cardak *et al.* (2015) reported that the highest HPC was found to be $85±0.2x10^{8}$ CFU/100 ml in the seawater samples which were taken from the depth of 20 m the Istanbul Strait in the summer season and the lowest value was recorded as 57±0.2x10 CFU/100 ml with in the samples of Canakkale Strait in the autumn. These results showed that the aerobic mesophilic heterotrophic bacteria levels at Canakkale Strait were lower than the Istanbul Strait.

Identifying the metabolically active bacteria in the marine environment is important to determine the number of bacteria participated in the ecosystem cycles. It is known that increasing the metabolic active bacteria levels depend on the input nutrients into marine environments (Plante and Shriwer 1998; Stoderegger and Herndl 2001). The lowest metabolically active bacteria levels were recorded as 10.2±1.1% at the Prince's Islands seawater samples taken from 20 m depths (Altug and Bayrak 2003a), as 10.4% Istanbul Strait sample taken from 20 m depths, as 9% Papazburnu sample taken from 50 m depths (Altug *et al.* 2007a; Altug *et al.* 2011b) and as 10% the Canakkale Strait sample taken from 50 m depths in the winter season (Cardak *et al.* 2015). The highest metabolically active bacteria levels were recorded as 24.4% in the surface water in Küçükçekmece samples (Altug and Bayrak 2003a), as 36 % the samples which taken from Canakkale Strait (Altug *et al.* 2007a; Altug *et al.* 2011b) and 47% in the surface waters which were taken from 0-30 cm below of the Istanbul Strait in the summer season (Cardak *et al.* 2015).

## 5. Heavy Metal and Antibiotic Resistant Bacteria

Sources of metals in aquatic environments are natural or anthropogenic. However industrial activities such as ship dismantling and agriculture are incising heavy metals concentrations in seawater and sediment. Presence of these heavy metals in the marine environment may pose a serious threat to the environment because of their ability to persist for several decades (Kamala-Kannan and Lee 2008; Altug and Balkis 2009).

Although microorganisms are sensitive to various concentrations of heavy metals, they have mechanisms which enable them to proliferate in the environment by rapidly adapting to that environment and to convert heavy metals into harmless forms through biosorption or enzymatic transformation. Microorganisms develop various mechanisms in order to tolerate the metals. These mechanisms include converting into volatile form, extracellular precipitation, adsorbing cell surface, and intercellular accumulation. Also, bacteria perform chemical transformations of these metals. Heavy metal resistant microorganisms may be used in genetic transfer studies of the heavy metal resistance mechanism (De Rore *et al.* 1994; Cardak and Altug 2014). Thus, individual bacterial strains will develop their capacity to survive under toxicological stress and will be of importance in future bioremediation strategies. However, correlation is frequently observed in antibiotic resistance besides metal resistance because resistance genes in chromosome or plasmid are close to each other. Increases in antibiotic resistance lead to problems in the treatment of infectious diseases worldwide. Therefore, it is needed to be careful when pesticides, antimicrobials containing metals and antibiotics entering the environment are used (Kamala-Kannan and Lee 2008; Li and Ramakrishna 2011; Kacar *et al.* 2013).

Large amounts of antibiotics and metabolites are potentially released into the environment and this phenomenon is considered the most important factor for the evolution and selection of antibiotic resistance in bacterial pathogens (Allen *et al.* 1977). Spread of antimicrobial resistance is not necessarily restricted by phylogenetic, geographic, or ecological borders. Thus, use of antimicrobial agents in one ecological niche, such as in aquaculture, may impact the occurrence of antimicrobial resistance in other ecological niches, including the human environment. Previous studies confirmed that antibiotic resistance can be induced and spread rapidly among bacterial species (Wangand and Schaffner 2013). Therefore, water constitutes a way of dissemination of not only antibiotic resistant bacteria, but also the resistance genes, which genetically change in natural bacterial ecosystems (Baquero *et al.* 2008; Rosenblatt-Farrell 2009). The occurrence of antibiotic resistant bacteria (ARB) has been documented in various aquatic environments (Kümmerer 2004; Kim and Aga 2007; Schluter *et al.* 2007, Watkinson *et al.* 2007; Caplin *et al.* 2008; Vanneste *et al.* 2008). The studies showed that aquatic environment is potential reservoirs of ARB (Nonaka *et al.* 2000, 2007; Kim *et al.* 2003, 2004; Hoa *et al.* 2008). The prevalence and persistence of antibiotic resistance in bacterial pathogens are a threat to public health and a source of considerable concern (Andersson and Hughes 2010).

In a study by Kimiran-Erdem *et al.* (2007), a hundred *Enterococcus* strains were isolated from seawater samples collected from coastal areas of Istanbul. The species distribution was as follows *Enterococcus faecalis* (96%), *Enterococcus gallinarum* (3%) and *Enterococcus solitaries* (1%). The resistance of bacteria to both heavy metals (zinc [Zn], iron [Fe], cadmium [Cd], chrome [Cr], cobalt [Co]) and antibiotics (ampicillin 10 μg [AP], penicillin G 10 Units [PG], gentamycin 10 μg [GM], streptomycin 10 μg [S], chloramphenicol 10 μg [C], erythromycin 15 μg [E], kanamycin 30 μg [K], amikacin 30 μg [AK], nalidixic acid 30 μg [NA], and vancomycin 30 μg [VA]) was evaluated. None of the strains was resistant to VA. It was found that among the100 isolates, those that exhibit resistance to antibiotics, particularly NA, S and K, were also resistant all the heavy metals tested. To our knowledge this is the first report focusing on determination of resistance of environmental enterococci found in Istanbul against heavy metals and antibiotics.

Another study by Altug *et al.* (2007b) was investigated the frequency of some beta-lactam antibiotics and heavy metal resistance of *Enterobacteriaceae* members isolated from surface water of the Istanbul Strait, Golden Horn Estuary and Sea of Marmara. In all selected isolates, the highest resistance was found to Ceftazidim as 48 %. 55 % of the strains resistant to antibiotics were also resistant to heavy metal salts. In all selected isolates, the highest resistance was found against Zn amounting to 35 %. It was hypothesized that bacteria resistant to high concentrations of heavy metal salts would have potential capacities to tolerate or possibly degrade a variety of toxic materials and thus, would be important in environmental pollution bioremediation. Also indirect influences of bacterial pollution and negative environmental conditionals maybe assumed to be related to antibiotic-resistant strains. The fact that 55% of the bacteria resistant to antibiotics are also resistant to heavy metals suggests that transfer of resistance takes place via plasmids.

Cardak and Gencer (2010) were assessed bacteriological pollution indicators and their resistance to beta-lactam antibiotics in Çanakkale Strait surface waters between May and September 2010. It was reported that the highest level of indicator microorganisms found in center of Çanakkale, Kepez and Dardanos stations. Isolates showed elevated resistance to kanamycin, vancomycin and ampicillin. It was indicated that antibiotic resistance level which determined highly in coastal areas was showed that area was affected by land based pollution.

Sivri and Akbulut (2016) were reported the highest resistance rates to ampicillin (74.4%) and amoxicillin (47.4%) from 194 isolated strains of *E.coli* which were sampled from Istanbul's shoreline between January 2009 and December 2011. 84.4% of the isolates were found to be resistant to at least one or more antibiotic, 63.4% were resistance to 2 or more antibiotics and 24.7% were resistant to 5 or more antibiotics. In addition, no resistance was reported to the antibiotic imipenem.

Cardak *et al.* (2016) investigated the frequency of antibiotic resistance of *Enterobacteriaceae* and the presence of vancomycin-resistance genes in water samples taken from the Sea of Marmara, Istanbul and Canakkale Straits. Various colony-forming bacteria were isolated and tested against amoxicillin, ampicillin, aztreonam, ceftazidime, cefotaxime, cefuroxime, ofloxacin, vancomycin, tetracycline, kanamycin and gentamycin. Additionally the presences of Vancomycinresistance genes (vanA and vanB) were investigated. It was reported that the level of *Enterobacteriaceae* species was higher in the Sea of Marmara than the Istanbul Strait and the Canakkale Strait. Isolates showing resistance to the greatest number of antibiotics were identified from *E. coli* isolates. The resistances of the selected bacterial isolates were as follows: kanamycin (82%), vancomycin (78%) and ampicillin (60%). Some intermediately vancomycin-resistant *Enterobacteriaceae* isolates had the vanA gene. The study provided evidence of widespread bacterial resistance to clinically relevant antibiotics in marine environments.

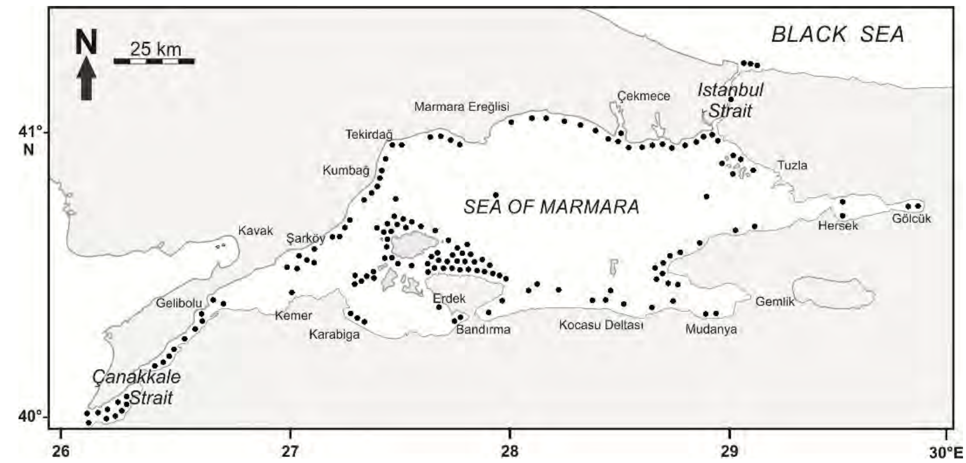


**Figure 1** Antibiotic and heavy metal resistance samples taken from the Sea of Marmara, Istanbul and Canakkale Straits, Turkey.

Another study was focused on fecal indicator bacteria concentrations and antibiotic resistance of isolated Gram negative bacilli from Kucukcekmece Lagoon surface waters between 2006 and 2008 (Sivri *et al.* 2012b). It was reported that a total of 232 Gram negative bacilli were isolated and screened for antibiotic resistance against 9 antibiotics. Isolated bacteria were most resistant against ampicillin (76.29%) and most sensitive against amikacin (93.56%). 8.6% (20 out of 232) of coliform isolates were found to contain class 1 and/or class 2 integrons. Integrons harbored various gene cassettes, including *dfrA12, dfrA15, dfrA17, aadA1, aadA2, aadA5,* $bla_{OXA\text{-}30}$ *and sat2*. As a result it was indicted that there is a heavy fecal contamination in Kucukcekmece Lagoon which might probably be due to intensive anthropogenic activities. There is public health risk if that resistance genes are transferred from environmental bacterial isolates to human microbiota bacteria (Altug *et al.* 2007b, Sivri *et al.* 2010, Sivri *et al.* 2011).

## 6. Microbial Degradation of Petroleum Hydrocarbon Contaminants

The fate of spilled oil in the marine environments depends on a number of factors such as evaporation, dissolution, microbial degradation and photooxidation. Understanding the degradation capability of bacteria and selecting of the most suitable oil degrading bacteria are important for bioremediation process (Reisfeld *et al.* 1972). It’s important that determining the best candidate strains which were isolated from potentially hydrocarbon polluted marine areas for furthers bioremediation studies. The studies to investigate the petroleum hydrocarbon degradation ability of the bacteria isolated from the Sea of Marmara are summarized below.

Altug *et al.* (2007c) investigated the bacteria which were isolated potentially hydrocarbon polluted areas from the Sea of Marmara and tested with respect to their oil degradation effect against different kind of crude oil samples (Lebanon, Iranian, Russian and Turkey). *Serratia marcescens* PÇ05, *Escherichia coli* PÇ01, *Eikenella corrodens* PÇ02, *Vibrio fluvialis* PÇ04, *Enterobacter cloace* PÇ06 strains were reported as haydrocarbon degarading strains.

The mixed cultures of *V. fluvialis, S. marcescens* and *Klebsiella pneumoniae* isolated from the Sea of Marmara have been reported as effecive against Batman crude oil (Cardak *et al.* 2007). However, the *Enterobacter sakazakii* isolated from the Sea of Marmara reported as a candidate species that can be used in bioremediation of oil pollution and it followed by *E. feacalis* and *Eikenella corrodens,* respectively (Altug *et al.* 2009c). Ciftci and Altug (2010b) reported that *E. sakazakii*-112 was recorded as the best candidate species between bacteria isolated from the Sea of Marmara for bioremediation studies.

Total 103 wild bacterial strains isolated from different locations in Turkey were investigated to better understand the oil degradation capacity. *Escherichia coli* MDK04, *Bacillus subtilis* BR02, *Vibrio fluvialis* MD03, *Staphylococcus haemolyticus* GA01, *Pseudomonas aeruginosa* BR03 strains and their mixed cultures determined and reported as candidate strains (Altug *et al.* 2011b). These studies outlined above will be an advantage in future oil pollution bioremediation studies in the Sea of Marmara.

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**PHYTOPLANKTON OF THE SEA OF MARMARA: A REVIEW**

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## 1. Introduction

The first studies on plankton were systematic research; however ecologic research conducted to reveal the relationship between productivity and planktonic organisms stand forefront today. Initial studies on phytoplankton in the Sea of Marmara and the straits were carried out in 1974 (Artuz 1974). Phytoplankton studies increased especially after 2000s (Table 1), not only detection of species but also their abundance and relationship with environmental variables started to be analyzed in detail. Most of the studies are regional studies including bays and gulfs; and generally involve data of seasonal sampling periods.

**Table 1.** Distribution of phytoplankton research in the Turkish Straits System.

| **Period** | **Reserach Number** | **Literatures** |
|---|---|---|
| 1970-1980 | 1 | Artuz (1974) |
| 1981-1990 | 2 | Bingel *et al.* (1986); Aubert *et al.* (1990) |
| 1991-2000 | 3 | Uysal (1996); Uysal and Unsal (1996); Balkis (2000). |
| 2001-2010 | 21 | Aktan and Aykulu (2003; 2005); Aktan *et al.* (2003, 2005); Balkis (2003, 2004); Balkis *et al.* (2004); Tas and Okus (2003, 2004); Deniz *et al.* (2006); Okus and Tas (2007); Tas *et al.* (2006, 2009); Turkoglu (2008); Deniz and Tas (2009); Turkoglu (2010a, b); Turkoglu and Erdogan (2010); Turkoglu and Oner (2010); Albayrak *et al.* (2010); Tüfekci *et al.* (2010). |
| 2011- | 8 | Altug *et al.* (2011); Balkis *et al.* (2011); Tas *et al.* (2011); Aktan *et al.* (2014); Balkis and Toklu-Alicli (2014); Tas (2015); Tas and Yilmaz (2015); Tas and Lundholm (2016). |

In accordance with the current literature, phytoplankton samples were collected via plankton nets with different mesh sizes or water samplers with 1-5 litre capacity, and protected by means of acidic lugol or neutralized formaldehyde solution. Most researchers have referred to fundamental resources such as Lebour (1930), Cupp (1943), Tregouboff and Rose (1957), Hendey (1964), Sournia (1968, 1986), Steidinger and

Williams (1970), Drebes (1974), Taylor (1976), Rampi and Bernhard (1978, 1980), Dodge (1982), Ricard (1987), Balech (1988), Delgado and Fortuno (1991), Hasle and Syvertsen (1997), Steidinger and Tangen (1997), Throndsen (1997) for the identification of species. In the present study, MarBEF data system (http://www.marbef.org/data/erms.php) and WoRMS World Register of Marine Species (http://www.marinespecies.org/) were used for the systematics and current naming of the detected species.

The first check-list study was conducted in 2004 in the region (Balkis 2004), a total of 168 phytoplankton species were reported. Having increased in the Sea of Marmara including the straits after the year 2004, phytoplankton studies have reported 333 phytoplankton species, 40 of which are in genus level, until today (Table 2). Species list was designed in accordance with the published articles conducted in the region; however three studies which were conducted in 1974 and 1990 and consisted of project report and master's thesis (Artuz 1974; Bingel *et al.* 1986; Aubert *et al.* 1990) were included in the list since they were the first phytoplankton studies conducted in the Sea of Marmara. In addition, the species list gave place to studies conducted on benthic microalgae living in sediment that can pass into water column through the mixture of water (Aktan and Aykulu 2003, 2005; Aktan *et al.* 2014). Changes especially in genus level during current naming of species are presented in the table along with new naming of the species reported in the region. The dinoflagellate genus *Tripos* Bory is here given as a new nomenclature name which replaces *Neoceratium*, marine species of *Ceratium*.

The highest number of species was found in Bacillariophyceae with 162 species (49%) followed by Dinophyceae with 124 species (37%) (Table 2 and 3). The contribution of other groups (Cyanophyceae, Cryptophyceae, Raphidophyceae, Chrysophyceae, Dictyochophyceae, Prymnesiophyceae, Euglenophyceae, Prasinophyceae and Chlorophyceae) to the number of species in the region is 14% (47 species). The highest number of species was found in genus *Protoperidinium* (35 species) of Dinophyceae and genus *Chaetoceros* (29 species) of Bacillariophyceae. *Protoperidinium* genus, which is dominant in terms of the number of species within dinoflagellates, was represented with one species in the Bosporus. Similarly, the number of representatives of this genus in the Dardanelles was very few (8 species). Of this genus, 16 species and 30 species were reported from the Golden Horn Estuary and the Sea of Marmara, respectively. *Dinophysis* and *Tripos*, which are dominant genus of dinoflagellates; and *Chaetoceros,* which is the dominant genus of diatoms, have very limited number of representatives in the Bosporus. The reasons of regional differences in genus in terms of their number of species can be ranged as follows; general hydrographical conditions such as salinity, flow regime etc. and adaptation to the environment.

**Table 2.** Phytoplankton species reported from the Turkish Straits System. B: Bosphorus (=İstanbul Strait); SM: Sea of Marmara; D: Dardanelles (=Çanakkale Strait); GHE: Golden Horn Estuary

| **Species** | **B** | **GHE** | **SM** | **D** |
|---|---|---|---|---|
| **Cyanophyceae** | | | | |
| *Anabaena* sp. | | | + | |
| *Aphanocapsa* sp. | | | + | |
| *Aphanoteche* sp. | + | | | |
| *Lyngbya* sp. | | | + | |
| *Merismopedia glauca* (Ehrenberg) Kützing | + | | + | |
| *Merismopedia tenuissima* Lemmermann | | | + | |
| *Microcystis* cf. *aeruginosa* (Kützing) Kützing | | + | | |
| *Oscillatoria limosa* C.Agardh ex Gomont | + | | + | |
| *Oscillatoria tenuis* C.Agardh ex Gomont | + | | + | |
| *Oscillatoria* sp. | | + | + | |
| *Phormidium chalybeum* (Mertens ex Gomont) Anagnostidis & Komárek [=*Oscillatoria chalybea* Mertens ex Gomont] | | | + | |
| *Phormidium* sp. | + | | | |
| *Planktothrix* sp. | | | + | |
| *Pseudoanabaena* sp. | | | + | |
| *Schizothrix* sp. | | | + | |
| *Spirulina* sp. | + | | + | |
| *Synechococcus* sp. | + | | | |
| | | | | |
| **Bacillariophyceae** | | | | |
| *Achnanthes brevipes* Agardh | | | + | |
| *Achnanthes* sp. | + | | | |
| *Actinocyclus* sp. | | + | | |
| *Amphipleura* sp. | + | | | |
| *Amphora delicatissima* Krasske | | | + | |
| *Amphora ovalis* (Kützing) Kützing | + | | + | |
| *Aneumastus tuscula* (Ehrenberg) D.G.Mann & A.J.Stickle (= *Navicula tuscula* Ehrenberg) | + | | + | |
| *Anorthoneis excentrica* (Donkin) Grunow | | | + | |
| *Asterionella bleakeleyii* W. Smith | | | + | |
| *Asterionellopsis glacialis* (Castracane) Round | | + | + | |
| *Asterolampra grevillei* (Wallich) Greville | | | | + |

| | | | | |
|---|---|---|---|---|
| *Bacillaria paxillifera* (O. F. Müller) Hendey | | | + | |
| *Bacteriastrum delicatulum* Cleve | | | + | |
| *Bacteriastrum hyalinum* Lauder | | + | + | |
| *Caloneis* sp. | | + | + | |
| *Cerataulina pelagica* (Cleve) Hendey (=*Cerataulina bergonii* (H.Peragallo) Schütt | | + | + | + |
| *Ceratoneis closterium* Ehrenberg (=*Cylindrotheca closterium* (Ehrenberg) Reimann and Lewin = *Nitzschia closterium* (Ehrenberg) W.Smith | + | + | + | + |
| *Chaetoceros affinis* Lauder | | + | + | |
| *Chaetoceros brevis* Schütt | | + | + | |
| *Chaetoceros compressus* Lauder | | + | + | |
| *Chaetoceros constrictus* Gran | | | + | |
| *Chaetoceros costatus* Pavillard | | | + | |
| *Chaetoceros criophilus* Castracane | | + | | |
| *Chaetoceros curvisetus* Cleve | + | + | + | |
| *Chaetoceros danicus* Cleve | | | + | |
| *Chaetoceros debilis* Cleve | | + | + | |
| *Chaetoceros decipiens* Cleve | | + | + | |
| *Chaetoceros densus* (Cleve) Cleve | | | + | |
| *Chaetoceros diadema* (Ehrenberg) Gran | | + | + | |
| *Chaetoceros didymus* Ehrenberg | | + | + | |
| *Chaetoceros diversus* Cleve | | | + | |
| *Chaetoceros fragilis* Meunier | | + | + | |
| *Chaetoceros holsaticus* Schütt | | + | + | |
| *Chaetoceros laciniosus* Schütt | | | + | |
| *Chaetoceros lauderi* Ralfs in Lauder | | | + | |
| *Chaetoceros lorenzianus* Grunow | | | + | |
| *Chaetoceros messanense* Castracane | | + | | |
| *Chaetoceros peruvianus* Brightwell | | | + | |
| *Chaetoceros rostratus* Lauder | | | + | |
| *Chaetoceros similis* Cleve | | + | | |
| *Chaetoceros simplex* Ostenfeld | | | + | |
| *Chaetoceros socialis* Lauder | | + | + | |
| *Chaetoceros subsecundus (*Grunow ex Van Heurck) Hustedt | + | | | |
| *Chaetoceros tortissimus* Gran | | + | + | |
| *Chaetoceros wighamii* Brightwell | | + | | |
| *Chaetoceros willei* Gran [=*Chaetoceros affinis* var. *willei* | | + | | |

| | | | | |
|---|---|---|---|---|
| (Gran) Hustedt] | | | | |
| *Climacosphenia* sp. | + | | + | + |
| *Cocconeis scutellum* Ehrenberg | + | | + | |
| *Coscinodiscus centralis* Ehrenberg | | | + | |
| *Coscinodiscus concinnus* W.Smith | | + | + | |
| *Coscinodiscus granii* Gough | | | + | |
| *Coscinodiscus lineatus* Ehrenberg | | | + | |
| *Coscinodiscus oculus-iridis* (Ehrenberg) Ehrenberg | | + | | |
| *Coscinodiscus perforatus* Ehrenberg | | + | + | |
| *Coscinodiscus radiatus* Ehrenberg | | + | + | |
| *Cyclotella* sp. | + | | | |
| *Cymbella* sp. | | | + | |
| *Dactyliosolen fragilissimus* (Bergon) Hasle (=*Rhizosolenia fragilissima* Bergon) | | + | + | + |
| *Detonula confervacea* (Cleve) Gran | | + | + | |
| *Detonula pumila* (Castracane) Gran [=*Schroederella delicatula* (H.Peragallo) Pavillard] | | + | + | + |
| *Diploneis bombus* (Ehrenberg) Cleve | | | + | |
| *Diploneis* sp. | + | | | |
| *Ditylum brightwellii* (T. West) Grunow in Van Heurck | + | + | + | |
| *Entomoneis alata (*Ehrenberg) Ehrenberg (=*Amphiprora alata* (Ehrenberg) Kützing) | | | + | |
| *Fragilaria* sp. | + | | | |
| *Fragilariopsis cylindrus* (Grunow) Krieger | | + | | |
| *Fragilariopsis oceanica* (Cleve) Hasle (=*Fragilaria oceanica* Cleve) | | | + | |
| *Grammatophora angulosa* Ehrenberg | | | | + |
| *Grammatophora marina* (Lyngbye) Kützing | + | | + | + |
| *Guinardia cylindrus* (Cleve) Hasle | | | + | |
| *Guinardia delicatula* (Cleve) Hasle (=*Rhizosolenia delicatula* Cleve) | | + | + | |
| *Guinardia flaccida* (Castracane) Peragallo | | + | + | |
| *Guinardia striata* (Stolterfoth) Hasle (=*Rhizosolenia stolterfothii* H. Peragallo) | | | + | |
| *Gyrosigma fasciola* (Ehrenberg) Cleve | + | | + | |
| *Halamphora coffeaeformis* (C.Agardh) Levkov [=*Amphora coffeaeformis* (C.Agardh) Kützing] | | | + | |
| *Halamphora costata* (W.Smith) Levkov (=*Amphora costata* W.Smith) | | | + | |

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|---|---|---|---|---|
| *Halamphora exigua* (Gregory) Levkov (=*Amphora exigua* Gregory) | | | + | |
| *Hantzschia amphioxys* (Ehrenberg) Grunow | + | | + | |
| *Helicotheca tamesis* (Shrubsole) Ricard | | | + | |
| *Hemiaulus hauckii* Grunow in Van Heurck | | | + | + |
| *Hemiaulus membranaceus* Cleve | | + | | |
| *Hemiaulus sinensis* Greville | | | + | |
| *Lauderia annulata* Cleve (= *L. borealis* Gran) | | | + | |
| *Leptocylindrus danicus* Cleve | + | + | + | + |
| *Leptocylindrus mediterraneus* (H.Peragallo) Hasle [=*Dactyliosolen mediterraneus* (Peragallo) Peragallo] | | | + | |
| *Leptocylindrus minimus* Gran | + | + | + | |
| *Licmophora abbreviata* C.Agardh | | | + | + |
| *Licmophora flabellata* (Greville) C.Agardh | | + | + | |
| *Licmophora paradoxa* (Lyngbye) C.Agardh | + | | + | |
| *Lyrella lyra* (Ehrenberg) Karajeva (=*Navicula lyra* Ehrenberg) | + | | + | |
| *Melosira moniliformis* (Müller) C.Agardh | + | + | + | |
| *Melosira nummuloides* C.Agardh | | + | + | |
| *Navicula cryptocephala* Kützing | + | | + | |
| *Navicula directa* (W.Smith) Ralfs | | | + | |
| *Navicula menisculus* Schumann | | | + | |
| *Navicula palpebralis* Brébisson *ex* W.Smith | + | | + | |
| *Navicula radiosa* var. *tenella* (Brébisson ex Kützing) Van Heurck | | | + | |
| *Navicula ramosissima* (C.Agardh) Cleve (=*N. ramosissima* var. *mucosa* (Aleem) Hendey | + | | + | |
| *Navicula tripunctata* (O.F.Müller) Bory de Saint-Vincent | | | + | |
| *Navicula viridula* var. *rostellata* (Kützing) Cleve (= *Navicula rostellata* Kütz.) | | | + | |
| *Neocalyptrella robusta* (G.Norman ex Ralfs) Hernández-Becerril & Meave del Castillo (=*Rhizosolenia robusta* G.Norman ex Ralfs) | | | + | |
| *Nitzschia frustulum* (Kützing) Grunow | | | + | |
| *Nitzschia longissima* (Brébisson) Ralfs | | + | + | + |
| *Nitzschia lorenziana* Grunow | | | + | |
| *Nitzschia palea* (Kützing) W.Smith | + | | + | |
| *Nitzschia rectilonga* Takano | | | + | |
| *Nitzschia sigma* (Kützing) W.Smith | | | + | |

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|---|---|---|---|---|
| *Nitzschia sigmoidea* (Nitzsch) W.Smith | | | + | |
| *Odontella sinensis* (Greville) Grunow | | | + | |
| *Paralia sulcata* (Ehrenberg) Cleve | | + | | |
| *Petrodictyon gemma* (Ehrenberg) D.G.Mann (=Surirella gemma Ehrenberg) | | + | | |
| *Petroneis humerosa* (Brébisson ex W.Smith) A.J.Stickle & D.G.Mann | + | | + | |
| *Pinnularia* sp. | + | | | |
| *Placoneis placentula (*Ehrenberg) Mereschkowsky [=*Navicula placentula* (Ehrenberg) Kützing] | + | | | |
| *Pleurosigma angulatum* (Queckett) W.Smith | | | + | |
| *Pleurosigma normanii* Ralfs in Pritchard | | + | + | |
| *Pleurosigma reversum* Gregory | | | + | |
| *Pleurosigma salinarum* (Grunow) Grunow | | | + | |
| *Pleurosigma* sp. | + | | | |
| *Proboscia alata* (Brigtwell) Sundstrôm (=*Rhizosolenia alata* Brightwell) | + | + | + | + |
| *Psammodictyon panduriforme (*W.Gregory) D.G.Mann | | | + | |
| *Pseudo-nitzschia calliantha* Lundholm, Moestrup & Hasle | | + | | |
| *Pseudo-nitzschia delicatissima* (Cleve) Heiden in Heiden and Kolbe | + | + | + | + |
| *Pseudo-nitzschia fraudulenta* (Cleve) Hasle | | | + | |
| *Pseudo-nitzschia pseudodelicatissima* (Hasle) Hasle | | | + | |
| *Pseudo-nitzschia pungens* (Grunow ex P.T.Cleve) Hasle | | + | + | + |
| *Pseudo-nitzschia seriata* (Cleve) H. Peragallo | + | + | + | |
| *Pseudosolenia calcar-avis* (Schultze) Sundstrôm (=*Rhizosolenia calcar-avis* Schultze) | | + | + | + |
| *Rhaphoneis* sp. | | + | | |
| *Rhizosolenia faeroensis* Ostenfeld | | | + | |
| *Rhizosolenia hebetata* Bailey | + | + | + | |
| *Rhizosolenia imbricata* Brightwell | | + | + | |
| *Rhizosolenia setigera* Brightwell | + | + | + | + |
| *Rhizosolenia styliformis* Brightwell | | + | + | |
| *Rhizosolenia temperei* H.Peragallo | | | + | |
| *Sellaphora pupula* (Kützing) Mereschkovsky (=*Navicula pupula* Kützing) | + | | | |
| *Skeletonema costatum* (Greville) Cleve | + | + | + | + |
| *Skeletonema* cf. *marinoi* Sarno & Zingone | | + | | |
| *Stellarima stellaris* (Roper) G.R.Hasle & P.A.Sims | | + | + | |

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|---|---|---|---|---|
| *Stephanopyxis turris* (Greville) Ralfs | | | + | |
| *Striatella unipunctata* (Lyngbye) Agardh | + | | + | + |
| *Surirella* sp. | + | | | |
| *Synedra parva* Kützing | | | + | |
| *Synedra* sp. | | | | + |
| *Tabularia fasciculata* (C.Agardh) D.M.Williams & Round [=*Synedra tabulata* (C.Agardh) Kützing) | + | | + | |
| *Thalassionema frauenfeldii (*Grunow) Tempère & Peragallo [=*Thalassiothrix frauenfeldii* (Grunow) Grunow] | | + | + | + |
| *Thalassionema nitzschioides* (Grunow) Mereschkowsky | | + | + | + |
| *Thalassiosira allenii* Takano | | + | + | |
| *Thalassiosira angulata* (Gregory) Hasle [=*Thalassiosira decipiens* (Grunow) E.G.Jørgensen] | | + | + | |
| *Thalassiosira anguste-lineata* (A.Schmidt) G.Fryxell and Hasle | | + | + | |
| *Thalassiosira antarctica* Comber | | | + | |
| *Thalassiosira eccentrica* (Ehrenberg) Cleve (=*Coscinodiscus exentricus* Ehrenberg) | | + | + | |
| *Thalassiosira fragilis* G.Fryxell | | | + | |
| *Thalassiosira gravida* Cleve | | + | + | |
| *Thalassiosira hyalina* (Grunow) Gran | | + | | |
| *Thalassiosira nordenskioeldii* Cleve | | | + | |
| *Thalassiosira rotula* Meunier | | + | + | |
| *Thalassiothrix longissima* Cleve & Grunow | | + | + | + |
| *Toxonidea insignis* Donkin | | | + | |
| *Triceratium* sp. | | + | | |
| *Trigonium alternans* (Bailey) A.Mann [=*Biddulphia alternans* (Bailey) Van Heurck] | | + | | |
| *Tryblionella apiculata* Gregory [=*Nitzschia apiculata* (Gregory) Grunow] | | | + | |
| | | | | |
| **Dinophyceae** | | | | |
| *Akashiwo sanguinea* (K.Hirasaka) G.Hansen & Ø.Moestrup (=*Gymnodinium sanguineum* Hirasaka) | | + | + | |
| *Alexandrium minutum* Halim | | | + | |
| *Amphidinium sphenoides* WüIff | | | + | |
| *Amphisolenia* sp. | | | + | |
| *Amylax triacantha* (Jörgensen) Sournia (=*Gonyaulax triacantha* Jörgensen) | | + | | |

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|---|---|---|---|---|
| *Archaeperidinium minutum* (Kofoid) Jørgensen (=*Protoperidinium minutum* (Kofoid) Loeblich III) | | + | + | |
| *Ceratocorys armata* (Schütt) Kofoid | | | + | |
| *Cladopyxis caryophyllum* (Kofoid) Pavillard | | | + | |
| *Dinophysis acuminata* Claparède and Lachmann | | + | + | + |
| *Dinophysis acuta* Ehrenberg | | + | + | |
| *Dinophysis caudata* Saville-Kent | | + | + | + |
| *Dinophysis fortii* Pavillard | | + | + | |
| *Dinophysis hastata* Stein | | + | + | |
| *Dinophysis odiosa* (Pavillard) Tai and Skogsberg | | | + | |
| *Dinophysis ovata* Claparéde and Lachmann | | | + | |
| *Dinophysis ovum* Schütt | + | | + | |
| *Dinophysis punctata* Jorgensen | | | + | |
| *Dinophysis rudgei* Murray & Whitting | | | | + |
| *Dinophysis sacculus* Stein | | + | + | |
| *Dinophysis schroederi* Pavillard | + | | | |
| *Dinophysis sphaerica* Stein | + | | | |
| *Dinophysis tripos* Gourret | | | + | |
| *Diplopsalis lenticula* Bergh | | + | + | + |
| *Dissodinium pseudocalani* (Gonnert) Drebes ex Elbrachter & Drebes | | | + | |
| *Dissodium* sp. | | + | | |
| *Gonyaulax diegensis* Kofoid | | | + | |
| *Gonyaulax fragilis* (Schütt) Kofoid | | + | + | |
| *Gonyaulax kofoidii* Pavillard | + | | | |
| *Gonyaulax monacantha* Pavillard | + | | + | |
| *Gotoius abei* Matsuoka | | | + | |
| *Gymnodinium biconicum* J.Schiller | + | | | |
| *Gymnodinium catenatum* H.W.Graham | | + | | |
| *Gymnodinium simplex* (Lohmann) Kofoid and Swezy | + | | + | + |
| *Gyrodinium fusiforme* Kofoid & Swezy | | | + | |
| *Gyrodinium spirale* (Bergh) Kofoid and Swezy | | | + | + |
| *Heterocapsa triquetra* (Ehrenberg) Stein | | + | + | + |
| *Kofoidinium velleloides* Pavillard | | | + | |
| *Lingulodinium polyedrum* (Stein) Dodge | | + | + | |
| *Mesoporos perforatus* (Gran) Lillick [=*Porella perforata* (Gran) Schiller] | | | + | |
| *Noctiluca scintillans* (Macartney) Kofoid and Swezy | | + | + | + |

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|---|---|---|---|---|
| *Ornithocercus quadratus* Schütt | | | + | |
| *Oxyphysis oxytoxoides* Kofoid | | + | + | |
| *Oxytoxum scolopax* Stein | | | + | + |
| *Palaeophalacroma* sp. | | | + | |
| *Phalacroma doryphorum* Stein, 1883 | + | | | |
| *Phalacroma rotundatum (*Claparéde and Lachmann) Kofoid and Michener | | + | + | + |
| *Podolampas elegans* Schütt | | | | + |
| *Podolampas palmipes* Stein | | + | + | |
| *Polykrikos kofoidii* Chatton | | + | | |
| *Polykrikos schwartzii* Bütschli | | | + | |
| *Prorocentrum arcuatum* Issel | | + | + | |
| *Prorocentrum compressum* (Bailey) Abé | | | + | + |
| *Prorocentrum cordatum* (Ostenfeld) Dodge [=*Prorocentrum minimum* (Pavillard) J.Schiller] | | + | + | + |
| *Prorocentrum dentatum* Stein | | | + | |
| *Prorocentrum gracile* Schütt | | + | + | |
| *Prorocentrum lima* (Ehrenberg) F.Stein | + | | + | + |
| *Prorocentrum micans* Ehrenberg | | + | + | + |
| *Prorocentrum scutellum* Schröder | + | + | + | + |
| *Prorocentrum triestinum* Schiller | | + | + | + |
| *Protoceratium reticulatum (*Claparède & Lachmann) Bütschli (=*Gonyaulax grindleyi* Reinecke) | | | + | + |
| *Protoperidinium bipes* (Paulsen) Balech | | | + | |
| *Protoperidinium brevipes* (Paulsen) Balech | | + | + | |
| *Protoperidinium brochii* (Kofoid and Swezy) Balech | | | + | |
| *Protoperidinium cerasus* (Paulsen) Balech | | | | + |
| *Protoperidinium claudicans* (Paulsen) Balech | | + | + | |
| *Protoperidinium conicum* (Gran) Balech | | + | + | |
| *Protoperidinium crassipes* (Kofoid) Balech | | | + | |
| *Protoperidinium curtipes* (Jørgensen) Balech | | | + | |
| *Protoperidinium curvipes* (Ostenfeld) Balech | | | + | |
| *Protoperidinium depressum* (Bailey) Balech | | + | + | |
| *Protoperidinium diabolus* (Cleve) Balech | | | + | |
| *Protoperidinium divergens* (Ehrenberg) Balech | | + | + | + |
| *Protoperidinium globulum* (Stein) Balech | | | + | |
| *Protoperidinium grande* (Kofoid) Balech | | + | + | |
| *Protoperidinium granii* (Ostenfeld in Paulsen) Balech | | + | + | + |

| | | | | |
|---|---|---|---|---|
| *Protoperidinium leonis* (Pavillard) Balech | | + | + | |
| *Protoperidinium longipes* Balech | | | + | + |
| *Protoperidinium mediterraneum* (Kofoid) Balech | | | + | |
| *Protoperidinium mite* (Pavillard) Balech | | | + | |
| *Protoperidinium oblongum (*Aurivillius) Parke & Dodge | | + | + | |
| *Protoperidinium oceanicum* (Vanhöffen) Balech | | | + | |
| *Protoperidinium ovatum* Pouchet | | | + | |
| *Protoperidinium ovum* (Schiller) Balech | | | | + |
| *Protoperidinium paulsenii* Pavillard | | | + | |
| *Protoperidinium pallidum* (Ostenfeld) Balech | | + | + | |
| *Protoperidinium pellucidum* Bergh | | + | + | |
| *Protoperidinium pentagonum* (Gran) Balech | | + | + | |
| *Protoperidinium punctulatum* (Paulsen) Balech | | + | + | |
| *Protoperidinium pyriforme* (Paulsen) Balech | | + | + | |
| *Protoperidinium quarnerense* (B.Schröder) Balech | | | | + |
| *Protoperidinium quinquecorne* (Abé) Balech (=*Peridinium quinquecorne* Abé) | | | | + |
| *Protoperidinium simulum* (Paulsen) Balech | | | + | |
| *Protoperidinium steinii* (Jörgensen) Balech | + | + | + | + |
| *Protoperidinium subinerme* (Paulsen) Loeblich III | | | + | |
| *Protoperidinium* cf. *thorianum* (Paulsen) Balech | | + | | |
| *Pyrophacus horologium* Stein | | + | + | + |
| *Pyrophacus steinii* (Schiller) Wall & Dale | | | + | |
| *Pyrocystis hamulus* Cleve | | | + | |
| *Pyrodinium* sp. | | | + | |
| *Scaphodinium mirabile* Margalef | | | + | |
| *Scrippsiella trochoidea* (Stein) Loeblich III | | + | + | + |
| *Spiraulax jolliffei* (Murray et Whitting) Kofoid (=*Spiraulax kofoidii* Graham) | + | | | |
| *Torodinium* sp. | | | + | |
| *Triadinium polyedricum* (Pouchet) Dodge [=*Goniodoma polyedricum* (Pouchet) Jørgensen] | + | | + | + |
| *Tripos arietinus* (Cleve) F.Gómez | | + | + | |
| *Tripos candelabrus* (Ehrenberg) F.Gómez | | | + | + |
| *Tripos carriensis* (Gourret) F.Gómez | | | + | |
| *Tripos contortus* var. *karstenii* (Pavillard) F.Gómez | | | + | |
| *Tripos* cf. *dens* (Ostenfeld & Johannes Schmidt) F.Gómez | | | + | |
| *Tripos furca* (Ehrenberg) F.Gómez | + | + | + | + |

| | | | | |
|---|---|---|---|---|
| *Tripos fusus* (Ehrenberg) F.Gómez | + | + | + | + |
| *Tripos gibberus* (Gourret) F.Gómez | | | + | |
| *Tripos horridus* (Cleve) F.Gómez | | + | + | |
| *Tripos inflatus* (Kofoid) F.Gómez | | | + | |
| *Tripos kofoidii* (Jörgensen) F.Gómez | | | + | |
| *Tripos lineatus* (Ehrenberg) F.Gómez | | + | + | |
| *Tripos longipes* (J.W.Bailey) F.Gómez | | | + | |
| *Tripos longirostrus* (Gourret) F.Gómez | | | + | |
| *Tripos macroceros* (Ehrenberg) F.Gómez | | + | + | + |
| *Tripos minutus* (Jörgensen) F.Gómez | | | + | |
| *Tripos muelleri* Bory (=*Ceratium tripos* (O. F. Müller) Nitzsch | + | + | + | + |
| *Tripos pentagonus* (Gourret) F.Gómez | | | + | + |
| *Tripos pulchellus* (Schröder) F.Gómez | | | + | |
| *Tripos trichoceros* (Ehrenberg) F.Gómez | | + | + | + |
| | | | | |
| **Cryptophyceae** | | | | |
| *Plagioselmis prolonga* Butcher ex G.Novarino, I.A.N.Lucas & S.Morrall | | + | | |
| | | | | |
| **Raphidophyceae** | | | | |
| *Fibrocapsa* sp. | | + | | |
| *Heterosigma akashiwo* (Y.Hada) Y.Hada ex Y.Hara & M.Chihara | | + | + | |
| | | | | |
| **Chrysophyceae** | | | | |
| *Bicosoeca mediterranea* Pavillard | | | + | |
| *Dinobryon balticum* (Schütt) Lemmermann | | | + | |
| *Ochromonas* sp. | | | + | |
| | | | | |
| **Dictyochophyceae** | | | | |
| *Dictyocha antarctica* Lohmann | | | + | |
| *Dictyocha crux* Ehrenberg | | | + | |
| *Dictyocha fibula* Ehrenberg | + | + | + | + |
| *Dictyocha speculum* Ehrenberg | | + | + | + |
| *Octactis octonaria* (Ehrenberg) Hovasse | | + | + | + |
| | | | | |
| **Prymnesiophyceae=Haptophyceae** | | | | |
| *Anacanthoica acanthos* (Schiller) Deflandre | + | | | |

| | | | | |
|---|---|---|---|---|
| *Calciosolenia* sp. | | | + | |
| *Calyptrosphaera* sp. | + | | | |
| *Coccolithus pelagicus* (Wallich) Schiller | + | | + | |
| *Emiliania huxleyi* (Lohmann) Hay and Mohler | + | | + | + |
| *Rhabdosphaera* sp. | + | | | |
| *Syracosphaera pulchra* Lohmann | | | + | + |
| *Syracosphaera* sp. | + | | | |
| | | | | |
| **Euglenophyceae** | | | | |
| *Euglena viridis* Ehrenberg | | + | + | |
| *Eutreptiella marina* da Cunha | | + | | |
| *Eutreptiella* sp. | | + | + | |
| | | | | |
| **Prasinophyceae** | | | | |
| *Halosphaera viridis* Schmitz | | + | + | |
| *Pyramimonas grossii* Parke | | + | + | |
| *Tetraselmis* sp. | | | + | |
| | | | | |
| **Chlorophyceae** | | | | |
| *Monoraphidium* sp. | | | + | |
| *Pediastrum boryanum* (Turpin) Meneghini | | | + | |
| *Pediastrum simplex* (Meyen) Lemm. | | | + | |
| *Scenedesmus quadricauda* (Turpin) Brébisson | | | + | |
| *Sphaerocystis planctonica* (Korshikov) Bourrelly | + | | | |
| **Total species number** | **70** | **135** | **273** | **64** |

The highest number of species was obtained from the Sea of Marmara where the studies were most intensely conducted (273 species, 82%), followed by the Golden Horn Estuary with 135 species (41%), the Bosphorus (Istanbul Strait) with 70 species (21%) and the Dardanelles (Çanakkale Strait) with 64 species (19%), respectively. Advancement of technology increased plankton studies conducted especially after the year 2000 and the reports on the species in the region increased as well. Since the Sea of Marmara along with the Straits involves surface waters in low salinity and deep waters in high salinity, the number of species reported in the region differs due to the presence of species that can adapt to various salinity values.

**Table 3.** Class, genus, taxa numbers and percentage (%) distributions of phytoplankton from the Turkish Strait System.

| Class | Genus | Taxa | % |
|---|---|---|---|
| Cyanophyceae | 13 | **17** taxa (seven of them at genus level) | 5.1 |
| Bacillariophyceae | 70 | **162** taxa (15 of them at genus level) | 48.6 |
| Dinophyceae | 39 | **124** taxa (five of them at genus level) | 37.2 |
| Cryptophyceae | 1 | **1** taxa | 0.3 |
| Raphidophyceae | 2 | **2** taxa (one of them at genus level) | 0.6 |
| Chrysophyceae | 3 | **3** taxa (one of them at genus level) | 0.9 |
| Dictyochophyceae | 2 | **5** taxa | 1.5 |
| Prymnesiophyceae | 7 | **8** taxa (four of them at genus level) | 2.5 |
| Euglenophyceae | 2 | **3** taxa (one of them at genus level) | 0.9 |
| Prasinophyceae | 3 | **3** taxa (one of them at genus level) | 0.9 |
| Chlorophyceae | 4 | **5** taxa (one of them at genus level) | 1.5 |
| | 146 | **333** taxa (36 of them at genus level) | |

The finding, which revealed that diatoms were dominant in the region in terms of number of species, is in parallel with the studies conducted in northwest coasts (Velasquez and Cruzado 1995; 51% diatoms, 36% dinoflagellates) and northeast coasts (Polat and Piner 2002; diatoms represented 57.4% and dinoflagellates 37.2%) of the Mediterranean. In addition, in the Aegean Sea, diatoms and dinoflagellate species were reported with the rates of 45.8% and 41.2%, respectively (Koray 1994). In a study conducted around Bozcaada Island in the Aegean Sea reported that dinoflagellates (50%) were more dominant than diatoms (47%) in terms of the number of species (Balkis 2009). In a study conducted in Villefranche Bay, northwest coasts of the Mediterranean (Gomez and Gorsky 2003; 52% dinoflagellates, 43% diatoms), in the Gulf of Genoa (Bernhard and Rampi 1967; 48% dinoflagellates, 31% diatoms) and the Sea of Marmara (Balkis 2003; 52% dinoflagellates, 40% diatoms) reported that dinoflagellates have more number of species than diatoms. Regional climate changes, increased temperature, industrialization and anthropogenic pressures may cause regional differences in species diversity (Gomez and Claustre 2003). Involving comprehensive studies conducted in the region, the present study tries to reveal a current phytoplankton species composition.

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## BIODIVERSITY OF MACROFLORA OF THE SEA OF MARMARA, TURKEY

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### 1. Introduction

The first paper in which macroalgae from the Sea of Marmara (Turkey) was made by Buxbaum (1728), who recorded marine macroalgal species under pre-Linnean name *Fucus* from İstanbul and Princes Islands. Plate 8, Figure 3 in Buxbaum ("*Fucus humilis*") from Kınalıada, which was part of the protologue in Gmelin's account of *Fucus serra*, was designated the lectotype of Fucus serra S.G. Gmelin, and a collection made by J. Feldmann in MICH was proposed to serve as the epitype of *Gelidium serra* (S.G.Gmel.) E. Taşkın and M.J. Wynne by Taşkın and Wynne (2013) (Figure 1).

Forsskål (1775) collected some marine algae from İstanbul, Dardanelles, and Tekirdağ, and he reported 16 species of seaweeds totally from Turkey (Taşkın and Pedersen 2008). Lamouroux (1822) identified 43 algal taxa (species and infrapecies) from different localities on the coasts of the Mediterranean Sea and the Black Sea of Turkey, Italy, Greece and the Ukraine. 22 seaweeds were reported from Istanbul, Izmit (Sea of Marmara, Turkey), and these species were collected by Dumont d'Urville in 1820. A re-examination of the specimens of Turkish marine algae reported by Lamouroux (1822) has been made, and observations on their present taxonomic and nomenclatural status were offered by Taşkın (2014a). Rigler (1852) given 34 marine algal taxa from İstanbul. Fritsch (1899) reported 63 macroalgal taxa from Bosphorus, Büyükada, Haliç etc. in İstanbul (Sea of Marmara). Sauvageau (1912) named *Cystoseira bosphorica* (type locality: Bosphorus, Turkey) on the basis the plant was collected by Thuret from Turkey in 1840.

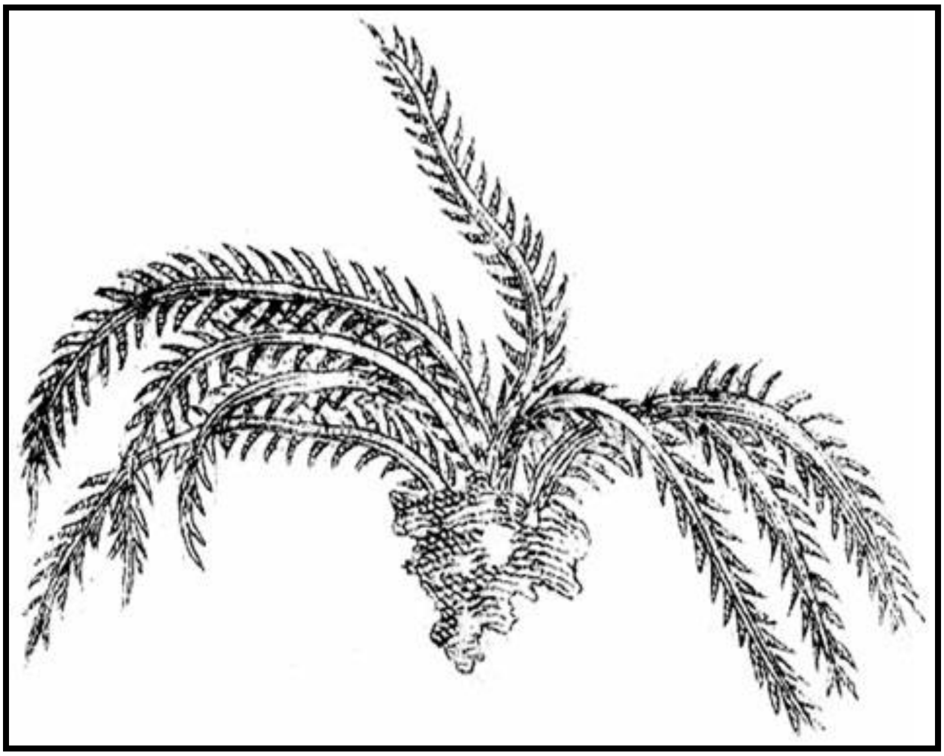

**Figure 1.** Reproduction of pl. VIII, Figure 3. *"Fucus humilis"* (Buxbaum 1728) from Kınalıada (İstanbul). The lectotype of *Fucus serra* S.G. Gmelin.

The marine algae of the Sea of Marmara (Turkey) have been also investigated by Öztığ (1957, 1962), Güven and Öztığ (1971), Zeybek and Güner (1973), Aysel *et al.* (1991, 1993, 2000, 2006), Güven *et al.* (1991), Koç and Aydın (2001), Erduğan *et al.* (2002), Turna and Ertan (2005), Taşkın (2008, 2012, 2013a,b, 2014b), Taşkın *et al.* (2003, 2006, 2012), Taşkın and Öztürk (2007), Taşkın and Pedersen (2012), Taşkın and Wynne (2013), Taşkın and Sukatar (2013). Distribution of rhodoliths and maerls (red algae) in southern shelf of the Sea of Marmara was studied by Atabey (1998).

In total, 600 marine benthic macroalgae have been reported from Turkey, including 150 Phaeophyceae (brown algae) (25%), 330 Rhodophyta (red algae) (55%) and 120 Chlorophyta (green algae) (20%), and 34 of which are alien taxa (5,66%) (Taşkın *et al.* 2008, 2011; Taşkın 2015; Taşkın and Öztürk 2013; Crocetta *et al.* 2015) (Table 1). Turkey has 53,71% of the Mediterranean macrobenthic algal flora (Taşkın 2015).

**Table 1.** Biodiversity of Turkish macrobenthic algal flora and its percentage (%).

| Macroalgal groups | No. taxa | % taxa | No. alien taxa | % alien taxa |
|---|---|---|---|---|
| Phaeophyceae (Brown algae) | 150 | 25 | 14 | 9,33 |
| Rhodophyta (Red algae) | 330 | 55 | 14 | 4,24 |
| Chlorophyta (Green algae) | 120 | 20 | 6 | 5 |
| Total taxa | 600 | 100 | 34 | 5,66 |

The Sea of Marmara located in the northwest side of Turkey, and it is an inland sea, that connects the Black Sea to the Aegean Sea, and it separates Asia and European continets. Numbers of marine macroalgal taxa in the some areas from the Sea of Marmara (Turkey) are given in Table 2, and the areas are showing in Figure 2. The highest taxa were found in three stations, 382 taxa in Dardanelles, 224 taxa in Şarköy and 182 taxa in Gelibolu, respectively.

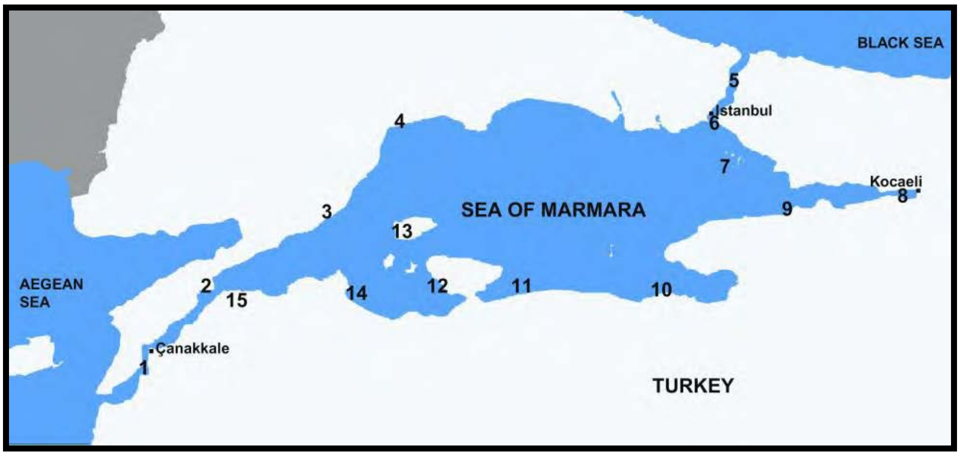


**Figure 2.** Documented marine algal studies in the some areas from the Sea of Marmara, Turkey [1-Dardanelles (Çanakkale); 2-Gelibolu; 3-Şarköy; 4-Tekirdağ; 5- Bosphorus (İstanbul); 6- İstanbul; 7- Princes Islands; 8-Kocaeli; 9-Yalova; 10-Mudanya; 11-Bandırma; 12-Erdek; 13-Paşalimanı-Marmara Adası; 14-Karabiga; 15-Lapseki].

**Table 2.** Numbers of marine algal and marine phanerogams taxa from the some areas in the Sea of Marmara. [Ph: Phaeophceae; Rh: Rhodophyta; Ch: Chlorophyta; Sp: Spermatophyta].

| Area/Station | Reference | Macroalgal groups | | | | Total taxa |
|---|---|---|---|---|---|---|
| | | Ph. | Rh. | Ch. | Sp. | |
| Dardanelles-Çanakkale | Aysel *et al*. (2000), Taşkın *et al*. (2003) | 95 | 214 | 73 | 4 | 386 |
| Gelibolu | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 60 | 90 | 32 | 4 | 186 |
| Şarköy | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 62 | 126 | 36 | 3 | 227 |
| Tekirdağ | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 30 | 70 | 22 | 3 | 125 |
| Bosphorus (İstanbul) | Aysel et al. (1991, 1993), Turna and Ertan (2005), Taşkın *et al*. (2016) | 25 | 65 | 35 | 2 | 127 |
| İstanbul | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 22 | 80 | 30 | 2 | 134 |
| Princes Islands | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 30 | 60 | 28 | - | 118 |
| Kocaeli | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 8 | 35 | 25 | - | 68 |
| Yalova | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 17 | 45 | 22 | 1 | 85 |
| Mudanya (Bursa) | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 25 | 55 | 26 | 2 | 108 |
| Bandırma | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 22 | 46 | 28 | 3 | 99 |
| Erdek | Aysel et al. (1991, 1993), Taşkın *et al*. (2016) | 40 | 58 | 20 | 4 | 122 |
| Marmara Adası-Paşalimanı Adası | Taşkın *et al*. (2016) | 60 | 80 | 35 | 4 | 179 |
| Karabiga | Taşkın *et al*. (2016) | 24 | 40 | 15 | 3 | 82 |
| Lapseki | Taşkın *et al*. (2016) | 55 | 60 | 25 | 4 | 144 |

## 2. Current status of marine macroalgal flora in the Sea of Marmara (Turkey)

The Sea of Marmara has been indicated as very high levels of pollution by several industrial complexes, municipal wastewater, agricultural chemicals and oil pollution (Aydınol *et al.* 2012), and the origin of pollutants were mainly reported from anthropogenic disturbance (e.g. İstanbul City), İzmit Bay, and Gulf of Gemlik., and where opportunistic marine macroalgal species are dominant (e.g. *Ulva* spp., *Cladophora* spp., *Gracilaria gracilis*, etc.).

Taşkın and Öztürk (2013) reported 400 taxa at specific and infraspecific level of the marine benthic macroalgae in the Sea of Marmara, 105 of which brown algae (Phaeophyceae) (26,25%), 225 of which red algae (Rhodophyta) (56,25%), and 70 of which green algae (Chlorophyta) (17,50%) (Table 3, Figure 3).

Brown algae are common in Dardanelles, Gelibolu, Şarköy, Lapseki, Paşalimanı Island, Kapıdağ, and Erdek. Twelve *Cystoseira* taxa are distributed in the Sea of Marmara, and this genus species are indicated for pristine states. *Cystoseira barbata*, *Cystoseira crinita*, *Cystoseira foeniculacea* are common in Gelibolu, Şarköy, Paşalimanı Island, and Lapseki (Figs. 4-8). The members of order Ectocarpales (eg. *Asperococcus* spp., *Ectocarpus* spp., *Colpomenia sinuosa*, *Scytosiphon lomentaria*, *Cladosiphon* spp., *Petalonia fascia*, etc.) are shown in spring in the midlittoral zone and the infralittoral zone and these species are known in degraded states. Deep brown alga *Laminaria rodriguezii* was reported from Princes Islands (İstanbul), its conservation status "endangered".

In the Sea of Marmara, red algae are common in İstanbul, Gelibolu, Lapseki, Paşalimanı Island, Yalova, Kocaeli, Bandırma, Dardanelles. The members of order Ceramiales are common in all sites in the midlittoral zone and the infralittoral zone (Figure 9), *Laurencia spp., Palisada spp., Ceramium* spp., *Polysiphonia* spp., *Boergeseniella fruticulosa* are common in coasts of the Sea of Marmara. Calcareous red algal order Corallinales members are known from Gelibolu, Şarköy, Dardanelles, Tekirdağ, Üsküdar, Bandırma, Erdek, Lapseki, Paşalimanı and Marmara Islands. *Corallina officinalis*, *Ellisolandia elongata, Haliptilon attenuatum* are found as epilithic or epiphytic on *Cystoseira* (Figs. 5,8), *Phymatolithon lenormandii* is found as epilithic, and *Hydrolithon farinosum* is found as epiphytic on leaf of *Cymodocea nodosa*. Other red algal species *Gracilaria bursa-pastoris, Nitophyllum punctatum, Pyropia leucosticta* are found abundantly in the coasts of the Sea of Marmara in Spring (Figure 10). *Chylocladia verticillata* is common as epiphytic on the brown alga *Cystoseira* in Paşalimanı Island (Figure 7). Opportunistic red alga *Gracilaria gracilis* is common in İzmit Bay, where is known a degraded site (Figure 11).

Oppotunistic green algal genera *Ulva*, *Cladophora*, *Codium* are known from degraded coasts. *Ulva* species (*U. compressa*, *U. intestinalis, U. linza, U. rigida,* etc.) are common in the midlittoral zone and the infralittoral zone in the Sea of Marmara (Figs. 12-13). *Cladophora* species are bloomed in Spring in Edincik, Kapıdağ (Erdek) (Figs. 14-15). Invasive marine alga *Codium fragile* is distributed as abundant in all coast of the Sea of Marmara. Other green algal genera *Bryopsis* (*B. corymbosa*, *B. hypnoides*, *B. plumosa*) and *Chaeotomorpha* (*C. aerea*, *C. linum*) speceis are also common in the midlittoral zone and the infralittoral zone.

Some marine algal taxa were reported in the Sea of Marmara that they are known as rare species: brown algae *Botrytella micromora* Bory*, Compsonema minutum* (C. Agardh) Kuckuck, *Compsonema saxicola* (Kuckuck) Kuckuck, *Hecatonema terminale* (Kütz.) Kylin, *Kuckuckia spinosa* (Kütz.) Kornmann, *Microcoryne ocellata* Strömfelt, *Microspongium gelatinosum* Reinke, *Pseudolithoderma adriaticum* (Hauck) Verlaque, *Streblonema parasiticum* (Sauvageau) Levring, *Ulonema rhizophorum* Foslie, red algae *Lomentaria ercegovicii* Verlaque *et al. Osmundea pelagiensis* G.Furnari, and green alga *Ulva multiramosa* E.Taşkın.

**Table 3.** Biodiversity of Turkish and the Sea of Marmara macrobenthic algal flora and its percentage (%).

| Macroalgal groups | Sea of Marmara | No. taxa of Turkey | % taxa of Sea of Marmara /Turkey |
|---|---|---|---|
| Phaeophyceae | 105 | 150 | 70 |
| Rhodophyta | 225 | 330 | 68,18 |
| Chlorophyta | 70 | 120 | 58,33 |
| Total taxa | 400 | 600 | 66,66 |

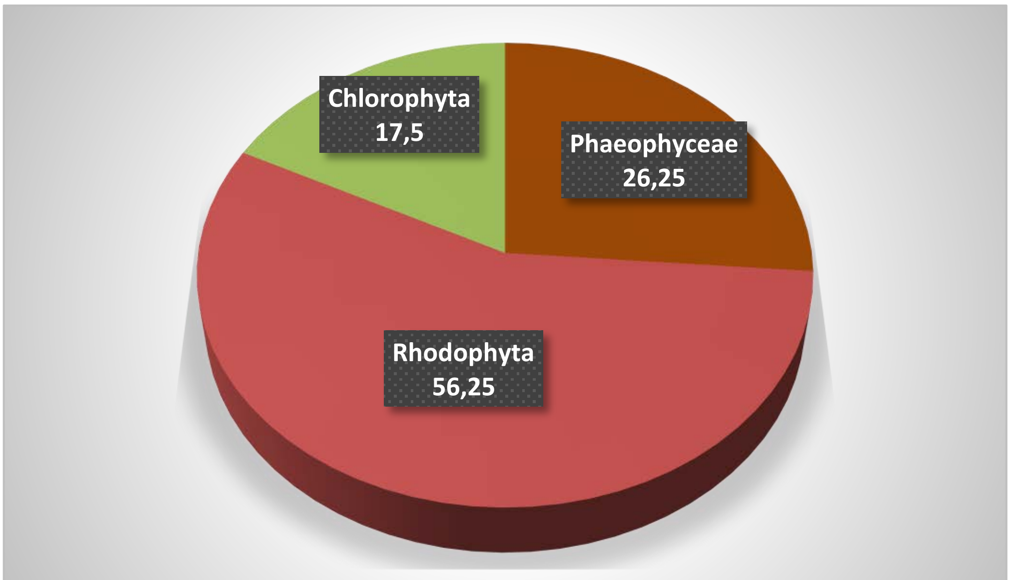


**Figure 3.** Percentage (%) of macrobenthic algal flora in the Sea of Marmara.


**Figure 4**. Macroalgal vegetation in the Sea of Marmara, May 2015 (0,5 m, Şarköy, Tekirdağ, Turkey) (a: *Cystoseira barbata*, b: *Ulva intestinalis*, c: *Scytosiphon lomentaria*). (Photo: E.Taşkın).

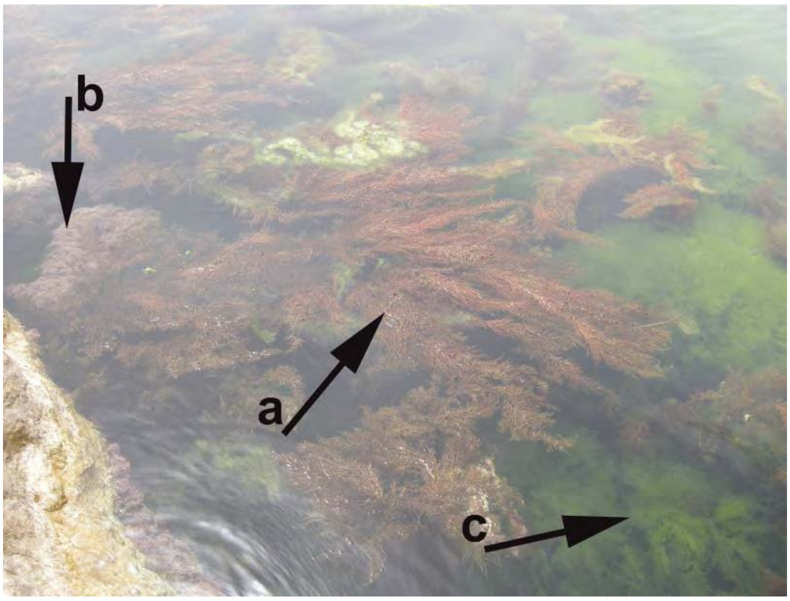


**Figure 5**. Macroalgal vegetation in the Sea of Marmara, May 2013 (0,5 m, Şarköy, Tekirdağ, Turkey) (a: *Cystoseira barbata*, b: *Corallina officinalis*, c: *Ulva linza*). (Photo: E.Taşkın).

**Figure 6**. Brown alga *Cystoseira* species in the Sea of Marmara, May 2015 (1 m, Paşalimanı Island, Balıkesir, Turkey). (Photo: E.Taşkın).

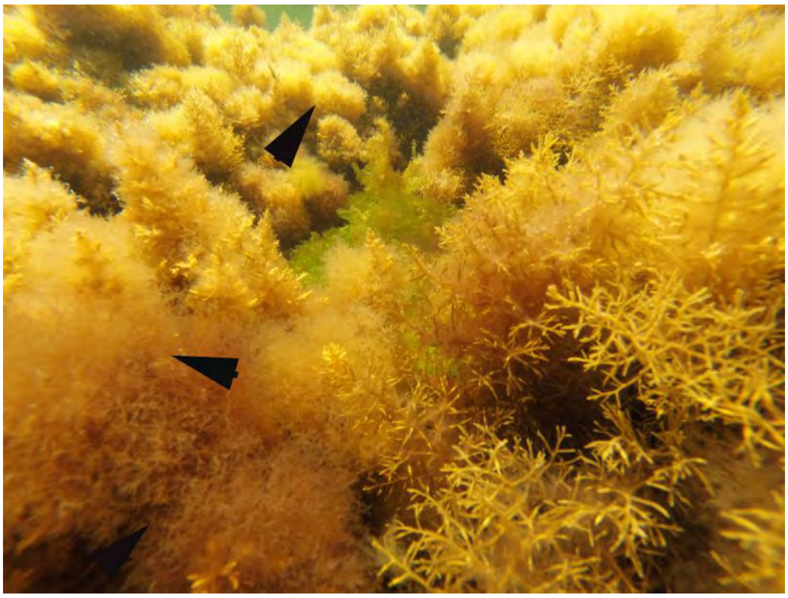

**Figure 7**. Epiphytic red alga *Chylocladia verticillata* (arrowheads) on the brown alga *Cystoseira* in the Sea of Marmara, May 2015 (1 m, Paşalimanı Island, Balıkesir, Turkey). (Photo: E.Taşkın).

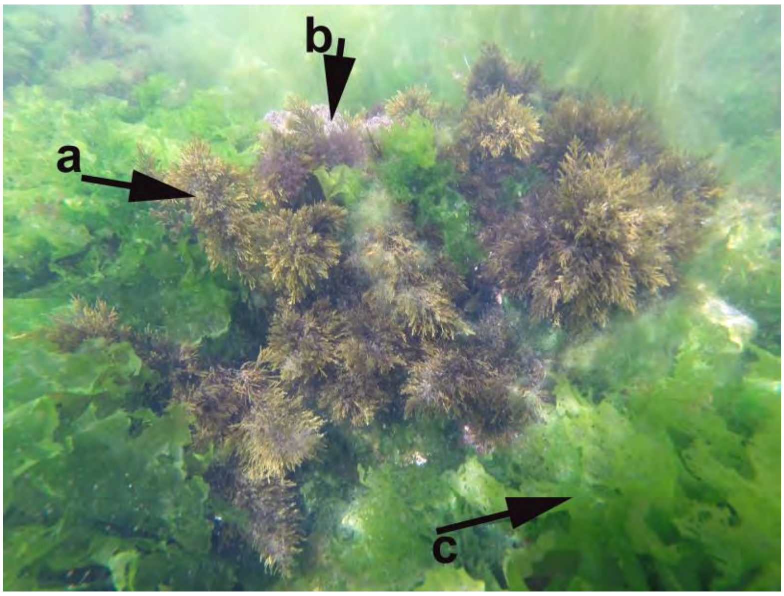


**Figure 8**. Macroalgal vegetation in the Sea of Marmara, November 2015 (1 m, Şarköy, Tekirdağ, Turkey) (a: *Cystoseira barbata*, b: *Corallina officinalis*, c: *Ulva rigida*). (Photo: E.Taşkın).


**Figure 9**. Macroalgal vegetation in the Sea of Marmara, May 2015 (1 m, Hereke, Kocaeli, Turkey) (a: *Ulva rigida*, b: *Ceramium virgatum*). (Photo: E.Taşkın).

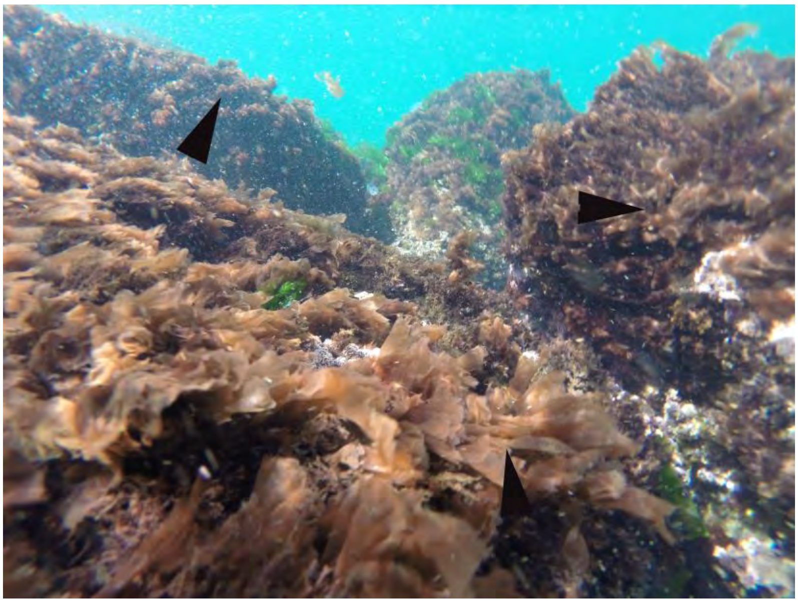

**Figure 10**. Red alga *Porphyra* (arrowheads) in the Sea of Marmara, May 2015 (1 m, Üsküdar, İstanbul, Turkey). (Photo: E.Taşkın).

**Figure 11**. Opportunistic red alga *Gracilaria gracilis* blooms in the Sea of Marmara, November 2015 (İzmit, Kocaeli, Turkey). (Photo: E.Taşkın).

**Figure 12**. Opportunistic green alga *Ulva* in the Sea of Marmara, May 2015 (1 m, Yalova, Turkey). (Photo: E.Taşkın).

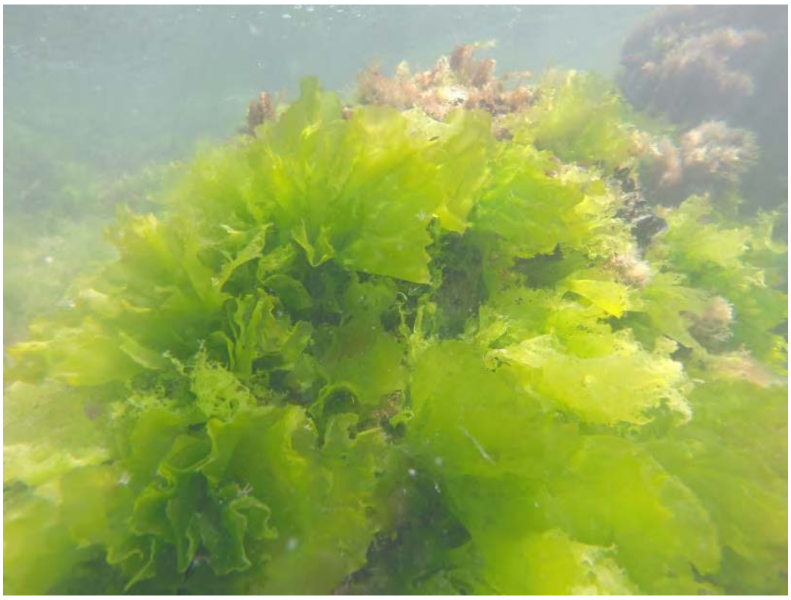

**Figure 13**. Opportunistic green alga *Ulva rigida* in the Sea of Marmara, May 2015 (1 m, Şarköy, Tekirdağ, Turkey). (Photo: E.Taşkın).

**Figure 14**. Opportunistic green alga *Cladophora* sp. in the Sea of Marmara, May 2015 (1 m, Erdek, Balıkesir, Turkey). (Photo: E.Taşkın).

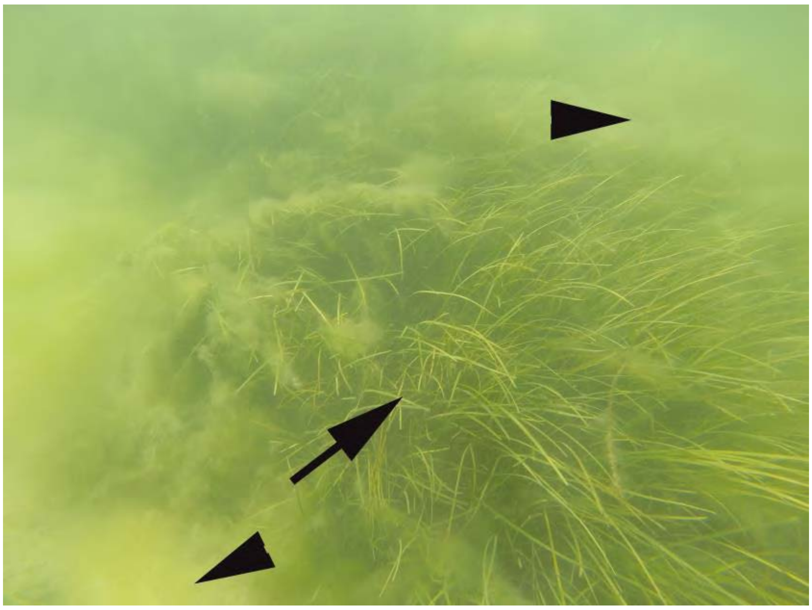

**Figure 15**. Opportunistic green alga *Cladophora* sp. (arrowheads) with *Cymodocea nodosa* (arrow) in the Sea of Marmara, May 2015 (1 m, Kapıdağ, Balıkesir, Turkey). (Photo: E.Taşkın).

## 3. Current status of marine phanerogams in the Sea of Marmara (Turkey)

Marine phanerogams (seagrasses, marine flowering plants, marine angiosperms) beds and meadows are found in bays, coves, brackish waters and they are a haven for mollusk, crabs, fish, and other organisms. Six marine phanerogams known in Turkey (Taşkın *et al*. 2008; Akçalı and Cirik 2015), four of which marine phanerogams known in the Sea of Marmara are; *Cymodocea nodosa* (Ucria) Ascherson, *Posidonia oceanica* (L.) Delile, *Zostera marina* L. and *Zostera noltei* Homermann (Taşkın *et al*. 2008). There are several studies that examine marine fanerogams meadows spreading out along the coast of the Sea of Marmara (Yüksek and Okuş 2004; Meinesz *et al*. 2009; Cirik *et al*. 2010; Cirik and Akçalı 2013; Taşkın *et al.* 2016).

*Cymodocea nodosa* is common in the Sea of Marmara, while *Posidonia oceanica* is distributed only in small area (Dardanelles, Kapıdağ and Paşalimanı Island) in the Sea of Marmara (Figure 16-18). *Zostera marina* and *Zostera noltii* are found together with *C. nodosa* beds (Figure 19).

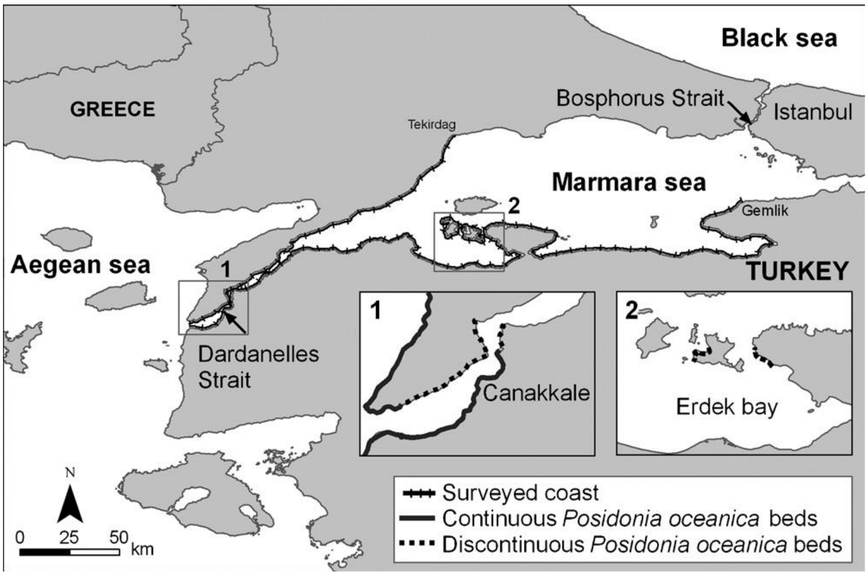


**Figure 16.** Distribution of *Posidonia oceanica* in the Dardanelles and in the Sea of Marmara (Meinesz *et al.* 2009).

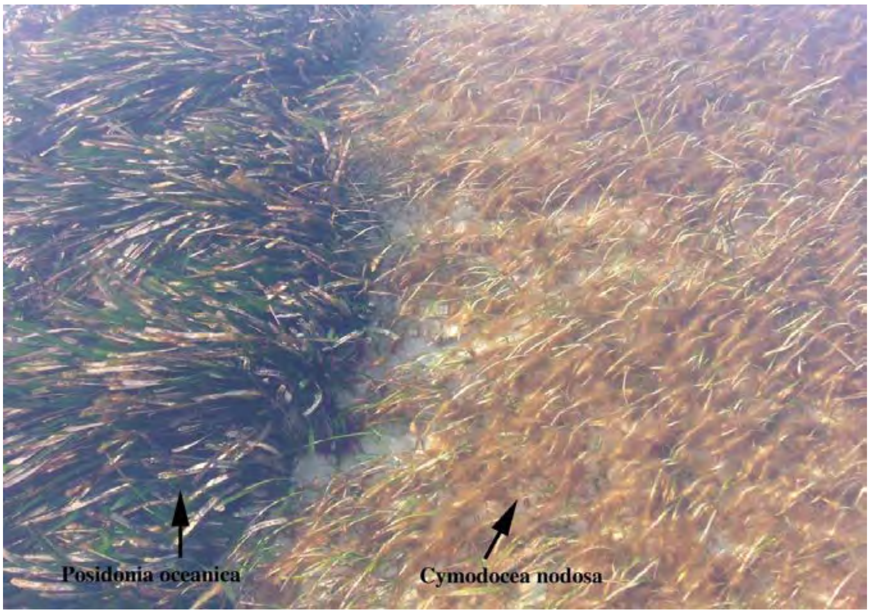


**Figure 17.** *Posidonia oceanica* and *Cymodocea nodosa* (with brown algal epiphytes) in the Sea of Marmara, November 2011 (1 m, Dardanelles, Çanakkale, Turkey). (Photo: E.Taşkın).

**Figure 18.** *Cymodocea nodosa* (benthic and floating) in the Sea of Marmara, June 2016 (1 m, Erdek, Balıkesir, Turkey). (Photo: E.Taşkın).

**Figure 19.** *Cymodocea nodosa* and *Zostera noltii* beds in the Sea of Marmara, May 2015 (1 m, Kapıdağ, Balıkesir, Turkey). (Photo: E.Taşkın).

### 4. Alien marine algae in the Sea of Marmara (Turkey)

Alien and invasive marine macrophytes introduced into the Mediterranean Sea by aquaculture, by shipping, via Suez Canal, by fouling, by ballast water and by accidental escape from aquarium. Verlaque *et al.* (2015) reported 110 exotic marine macrophytes species in the Mediterranean Sea. A list of accepted introduced marine macroalgae occuring on the coasts of Turkey was consist of 14 Rhodophyta (red algae), 14 Phaeophyceae (brown algae), and 6 Chlorophyta (green algae) for a total of 34 taxa at specific and infraspecific level, 20 of which were reported from the Sea of Marmara, Turkey (Taşkın *et al*. 2011) (Table 4). Of them, the Chlorophyta *Codium fragile* (Figs 20-22) and the red alga *Polysiphonia morrowii* are common in all sites of the Sea of Marmara, and this species shows an invasive behaviour. Brown alga *Colpomenia peregrina* is abundant in Spring at Dardanelles. Newly, an alien red alga *Antithamnion hubbsii* was reported from Dardanelles, Sea of Marmara for the first time (Figure 23).

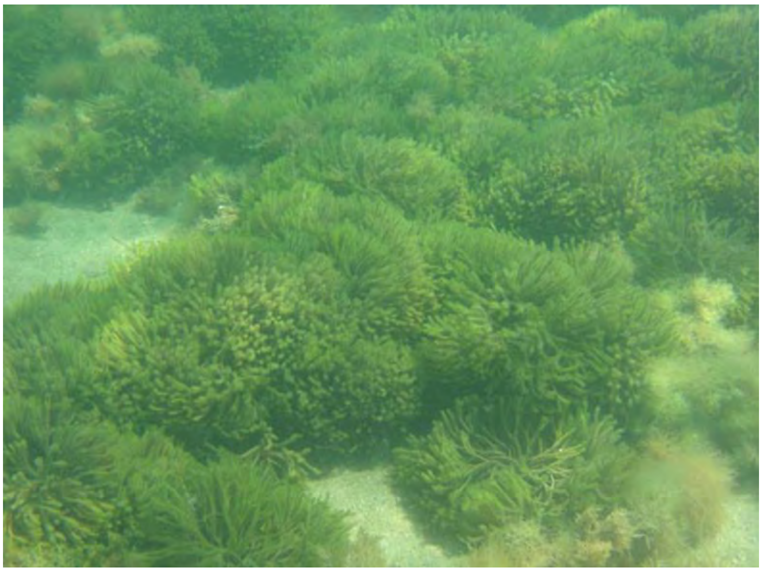

**Figure 20.** Invasive green alga *Codium fragile* from Karabiga in the Sea of Marmara, Turkey (8 m). (Photo: E.Taşkın).

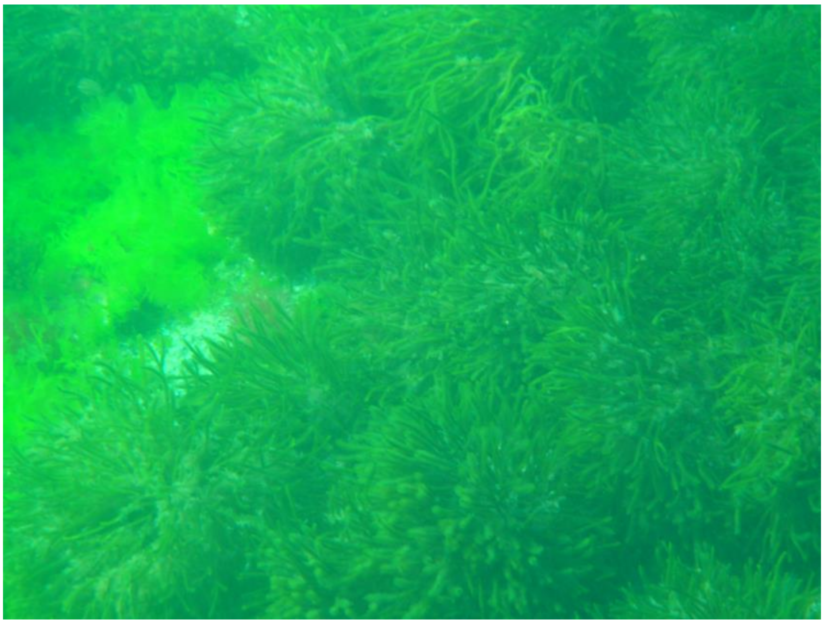

**Figure 21.** Invasive green alga *Codium fragile* from Yandros Island in the Sea of Marmara, Turkey, November 2015 (5 m). (Photo: E.Taşkın).

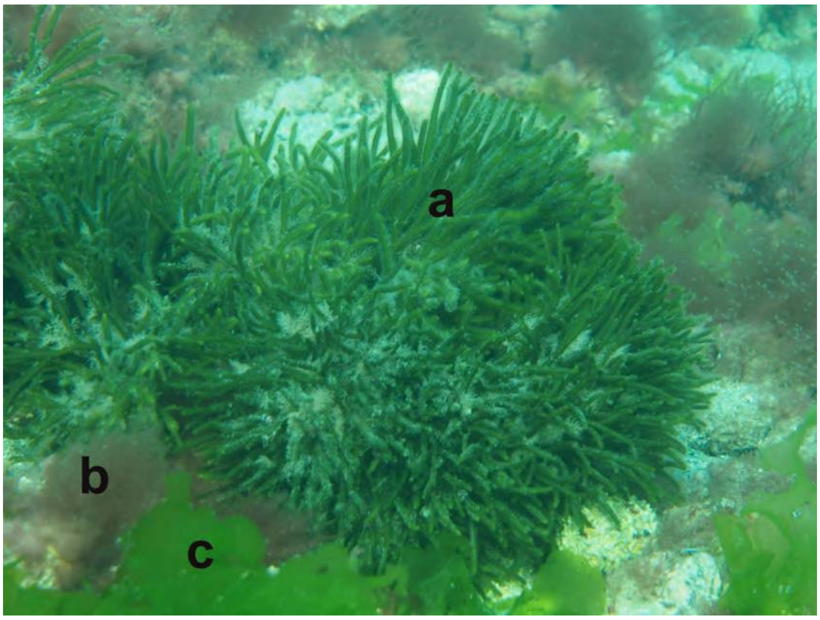


**Figure 22.** Invasive green alga *Codium fragile* (a), native red alga *Polysiphonia elongata* (b), and native green alga *Ulva rigida* (c) from Yandros Island in the Sea of Marmara, Turkey, November 2015 (20 m). (Photo: E.Taşkın).

**Figure 23.** Alien red alga *Antithamnion hubbsii*, Çanakkale, Sea of Marmara, Turkey.

**Table 4.** Alien and invasive marine macroalgae in the Sea of Marmara (Turkey). [A=Atlantic; IP=Indo-Pacific; AL=Alien; E=Established]

| Taxa | Vector of introduction | Origin | Status | World distribution |
|---|---|---|---|---|
| **Rhodophyta (red algae)** | | | | |
| *Antithamnion hubbsii* E.Y.Dawson | By ship | A, IP | AL | Atlantic ocean, Pacific ocean and Indian ocean |
| *Chondria collinsiana* M. Howe | By Suez Canal | IP | AL | Atlantic ocean, Pacific ocean and Indian ocean |
| *Colaconema codicola* (Børgesen) Stegenga, J.J.Bolton, and R.J.Anderson | By ship | IP | E | Atlantic ocean, Pacific ocean and Indian ocean |
| *Falkenbergia rufolanosa* (Harvey) Schmitz (Tetrasporophyteof *Asparagopsis armata* Harvey) | By fouling | IP | E | Atlantic ocean, Pacific ocean and Indian ocean |
| *Griffithsia corallinoides* (L.) Trevisan | By Gibraltar | A, IP | E | Atlantic ocean, Pacific ocean and Indian ocean |
| *Polysiphonia morrowii Harvey* | By aquaculture | IP | E | Atlantic ocean and Pacific ocean |
| *Rhodophysema georgii* Batters | By aquaculture | A, IP | AL | Atlantic ocean and Pacific ocean |
| *Trailliella intricata* Batters (Tetrasporophyte of *Bonnemasoinia hamifera* Hariot) | By fouling | IP | E | Atlantic ocean and Pacific ocean |
| **Phaeophyceae (brown algae)** | | | | |
| *Botrytella parva* (Takamatsu) H.-S.Kim | By ship | IP | E | Pacific ocean |
| *Chorda filum* (L.) Stackhouse | By aquaculture | A, IP | E | Atlantic ocean and Pacific ocean |
| *Cladosiphon zosterae* (J.Agardh) Kylin | By fouling | A | E | Atlantic ocean and Pacific ocean |
| *Colpomenia peregrina* Sauvageau | By Gibraltar | IP | E | Atlantic ocean, Pacific ocean and Indian ocean |
| *Ectocarpus siliculosus* var. *hiemalis* (Crouan Frat *ex* Kjellman) T.Gallardo | By ship | A | AL | Atlantic ocean |
| *Halothrix lumbricalis* (Kützing) Reinke | By fouling | A, IP | AL | Atlantic ocean and Pacific ocean |
| *Litosiphon laminariae* (Lyngbye) | By | A | E | Atlantic ocean |

| | | | | |
|---|---|---|---|---|
| Harvey | aquaculture | | | |
| *Microspongium globosum* Reinke | By fouling or balast water | A | AL | Atlantic ocean |
| *Punctaria tenuissima* (C. Agardh) Greville | By fouling | A | E | Atlantic ocean and Pacific ocean |
| *Pylaiella littoralis* (L.) Kjellman | By aquaculture | A, IP | E | Atlantic ocean, Pacific ocean and Indian ocean |
| *Scytosiphon dotyi* M.J. Wynne | By aquaculture | A, IP | E | Atlantic ocean and Pacific ocean |
| **Chlorophyta (green algae)** | | | | |
| *Codium fragile* subsp. *fragile* (Suringar) Hariot | By aquaculture | IP | E | Atlantic ocean and Pacific ocean |


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**MICROZOOPLANKTON (TINTINNIDS) OF THE SEA OF MARMARA: A REVIEW**

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## 1. Introduction

Tintinnids included in Ciliophora group are the most important members of planktonic ciliates in sea environment and they are the most important consumers of ultra- and nanoplanktons along with small diatoms on trophic level in pelagic ecosystem (Cosper 1972). Tintinnids have significant role in biochemical cycle of carbon and energy flow because of their high metabolic rates, abilities to consume food source and breed rapidly (Dolan 1997; Godhantaraman 2001; Bachy *et al.* 2012). In addition, they are also food sources for heterotrophic organisms in a proper size to digest them (Gold 1970; Dolan *et al.* 1999; Dolan and Gallegos 2001). These basic-structured organisms, which have a cosmopolite distribution in seas and oceans, can be found only as cyst under non-suitable conditions since movement organelles function solely in marine environment.

Some researchers have investigated cellular organization of tintinnid species over world seas (Campbell 1926, 1927; Hofker 1931; Biernacka 1952). However, most of these research are on taxonomy and systematics of them. There are two fundamental reasons of it: The challenge of conducting experimental studies on them under laboratory conditions and constriction of organism during fixation of plankton samples including tintinnids or abandonment of organism from lorica (Gold 1968, 1969). Therefore, classification is mostly based on lorica morphology. Vase, bowl or tube formed lorica surrounding protoplasts is very important for the identification of species (Laval-Peuto 1981, 1983; Wasik and Mikolajczyk 1994). Structure and shape of lorica may differ by three important factors. The first of them is quality and quantity of lorica material; the second is environmental factors such as biotic and abiotic factors during development and the last one is cell cycle (Agatha *et al.* 2013). In last decade, phylogenetic studies have started to be conducted and it has been emphasized that classification of this species may differ; it has been asserted that various species defined as different species by lorica appearance could be different forms of the same species (Agatha and Strüder-Kypke 2007, 2012; Sacca *et al.* 2008; Agatha 2010; Bachy *et al.*

2012). It should be kept in mind that loricas of tintinnid species can show polymorphism in high level (Laval-Peuto and Brownlee 1986).

According to the literature, tintinnids were collected from the Sea of Marmara using plankton nets or water samplers and preserved in Lugol's solution or neutralized formaldehyde. Most researchers referred to Trégouboff and Rose (1957), Balech (1959), Marshall (1969), Koray and Özel (1983), Chihara and Murano (1997), Alder (1999), Thompson *et al.* (1999), Polat *et al.* (2001), Balkis (2004), Urrutxurtu (2004) and Abboud-Abi Saab (2008) for identifying tintinnid morphospecies. MarBEF data system (http://www.marbef.org/data/erms.php) was also used as a source for current species names.

This study aims to determine tintinnid species having a significant place in food web and included in few studies in the Sea of Marmara and to reveal the species abundance and the periods which it increases. Studies conducted on tintinnid species in Turkish coastal waters are mostly systematic researches and there are limited studies on ecologies of the species (Koray and Özel 1983; Koray *et al.* 1992; Balkis and Wasik 2005; Balkis 2004; Balkis and Toklu-Alicli 2009; Durmus and Balkis 2014). A study conducted in 2014 reported 109 tintinnid species in Turkish coastal waters and listed these species with detected seas (Balkis and Koray 2014). In a literature review study conducted by Balkis and Koray (2014), 15 species were reported in the Sea of Marmara. This species number is 14% of the total number of species and less than the number of known species in the Black Sea (21%). Afterwards, Durmus and Balkis (2014) conducted a study at Gulf of Gemlik and brought contribution to tintinnid species in Turkey with 3 new recorded species and with 18 recorded species from the Sea of Marmara. In this way, number of tintinnid species in the Sea of Marmara was detected as 33 (30%) (Figure 1; Table 1), this species number was recorded as 112 for Turkish coastal waters.

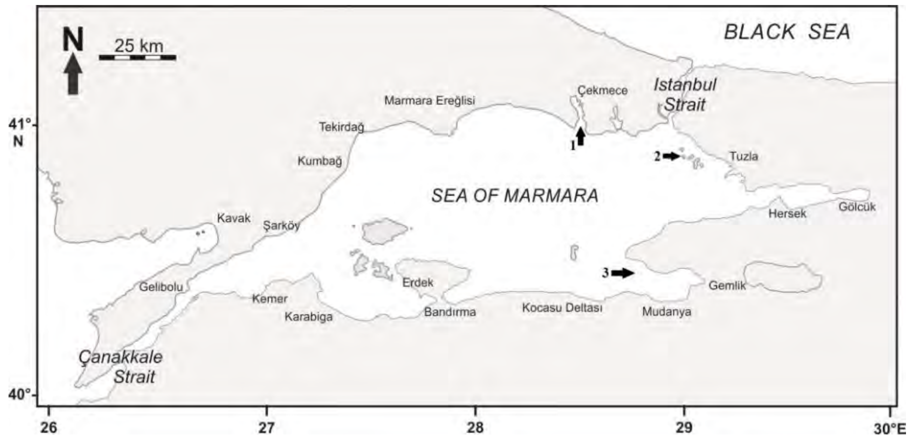


**Figure 1.** Sampling areas in the Sea of Marmara (1-the Büyükçekmece Bay; 2-the Prince Islands (Kaşık Island); 3-the Gulf of Gemlik).

**Table 1.** Tintinnid species reported from the Sea of Marmara and ecologic tolerances in studies conducted on various seas of Turkey (Koray and Özel 1983; Koray *et al.* 1992; Balkis and Wasik 2005; Balkis 2004; Balkis and Toklu-Alicli 2009; Durmus and Balkis 2014).

| | **Tintinnid species** | **References in the Sea of Marmara** | **Temperature (min-max °C)** | **Salinity (min-max ‰)** |
|---|---|---|---|---|
| 1 | *Amphorellopsis tetragona* (Jørgensen) Kofoid and Campbell, 1929 | Toklu-Alicli *et al.* 2010; Durmus and Balkis 2014 | 8.7-22.9 | 15.5-36 |
| 2 | *Amphorides amphora* (Claparède and Lachmann) Strand, 1926 | Balkis 2004 | 13.2-26.5 | 21.1-37.8 |
| 3 | *Amphorides quadrilineata* (Claparède and Lachmann) Strand, 1926 | Durmus and Balkis 2014 | 8.7-26.5 | 17.8-40.6 |
| 4 | *Codonellopsis morchella* (Cleve) Jörgensen, 1924 | Durmus and Balkis 2014 | 9.2-19.4 | 15.9-30.3 |
| 5 | *Codonellopsis orthoceras* (Haeckel) Jörgensen, 1924 | Balkis 2004 | 12-19.2 | 19.9-38.7 |
| 6 | *Codonellopsis schabi* (Brandt) Kofoid and Campbell, 1929 | Balkis 2004; Durmus and Balkis 2014 | 13-24.5 | 17.8-38.2 |
| 7 | *Dictyocysta* sp. | Durmus and Balkis 2014 | 9.6 | 20.3 |
| 8 | *Eutintinnus apertus* Kofoid and Campbell, 1929 | Balkis 2004; Durmus and Balkis 2014 | 13.2-27 | 16.4-40.6 |
| 9 | *Eutintinnus fraknoi* (Daday) Kofoid and Campbell, 1939 | Balkis 2004 | 13.2-25.7 | 19.7-40.6 |
| 10 | *Eutintinnus lususundae* (Entz) Kofoid and Campbell, 1939 | Balkis 2004; Durmus and Balkis 2014 | 11-29.3 | 15-40.6 |
| 11 | *Eutintinnus medius* (Kofoid & Campbell) Kofoid & Campbell, 1939 | Durmuş and Balkis 2014 | 25.9-28 | 16.4-17 |
| 12 | *Eutintinnus tubulosus* (Ostenfeld) Kofoid and Campbell, 1939 | Durmus and Balkis 2014 | 11-29.1 | 16.1-37.4 |
| 13 | *Favella campanula* (Schmidt) Jörgensen, 1924 | Balkis 2004 | 16.5-24.5 | 19.7-38.7 |
| 14 | *Favella ehrenbergii* (Claparede and Lachmann) Jörgensen, 1924 | Balkis 2004; Durmus and Balkis 2014 | 7.3-29.3 | 15.9-38.7 |
| 15 | *Helicostomella subulata* (Ehrenberg) Jörgensen, 1924 | Balkis 2004; Durmus and Balkis 2014 | 8.7-28.3 | 15-40.6 |
| 16 | *Metacylis jörgensenii* (Cleve) Kofoid and Campbell, 1929 | Balkis 2004; Durmus and Balkis 2014 | 8.6-28.3 | 16.1-40.6 |
| 17 | *Metacylis mediterranea* (Mereschkowsky) Jörgensen, 1924 | Durmus and Balkis 2014 | 22.9-28.3 | 16.4-18.1 |
| 18 | *Metacylis mereschkowskii* Kofoid and Campbell, 1929 | Durmus and Balkis 2014 | 16.5-28.3 | 16.4-21.9 |
| 19 | *Rhizodomus tagatzi* Strelkow and Wirketis, 1950 (=*Tintinnopsis corniger* Hada, 1964) | Durmus *et al.* 2011 | 18-28.3 | 16-38.7 |
| 20 | *Salpingella acuminata* (Claparède and Lachmann) Jorgensen, 1924 | Durmus and Balkis 2014 | 13-18.5 | 18.7-37.6 |
| 21 | *Salpingella decurtata* Jörgensen, 1924 | Durmus and Balkis 2014 | 12.2-29.1 | 16.1-37.4 |
| 22 | *Schmidingerella serrata* (Möbius) Agatha & Strüder-Kypke, 2012 [=Favella serrata (Möbius) Jörgensen, 1924] | Balkis 2004 | 14.7-26.5 | 20.2-38.7 |
| 23 | *Steenstrupiella steenstrupii* (Claparède and Lachmann) Kofoid and Campbell, 1929 | Balkis 2004 | 13-24.5 | 22.3-38.3 |

| | | | | |
|---|---|---|---|---|
| 24 | *Stenosemella nivalis* (Meunier) Kofoid and Campbell, 1929 | Durmus and Balkis 2014 | 8.3-21 | 17.7-35.2 |
| 25 | *Stenosemella ventricosa* (Claperede and Lachmann) Jörgensen, 1924 | Durmus and Balkis 2014 | 8.2-21 | 15.9-38.7 |
| 26 | *Tintinnopsis acuminata* Daday, 1887 | Durmus and Balkis 2014 | 12.2-26.8 | 15-36 |
| 27 | *Tintinnopsis beroidea* Stein, 1867 | Durmus and Balkis 2014 | 16-25.5 | 16.8-38.7 |
| 28 | *Tintinnopsis buetschlii* Daday, 1887 | Durmus and Balkis 2014 | 9.3-18 | 19-38.7 |
| 29 | *Tintinnopsis campanula* (Ehrenberg) Daday, 1887 | Durmus and Balkis 2014 | 8.4-29.1 | 15-38.7 |
| 30 | *Tintinnopsis compressa* Daday, 1887 | Durmus and Balkis 2014 | 9.2-26 | 19.6-38.7 |
| 31 | *Tintinnopsis radix* (Imhof) Brandt, 1907 | Balkis 2004 | 9.2-27.5 | 16-40.6 |
| 32 | *Tintinnopsis urnula* Meunier, 1910 | Durmus and Balkis 2014 | 17.7-18.5 | 17.1-19.5 |
| 33 | *Xystonella treforti* (Daday) Laackmann, 1909 | Durmus and Balkis 2014 | 13.8-17.2 | 18.7-37.5 |

The first study conducted on tintinnid species in the Sea of Marmara evaluated materials collected from Büyükçekmece Bay in the years of 1998-1999; and presence of 14 species was detected (Balkis 2004). In this study, it was reported that *Favella* and *Eutintinnus* genera are dominant in terms of species and individual number and the most abundantly found species is *E. fraknoi*. In addition, it was emphasized that tintinnid species decrease in winter and early spring periods when phytoplankton increases; *F. serrata* (=*Schmidingerella serrata*) is more affected by temperature changes while *E. lususundae* is more affected by salinity changes. In this study conducted at Büyükçekmece Bay, tintinnid species reached the highest abundance in November (autumn) ($1.2x10^3$ ind. $L^{-1}$). In another study conducted around Kaşık Island in the Sea of Marmara in 2008, *Amphorellopsis tetragona* (Jørgensen) Kofoid and Campbell, 1929 which is a cosmopolit species, was reported as a new recorded for Turkish coastal waters (Toklu-Alicli *et al.* 2010). In upcoming years, in a study conducted at Gulf of Gemlik in 2010, a new registry species [*Rhizodomus tagatzi* Strelkow and Wirketis, 1950 (=*Tintinnopsis corniger* Hada 1964] was contributed to species diversity (Durmus *et al.* 2011). 13 species of *Tintinnopsis* genus are known in Turkish coastal waters while it has been reported only 2 species of this genus live in the Sea of Marmara (*Rhizodomus tagatzi* reported as *T. corniger* and *T. radix*). This situation indicates limited number of studies conducted on this subject. In order to fulfill this lack, a comprehensive study was conducted at Gulf of Gemlik (Durmus and Balkis 2014) and it was reported that 28 tintinnid species live in the Sea of Marmara along with new registry species notifications for both this particular sea and Turkish coastal waters. In this study, it was found that *Tintinnopsis* genus is dominant in terms of species (8) and individual number. The highest number of tintinnid species was found in October (14 species) and the lowest number was found in May (3 species). Maximum abundance of sampling tintinnid species in 2010 was found in October ($1.7x10^3$ ind. $L^{-1}$) and in this period, *T. corniger* and *A. tetragona* were detected as the most abundant species (640 ind. $L^{-1}$).

Abundance of tintinnids were examined in near seas and *F. campanula* and *H. subulata* were reported in eutrophied inner zones of Gulf of İzmir during excessive increase period of *Ceratoneis closterium* reported as *N. closterium* (Koray *et al.* 1992). At the same gulf, *Favella, Tintinnopsis, Helicostomella* and *Salpingella* were the most commonly found genera, *Dadayiella ganymedes* reached $48.5 \times 10^3$ ind. $L^{-1}$ in spring and started to increase and had grazing effect particularly in period when diatoms started to increase (Çolak-Sabancı and Koray 2001). In another study, it was found that an abiotic factor, temperature had significant effect on qualitative distribution of tintinnid species (Polat *et al.* 2001).

Ciliates are an important component of the prey field available to zooplankton, fish larvae, and benthic invertebrates, particularly when phytoplankton biomass is low or dominated by small size cells (Stoecker 2013). Experimental data on predation on tintinnids are rare. Stoecker (2013) listed predators of tintinnids. Therefore, predators of tintinnid species detected in the Sea of Marmara according to the list of Stoecker (2013) and also biogeographical distributions are presented in Table 2. Most of the known species are cosmopolit and neritic. Only *Xystonella* genus is warm-water. It can be seen that majority of the species could adapt to low temperature and salinity values and they have great tolerances (Table 1).

Some of the predator species in Table 2 were reported in the Sea of Marmara. *Acartia clausi* in spring (Toklu-Alicli *et al.* 2014), autumn (Isinibilir *et al.* 2008, 2014); *Noctiluca scintillans* in spring (Balkis 2004, Yilmaz *et al.* 2005), summer (Isinibilir-Okyar *et al.* 2015); *Aurelia aurita* in summer period (Mavili 2008); *Mnemiopsis leidyi* in autumn (Shiganova *et al.* 1995), summer (Mavili 2008); *Centropages typicus* in summer (Toklu-Alicli *et al.* 2014), *Evadne nordmanni* in spring (Isinibilir-Okyar *et al.* 2015) and *Penilia* sp. in autumn (Isinibilir *et al.* 2008, Isinibilir-Okyar *et al.* 2015), summer (Isinibilir 2010, Toklu-Alicli *et al.* 2014) reached to high abundance. However, it is not possible to reveal clearly the role of predator-prey interactions between zooplankton and tintinnids in the food-web of the Sea of Marmara, because there is no study which carried on tintinnids and their predators in the Turkish coastal waters. There are some spatial and temporal differences about the predators diversity and abundance in the recent studies. Although, the fish species (*Syngnathus* sp., *Sprattus sprattus* and *Labrus bergylta*) which are predators on tintinnids at the larval stage were recorded in the Sea of Marmara, there is no any scientific data about their abundance. The comprehensive studies will be needed on tintinnids which have important role in the marine food-web and their predator-prey interactions with other plankton groups.

**Table 2.** Biogeographic distributions patterns and predators of tintinnids (Pierce and Turner 1993; Stoecker 2013)

| | Tintinnid species | Predators | Biogeographic Distribution |
|---|---|---|---|
| 1 | *Amphorellopsis tetragona* | | Cosmopolitan |
| 2 | *Amphorides amphora* | | Cosmopolitan |
| 3 | *Amphorides quadrilineata* | | |
| 4 | *Codonellopsis morchella* | *Ammodytes personatus, Lamprometra palmata* and some crinoids | Cosmopolitan |
| 5 | *Codonellopsis orthoceras* | | |
| 6 | *Codonellopsis schabi* | | |
| | *Codonellopsis* sp. | *Acartia* sp., *Leiostomus xanthurus, Myrophis* sp., *Noctiluca scintillans* | |
| 7 | *Dictyocysta* sp. | *Leiostomus xanthurus* | Cosmopolitan |
| 8 | *Eutintinnus apertus* | | Cosmopolitan |
| 9 | *Eutintinnus fraknoi* | | |
| 10 | *Eutintinnus lususundae* | | |
| 11 | *Eutintinnus medius* | | |
| 12 | *Eutintinnus tubulosus* | *Levanderina fissa* | |
| | *Eutintinnus* sp. | *Acartia hongi, Acartia tonsa, Acartia* sp., Salps | |
| 13 | *Favella campanula* | | Neritic |
| 14 | *Favella ehrenbergii* | *Aratus pisonii*, *Aurelia aurita, Syngnathus* sp. | |
| | *Favella* sp. | *Acartia tonsa, Ammotretis rostratus, Aurelia aurita, Brevoortia patronus, Mnemiopsis leidyi, Rhombosolea tapirina* | |
| 15 | *Helicostomella subulata* | *Calanus finmarchicus, Centropages typicus, Phoronis* sp. | Neritic |
| | *Helicostomella* sp. | *Meganyctiphanes norvegica, Parasagitta elegans* | |
| 16 | *Metacylis jörgensenii* | | Neritic |
| 17 | *Metacylis mediterranea* | | |
| 18 | *Metacylis mereschkowskii* | | |
| | *Metacylis* sp. | *Acartia* (*Acartiura*) *clausi* | |
| 19 | *Rhizodomus tagatzi* | | Neritic |
| 20 | *Salpingella acuminata* | | Cosmopolitan |
| 21 | *Salpingella decurtata* | | |
| | *Salpingella* sp. | *Subeucalanus pileatus* | |
| 22 | *Schmidingerella serrata* | | Neritic |
| 23 | *Steenstrupiella steenstrupii* | | Cosmopolitan |
| 24 | *Stenosemella nivalis* | *Ammodytes personatus, Noctiluca scintillans* | Neritic |
| 25 | *Stenosemella ventricosa* | *Calanus finmarchicus, Clupea harengus, Melanogrammus aeglefinus, Phrynorhombus norvegicus, Solea ovata, Sprattus sprattus* | |
| | *Stenosemella* sp. | *Atherinopsis californiensis, Genyonemus lineatus, Leiostomus xanthurus, Leuresthes tenuis, Micropogonias undulatus, Paralabrax* sp., *Paralichthys californicus, Seriphus politus.* | |
| 26 | *Tintinnopsis acuminata* | *Favella* sp. | Neritic |
| 27 | *Tintinnopsis beroidea* | *Acartia tonsa, Labrus bergylta, Phoronis* sp., *Schmidingerella serrata* | |
| 28 | *Tintinnopsis buetschlii* | | |
| 29 | *Tintinnopsis campanula* | | |
| 30 | *Tintinnopsis compressa* | | |
| 31 | *Tintinnopsis radix* | | |
| 32 | *Tintinnopsis urnula* | | |
| | *Tintinnopsis* sp. | *Acartia tonsa, Ammotretis rostratus, Aurelia aurita,* Bivalve and gastropod *veligers, Clupea harengus,* Cyphonautes (bryozoan larvae), Doliolids, *Evadne nordmanni, Leiostomus xanthurus, Mallotus villosus, Mnemiopsis leidyi, Mytilus edulis, Noctiluca scintillans*, *Oikopleura vanhoeffeni*, *Penilia* sp., *Rhombosolea tapirina,* Salps, *Synchaeta vorax* | |
| 33 | *Xystonella treforti* | | Warm water |
| | *Xystonella* sp. | | |

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## ZOOPLANKTON OF THE SEA OF MARMARA

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### 1. Introduction

Zooplankton, together with phytoplankton, constitutes the base of aquatic food webs and plays a crucial role in global biogeochemical cycles. Copepods, as the prominent component of zooplankton, are accepted as the most abundant multicellular organism on Earth, even surpassing insect population by a couple of orders of magnitude (Schminke 2007). As the most important grazers in the marine food webs, zooplankton provides the flow of trophic energy to higher levels and also drives the biological pump by supplying organic matter to the deeper parts of the ocean through fast sinking fecal pellets, regeneration of nitrogen and their carcasses; and thus feeding the microbial loop and detrital feeders of the benthos (Ruhl and Smith 2004). The functioning of biological pump is off greater importance in the era of climate change, since the storage of atmospheric carbon converted to biomass by phytoplankton relies zooplankton to speed up the sinking of organic matter via both vertical migration and fecal pellets.

The poikilothermic physiology and short life span of zooplankton makes the group a prompt indicator of changing environmental conditions, particularly of climate change (Hays *et al.* 2005) and monitoring shifts in zooplankton abundance patterns, species assemblages and community structure could be used to assess the health of an aquatic ecosystem. The vulnerability of the upper layer zooplankton dynamics to climate change is more pronounced in stratified systems by enhancing stratification even stronger, such as the Sea of Marmara (Richardson 2008; Coma *et al.* 2009).

The physicochemical and biological processes in the Sea of Marmara are discussed in detail within the current book or in earlier work (e.g. Besiktepe *et al.* 1994, Polat and Tugrul 1995). The most important feature of the basin is the permanently thermo-haline stratified water column, shaping the biological communities it harbors. This physical barrier also limits evolution of zooplankton communities, by strictly limiting vertical migration (Mutlu 2005). This chapter presents a brief evaluation of zooplankton studies in the basin, with notes on the abrupt changes due to anthropogenic forcing and invasive species.

## 2. Historical Data

Twenty studies were evaluated to explain the last four decades of zooplankton studies in the Sea of Marmara (Table 1). According to the distribution of sampling regions, sub regions of the basin were designated to present over all change in the basin (Figure 1).

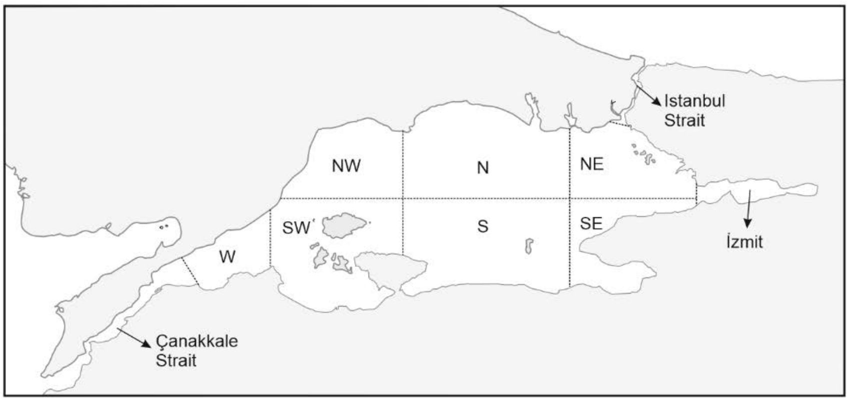


**Figure 1.** Map and regions of the Sea of Marmara.

Evaluation of zooplankton studies in chronological order showed the scaricity of zooplankton data before the end of 1990s and also lack of abudance data. Majority of earlier studies either provided information as species list or relative abundance, without information on the abundance. The most important outcomes were derived from time-series data collected from 1997 to 2007. The interruption in this data set due to funders after 2008 limits us to better understand the current dynamics, and there is an urgent need to resume continuing the timeseries oceanographic data collection in the basin in at least monthly intervals.

## 3. Species composition

The Sea of Marmara with its saline, oxygen deficient lower layer and highly productive brackish upper layer provides habitat for a wide range of zooplankton species and also acts as a corridor for the "Mediterranization of the Black Sea" (Kovalev *et al.* 1999). A total of 129 Copepoda and 6 Cladocera species were registered in the Sea of Marmara, with earliest records starting from Demir's work in 1950s (Table 2). Among available literature, Unal *et al.* (2000) provided the most detailed list with 111 copepod species, 12 being at genus level. A detailed list of all Copepoda species of Turkish seas, including benthic and parasitic forms, has been presented in Bakir *et al.* (2014). Although results imply a significant diversity of copepods, the high numbers are due to high diversity at the Mediterranean originated lower layer, while upper layer is dominated by relatively few species, but in much higher biomass when compared to the lower layer (Ünal *et al.* 2000). The most abundant upper layer copepod species are *Acartia clausi, Paracalanus parvus, Pseudocalanus elongatus, Centropages kröyeri, C. typicus* and *Oithiona similis*; while lower layer is populated by *Calanus euxinus, Calocalanus* sp., *Clausocalanus* sp. and *Ctenocalanus* sp.. Besides copepods, cladocerans also played a significant role in the Sea of Marmara and are represented by 6 species; *Penilia avirostris* and *Pleopis polyphemoides* being the most important ones. Although registered previously, A*nomalocera petersoni, Copilia quadrata, Corycaeus furcifer, Corycella rostrata, Eucalanus attenuatus, Labidocera brunescens, Parapontella brevicornis, Pontella lobiancoi, Pontella mediterranea* and *Pontellopsis villosa* were not encountered in samples for the last two decades (Isinibilir 2010b).

**Table 1.** Year, sampling frequency and coverage of datasets reviewed. For regions please refer to Figure 1.

| Sampling Year | Sampling Frequency | Data Coverage | Region | Reference |
|---|---|---|---|---|
| 1977 | Summer | Species list/ abundance | W | Cebeci and Tarkan 1990 |
| 1978 | Spring | Species list/ abundance | Marmara | Cebeci and Tarkan 1990 |
| 1979 | Spring | Species list/ abundance | SW | Cebeci and Tarkan 1990 |
| 1986-1990 | Spring-winter | Species list | Marmara | Benli *et al.* 2001 |
| 1997-1998 | Biweekly | Abundance | NE | Yuksek *et al.* 2002 |
| 1998 | Spring | Species list/ abundance | NW-N-NE | Unal *et al.* 2000 |
| 1999 | Autumn | Abundance/Acoustic | NE | Mutlu 2005 |
| 1999-2000 | Seasonal | Species list/ abundance | NE | Tarkan *et al.* 2005 |
| 2000 | Summer | Abundance | North/ Canakkale | Tarkan *et al.* 2000 |
| 2001-2002 | Monthly | Species list/ abundance | Izmit | Isinibilir *et al.* 2008 |
| 2001-2002 | Monthly | Abundance | NE | Yilmaz *et al.* 2005 |
| 2004-2007 | Monthly | Abundance | NE | Yilmaz 2015 |
| 2005 | Autumn | Physiology | NE | Hubareva *et al.* 2008 |
| 2005 | Autumn | Species list/ abundance/ physiology | NE | Svetlichny *et al.* 2006 |
| 2005-2006 | Monthly | Abundance | NE | Isinibilir 2009 |
| 2005-2006 | Seasonal | Species list/ abundance | Marmara | Yilmaz *et al.* 2012 |
| 2005-2008 | Seasonal | Species list/ abundance/ physiology | NE | Isinibilir *et al.* 2011 |
| 2005-2009 | Seasonal | Abundance | NE | Isinibilir *et al.* 2014 |
| 2006-2007 | Biweekly | Abundance | Çanakkale | Buyukateş and Inanmaz 2009 |
| 2006-2007 | Seasonal | Abundance | SW-S | Isinibilir 2010a |
| 2006-2008 | Seasonally | Species list/ abundance | SW | Toklu-Alicli *et al*. 2014 |
| 2008 | Monthly April-December | Species list/ abundance | NE | Isinibilir-Okyar *et al.* 2015 |

*A. clausi* is among the most abundant species throughout the year. Although the species' abundance was lower in 1970's, its contribution to copepod biomass increased significantly in 1980's and 1990's, probably due to eutrophication and tolerance of the species to pollution (Zagorodnyaya *et al.* 1999). The intrusion of *A.tonsa* in 1990's resulted in denser presence of the genus in warmer periods of the year (Gubanova 1999). Longterm datasets from the Northern Black Sea also supported the change mechanism where due to anthropogenic eutrophication biomass of *A. clausi* increased from 17% (1964) to 85% (1994) in 30 years (Kideys *et al.* 2000). The warming trend in the Sea of Marmara upper layer (Altiok and Kayisoglu 2015) caused a decrease pattern in *A. clausi* abundance and accompanied with an increase in thermophilic *Paracalanus parvus* as derived from 10-year monthly observations in the basin (Yilmaz, unpulished data). A similar trend was observed for the Adriatic Sea in a time scale of 20 years (Camatti *et al.* 2008).

In the vicinity of Istanbul Metropolis, the upper layer zooplankton in cooler periods of the year was dominated by copepods *Acartia clausi* and *Oithona similis* and cladoceran *Pleopis polyphemoides*. Seasonal contribution of meroplankton, particularly bivalve larvae and cirriped nauplius larvae, were also evident in winter period, during or before the annual phytoplankton increase in the region observed in winter. Cladoceran *Penilia avirostris* was the most important species during summer, responsible from the annual peak abundance levels of total zooplankton. Copepods *Acartia tonsa, Paracalanus parvus*, appendicularian *Oikopleura dioica* and chaetognath *Sagitta setosa* are other important warm-water species for the region.

**Table 2.** Registered pelagic Copepoda and Cladocera species of the Sea of Marmara (Demir 1955; Demir 1958; Demir 1959; Tarkan and Erguven 1988; Ünal *et al.* 2000; Benli *et al.* 2001; Svetlichny *et al.* 2006; Isinibilir *et al.* 2008; Yilmaz 2008; Isinibilir *et al.* 2011; Doğan and İşinibilir 2016).

| | |
|---|---|
| **Copepoda** | *Calocalanus pavo* Dana 1849 |
| *Acartia clausi* Giesbrecht 1881 | *Calocalanus pavoninus* Farran 1936 |
| *Acartia longiremis* Lilljeborg 1853 | *Calocalanus plumatus* Shmeleva 1965 |
| *Acartia negligens* Dana 1849 | *Calocalanus styliremi* Giesbrecht 1888 |
| *Acartia tonsa* Dana 1849 | *Calocalanus tenuis* Farrran 1926 |
| *Acrocalanus gibber* Giesbrecht 1888 | *Candacia giesbrechti* Grice & Lawson 1977 |
| *Acrocalanus longicornis* Giesbrecht 1888 | *Candacia longimana* Claus 1863 |
| *Acrocalanus monachus* Giesbrecht 1888 | *Candacia parasimplex* Brodsky 1962 |
| *Aetideus armatus* Boeck 1872 | *Candacia tenuimana* (Giesbrecht 1889) |
| *Aetideus giesbrechti* Cleve 1904 | *Centropages furcatus* (Dana 1849) |
| *Anomalocera petersoni* Templeton 1837 | *Centropages kröyeri* Giesbrecht 1892 |
| *Calanoides carinatus* Crouer 1848 | *Centropages ponticus* Karavaev 1894 |
| *Calanopia elliptica* Dana 1884 | *Centropages typicus* Kröyer 1849 |
| *Calanopia metu* Uysal & Shmeleva 2000 | *Chiridius poppei* Giesbrecht 1892 |
| *Calanus euxinus* Hulsemann 1991 | *Clausocalanus arcuicornis* (Dana 1849) |
| *Calanus helgolandicus*(Claus 1963) | *Clausocalanus furcatus* (Brady 1883) |
| *Calocalanus adriaticus* Shmeleva 1965 | *Clausocalanus jobei* Frost & Fleminger 1968 |
| *Calocalanus contractus* Farran 1926 | *Clausocalanus mastigophorus* (Claus 1863) |
| *Calocalanus minor* Shmeleva 1980 | *Clausocalanus minor* Sewell 1929 |

*Clausocalanus parapergens* Frost & Fleminger 1968
*Clausocalanus paululus* Farran 1926
*Clausocalanus pergens* Farran 1926
*Clytemnestra rostrata* (Brady 1883)
*Copilia quadrata* Dana 1849
*Corycaeus clausi* F. Dahl 1894
*Corycaeus furcifer* Claus 1863
*Corycaeus limbatus* Bradyi 1883
*Corycaeus typicus* (Krouer 1849)
*Corycella rostrata* (Claus 1863)
*Ctenocalanus citer* Bowman & Heron 1971
*Ctenocalanus vanus* Giesbrecht 1888
*Diaixis pygmaea* (Scott T. 1899)
*Euaetideus giesbrechti* Cleve 1910
*Euaugaptilus* sp.
*Eucalanus attenuatus* (Dana 1849)
*Eucalanus subcrassus* Giesbrecht 1888
*Euchaeta acuta* Giesbrecht 1892
*Euchaeta hebes* Giesbrecht 1888
*Euchaeta marina* (Prestandrea 1833)
*Euchirella* sp.
*Euterpina acutifrons* (Dana 1847)
*Gaetanus* sp.
*Haloptilus spiniceps* (Giesbrecht 1892)
*Heterorhabdus papilliger* Claus 1863
*Labidocera brunescens* (Czerniavski 1868)
*Longipedia* sp.
*Lubbockia squillimana* Claus 1863
*Lucicutia clausi* (Giesbrecht 1889)
*Lucicutia flavicornis* (Claus 1863)
*Lucicutia gemina* Farran 1926
*Lucicutia longicornis* (Giesbrecht 1889)
*Lucicutia paraclausi* Park 1970
*Macrosetella gracilis* (Dana 1848)
*Mecynocera clausi* Thompson 1888
*Mesocalanus tenuicornis* (Dana 1849)
*Metridia lucens* Boeck 1865
*Microcalanus pygmaeus* (Sars 1900)
*Microcalanus pusillus* Sars 1903
*Microsetella norvegica* (Boeck 1864)
*Microsetella rosea* (Dana 1848)
*Monstrilla* sp.
*Mormonilla minor* Giesbrecht 1891
*Nannocalanus minor* (Claus 1863)
*Neocalanus gracilis* (Dana 1849)
*Neocalanus tenuicornis* (Dana 1849)
*Oithona davisae* Ferrari & Orsi 1984
*Oithona decipiens* Farran 1913
*Oithona nana* Giesbrecht 1893
*Oithona plumifera* Baird 1843
*Oithona setigera* (Dana 1849)
*Oithona similis* Claus 1866
*Oithona tenuis* Rosendorn 1917
*Oncaea bathyalis* Shmeleva 1968
*Oncaea conifera* Giesbrecht 1891
*Oncaea ivlevi* Shmeleva 1966
*Oncaea media* Giesbrecht 1891
*Oncaea mediterranea* (Claus 1863)
*Oncaea minuta* Giesbrecht 1892
*Oncaea ornata* Giesbrecht 1891
*Oncaea subtilils* Giesbrecht 1892
*Oncaea tregoubovi* Shmeleva 1968
*Oncaea venella* Farran 1929
*Oncaea venusta* Philippi 1843
*Oncaea zernovi* Shmeleva 1966
*Paracalanus aculeatus* Giesbrecht 1888
*Paracalanus denudatus* Sewell 1929
*Paracalanus nanus* Sars G.O., 1925
*Paracalanus parvus* (Claus 1863)
*Paracalanus pygmaeus* Claus 1863
*Paracalanus* sp.
*Paracartia latisetosa* (Krichagin *1873)*
*Paradisco* sp.
*Parapontella brevicornis* (Lubbock 1857)
*Paroithona parvula* Farran 1908
*Parvocalanus crassirostris* (Dahl 1894)
*Parvocalanus elegans* Andronov 1972
*Parvocalanus latus* Andronov, 1972
*Pleuromamma abdominalis* (Lubbock 1856)
*Pleuromamma gracilis* (Claus 1863)
*Pontella lobiancoi* Canu 1863
*Pontella mediterranea* Claus 1863
*Pontellopsis villosa* Brady 1883
*Pseudocalanus elongatus* (Boeck 1865)
*Scolecithricella abyssalis* (Giesbrecht 1888)
*Scolecithricella emarginate* Farran 1905
*Scolecithricella vittata* (Giesbrecht 1892)
*Spinocalanus caudatus* Sars 1920
*Spinocalanus magnus* Wolfenden 1904
*Temora stylifera* Dana 1849
Triconia similis (Sars 1918)
*Undinula vulgaris* (Dana 1849)
**Cladocera**
*Evadne nordmanni* Loven 1836
*Evadne spinifera* Müller P. E. 1867
*Penilia avirostris* Dana 1849
*Pleopis polyphemoides* (Leuckart 1859)
*Pseudoevadne tergestina* (Claus 1877)
*Podon intermedius* Lilljeborg 1853

Although upper layer community structure has a clear seasonality, lower layer presented a different structure with overall dominance of copepods. Discrete multi-layer net samplings and acoustic surveys revealed that diurnal vertical migration is limited due to high stratification and the main zooplankton biomass is confined to upper layer (Mutlu 2005). Basin wide seasonal samplings in 2005-2006 confirmed the evolution of different communities in both layers and also lack of any seasonal spatio-temporal pattern in the lower layer (Yilmaz *et al.* 2012).

The salinity gradients between upper layer and lower layer of the Sea of Marmara increased natural mortality rates in copepods. Although Black Sea originated copepod species dominated the upper layer (<70%), more than half of these taxa appeared to be dead at the lower layer, below the salinity gradient (Svetlichny *et al.* 2006). Non-consumptive mortality of copepods in the vicinity of the Strait of Isanbul were detected very high due to mass mortality of the Mediterranean species *Oncaea minuta* (40%) and the Black Sea species *Acartia clausi* (80%) (Isinibilir *et al.* 2011). The experiments on decomposition time of carcasses revealed that zooplankton carcasses reach successfully to lower layers and contributes to bacterial processes based on the body densities and sinking speed (Isinibilir *et al.* 2011).

## 4. Group composition

World oceans are dominated by a high biomass of copepods with seasonal peaks of Cladocera abundance in temperate seas. However the Sea of Marmara possesses a different structure when compared to the world oceans and the neighboring Black Sea, with dominance of Cladocera for extended periods, with an annual contribution of 40-47 % of Cladocera (Figure 3). Limited historical data from late 1970s demonstrated a less pronounced abundance of cladocerans 40 years ago, with a cumulative abundance varying between 1.2 – 1.5% in August 1977, March 1978 and May 1979 (Cebeci and Tarkan 1990). Currently these months are dominated by *Pleopis* (March), *Evadne* (May) and *Penilia* (August). This change in dominance patterns may indicate a change in the size of available prey, since *Penilia*, as a very effective filter feeder, can feed on very small prey, including bacterioplankton (Turner *et al.* 1988).

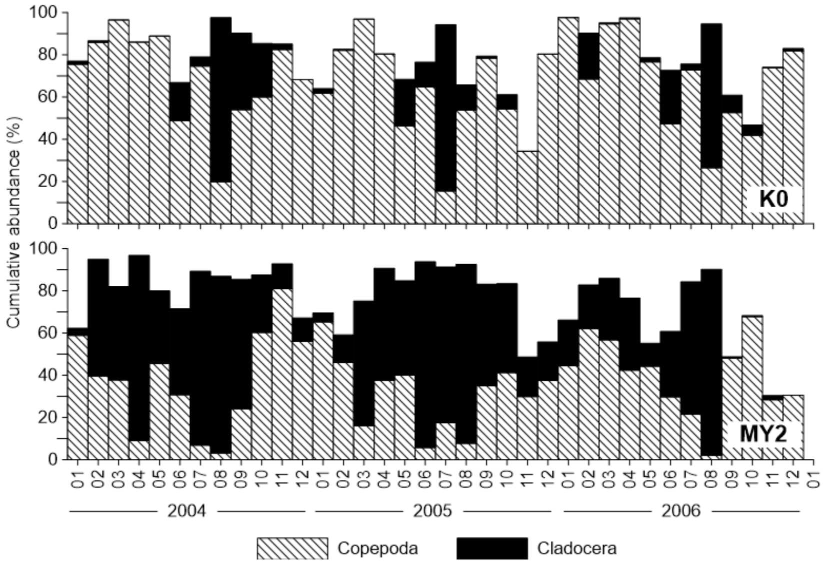


**Figure 3**. Change in cumulative Cladocera and Copepoda abundance in the Black Sea entrance of the Strait of Istanbul (K0) and North-eastern Sea of Marmara (MY2) in 2004-2006.

Although the gross growth efficiency of *Penilia* is reported similar to marine copepods under normal food conditions and to be slightly higher under low food conditions (Atienza *et al.* 2007), the extended presence and abundance levels in the Sea of Marmara points to different mechanisms. The parthenogenesis and continuous somatic growth of the species is known to cause outbursts in the population (Egloff *et al.* 1997). High productivity of the upper layer should have also strengthened the succession of the cladocerans, particularly the thermophilic filter feeder *Penilia avirostris* and eurythermal *Pleopis polyphemoides*. The stratified upper layer of the Sea of Marmara may enhance feeding rates of *Penilia* through concentrating the prey in a relatively thin layer and keeping the neonates in the prey-rich upper strata. Isinibilir *et al.* (2011) reported that body densities of cladocerans are highly similiar to the Marmara upper layer, therefore although the cladocerans are distributed in the whole aerobic zone in the Black Sea, they cannot descent to the denser deeper strata of the Sea of Marmara, but concentrate at the upper layer. Studies conducted at stations along a transect from the Black Sea to the Sea of Marmara showed that number of copepods in plankton decreased while cladocerans increased from Black Sea to the Sea of Marmara along the Strait of Istanbul (Svetlichny *et al.* 2006). As discussed further below, decline in Cladocera in 2006-2007 is due to the predation by *Liriope tetraphylla.*

Appendicularians and chaetognaths are other important components of zooplankton in warmer periods of the year. Although being rare, historical data reveals a maximum of 34.2% contribution of *Oikopleura dioica* to total zooplankton, whereas maximum cumulative abundance of *Sagitta setosa* was 9.6%. Around the coastal areas seasonal peaks of meroplankton, particularly bivalve veligers (maximum 33.6%) and Cirripedia nauplius larva (maximum 42.7%), could also constitute a significant fraction of total zooplankton (Yilmaz 2002, 2015).

## 5. Spatial variability and abundance patterns

The basin-wide seasonal studies in the Sea of Marmara showed distinct spatial patterns in community structure. One of the most important factors regulating the dispersal of communities are the eddies formed by the Strait of Istanbul's jet flow. The major circulation patterns are well known at the Sea of Marmara (Besiktepe *et al.* 1994). The results of the hierarchical agglomerative cluster analyses of seasonal zooplankton sampling network of 2005-2006 cruises provided information on increased abundance of pollution/eutrophication tolerant species at highly populated and/or industrialized areas of the basin as well as east/west differentiation of open sea zooplankton communities flow (Yilmaz *et al.* 2012). The most prominent differentiation has been observed in September and December. In both samplings the western community was separated from the eastern ones either by absence or very low abundance of pollution tolerant species, namely *Acartia clausi, Oithona similis, Pleopis polyphemoides,* and Cirripedia nauplius and cypris larva. The results demonstrated that in addition to water masses, anthropogenic impact is also a major driver in mesoscale differentiation.

The abundance patterns in the Sea of Marmara is highly region specific. Comparative studies pointed to very high zooplankton abundance in industrialized regions and around port areas such as Izmit, Bandirma and Gemlik bays as well as in the vicinity of Istanbul Metropolitan area. However zooplankton abundance significantly declines towards west and open regions. One of the best studied region is the NE sector due to its proximity to Istanbul (Figure 1). One of the earliest data from the region implies an average total abundance of 566 ind. $m^{-3}$ in March 1978 (Cebeci and Tarkan 1990). In the following years publications were generally related to species lists or cumulative group abundances, lacking information on total zooplankton (Table 1). Following the onset of routine monitoring studies in the area in 1997, the gathered high resolution timeserise data provided a better understanding of the zooplankton patterns. In all years from 1997 to 2007, cladocerans were the main drivers of high zooplankton abundance. The abundance peaks were usually observed in July-September and the highest abundance was 26,746 ind.$m^{-3}$ in July 2005. Despite of the collapse of zooplankton stocks in 2006-2007, a slight increase trend is noteworthy within the data (Yuksek *et al.* 2002; Yilmaz *et al.* 2005; Yilmaz 2015). For other areas of the Sea of Marmara very few information exists. In İzmit Bay, as the most polluted region of the Sea of Marmara, zooplankton densities were much higher than reported for the NE sector. During a yearlong monthly monitoring effort, highest zooplankton abundance was detected as 79,332 ind.m$^{-3}$ in October 2001, once again due to high contribution of *Penilia* (Isinibilir *et al.* 2008).

## 6. Trophic cascades in plankton and invasive species

Invasion of the Black Sea by the comb jelly *Mnemiopsis leidyi* constitutes one of the best examples of trophic cascades in the pelagic realm (Kideys 2002). Although the successful establishment of the species is linked to many factors including pollution, eutrophication, decreased light attenuation and change in the size distribution of phytoplankton, over fishing appeared to be the triggering factor of cascading effects in plankton (Daskalov 2002; Aksnes 2007; Daskalov *et al.* 2007). The niche of small pelagic fish, highly overfished and whose feeding capability is visually constrained due to low light attenuation has been replaced by the invasive *M. leidyi.* The rapid decline in zooplankton stocks due to very high ctenophore biomass further limited recruitment of small pelagic fishes by reduction in fodder zooplankton for the larvae (Shiganova 1998; Mutlu 1999). As an extension of the Black Sea, upper layer of the Sea of Marmara also affected by the *M. leidyi* invasion, significantly depleting zooplankton and eventually collapsing anchovy stocks that constitute the second important fishery ground of the nation after the Black Sea (Shiganova *et al.* 1995), however lack of routine plankton surveys during these changes limited our understanding of invasion dynamics and fate of zooplankton.

Approximately 15 years later a small holoplanktonic hydromedusa, *Liriope tetraphylla*, underwent a sudden population development and triggered cascading effects in the planktonic foodweb of the Sea of Marmara. Although the species is a common member of the Mediterranean plankton (Buecher *et al.* 1997), it was first registered in the Sea of Marmara in 2005 (Isinibilir *et al.* 2010). *L. tetraphylla* abundance reached bloom levels in 2006 and 2007 with a maximum abundance of 2978 ind.m$^{-3}$ (Yilmaz 2015). In the meanwhile, Mediterranean Sea time series datasets covering a 30-year period depicted a maximum abundance of 65 ind. m$^{-3}$ (Yilmaz 2015 and references therein). The exponential growth of this new gelatinous predator caused a temporal regime shift from a Copepoda/Cladocera controlled system to a jellyfish controlled one; as marked by a drastic decline in Cladocera abundance and shift in overall zooplankton community structure. The elimination of one of the most important filter feeder, *Penilia avirostris*, from the system and decline in total zooplankton abundance is proposed to cause a shift in phytoplankton size structure and abundance, thus eventually leading to a massive basin-wide mucilage event affecting benthos and small pelagic fisheries (Yilmaz 2015). Phytoplankton studies during and after the mucilage period showed higher abundance of well-known mucilage producing species (Balkis *et al.* 2011; Polat Beken *et al.* 2011).

In addition to episodic events stated above, the heterotrophic dinoflagellate *Noctiluca scintillans* is among the most important competitors of zooplankton, limiting stocks through both bottom-up and top-down forcing (Yilmaz *et al.* 2005). The lowest periods of zooplankton abundance are witnesses during the annual spring and November blooms of *N. scintillans*. The resident *Aurelia aurita* population also possess a predation pressure on Marmara zooplankton.

## 7. Conclusion

The Sea of Marmara zooplankton community has strong spatial and temporal differences both in terms of species assemblages and abundance, even from the neighboring Black and Aegean seas. Stratification and higher chlorophyll a levels of the basin revealed in a higher contribution of cladocerans to zooplankton abundance. The highly thermo-haline stratified water column caused evolution of two distinct communities; Black Sea originated upper layer with clear spatio-temporal patterns and a distinct dominance of cladocera and Mediterranean Sea originated lower layer, lacking spatial patterns and harboring a diverse copepod community. As demonstrated in 2006-2007, modification of zooplankton communities through invasive species or anthropogenic perturbations may yield to cascading effects in the pelagic food web, eventually affecting fish stocks and fisheries.

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**JELLYFISH SPECIES OF THE SEA OF MARMARA**

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## 1. Introduction

Jellyfish may excessively affect pelagic food web by exerting a top-down control on their ecosystems (Mountford 1980). This has been well documented in estuaries and enclosed seas (Kremer and Nixon 1976; Mutlu 1999; 2001; Mutlu and Bingel 1999). Many studies indicates that the environmental changes caused by intensive human activity (e.g., eutrophication, overfishing, translocations, habitat modification, etc.) and climate change are all contributors to jellyfish blooms (Arai 2001, Purcell *et al.* 2007, Richardson *et al.* 2009). In recent years, the warning signs of ecological deterioration such as algal blooms, fishery collapse, massive mucilage events and jellyfish blooms have increased significantly in the Sea of Marmara (Zengin and Mutlu 2000; Isinibilir 2011; 2012; Turkoglu 2013; Isinibilir-Okyar *et al.* 2015; Yılmaz 2015).

The Sea of Marmara, connected to the Black and Aegean seas by the Strait of Istanbul and Dardanelles straits, is an inland sea forming a transition zone between the Black Sea and the Mediterranean Sea. Furthermore, the Sea of Marmara has permanent two-layered water system and plays significant role on biodiversity of the Black Sea and the Aegean Sea. In recent years, the Sea has been undergoing profound changes, in terms of jellyfish bloom and mucilage formation. The ctenophore *Mnemiopsis leidyi* was introduced into the Sea of Marmara in early 1990s and effected all ecosystem (Isinibilir *et al.* 2004; Isinibilir 2012). *Beroe ovata*, *Chrysaora hysoscella* and *Liriope tetraphylla* are other important invasive species for the region (Isinibilir *et al.* 2010; Isinibilir 2012). Latest studies showed that quantities of jellyfish have been increasing in the Sea of Marmara in the last decade (Isinibilir *et al.* 2010; 2015).

This chapter aims to describe distribution of important jellyfish species in the Sea of Marmara, with likely drivers of increasing jellyfish populations.

## 2. Historical Data

Table 1 provides 62 Hydrozoa, 6 Scyphozoa, 1 Staurozoa, and 4 Ctenophora, species registered in the Sea of Marmara. Earliest studies on jellyfish started from Demir's work in 1952. Later, several other researchers provided data on abundance, distribution and biodiversity of jellyfish species in the Sea of Marmara (Ünsal 1995; Kıdeys and Niermann 1994; Shiganova *et al.* 1995; Tarkan *et al.* 2000, Albayrak and Balkis 2000; Isinibilir and Tarkan 2001; Inanmaz *et al.* 2002; Mavili 2008; Isinibilir *et al.* 2010, 2015; Isinibilir 2011, 2012, 2014a,b; Yılmaz 2015; Yılmaz *et al.* 2016).

**Table 1.** Polip (P) and medusa (M) stages of registered Cnidaria and Ctenophora species in the Sea of Marmara. Demir 1952 (1), Ünsal 1995 (2), Albayrak and Balkis 2000 (3), Marques *et al.* 2000 (4), Inanmaz *et al.* 2002 (5), Isinibilir 2004 (6), Isinibilir *et al.* 2010 (7), Çınar *et al.* 2014 (8), Isinibilir 2012 (9), Isinibilir *et al*. 2015 (10). syn*:* Synonym.

| SPECIES | Stages | Referances |
|---|---|---|
| **CNIDARIA** | | |
| **Hydrozoa** | | |
| *Acryptolaria conferta* (Allman, 1877) | P | 2 |
| *Aglaophenia dichotoma* Kirchenpauer, 1872 | P | 8 |
| *Aglaophenia elongata* Meneghini, 1845 | P | 8 |
| *Aglaophenia octodonta* Heller, 1868 | P | 8 |
| *Aglaophenia pluma* (Linnaeus, 1758) | P | 1 |
| *Aglaura hemistoma* Péron & Lesueur, 1810 | M | 7 |
| *Antennella secundaria* (Gmelin, 1791) | P | 8 |
| *Anthohebella parasitica* (Ciamician, 1880) | P | 8 |
| *Bougainvillia muscus* (syn: *B. fruticosa, B. ramosa*) (Allman, 1863) | P | 1 |
| *Campanulina repens* (syn: *Phialella quadrata*) Allman, 1864 | P | 1 |
| *Cladonema radiatum* Dujardin, 1843 | P | 8 |
| *Clytia gracilis* (Sars, 1850) | P | 8 |
| *Clytia hemisphaerica* (Linnaeus, 1767) | P | 1 |
| *Coryne* (syn: *Syncoryne*) *eximia* Allman, 1859 | P | 1 |
| *Dicoryne conferta* (Alder, 1856) | P | 2 |
| *Ectopleura* (syn: *Tubularia*) *larynx* (Ellis & Solander, 1786) | P | 1 |
| *Eudendrium armstongi* Stechow, 1909 | P | 8 |
| *Eudendrium capillare* Alder, 1856 | P | 1 |
| *Eudendrium merulum* Watson, 1985 | P | 4 |
| *Eudendrium rameum* (Pallas, 1766) | P | 1 |
| *Eudendrium ramosum* (Linneaus, 1758) | P | 2 |
| *Filellum serpens* (Hassall, 1848) | P | 2 |
| *Filellum serratum* (Clarke, 1879) | P | 2 |
| *Gastroblasta raffaelei* Lang, 1886 | M | 10 |
| *Gonothyraea gracilis* Allman, 1864 | P | 1 |
| *Gonothyraea loveni* (syn: *G. hyalina*) (Allman, 1859) | P | 1 |
| *Halecium beanii* (Johnston, 1838) | P | 1 |
| *Halecium halecinum* (Linnaeus, 1758) | P | 2 |
| *Halecium labrosum* Alder, 1859 | P | 3 |
| *Hartlaubella* (syn: *Obelia) gelatinosa* (Pallas, 1766) | P | 1 |
| *Hydractinia carnea* (syn: *Podycoryne cornea*) (M. Sars, 1846) | P | 1 |
| *Hydractinia echinata* (Fleming, 1828) | P | 2 |
| *Kirchenpaueria* (syn: *Plumularia* andV*entromma*) *halecioides* (Alder, 1859) | P | 1 |
| *Koellikerina fasciculata* (Péron and Lesueur, 1810) | M | 10 |
| *Lafoea dumosa* (syn: *L. gracillima*) (Fleming, 1820) | P | 1 |
| *Laomedea angulata* (syn: *Campanularia angulata*) Hincks, 1861 | P | 1 |
| *Laomedea exigua* Sars, 1857 | P | 2 |
| *Laomedea flexuosa* Alder, 1857 | P | 2 |
| *Leuckartiara octona* (syn: *Perigonimus repens*) (Fleming, 1823) | P | 1 |
| *Liriope tetraphylla* Chamisso & Eysenhardt, 1821 | M | 7 |
| *Lytocarpia* (syn: *Thecocarpus*) *myriophyllum* (Linnaeus, | P | 2 |

| | | |
|---|---|---|
| 1758) | | |
| *Modeeria rotunda* (syn: *Stegopoma fastigiatum*) (Quoy&Gaimard, 1827) | P | 2 |
| *Muggiaea kochii* (Will, 1844) | P | 8 |
| *Nemertesia antennina* (Linnaeus, 1758) | P | 2 |
| *Nemertesia ramosa* (Lamarck, 1816) | P | 2 |
| *Nemertesia tetrasticha* Meneghini, 1845 | P | 8 |
| *Neoturris pileata* (Forskal, 1775) | M | 7 |
| *Obelia bidentata* (syn: *O. bicuspidata*) Clarke, 1875 | P | 1 |
| *Obelia dichotoma* (Linnaeus, 1758) | P | 1 |
| *Obelia longissima* (syn: *O. flabellata*) (Pallas, 1766) | P | 2 |
| *Orthopyxis caliculata (*syn: *O. integra)* (MacGillivray, 1842) | P | 2 |
| *Plumularia syriaca* Billard, 1931 | P | 2 |
| *Podocoryna carnea* M. Sars, 1846 | P | 8 |
| *Podocorynoides minima* (Trinci, 1903) | M | 10 |
| *Rhizoragium arenosum (*syn: *Atracylis arenosa)* (Alder, 1862) | P | 1 |
| *Sarsia tubulosa* (syn: *Syncoryne sarsii*) (M.Sars, 1835) | P | 1 |
| *Sertularella crassicaulis* (Heller, 1868) | P | 8 |
| *Sertularella ellisii* (Deshayes & Milne Edwards, 1836) | P | 8 |
| *Sertularella polyzonias* (Linnaeus, 1758) | P | 1 |
| *Solmundella bitentaculata* Quoy & Gaimard, 1833 | M | 7 |
| *Tubularia indivisa (*syn: *Tubularia simplex)*Linnaeus, 1758 | P | 3 |
| *Lensia* sp. | M | 6 |
| **Staurozoa** | | |
| *Lucernariopsis campanulata* (Lamouroux, 1815) | P | 1 |
| **Scyphozoa** | | |
| *Aurelia aurita* (Linné, 1758) | M, P | 1 |
| *Chrysaora hysoscella* (Linné, 1766) | M | 5 |
| *Discomedusa lobata* Claus, 1877 | M | 10 |
| *Paraphyllina ransoni* Russell, 1956 | M | 7 |
| *Periphylla periphylla* (Peron & Lesueur, 1810) | P | 8 |
| *Rhizostoma pulmo* (Macri, 1778) | M | 6 |
| **CTENOPHORA** | | |
| *Beroe ovata* Chamisso &Eysenhardt, 1821 | M | 9 |
| *Mnemiopsis leidyi* (Agassiz, 1865) | M | 9 |
| *Pleurobrachia pileus* (Müller, 1776) | M | 9 |
| *Pleurobrachia rhodopis* Chun, 1879 | M | 1 |

## 3. Native jellyfish species

The Sea of Marmara has two native schyphozoa species (*Aurelia aurita* and *Rhizostoma pulmo*) and one ctenophore species (*Pleurobrachia pileus*). Another species of *Pleurobrachia* (*P. rhodopis*) has been recorded in the Sea of Marmara by Demir (1952), however this species was never reported again. In 1992, *P. pileus* biomass in the Sea of Marmara reached a maximum value of 6.9 g.m$^{-3}$ (Shiganova *et al.* 1995). *P. pileus* was absent in the summer and autumn of 2001 and autumn of 2002 in the Izmit Bay, northeastern Sea of Marmara (Isinibilir 2012). The maximum abundance (54.52 ind.m$^{-3}$) and biomass (32.46 g.m$^{-3}$) in the Izmit Bay were the highest in the spring 2002 (Isinibilir 2012). In the southern part of the Sea of Marmara, *P. pileus* was found all seasons, except autumn (Isinibilir 2011). It was distributed all coastal area from Bandırma Bay to the Dardanelles. The maximum abundance of *P. pileus* was in summer 2007 (9.6 ind.m$^{-3}$) in the southern Sea of Marmara (Isinibilir 2011). During the 2007-

2008 mucilage periods in the Izmit Bay, latest increase of its abundance in the Sea of Marmara have been registered in May 2008, with a maximum abundance of 10,61 $ind.m^{-3}$ (Isinibilir 2014b). Isinibilir-Okyar (2015) informed that *P. pileus* is found both layer of the Sea of Marmara. Maximum length of *P. pileus* in the Sea of Marmara was 21 mm (Isinibilir 2011).

*Aurelia aurita* is the most important jellyfish species for the basin with yearlong occurrence and prolonged blooms with high biomass. The *Aurelia* dynamics in the Sea of Marmara is highly dependent on the Black Sea inflow and new production in the Strait of Istanbul (Yilmaz *et al*. 2016) as can be followed from very high biomass levels encountered in the Strait of Istanbul (e.g. 13177.9 $g.m^{-3}$ in March 2016). The distribution of *Aurelia* is higher at coastal areas and bays and surface patches are also subject to wind advection. During 2001-2002, maximum biomass of the species in Izmit Bay was 160.5 $g.m^{-3}$ (Isinibilir 2012). In southern regions of the Sea of Marmara maximum abundance was encountered in Erdek Bay (11 $ind.m^{-3}$) (Isinibilir 2011). The abundance significantly declined during the 2007-2008 mucilage events and highest abundance was detected as 0.4 $ind.m^{-3}$ (Isinibilir *et al.* 2015). The biweekly samplings in the Strait of Istanbul in June 2014 – May 2016 showed that the species has the population peaks in January-May period and lowest densities were observed in summer (Yilmaz *et al.* 2016). SCUBA dives performed in the Strait of Istanbul and Prince Islands showed that larger individuals were usually distributed at the intermediate and lower layers, while the upper layer was populated by smaller individuals (Yilmaz *et al.* 2016).

*Rhizostoma pulmo* (Macri, 1778) is one of the most important scyphozoan jellyfish species blooming along the Marmara coasts, as well as, *Aurelia aurita*. This species were observed in the Sea of Marmara, with increases from August till December in Izmit Bay (Isinibilir 2004). *R. pulmo* outbursts were seen in the Erdek Bay in both July 2006 and June 2007 (Isinibilir 2011). Mavili (2008) reported that *R. pulmo* are widely distributed in the the Sea of Marmara.

## 4. Alien Jellyfish Species

*M. leidyi,* a voracious zooplanktivorous ctenophore, was accidentally introducedto the Black Sea in early 1980's, almost certainly with ballast water from the northwestern Atlantic coasts of USA (Vinogradov *et al.* 1989). In the following years, *Mnemiopsis* invaded the Sea of Marmara via surface currents flowing from the Black Sea through the Strait of Istanbul. The first appearance of *Mnemiopsis* in the Sea of Marmara was 1992 (Shiganova *et al.* 1995), when the levels of *M. leidyi* were already lower in the Black Sea than in 1988 and 1989. Later, several other researchers provided data on abundance and distribution of this ctenophore in the Sea of Marmara (Kıdeys and Niermann 1994; Shiganova *et al.* 1995; Isinibilir and Tarkan 2001; Isinibilir 2011; 2012; 2014a, b). In early October 1992, the average numbers of *M. leidyi* were 27 ind. $m^{-3}$ (Shiganova *et al.* 1995), while in July 1993 abundances were observed as low as 0.1 ind. $m^{-3}$ (Kideys and Niermann 1994). But in August 2000, higher values of *M. leidyi* were reported again from the Sea of Marmara, (12.9 ind. $m^{-3}$) (Isinibilir and Tarkan 2001) and dropped again to 1.62 ind. $m^{-3}$ in August 2001 (Isinibilir *et al.* 2004). In 2001-2002, *M. leidyi* population was already declined due to *B. ovata* and highest biomass in Izmit Bay was 34.8 g.m$^{-3}$ (Isinibilir *et al.* 2012). In 2006, average *M. leidyi* abundance at Erdek Bay was 1.3 ind.m$^{-3}$ (Isinibilir 2011). Latest increase of *M. leidyi* abundance in the Sea of Marmara have been registered in August 2008 during the 2007-2008 mucilage event, with a maximum abundance of 58 ind.m$^{-3}$ and biomass of 353 g.m$^{-3}$ in Izmit Bay (Isinibilir 2014a). Maximum length of *M. leidyi* in the Sea of Marmara was 170 mm (Isinibilir 2012).

Approximately same time with *Mnemiopsis,* its predator, *Beroe ovata,* was also recorded for the first time in the Sea of Marmara in 1992 (Shiganova *et al.* 1995). In 1999, two individuals of *B. ovata* were found near the Strait of Istanbul (Tarkan *et al.* 2000). Although *B. ovata* was not detected in 2000 (Isinibilir and Tarkan 2001), eight mostly large individuals were sampled in August 2001, with an average abundance of 0.3 ind.m$^{-3}$ (Isinibilir *et al.* 2004). *B. ovata* was absent in the winter and spring of 2002 in the eutrophic Izmit Bay (Isinibilir 2012). While the highest maximum abundance (772.5 ind.m$^{-3}$) in the Izmit Bay was recorded in autumn 2001, the maximum biomass (422.7 g.m$^{-3}$) was the highest in the summer 2001 (Isinibilir 2012). The species disappeared from Izmit Bay in 2008 and was only observed in September, with a low abundance just prior to the mucilage event (Isinibilir 2014a). In the southern part of the Sea of Marmara, *B. ovata* was found only in autumn (Isinibilir 2011). *B. ovata* was mainly distributed in the waters of Erdek and Bandırma Bay (Mean abundance: 1.02 ind.m$^{-3}$, maximum abundance: 4.3 ind.m$^{-3}$) (Isinibilir 2011). Maximum length of *B. ovata* in the Sea of Marmara was 160 mm (Isinibilir 2012).

Although *Chrysaora hysoscella* (Linnaeus, 1767) is commonly distributed in the Aegean Sea and the Mediterranean Sea, the first occurrence of the species in the Sea of Marmara was in 2000 in the southwest region (Inanmaz *et al.* 2002). The magnitude of blooms increased in coastal areas in the 2000s, which have caused ecological and economic losses in the basin. The blooms of *Chrysaora* had impacted tourism at beaches due to stings (Isinibilir 2015). Therefore, some tourism operators and local municipalities have installed jellyfish nets against *C. hysoscella*. The mean abundance of *C. hysoscella* increased from 2001 to 2009, but then it was sharply decreased in 2010 and since then it observed sporadically. Isinibilir (2015) reported high numbers in the coastal areas of the basin, particularly in the Izmit Bay and its maximum diameter was 35 cm in June 2009.

By far the most notorious jellyfish species in the Mediterranean is the mauve stinger, *Pelagia noctiluca*. Since this scyphozoan species lacks a polyp phase and therefore is holoplanktonic, the distribution is not restricted to the coastal waters. However wind or water masses advected blooms of this jellyfish frequently occur near shorelines, inflicting painful but non-fatal stings to up to tens of thousands of seabathers each year (Purcell *et al.* 2007, Brotz and Pauly 2012). Alpaslan (2001) informed that *Pelagia noctiluca* was found rarely during winter and generally during spring in the Çanakkale Harbor, located on the Strait of Canakkale. This observation implies that a fraction of the population enters the Strait via lower layer flows and there is a potential risk for a future invasion of the Sea of Marmara by this stinging jellyfish species.

*Liriope tetraphylla* is a small, epipelagic Trachymedusae species that shows direct development, without a fixed hydroid stage (Russell 1953). The species is known to feed on herbivorous and carnivorous zooplankton, as well as on fish eggs and larva (Larson 1987). Although the species is described as an oceanic form (Russell 1953); it is more frequently observed in coastal areas in greater numbers than in offshore regions (Buecher *et al.* 1997). *L. tetraphylla* is a common and abundant hydromedusan species in the Mediterranean and also recorded in the Black Sea (Bouillon *et al.* 2004). The species first occurrence in the Sea of Marmara was September 2005 (Isinibilir *et al.* 2010) and caused coherent blooms in 2006 and 2007. When the magnitude of these were compared to historical Mediterranean Sea datasets, an extreme population increase of *L. tetraphylla* was noticed in the Sea of Marmara (Yılmaz 2015). Even during the settlement period (2005), *Liriope* abundance was significantly higher than the maximum abundance observed between 1966 and 1997 (65 ind.m$^{-3}$) in the Western Mediterranean and Adriatic seas (Buecher *et al.* 1997, Yılmaz 2015). The peak abundance levels reached in 2006 (2978 ind.m$^{-3}$) and 2007 (2822 ind.m$^{-3}$) are far greater than those recorded in available data on *L. tetraphylla* abundances (Yılmaz 2015).

*Aglaura hemistoma* was first recorded in the upper layer of Izmit Bay in July 2001 (Isinibilir *et al*. 2010). The species generally had higher densities in autumn and winter. A remarkable increase in the abundance of *A. hemistoma* was in the end of August 2001, with a maximum of 604 ind.m$^{-3}$. The species was also observed in the lower layer near Prince Islands in 2008 (Isinibilir Okyar *et al.* 2015). Doğan (2016) reported the distribution of species in the Büyükçekmece Bay in July- November 2014.

New introductions of jellyfish continue to be documented in the Sea of Marmara in recent years. In 2008, the first sighting of the deep sea scyphomedusan *Paraphyllina ransoni* was reported from the lower layer of Izmit Bay (Isinibilir *et al.* 2010). In March 2011, *Discomedusa lobata* was sampled from the lower layer (25–90 m) in Izmit Bayand established a population (Isinibilir *et al.* 2015). In addition smaller species; *Solmundella bitentaculata*, *Neoturris pileata*, *Podocorynoides minima, Koellikerina fasciculata* and *Gastroblasta raffaelei* were also recorded for the first time in the Sea of Marmara (Isinibilir *et al.* 2010; 2015).

## 5. The triggering mechanism of jellyfish blooms in the Sea of Marmara

The introductions of jellyfish into the Sea of Marmara probably occur through either the lower layer flow of the Dardanelles from the Aegean Sea or upper layer flow of the Strait of Istanbul, since majority of reported jellyfish species except *Mnemiopsis* and *Beroe* were already present in the Mediterranean and the Black Sea. On the other hand, ballast water may have also acted as an important vector for introduction of some of these species. In addition to introduced species, it is known than anthropogenic impacts on marine environment cause increases in jellyfish populations (Purcell *et al.* 2007, Richardson *et al.* 2009). These include eutrophication, global warming, overfishing and coastal development.

Warmer temperature due to global warming could be benefited by some jellyfish species in the Sea of Marmara through accelerating medusa growth and ephyrae production and altering phenology. Jellyfish belonging to the genus *Aurelia* have also been shown to benefit from warmer temperatures through increased growth (Widmer 2005) and enhanced asexual reproduction (Purcell *et al.* 2009, Han and Uye 2010), which could be involved in the increase in *Aurelia aurita* population of the Sea of Marmara. Isinibilir-Okyar (2015) informed that average temperature of the Sea of Marmara increased almost 2 °C above the previous years. In last years, an increase in the *A. aurita* abundance was observed in the Sea of Marmara (Isinibilir, unpublished data). A recent study on metagenic development strategies of the species in the Strait of Istanbul showed that the life cycle of the species benefits various salinity and temperature conditions (Yilmaz, unpublished data).

Excessive nutrient additions from human sources may create favorable conditions for jellyfish proliferations through increased food availability, decreased water clarity, and decreased dissolved oxygen (DO) concentrations (Arai 2001). Some jellyfish species have been shown to benefit from eutrophication in other systems (e.g. Kideys 1994; Stoner *et al.* 2011) and therefore similar mechanisms may be at work in the Sea of Marmara. Morkoç *et al.* (1997) and Tüfekçi *et al.* (2010) classified the Sea of Marmara as a eutrophic sea due to deviated Redfield ratios and high nutrient concentrations.

Overfishing is recognized as a major factor increasing jellyfish blooms through removing jellyfish predators and competitors (Daskalov *et al.* 2007). The Sea of Marmara is the second most important fisheries ground for Turkey and the fishing industry has been significantly affected by jellyfish increases in the last decades (Isinibilir and Yılmaz, in press).

In the Sea of Marmara, artificial substrates including docks, marinas, reclaimed areas from the sea and artificial reefs provide new surfaces to be habited by polyps. Many studies reports importance of artificial substrates in jellyfish blooms (e.g. Di Camillo *et al.* 2010) and majority of reported jellyfish blooms have occurred in heavily populated areas surrounding semi-enclosed water bodies (Purcell *et al.* 2007).

Invasive jellyfish species of the Sea of Marmara are often associated with some of the jellyfish blooms and may be a continuous problem due to intense shipping activities and deteriorated marine ecosystems, as demonstrated by the *Mnemiopsis* (Isinibilir 2012) and *Liriope* (Isinibilir *et al.* 2010; Yılmaz 2015) invasions. The heavy maritime traffic in the Sea of Marmara and high number of important port areas may increase the risk of invasive species introduction.

Izmit Bay constitutes the best example of the correlation between jellyfish proliferations and anthropogenic impacts in the Sea of Marmara. Izmit Bay, located on the NE Sea of Marmara, is an elongated semi enclosed bay with a length of 50 km and width varying between 2 and 10 km. Izmit Bay, as one of the most important industrial areas in the Sea of Marmara and has been subjected to severe pollution problems (Morkoc *et al.* 2001). The August 1999 earthquake (magnitude 7.4 on the Richter scale), caused the destruction of waste-water discharge systems and spill of refined petroleum and crude oil to the bay following a refinery fire (Scawthorn and Johnson 2000; Balkıs 2003). After the earthquake, the increasing organic and inorganic loads into the bay have stimulated dense phytoplankton blooms (Tas and Okus 2004) which locally caused saturated dissolved oxygen concentrations in the eastern basin in the autumn of 1999 (Balkıs 2003). Today the bay receives effluents from more than 300 industrial facilities, together with the untreated domestic waste waters from populated areas (Isinibilir *et al.* 2008). This degraded ecosystem had high population of *A. aurita* and *R. pulmo* (Isinibilir *et al.* 2012). In the beginning of 2000s, two new invasive ctenophorans (*M. leidyi* and *B. ovata*) were recorded in the bay and began forming large blooms (Isinibilir *et al.* 2012). These large blooms constituted a major problem for the local fishery industry and decomposition of the jellyfish biomass increased nutrient regeneration. Furthermore, mucilage event of 2007-2008 showed the fragility of Marmara ecosystems and impacts of cascading effects due to changes in predator densities. The predation of *Liriope tetraphylla* in 2006 and 2007 is proposed to causes cascading effects in planktonic food web eventually leading to the collapse of crustacean zooplankton and occurrence of a massive basin wide mucilage phenomenon (Yılmaz 2015).

As a major shipping route and a biological corridor between two contrasting seas, Sea of Marmara is subject to sudden changes in the ecosystem due to anthropogenic perturbations and settlement of invasive species. Periodic monitoring of jellyfish distribution in the basin is crucial for assessing future impacts of jellyfish proliferations on ecosystem, fisheries and tourism.

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**BENTHIC FORAMINIFERAL FAUNA OF THE SEA OF MARMARA**

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## 1. Introduction

Foraminifera are single-celled protozoa having a life style as benthic on/within the sea floor and planktic in the water column of open seas. Their test size typically ranges between 50 and 500 µm although some benthic foraminifers may be a much larger size (about 15–20 cm). The majority of foraminiferal species are benthic which has longer fossil records (Cambrian-Modern). Foraminifera have a wide environmental range (e.g., marine and marginal marine environments, such as lagoons, estuaries, deltas, coastal marshes and mangroves) and exhibit variable density and diversity depending on environmental parameters. Physical, chemical and biological parameters, such as temperature, salinity, substrate type, turbidity, light, nutrients, oxygen, tidal energy and interspecific competition affect the distribution of foraminifera (Murray 1991a, b; 2006). These are interrelated, but some parameters like temperature and salinity limit foraminiferal distributions.

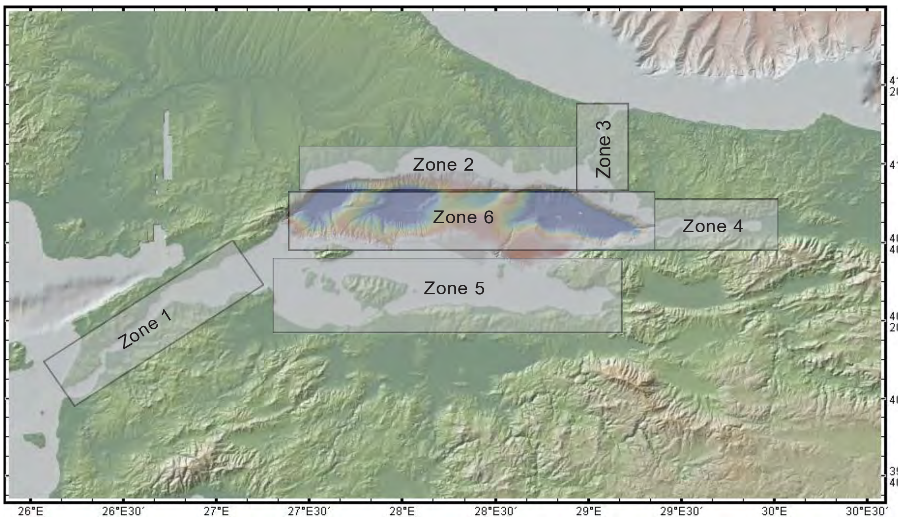
As a waterway between the saline Mediterranean Sea and brackish Black Sea, the Sea of Marmara is a marginal marine environment influenced by the physical, chemical and biological characteristics of the both seas. In a basic manner, the foraminiferal composition, diversity and density of a marginal marine environment differ from those of normal marine environments (Hayward *et al*. 1999; Sen Gupta 1999; Debenay *et al*. 2005; Melis and Violanti 2006; Koukousioura *et al*. 2011).

In the Sea of Marmara, recent foraminifers were investigated in surface sediments collected from the different water depths (Avşar 2002 and Meriç *et al*. 2009: Çanakkale Strait; Chendeş *et al*. 2004 and Phipps *et al*. 2010: southwestern shelf; Meriç *et al*. 2001: İstanbul Strait; Meriç *et al*. 2005: Gulf of Gemlik; Avşar *et al*. 2006: Gulf of Erdek; Sakınç 2008: northern and southern shelves; Avşar 2010: northern shelf; Kırcı-Elmas 2013: various environmental settings of the Sea of Marmara (Figure 1). The aim of this chapter is to present an aspect of benthic foraminiferal fauna of the Sea of Marmara using the major findings of the previous investigations.

## 2. Foraminiferal Distribution

Foraminiferal data in the Sea of Marmara is mainly based on total faunas including all stain and non-stained foraminifera (undifferentiated living + dead), except for Phipps *et al*. (2010). Therefore, we do not have any possibility for comparison the dead and living assemblages, since they analysed together in the samples. Phipps *et al.* (2010) studied the calcareous benthic foraminifera along a 350 m depth transect on the southwestern part of the Sea of Marmara and presented the data for dead assemblage, due to the rare occurrence of Rose Bengal stained individuals. They found relatively high percentage of living tests only at 70 m, representing 8% of the total assemblage.

The faunal analysis was carried out in different size limits in the Sea of Marmara (e.g., >250 µm; >125 µm; >63 µm). A comparison of foraminiferal densities and compositions between >63–>250 µm and >63–>125 µm displayed that the use of a 250 µm lower sieve limit caused a 95% reduction in the total number of specimens and the loss of abundant species as compared to the >63µm fraction (Kırcı-Elmas 2013). At the 125 µm threshold, the foraminiferal loss was highly variable (≤75%) and the dominance of some small species was erased completely. Therefore, variations in faunal distribution should be considered, due to the different quantitative approaches.




Zone 1 - Çanakkale Strait (ÇS): Avşar, 2002; Meriç et al., 2009; Kırcı-Elmas, 2013
Zone 2 - Northern Shelf (NS): Sakınç, 2008; Avşar, 2010; Kırcı-Elmas, 2013
Zone 3 - Golden Horn and İstanbul Strait (GH, İS): Meriç and Sakınç, 1990; Meriç et al., 2001
Zone 4 - Gulf of İzmit (Gİ): Meriç et al., 1995; Kırcı-Elmas, 2013
Zone 5 - Southern Shelf (SS): Chendeş et al., 2004; Meriç et al., 2005; Avşar et al., 2006; Sakınç, 2008; Phipps et al., 2010, Kırcı-Elmas, 2013
Zone 6 - Deep Basin (DB): Alavi, 1988; Kırcı-Elmas, et al., 2008

**Figure 1.** Locations of benthic foraminiferal studies from the different environmental settings of the Sea of Marmara (Multibeam bathymetry image from Rangin *et al.* 2001).

### 2.1. Çanakkale Strait

Avşar (2002) studied the benthic foraminiferal content of 10 sediment samples from the entrance of Aegean Sea-Çanakkale Strait and indicated the dominance of *Brizalina spathulata*, *Asterigerinata mamilla*, *Valvulineria bradyana* and *Porosononion* *subgranosum*. A total of 26 samples collected across the Çanakkale Strait were investigated by Meriç *et al.* (2009). The assemblages are represented by 73 genera and 118 species. When considering the total occurrences of foraminifera from all stations, the common species were *Ammonia compacta*, *Quinqueloculina seminula*, *Lobatula lobatula*, *Bulimina elongata*, *Brizalina alata*, *Ammonia tepida*, *Elphidium crispum*, *Valvulineria bradyana*, *Discorbinella bertheloti*, *Planorbulina mediterranensis*, *Cassidulina carinata*, *Sigmoilopsis schlumbergeri* and *Adelosina cliarensis*. Kırcı-Elmas (2013) stated that foraminiferal density in the Çanakkale Strait ranged between 2776 and 6864 individuals/10 g of dry sediment. The species richness was recorded as high, with average 85 species. *Cassidulina carinata* (max. 15.5%), *Brizalina spathulata* (max. 14.2%), *Valvulineria bradyana* (max. 10.5%), *Asterigerinata mamilla* (max. 10.5%), *Globocassidulina subglobosa* (max. 8.0%), *Bulimina aculeata* (max. 7.0%) were the most abundant species in the strait.

Sedimentation in the Çanakkale Strait is controlled by the current system, bathymetry and morphological structure of the strait. High current velocities (Özsoy *et al*. 1986) and high silt/clay ratio in the Dardanelles indicate that sediment accumulation on the channel is greatly controlled by current-induced hydro-sedimentary processes (Ergin and Bodur 1999). The thickness of the recent sediment is thin and usually sandy units with shell fragments and muddy sediments are observed (Meriç *et al*. 2009). Therefore, foraminiferal composition in the channel is also greatly affected by hydro-sedimentary processes.

### 2.2. Northern shelf

A rich benthic foraminiferal fauna was identified on the Northern Marmara shelf (Sakınç 2008; Avşar 2010; Kırcı-Elmas 2013). The assemblages are represented mainly by *Brizalina spathulata*, *Cassidulina carinata*, *Asterigerinata mamilla* and *Elphidium crispum*, together with subordinate numbers of *Globocassidulina subglobosa*, *Bulimina aculeata*, *B. marginata*, *Neoconorbina terquemi*, *Rosalina bradyi*, *Discorbinella bertheloti*, *Lobatula lobatula*, *Ammonia compacta*, *A. parkinsoniana*, *A. tepida* and *Cribroelphidium poeyanum* (Avşar 2010).

### 2.3. Golden Horn and İstanbul Strait

In the Golden Horn, several borehole samples were studied by Meriç and Sakınç (1990). Top of the boreholes includes *Eggerelloides scabrus*, *Bulimina elongata*, *B. marginata*, *Neoconorbina terquemi*, *Ammonia tepida* and *Elphidium crispum*.

A total of 86 species belonging to 44 genera were identified in the 26 surface samples from the İstanbul Strait (Meriç *et al*. 2001). Number of species decreased to north (entrance of Black Sea-İstanbul Strait: 7 genus and 8 species) from south (entrance of the Sea of Marmara-İstanbul Strait: 43 genus and 70 species). Although diversity is high, scarcity of number of individuals was associated with the current regime of the strait.

Kırcı-Elmas (2013) reported that the dominant taxa near the entrance to the İstanbul Strait (28 m water depth) are *Bulimina aculeata* (32.2%), *Bolivina variabilis*

(29.1%), *Ammonia tepida*, (14.2%) and *Bulimina elongata* (11.2%). At 65 m, the fauna is represented by *Cassidulina carinata* (31.5%), *Brizalina spathulata* (21.3%), *Bolivina variabilis* (11.8%), *Bulimina aculeata* (8.6%) and *Brizalina dilatata* (7.1%).

### 2.4. Gulf of İzmit

Foraminiferal investigation of eight boreholes drilled between Hersek Burnu and Kaba Burun showed that the assemblage of the top parts is dominated by *Ammonia compacta* and *A. parkinsoniana* along with subordinate species *Elphidium complanatum*, *E. crispum*, *E. macellum*, *Asterigerinata mamilla*, *Cibicides floridanus*, *Lobatula lobatula*, *Rosalina bradyi* and *Spiroplectinella sagittula* (Meriç *et al*. 1995). High dominance of genus *Ammonia* (80%) was also indicated in a surface sediment collected from 34 m water depth (Kırcı-Elmas 2013).

### 2.5. Southern shelf

Benthic foraminifers in the Gulf of Erdek were investigated in 15 surface sediment samples and a total of 74 species were identified (Avşar *et al*. 2006). The fauna had low density, but quite stable diversity indices consisting mainly of *Ammonia compacta*, *Cassidulina carinata*, *Discorbinella bertheloti*, *Cribroelphidium poeyanum* and *Elphidium crispum*. Shallow-water foraminiferal assemblages were systematically reported from 63 stations in the Gulf of Gemlik (Meriç *et al*. 2005). A total of 30 samples collected along a depth transect from the southwestern part of the Marmara Sea were studied by Chendeş *et al*. (2004) and Phipps *et al*. (2010), associated with the water mass characteristics measured at each station. Chendeş *et al*. (2004) identified two diverse assemblages related to the brackish Black Sea and saline Mediterranean Sea water masses. Later, Phipps *et al*. (2010) recorded 200 calcareous benthic foraminiferal species and identified three assemblages including: *Ammonia* spp. and *Elphidium* spp at 15–50 m; *Cassidulina carinata*, *Brizalina spathulata* and *Gyroidina umbonata* at 55–130 m and *Brizalina spathulata* and *Bulimina costata* at 140–350 m. Lower foraminiferal density and species richness were found at the Susurluk, Gönen, and Biga river mouths (Kırcı-Elmas 2013). The fauna was dominated by genera *Ammonia* and *Elphidium*.

### 2.6. Deep basins

Benthic foraminiferal content of the deep basin sediments were recorded from the core-top samples recovered from the Central and Çınarcık basins of the Sea of Marmara. Alavi (1988) showed that *Chilostomella mediterranensis*, *Brizalina alata*, *B. dilatata*, *B. spathulata*, *Melonis pompilioides*, *Cassidulina minuta*, *Nonionellla opima*, *Bulimina costata* and *Sigmoilinita tenuis* are the most dominant species in the Çınarcık Basin, whereas *Uvigerina mediterranea*, *Bulimina costata*, *B. marginata*, *Brizalina alata*, *Sigmoilinita tenuis*, *Melonis barleanum*, *M. pompilioides*, *Sigmoilopsis schlumbergeri* and *Spiroloculina excavata* were abundantly identified in the Central Basin (Kırcı-Elmas *et al*. 2008).

## 3. Alien foraminiferal species

*Cornuspiroides striolatus*, *Ishamella apertura*, *Cushmanina striatopunctata* and *Faujasina carinata* recorded by Sakınç (2008) and *Siphonina tubulosa* recorded by Kırcı-Elmas (2013) are alien species for the Sea of Marmara. *Cornuspiroides striolatus*, *Cushmanina striatopunctata* and *Siphonina tubulosa* were also found in Ildır-NW Karaburun Peninsula (Meriç, E., unpublished data), Çanakkale Strait (Meriç *et al*. 2009) and Samandağ-Hatay costline (Meriç *et al*. 2016), respectively. *Ishamella apertura* and *Faujasina carinata* were never described in the Mediterranean and Aegean Sea in the previous studies. These species were probably transported with ballast waters to the Sea of Marmara.

## 4. Faunal characterization

The general faunal character of the Sea of Marmara is greatly controlled by the salinity gradient related to the two-layer water stratification (see Physical Oceanography Section). Brackish shallow shelf area and normal marine salinity area dominated by diverse benthic foraminiferal assemblages (Figure 2). Distribution of shallow assemblage is associated with the Black Sea surface inflow, riverine discharges (additional freshwater and organic matter inputs) and salinity fluctuations due to seasonal vertical mixing. Deeper assemblage reflects more stable environmental conditions (e.g., salinity and temperature) established below ~40–50 m water depth.

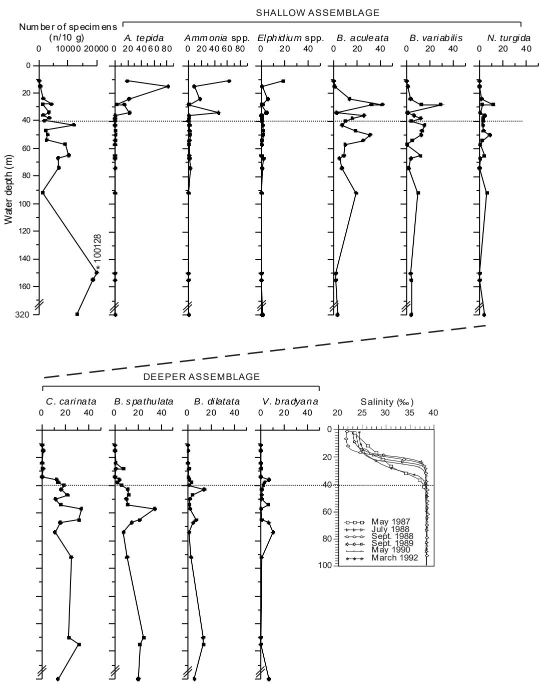



**Figure 2.** Relationship between foraminiferal distribution and salinity in the Sea of Marmara (modified from Kırcı-Elmas 2013).

Selected species from the different environmental settings of the Sea of Marmara are illustrated in Figures 3, 4 and 5. Figures 4 and 5 show the representative species (relative abundances >5%) for the benthic foraminiferal fauna of the Sea of Marmara.


**Figure 3.** Benthic foraminiferal species of the Sea of Marmara. All samples are from the Gulf of Gemlik. **1** *Rhabdammina abyssorum*, x15. **2** *Spiroplectinella sagittula*, x55. **3** *Eggerelloides scabrus*, x85. **4** *Textularia bocki*, x80. **5** *Textularia truncata*, x70. **6** *Spiroloculina tenuiseptata*, x60. **7** *Siphonaperta aspera*, x75. **8** *Cycloforina contorta*, x70. **9** *Cycloforina villafranca*, **9a:** x40 and **9b:** x45. **10** *Lachlanella undulata*, **10a:** x70 and **10b:** x80. **11** *Quinqueloculina seminula*, x60. **12** *Miliolinella subrotunda*, x95. **13** *Pyrgo anomala*, x75 (from Meriç *et al.* 2005).

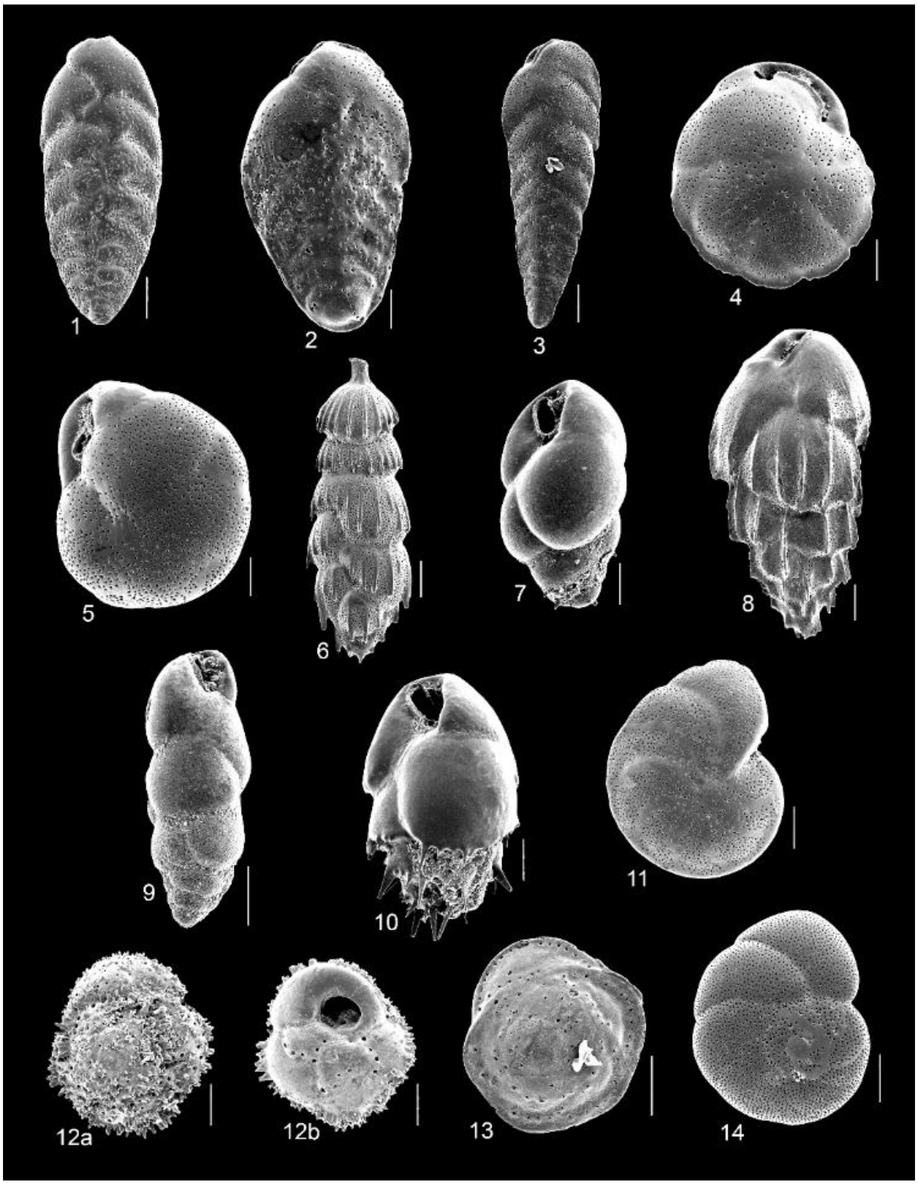



**Figure 4.** Benthic foraminiferal species of the Sea of Marmara. Scale bars = 50 µm unless noted otherwise. **1** *Bolivina variabilis*, NS. **2** *Brizalina dilatata*, SS. **3** *Brizalina spathulata*, NS, scale bar = 100 µm. **4** *Cassidulina carinata*, NS. **5** *Globocassidulina subglobosa*, NS. **6** *Rectuvigerina phlegeri*, NS. **7** *Bulimina aculeata*, NS. **8** *Bulimina costata*, NS. **9** *Bulimina elongata*, NS, scale bar = 100 µm. **10** *Bulimina marginata*, SS. **11** *Discorbinella bertheloti*, NS. **12** *Asterigerinata adriatica*, NS: **12a**, spiral side; **12b**, umbilical side. **13** *Asterigerinata mamilla*, SS, scale bar = 100 µm. **14** *Valvulineria bradyana*, DB, spiral side, scale bar = 100 µm (From Kırcı-Elmas 2013).

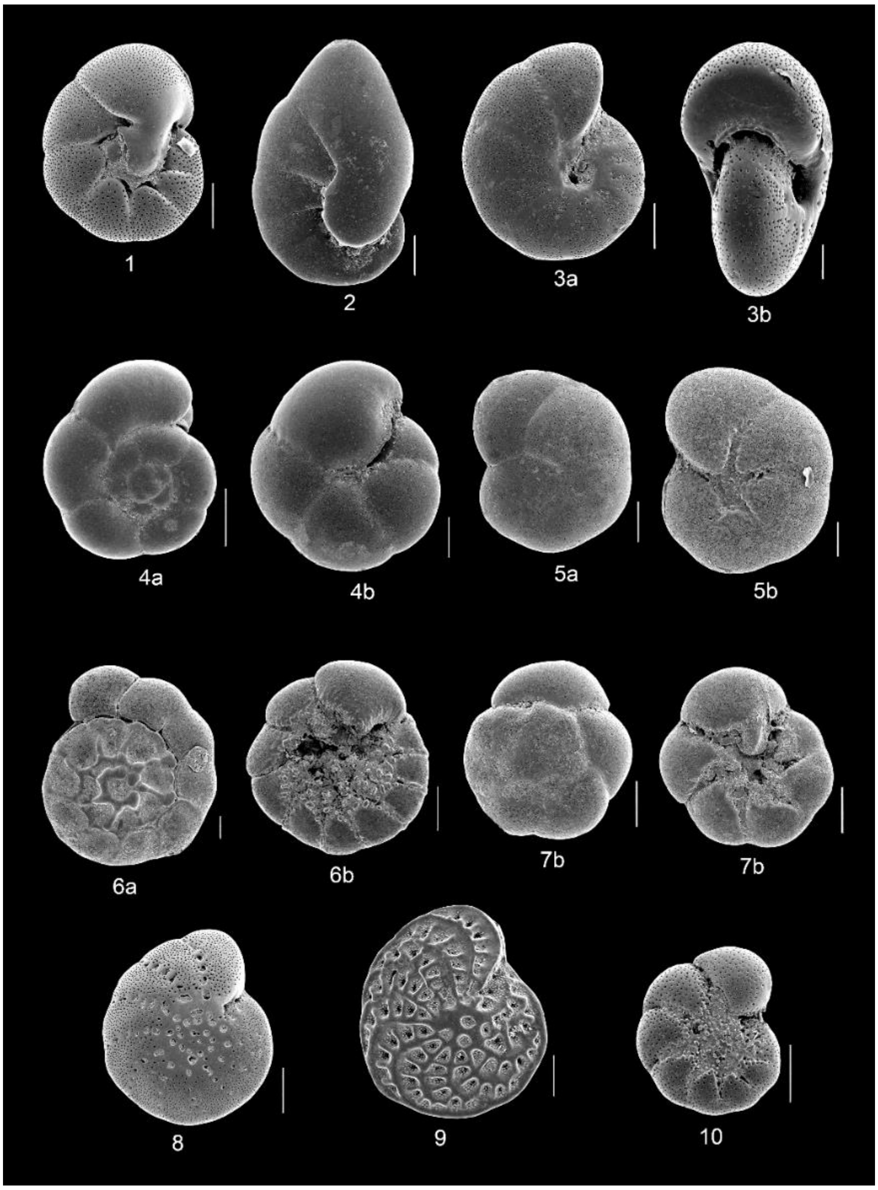



**Figure 5.** Benthic foraminiferal species of the Sea of Marmara. Scale bars = 100 μm unless noted otherwise. **1** *Valvulineria bradyana*, DB, umbilical side. **2** *Nonionella turgida*, SS, scale bar = 50 μm. **3** *Melonis barleanum*, ÇS: **3a**, sideview; **3b**, apertural view. **4** *Gyroidina umbonata*, SS: **4a**, spiral side; **4b**, umbilical side. **5** *Aubignyna perlucida*, SS, scale bar = 50 μm: **5a**, spiral side; **5b**, umbilical side. **6** *Ammonia compacta*, NS: **6a**, spiral side; **6b**, umbilical side. **7** *Ammonia tepida*, Gİ: **7a**, spiral side; **7b**, umbilical side. **8** *Cribroelphidium poeyanum*, SS. **9** *Elphidium macellum*, NS. **10** *Porosononion subgranosum*, SS (From Kırcı-Elmas 2013).

All benthic foraminiferal records (309 species) from the Sea of Marmara are listed in alphabetical order in Table 1. The highest species richness was observed at the southern shelf (247) in the Sea of Marmara. The İstanbul Strait and entrance of the İstanbul Strait-Sea of Marmara have relatively poor species richness (less than 90 species), due to proximity to fresh water source.

**Table 1.** Benthic foraminiferal distribution and species list in the Sea of Marmara (**ÇS:** Çanakkale Strait, **NS**: Northern Shelf, **DB**: Deep Basin, **SS:** Southern Shelf, **Gİ:** Gulf of İzmit, **GH:** Golden Horn, **İS:** İstanbul Strait).

| **FORAMINIFERAL SPECIES** | **LOCATIONS** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **ÇS** | **NS** | **DB** | **SS** | **Gİ** | **GH** | **İS** |
| *Adelosina carinatastriata* (Wiesner) | | * | | * | | | |
| *Adelosina cliarensis* (Heron-Allen & Earland) | * | * | | * | * | | * |
| *Adelosina dubia* (d'Orbigny) | | * | | * | | | |
| *Adelosina duthiersi* Schlumberger | * | | | | | | |
| *Adelosina elegans* (Williamson) | * | * | | * | | | |
| *Adelosina intricata* (Terquem) | * | * | | * | | | |
| *Adelosina longirostra* (d'Orbigny) | | * | | * | | | * |
| *Adelosina mediterranensis* (Le Calvez J. & Y.) | * | * | | * | * | | * |
| *Adelosina partschi* (d'Orbigny) | | * | | * | | | * |
| *Adelosina pulchella* (d'Orbigny) | * | * | | * | * | | * |
| *Adercotryma glomerata* (Brady) | | | * | | | | |
| *Ammodiscus planorbis* Höglund | | * | | | | | |
| *Ammoglobigerina globigeriniformis* (Parker & Jones) | * | | | | | | |
| *Ammonia compacta* (Hofker) | * | * | * | * | * | | * |
| *Ammonia parasovica* Stshedrina & Mayer | | | | | * | | |
| *Ammonia parkinsoniana* (d'Orbigny) | * | * | | * | * | | * |
| *Ammonia tepida* (Cushman) | * | * | * | * | * | * | * |
| *Ammoscalaria pseudospiralis* (Williamson) | | * | | * | | | |
| *Ammoscalaria runiana* (Heron-Allen & Earland) | | * | | * | | | |
| *Amphicoryna hispida* (d'Orbigny) | | | | * | | | |
| *Amphicoryna intercellularis* (Brady) | | | | * | | | |
| *Amphicoryna proxima* (Silvestri) | | | | * | | | |
| *Amphicoryna scalaris* (Batsch) | * | * | * | * | * | | * |
| *Amphistegina lobifera* Larsen | | | | * | | | |
| *Angulogerina angulosa* (Williamson) | * | * | | * | | | |
| *Articulina tubulosa* (Seguenza) | | * | * | | | | |
| *Astacolus crepidulus* (Fichtel & Moll) | * | * | | * | | | |
| *Asterigerinata adriatica* Haake | * | * | | * | | | |
| *Asterigerinata mamilla* (Williamson) | * | * | | * | * | | * |
| *Astrononion stelligerum* (d'Orbigny) | * | * | | * | | | * |
| *Aubignyna perlucida* (Heron-Allen & Earland) | | * | * | * | * | | |
| *Bigenerina nodosaria* d'Orbigny | * | * | * | * | | | |
| *Biloculinella depressa* (Wiesner) | * | * | | * | | | * |
| *Biloculinella elongata* (Wiesner) | | * | | * | | | |
| *Biloculinella globula* (Bornemann) | * | * | | * | | | |
| *Biloculinella inflata* (Wright) | | * | | * | | | |
| *Biloculinella labiata* (Schlumberger) | * | * | * | * | | | |
| *Biloculinella cylindrica* Todd | | | * | | | | |
| *Biloculinella wiesneri* (Le Calvez J. & Y.) | | * | | * | | | |
| *Bolivina aenariensis* (Costa) | | * | | * | | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *Bolivina albatrossi* Cushman | * | * | | | | | |
| *Bolivina pseudoplicata* Heron-Allen & Earland | | * | | | | | |
| *Bolivina pseudopuncata* Höglund | | | | * | | | |
| *Bolivina subsipnescens* Cushman | * | * | | * | | | |
| *Bolivina variabilis* (Williamson) | * | * | * | * | * | | |
| *Brizalina alata* (Seguenza) | * | * | * | * | * | | * |
| *Brizalina catanensis* (Seguenza) | | | | * | | | |
| *Brizalina dilatata* (Reuss) | * | * | * | * | * | | |
| *Brizalina earlandi* (Parr) | | * | | | | | |
| *Brizalina spathulata* (Williamson) | * | * | * | * | * | | * |
| *Brizalina striatula* (Cushman) | * | * | | * | | | |
| *Buccella granulata* (Di Napoli Alliata) | | * | | * | | | |
| *Bulimina aculeata* d'Orbigny | * | * | * | * | * | | |
| *Bulimina costata* d'Orbigny | * | * | * | * | | | |
| *Bulimina denudata* Cushman & Parker | | | | * | | | |
| *Bulimina elongata* d'Orbigny | * | * | * | * | * | * | * |
| *Bulimina marginata* d'Orbigny | * | * | * | * | * | * | |
| *Bulimina pagoda* Cushman | | | | * | | | |
| *Cassidulina carinata* Silvestri | * | * | | * | * | | * |
| *Cassidulina crassa* d'Orbigny | | * | | * | | | |
| *Cassidulina minuta* Cushman | | | * | | | | |
| *Cassidulina obtusa* Williamson | | | | * | | | |
| *Challengerella bradyi* Billman, Hottinger & Oesterle | * | | | * | | | |
| *Chilostomella mediterranensis* Cushman & Todd | * | * | * | * | | | * |
| *Chilostomella ovoidea* Reuss | * | | * | | | | |
| *Cibicidella variabilis* (d'Orbigny) | | * | | * | | | |
| *Cibicides advenum* (d'Orbigny) | | * | | * | | | * |
| *Cibicides dutemplei* (d'Orbigny) | | | | * | | | |
| *Cibicides floridanus* (Cushman) | | | | | * | | |
| *Cibicides refulgens* Montfort | | | | * | | | |
| *Cibicides ungerianus* (d'Orbigny) | | | | * | | | |
| *Cibicidoides pachyderma* (Rzehak) | * | | | * | | | |
| *Connemarella rudis* (Wright) | * | | | | | | |
| *Conorbella erecta* (Sidebottom) | | * | | | | | |
| *Conorbella imperatoria* (d'Orbigny) | | * | | | | | |
| *Cornuspira foliacea* (Philippi) | | * | | * | | | |
| *Cornuspira involvens* (Reuss) | | * | | * | | | |
| *Cornuspiroides striolatus* (Brady) | | | | * | | | |
| *Cribroelphidium poeyanum* (d'Orbigny) | * | * | * | * | * | | * |
| *Cushmanina striatopunctata* (Parker & Jones) | * | * | | * | | | |
| *Cycloforina colomi* (Le Calvez J. & Y.) | | | | | * | | |
| *Cycloforina contorta* (d'Orbigny) | * | * | * | * | * | | * |
| *Cycloforina juleana* (d'Orbigny) | | * | | * | * | | |
| *Cycloforina rugosa* (d'Orbigny) | | * | | * | * | | * |
| *Cycloforina tenuicollis* (Wiesner) | * | * | | * | | | * |
| *Cycloforina villafranca* (Le Calvez J. & Y.) | * | * | | * | | | * |
| *Dentalina albatrossi* (Cushman) | | | | * | | | |
| *Dentalina flintii* (Cushman) | * | | | * | | | |
| *Dentalina guttifera* d'Orbigny | * | * | | * | | | |
| *Dentalina inornata* d'Orbigny | | * | | * | | | |
| *Dentalina leguminiformis* (Batsch) | | | | * | | | * |

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|---|---|---|---|---|---|---|---|
| *Dentalina mucronata* Neugeboren | | | | * | | | |
| *Discammina compressa* (Goës) | | | | * | | | * |
| *Discorbinella bertheloti* (d'Orbigny) | * | * | | * | * | | * |
| *Eggerelloides advenus* (Cushman) | | | | | | | * |
| *Eggerelloides scabrus* (Williamson) | * | * | * | * | * | * | * |
| *Elphidium aculeatum* (d'Orbigny) | * | * | * | * | * | | * |
| *Elphidium advenum* (Cushman) | * | * | | * | * | | * |
| *Elphidium articulatum* (d'Orbigny) | | | | * | | | |
| *Elphidium complanatum* (d'Orbigny) | * | * | * | * | * | | * |
| *Elphidium crispum* (Linne) | * | * | * | * | * | * | * |
| *Elphidium depressulum* Cushman | * | * | | * | * | | |
| *Elphidium excavatum* (Terquem) | | | | * | | | |
| *Elphidium gerthi* Van Voorthuysen | * | * | * | * | * | | |
| *Elphidium granosum* (d'Orbigny) | | | | * | | | |
| *Elphidium incertum* (Williamson) | | * | | * | | | |
| *Elphidium jenseni* (Cushman) | | * | | | | | |
| *Elphidium macellum* (Fichtel & Moll) | * | * | | * | * | | |
| *Elphidium magellanicum* Heron-Allen & Earland | | | | * | | | |
| *Elphidium margaritaceum* Cushman | | | | * | | | |
| *Elphidium pauciloculum* (Cushman) | * | * | * | * | * | | |
| *Elphidium ponticum* (Dolgopolskaya & Pauli) | | * | | | | | |
| *Elphidium pulvereum* Todd | | * | | | | | * |
| *Elphidium punctatum* (Terquem) | * | * | | * | | | |
| *Elphidium reginum* (d'Orbigny) | | | | * | | | |
| *Epistominella vitrea* Parker | | | * | * | | | |
| *Eponides concameratus* (Montagu) | * | * | * | * | * | | * |
| *Faujasina carinata* d'Orbigny | | * | | | | | |
| *Favulina hexagona* (Montagu) | * | * | * | * | * | | |
| *Favulina scascalariformis* (Montagu) autore bak | * | | | | | | |
| *Fissurina castanea* Flint | | * | | * | | | |
| *Fissurina eburnea* (Buchner) | * | | | | | | |
| *Fissurina faba* (Balkwill & Millett) | | | | * | | | |
| *Fissurina lucida* (Williamson) | | * | | * | | | |
| *Fissurina neptunii* (Buchner) | | * | | * | | | |
| *Fissurina orbignyana* Seguenza | * | * | | * | | | |
| *Fissurina sidebottomi* Buchner | | | | * | | | |
| *Fursenkoina acuta* (d'Orbigny) | * | * | | * | | | |
| *Fursenkoina complanata* (Egger) | * | * | | * | | | |
| *Gavelinopsis praegeri* (Heron-Allen & Earland) | * | * | | * | | | |
| *Glandulina laevigata* (d'Orbigny) | | | | * | | | |
| *Globobulimina affinis* (d'Orbigny) | * | * | | * | | | * |
| *Globobulimina pseudospinescens* (Emiliani) | * | * | * | * | | | |
| *Globobulimina turgida* (Bailey) | | | | * | | | |
| *Globocassidulina oblonga* (Reuss) | | | | * | | | |
| *Globocassidulina subglobosa* (Brady) | * | * | * | * | | | |
| *Globulina myristiformis* (Williamson) | | * | | | * | | |
| *Guttulina lactea* (Walker & Jacob) | | | | * | | | |
| *Guttulina pulchella* d'Orbigny | | | | | | | * |
| *Gyroidina umbonata* (Silvestri) | * | * | * | * | * | | |
| *Gyroidinoides lamarckiana* (d'Orbigny) | | * | | * | | | |
| *Haplophragmoides canariensis* (d'Orbigny) | | * | | * | | | * |

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|---|---|---|---|---|---|---|---|
| *Haynesina depressula* (Walker & Jacob) | * | * | * | * | * | | |
| *Hopkinsinella glabra* (Millett) | | | | * | | | |
| *Hyalinea balthica* (Schröter) | * | * | * | * | * | | |
| *Hyalinonetrion gracillima* (Seguenza) | * | * | | * | | | |
| *Ishamella apertura* Buzas & Severin | | * | | * | | | |
| *Labrospira kosterensis* Höglund | | * | | | | | |
| *Lachlanella bicornis* (Walker & Jacob) | * | * | | * | * | | * |
| *Lachlanella undulata* (d'Orbigny) | * | * | | * | * | | * |
| *Laevidentalina ariena* (Patterson & Pettis) | | | | | | | |
| *Laevidentalina communis* (d'Orbigny) | | | | * | | | |
| *Laevidentalina inflexa* (Reuss) | | * | | * | | | |
| *Lagena doveyensis* Haynes | * | * | | * | | | |
| *Lagena laevis* (Montagu) | * | * | | * | | | |
| *Lagena nebulosa* (Cushman) | | * | * | * | | | |
| *Lagena semistriata* Williamson | * | * | | * | | | |
| *Lagena striata* (d'Orbigny) | * | * | * | * | | | |
| *Lagena substriata* Williamson | | | | * | | | |
| *Lagena strumosa* Reuss | * | * | | | | | |
| *Lagenammina difflugiformis* (Brady) | * | | | | | | |
| *Lagenammina fusiformis* (Williamson) | | * | | * | | | |
| *Lenticulina calcar* (Linné) | | * | | * | | | |
| *Lenticulina cultrata* (Montfort) | * | * | | * | * | | * |
| *Lenticulina gibba* (d'Orbigny) | | * | * | * | | | * |
| *Lenticulina orbicularis* (d'Orbigny) | | * | | * | | | |
| *Lenticulina thalmanni* (Hessland) | | | | | | | |
| *Lobatula lobatula* (Walker & Jacob) | * | * | | * | * | | * |
| *Marginulina costata* (Batsch) | | * | | * | | | |
| *Marginulina gummi* Saidova | * | | | * | | | |
| *Massilina gualtieriana* (d'Orbigny) | | * | | * | | | * |
| *Massilina secans* (d'Orbigny) | * | * | | * | * | | * |
| *Melonis barleanum* (Williamson) | * | * | * | * | | | |
| *Melonis pompilioides* (Fichtel & Moll) | * | | * | * | | | |
| *Miliolinella dilatata* (d'Orbigny) | | * | | * | | | |
| *Miliolinella elongata* Kruit | | | * | * | * | | |
| *Miliolinella grata* (Terquem) | | * | | * | | | |
| *Miliolinella labiosa* (d'Orbigny) | | | | * | | | |
| *Miliolinella semicostata* (Wiesner) | | * | | | | | * |
| *Miliolinella subrotunda* (Montagu) | * | * | * | * | * | | * |
| *Miliolinella webbiana* (d'Orbigny) | * | * | | * | | | * |
| *Neoconorbina terquemi* (Rzehak) | * | * | | * | * | * | |
| *Neoeponides bradyi* (Le Calvez) | * | * | | * | | | * |
| *Neolenticulina peregrina* (Schwager) | * | * | * | * | | | |
| *Nodosaria raphanus* (Linné) | | * | | | | | |
| *Nonion subturgidum* (Cushman) | | | | * | | | |
| *Nonionella opima* Cushman | | | * | * | | | |
| *Nonionella Stella* Cushman & Moyer | | | | * | | | |
| *Nonionella turgida* (Williamson) | * | * | * | * | * | | * |
| *Nouria polymorphinoides* Heron-Allen & Earland | | | | * | | | |
| *Nubecularia lucifuga* Defrance | | * | | * | | | |
| *Nummoloculina contraria* (d'Orbigny) | | | | * | | | |
| *Oolina acuticostata* (Reuss) | | | | * | | | |

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|---|---|---|---|---|---|---|---|
| *Oolina melo* d'Orbigny | | | | * | | | |
| *Ophthalmidium acutimalgo* (Brady) | | | * | * | | | |
| *Palliolatella orbignyana* (Seguenza) | | * | | * | | | |
| *Parafissurina staphyllearia* (Schwager) | * | * | | * | | | |
| *Parrellina verriculata* (Brady) | | | | * | | | |
| *Patellina corrugata* Williamson | | * | | * | | | |
| *Peneroplis pertusus* (Forskal) | * | | | * | | | |
| *Peneroplis planatus* (Fichtel & Moll) | * | | | * | | | |
| *Planoglabratella opercularis* (d'Orbigny) | * | | | | | | |
| *Planorbulina mediterranensis* d'Orbigny | * | * | | * | * | | * |
| *Polymorphina fistulosa* Williamson | * | | | | | | |
| *Polymorphina fistulosa* Williamson | * | | | | | | |
| *Porosononion subgranosum* (Egger) | * | * | * | * | * | | |
| *Protoglobobulimina pupoides* (d'Orbigny) | * | * | | | * | | |
| *Pseudoclavulina crustata* Cushman | * | | * | | | | |
| *Pseudoeponides falsobeccarii* Rouvillois | | | | * | | | |
| *Pseudotriloculina laevigata* (d'Orbigny) | | * | | * | * | | * |
| *Pseudotriloculina oblonga* (Montagu) | * | * | | * | | | * |
| *Pseudotriloculina rotunda* (d'Orbigny) | * | * | | * | | | * |
| *Pseudotriloculina sidebottomi* (Martinotti) | * | | | | | | |
| *Pullenia quinqueloba* (Reuss) | | | | * | | | |
| *Pyrgo anomala* (Schlumberger) | | * | * | * | | | |
| *Pyrgo comata* (Brady) | | | | | | | |
| *Pyrgo elongata* (d'Orbigny) | * | * | | * | * | | * |
| *Pyrgo inornata* (d'Orbigny) | | | | * | | | * |
| *Pyrgoella sphaera* (d'Orbigny) | * | | | | | | |
| *Quinqueloculina annectens* (Schlumberger) | | * | | * | | | |
| *Quinqueloculina berthelotiana* d'Orbigny | * | * | * | * | * | | |
| *Quinqueloculina bidentata* d'Orbigny | * | * | | * | | | * |
| *Quinqueloculina bosciana* d'Orbigny | * | * | | * | | | |
| *Quinqueloculina disparilis* d'Orbigny | | | | * | | | |
| *Quinqueloculina eburnea* (d'Orbigny) | * | | | | | | |
| *Quinqueloculina jugosa* Cushman | * | * | | | * | | * |
| *Quinqueloculina laevigata* d'Orbigny | * | * | | * | * | | * |
| *Quinqueloculina lamarckiana* d'Orbigny | * | * | | * | | | * |
| *Quinqueloculina limbata* d'Orbigny | * | * | | | * | | |
| *Quinqueloculina padana* Perconig | * | * | | * | | | |
| *Quinqueloculina parvula* Schlumberger | | * | * | * | | | * |
| *Quinqueloculina poeyana* d'Orbigny | | * | | * | | | |
| *Quinqueloculina pygmaea* Reuss | | | | * | | | |
| *Quinqueloculina seminula* (Linne) | * | * | * | * | * | | * |
| *Quinqueloculina stalkeri* Loeblich & Tappan | * | * | | * | | | |
| *Quinqueloculina stelligera* Schlumberger | * | | | * | | | |
| *Quinqueloculina undosa* Karrer | | | | | | | * |
| *Quinqueloculina viennensis* Le Calvez J. & Y. | | * | | * | | | * |
| *Ramulina globulifera* Brady | | * | | * | | | |
| *Rectuvigerina phlegeri* Le Calvez | * | * | | * | * | | * |
| *Reophax nanus* Rhumbler | | * | | | | | |
| *Reophax scorpiurus* Montfort | * | | | * | | | |
| *Reophax scottii* Chaster | | * | | | | | |
| *Reussella spinulosa* (Reuss) | * | * | | * | * | | * |

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|---|---|---|---|---|---|---|---|
| *Rhabdammina abyssorum* Sars | * | | | * | | | |
| *Robertina translucens* Cushman & Parker | | | | * | | | |
| *Rosalina bradyi* (Cushman) | * | * | * | * | * | | * |
| *Rosalina floridensis* (Cushman) | * | * | | * | | | * |
| *Rosalina globularis* d'Orbigny | * | * | | * | * | | * |
| *Rosalina macropora* (Hofker) | | | | | | | * |
| *Rosalina obtusa* d'Orbigny | | | | * | | | |
| *Saidovina karreriana* (Brady) | * | | | | | | |
| *Sigmoilina distorta* Phleger & Parker | | | * | | | | |
| *Sigmoilina sigmoidea* (Brady) | * | * | | * | | | |
| *Sigmoilinita costata* (Schlumberger) | * | * | | * | * | | * |
| *Sigmoilinita edwardsi* (Schlumberger) | * | | | * | | | |
| *Sigmoilinita tenuis* (Czjzek) | * | * | * | * | | | |
| *Sigmoilopsis schlumbergeri* (Silvestri) | * | * | * | * | | | * |
| *Sigmomorphina williamsoni* (Terquem) | | | | * | | | |
| *Sipholagena benevestita* (Buchner) | | * | | * | | | |
| *Siphonaperta aspera* (d'Orbigny) | * | * | | * | * | | |
| *Siphonaperta irregularis* (d'Orbigny) | | | | | * | | |
| *Siphonina bradyana* Cushman | * | | | | | | |
| *Siphonina reticulata* (Czjzek) | * | * | | * | | | |
| *Siphonina tubulosa* Cushman | | | * | | | | |
| *Siphotextularia concava* (Karrer) | * | * | | * | | | |
| *Sorites orbiculus* (Forskal) | * | | | | | | |
| *Sphaerogypsina globula* (Reuss) | * | * | | * | * | | * |
| *Sphaeroidina bulloides* d'Orbigny | * | * | * | * | | | |
| *Spirillina vivipara* Ehrenberg | * | * | * | * | | | |
| *Spiroloculina angulata* Cushman | | | | * | | | |
| *Spiroloculina angulosa* Terquem | * | * | | * | * | | * |
| *Spiroloculina antillarum* d'Orbigny | * | | | | | | |
| *Spiroloculina communis* Cushman & Todd | | | | * | | | |
| *Spiroloculina cymbium* d'Orbigny | * | * | | * | | | |
| *Spiroloculina depressa* d'Orbigny | * | * | | * | * | | * |
| *Spiroloculina dilatata* d'Orbigny | * | * | | * | | | * |
| *Spiroloculina excavata* d'Orbigny | * | * | * | * | * | | * |
| *Spiroloculina ornata* d'Orbigny | | | | * | * | | |
| *Spiroloculina tenuiseptata* Brady | * | * | | * | * | | |
| *Spiroplectinella sagittula* (Defrance) | * | * | * | * | * | | * |
| *Spiroplectinella wrightii* (Silvestri) | * | * | | * | | | |
| *Stainforthia concava* (Höglund) | | * | | * | | | |
| *Stomatorbina concentrica* (Parker & Jones) | * | * | | * | * | | |
| *Textularia agglutinans* d'Orbigny | * | * | | * | | | |
| *Textularia bocki* Höglund | * | * | | * | | | * |
| *Textularia calva* Lalicker | * | * | | * | | | |
| *Textularia conica* (d'Orbigny) | * | * | | * | | | |
| *Textularia cushmani* Said | | | | * | | | |
| *Textularia goesii* Cushman | | | | | | | * |
| *Textularia porrecta* Brady | | | | | | | * |
| *Textularia truncata* Höglund | * | * | | * | * | | * |
| *Trifarina angulosa* (Williamson) | | | | * | | | |
| *Trifarina fornasini* (Selli) | | | | * | | | |
| *Triloculina adriatica* Le Calvez J. & Y. | | | | * | | | * |

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|---|---|---|---|---|---|---|---|
| *Triloculina gibba* d'Orbigny | | | | * | | | |
| *Triloculina marioni* Schlumberger | * | * | | * | * | | * |
| *Triloculina plicata* Terquem | * | * | | * | | | |
| *Triloculina schreiberiana* d'Orbigny | | | | * | | | |
| *Triloculina schreiberiana* d'Orbigny | | * | | | | | |
| *Triloculina tricarinata* d'Orbigny | * | * | * | * | | | |
| *Triloculina planciana* d'Orbigny | | | | | | | * |
| *Triloculina trigonula* (Lamarck) | | | | | | | * |
| *Uvigerina mediterranea* Hofker | * | * | * | * | | | |
| *Uvigerina peregrina* Cushman | | * | | * | * | | |
| *Valvulineria bradyana* (Fornasini) | * | * | * | * | * | | * |
| *Valvulineria complanata* (d'Orbigny) | | | | * | | | |
| *Vertebralina striata* d'Orbigny | * | | | | | | |
| *Wellmanellinella striata* (Sidebottom) | | * | | | | | |
| **Species numbers** | **159** | **197** | **65** | **247** | **78** | **6** | **86** |
| **Total species number** | | | | **309** | | | |

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**SPONGES OF THE SEA OF MARMARA WITH A NEW RECORD FOR TURKISH SPONGE FAUNA**

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## 1. Introduction

The Sea of Marmara is a part of the Turkish Straits System together with the İstanbul and Çanakkale Straits. The sea is a small basin with 11,500 km² surface area and a maximum depth 1390 m. This basin is known as important biological corridor and an acclimatization zone for the biota of the Black Sea and Mediterranean Sea (Öztürk and Öztürk 1996; Öztürk 2002).

According to Topaloğlu *et al*. (2016) the earliest study on sponge species along the Turkish coasts was carried out by Colombo (1885) and five sponge species were listed from the Çanakkale Strait. Later 138 species in total have been recorded from the Turkish coasts (Topaloğlu *et al*. 2016). The total number of the Turkish sponge fauna became 140 with the addition by Gözcelioğlu (2015). Five new species have been added to Sponge fauna of Turkey by Evcen and Çınar (2015). The latest study performed by Evcen *et al*. (2016) and the authors of this paper added two more species to Turkish sponge fauna. Therefore, the current number of the sponge biota of Turkey recorded as 147 in total. Besides, 681 species are known from the Mediterranean Sea (Coll *et al*. 2010).

According to Topaloğlu *et al*. (2016) sponge studies in the Sea of Marmara are limited when compared to the other parts of the Mediterranean Sea. The earliest study on the sponges in the Sea of Marmara was reported by Demir (1952–1954) who found 10 sponge species around the Prince Islands and the İstanbul Strait. Three sponge species were reported by Caspers (1968); two species by Bayhan *et al.* (1989), one species by Okuş (1986), and 19 species by Topaloğlu (2001). Besides, the studies on the sponge culture and its economic importance were made by Dalkılıç (1982) and Gökalp (1974). Devedjian (1926) included the information about sponges harvested commercially in the Sea of Marmara. The latest study in the Sea of Marmara was performed by Topaloğlu *et al*. (2016) and reported 75 species from the Sea of Marmara in total.

This study reviews the existing literature on the sponge species of the Sea of Marmara with one additional new record for the marine fauna of Turkey. The aims of the study were to elucidate the sponge diversity in the Sea of Marmara and to give a checklist of sponge species that have been reported from the sea.

## 2. Material and Method

The sponge samples were collected from three stations in the Sea of Marmara (Yassıada and Balıkçı Island) (Figure 1) between August -November 2015. The depth of sampling is between 21 and 40 m and they were sampled by SCUBA diving. The samples were fixed by 4% formaldehyde solution. All samples were washed by tap water and preserved in 70% ethanol in the laboratory. Small portions were cut including ecto and endosomal parts together and prepared slides for spicules. The standard method by Rützler (1978) was used for the preparation of slides. Each type of spicules were identified, measured and photographed and species were identification by Marine Species Identification Portal and World Porifera Database.

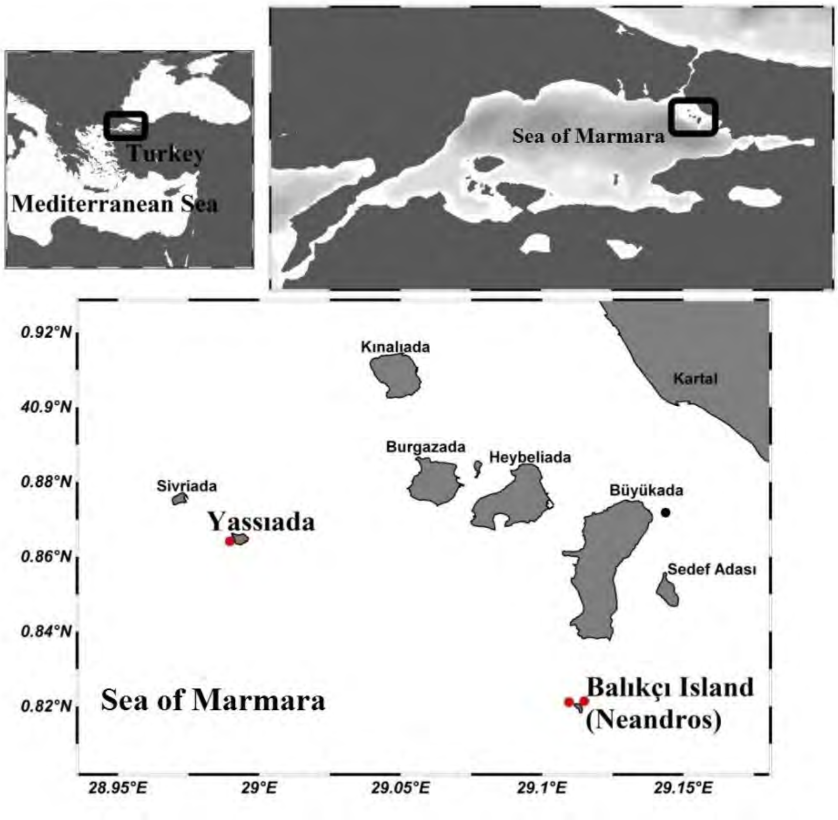


**Figure 1.** The map of the sampling stations.

## 3. Results and Discussion

One sponge specimen was identified as *Stelligera stuposa* (Ellis and Solander, 1786) which is a new record for the Turkish sponge fauna. The morphological and identification characters of the species are presented as below:

**Stelligeridae Lendenfeld, 1898**

***Stelligera stuposa* (Ellis and Solander, 1786)**

Boury-Esnault *et al.* 1994: 95, figure 69. Voultsiadou, 2005 :59.

**Material examined:** 5 specimens on rocks

**Description:** The body form is branching, erect, the branches slightly flattened to the end of point, rarely fused. Branching is dichotomous or polytomous. Stalk is around the 10 cm, or more. The color is yellow, brownish orange.

**Spicules:** Megascleres are styles (b), occasionally strongyles (c,e). Those of the extra-axial skeleton are long styles, and the divergent brushes consist of slender oxea or anisoxea (f). The microscleres are euasters (d) (14µm diameter). Styles 900-(910)-1000µm "to 2000µm" in length, strongyles 630-(760)-880µm, oxea 520-(610)-690µm (Figure 2).

**Habitat and Distribution:** The specimens found on rocks in those three stations. It was previously reported from the Aegean Sea (Voultsiadou 2005); Eastern Atlantic (Arndt 1935; Borojevic *et al*. 1968), the Western Mediterranean (Topsent 1934; Boury-Esnault *et al*. 1994) and the Adriatic (Lendenfeld 1896).

At the finally, the present study added a species. The sponge fauna of Turkey including Dysidea pallescens (Schmidt, 1862) reported by Ostroumof (1896) but not given by Topaloğlu et al. (2014 and 2016) makes 149 sponges known along the coasts of Turkey and 78 in the Sea of Marmara (Table 1.). Seven species of Calcerea belongs to five family, one species of Homoscleromorpha belongs to one family and 68 species of Demospongia belongs to 32 family were reported for biota of the Sea of Marmara.

Topaloğlu *et al*. (2016) reported *Paraleucilla magna* which is known as an invasive calcareous sponge (Longo *et al*. 2007). That was first reported alien sponge species in the area. The Sea of Marmara has very busy international marine traffic and this invasive species could have been transferred to the area by hull fouling or ballast water of ships. The dense population of this alien sponge species has been considered as a potential ecological risk for the native fauna according to Topaloğlu *et al*. (2016). The same study also reported two sponge species (*Thenea muricata* and *Rhizaxinella elongata*) at depths deeper than 100 m in the Sea of Marmara. These two deep water sponge species are one of the limited reports from the deep sea fauna of the Marmara Sea. Whereas, there are three depression about the median line of Sea of Marmara that deeper than 1000 meters. I assume that the number of the sponge fauna will be evaluated by more researches in these special zones. Beside this, to complete the list of sponge fauna of the Turkish coasts including the Sea of Marmara, more studies are needed in different habitats such as underwater caves.

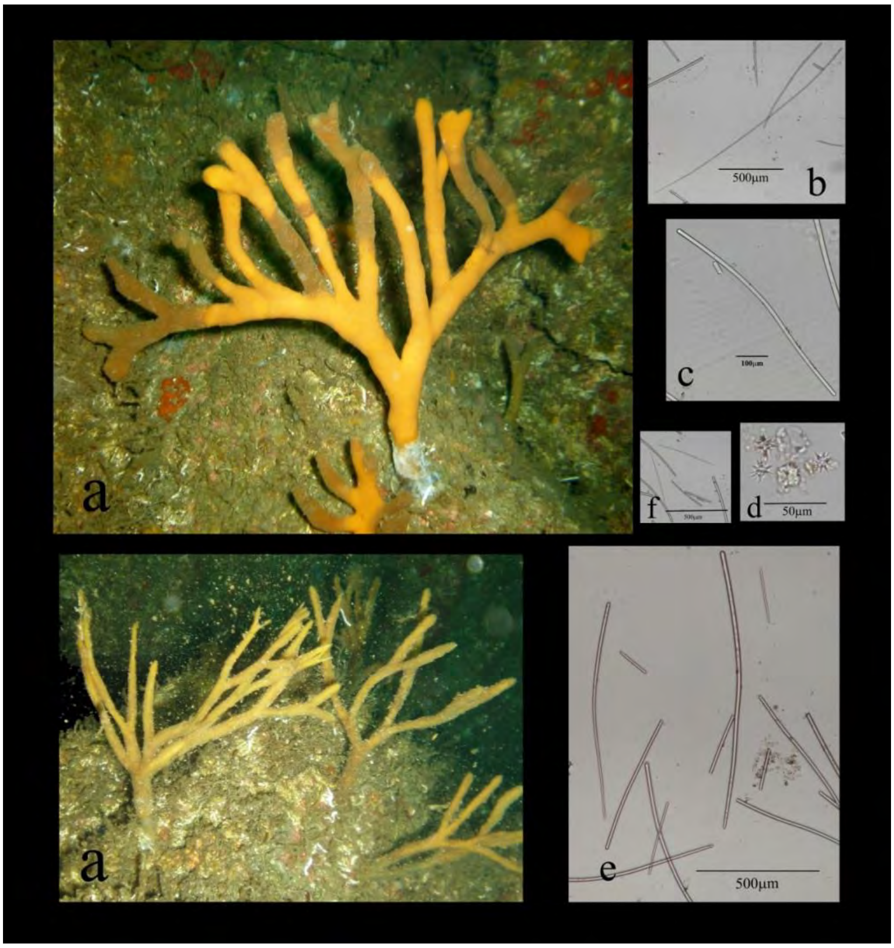


**Figure 2.** Photographs of *Stelligera stuposa* in situ (a); megascleres: styles: (b), strongyles (c,e), oxeas (f) and microscleres: euasters (d) (UW photo taken by Eda Topçu-Eryalçın)

**Table 1.** Check list of sponge species from the Sea of Marmara.

| Group/Species | Reference |
|---|---|
| **Phylum: PORIFERA** | |
| **Classis: CALCAREA** | |
| **Family: Amphoriscidae** | |
| *Paraleucilla magna* Klautau, Monteiro & Borojevic, 2004 | 14 |
| **Family: Sycattidae** | |
| *Sycon ciliatum* (Fabricius, 1780) | 2,3,14 |
| *Sycon raphanus* Schmidt, 1862 | 4,14 |
| *Sycon tuba* Lendenfeld, 1891 | 3 |
| **Family: Grantiidae** | |
| *Ute glabra* Schmidt, 1864 | 3 |
| *Leucandra aspera* (Schmidt, 1862) | 1,3,8 |
| **Family: Leucaltidae** | |
| *Ascandra contorta* (Bowerbank, 1866) | 14 |
| **Family: Leucosoleniidae** | |
| *Leucosolenia variabilis* (Haeckel, 1870) | 4 |
| **Classis: HOMOSCLEROMORPHA** | |
| **Family: Oscarellidae** | |
| *Oscarella lobularis* (Schmidt, 1862) | 1 |
| **Classis: DEMOSPONGIA** | |
| **Family: Tethyidae** | |
| *Tethya aurantium* (Pallas, 1766) | 1,3,4,11,14 |
| **Family: Spirastrellidae** | |
| *Diplastrella bistellata* (Schmidt, 1862) | 3 |
| **Family: Clionaidae** | |
| *Cliona celata* Grant, 1826 | 11,13 |
| *Cliona viridis* (Schmidt, 1862) | 3 |
| **Family: Suberitidae** | |
| *Aaptos aaptos* (Schmidt, 1864) | 1,11 |
| *Protosuberites denhartogi* Van Soest and de Kluijver, 2003 | 4 |
| *Rhizaxinella elongata* (Ridley & Dendy, 1886) | 14 |
| *Rhizaxinella pyrifera* (Delle Chiaje, 1828) | 12 |
| *Suberites carnosus* (Johnston, 1842) | 4,11 |
| *Suberites domuncula* (Olivi, 1792) | 1,3,4,11 |
| *Suberites ficus* (Johnston, 1842) | 11 |
| *Suberites massa* Nardo, 1847 | 3 |
| **Family: Polymastiidae** | |
| *Polymastia penicillus* (Montagu, 1814) | 14 |
| **Family: Chalinidae** | |
| *Chalinula limbata* (Montagu, 1818) | 4 |
| *Chalinula renieroides* Schmidt, 1868 | 14 |
| *Haliclona alba* (Schmidt, 1862) | 3 |
| *Haliclona* (*Gellius*) *fibulata* (Schmidt, 1862) | 3 |
| *Haliclona* (*Haliclona*) *simulans* (Johnston, 1842) | 7 |
| *Haliclona (Halichoclona) fulva* (Topsent, 1893) | 14 |

| | |
|---|---|
| *Haliclona* (*Rhizoniera*) *sarai* (Pulitzer-Finali, 1969) | 14 |
| *Haliclona* (*Reniera*) *aquaeductus* (Schmidt, 1862) | 3 |
| *Haliclona* (*Reniera*) *cinerea* (Grant, 1826) | 4,14 |
| *Haliclona* (*Reniera*) *mediterranea* Griessinger,1971 | 11,12 |
| **Family: Niphatidae** | |
| *Pachychalina rustica* Schmidt, 1868 | 3 |
| **Family: Callyspongiidae** | |
| *Siphonochalina coriacea* Schmidt, 1868 | 1 |
| **Family: Petrosiidae** | |
| *Petrosia* (*Petrosia*) *ficiformis* (Poiret, 1789) | 1, 11,14 |
| *Petrosia pulitzeri* (Pansini, 1996) | 11 |
| **Family: Dictyonellidae** | |
| *Acanthella acuta* Schmidt, 1862 | 11 |
| *Dictyonella obtusa* (Schmidt, 1862) | 3 |
| *Dictyonella plicata* (Schmidt, 1880) | 11 |
| **Family: Axinellidae** | |
| *Axinella cannabina* (Esper, 1794) | 3,11 |
| *Axinella damicornis* (Esper,1794) | 3,11 |
| *Axinella polypoides* Schmidt, 1862 | 11,14 |
| **Family: Stelligeridae** | |
| *Stelligera stuposa* (Ellis & Solander, 1786) | PS |
| **Family: Halichondriidae** | |
| *Ciocalypta penicillus* (Schmidt, 1862) | 11,14 |
| *Hymeniacidon perlevis* (Montagu, 1818) | 5 |
| *Halichondria* (*Halichondria*) *panicea* (Pallas, 1766) | 4 |
| *Halichondria* (*Eumastia*) *sitiens* (Schmidt, 1870) | 5 |
| **Family: Ancorinidae** | |
| *Ancorina cerebrum* (Schmidt, 1862) | 3 |
| **Family: Pachastrellidae** | |
| *Thenea muricata* (Bowerbank, 1858) | 3,14 |
| **Family: Geodiidae** | |
| *Geodia cydonium* (Jameson, 1811) | 1,3,4,11 |
| *Geodia conchilega* Schmidt, 1862 | 3 |
| *Geodia tuberosa* Schmidt, 1862 | 3 |
| **Family: Mycalidae** | |
| *Mycale* (*Aegogropila*) *contareni* (Martens, 1824) | 3 |
| *Mycale* (*Mycale*) *massa* (Schmidt, 1862) | 3 |
| **Family: Agelasidae** | |
| *Agelas oroides* (Schmidt, 1862) | 11 |
| **Family: Crellidae** | |
| *Crella (Crella) elegans* (Schmidt, 1862) | 5 |
| **Family: Hymedesmiidae** | |
| *Phorbas fictitius* (Bowerbank, 1866) | 3 |
| **Family: Tedaniidae** | |
| *Tedania* (*Tedania*) *anhelans* (Lieberkühn, 1859) | 3 |
| **Family: Crambeidae** | |
| *Crambe crambe* (Schmidt, 1862) | 14 |
| **Family: Raspailiidae** | |

| | |
|---|---|
| *Raspailia* (*Raspailia*) *viminalis* Schmidt, 1862 | 13,14 |
| *Raspailia* (*Parasyringella*) *agnata* (Topsent, 1896) | 14 |
| **Family: Microcionidae** | |
| *Clathria* (*Microciona*) *strepsitoxa* (Hope, 1889) | 11 |
| **Family: Irciniidae** | |
| *Ircinia variabilis* (Schmidt, 1862) | 1,3,14 |
| *Sarcotragus foetidus* Schmidt, 1862 | 3,14 |
| **Family: Timeidae** | |
| *Timea stellata* (Bowerbank, 1866) | 14 |
| **Family: Dysideidae** | |
| *Dysidea avara* (Schmidt, 1862) | 3 |
| *Dysidea fragilis* (Montagu, 1818) | 1,14 |
| *Dysidea incrustans* (Schmidt, 1862) | 2,3,14 |
| *Dysidea pallescens (Schmidt, 1862)* | 3 |
| *Pleraplysilla spinifera (Schulze, 1879)* | 14 |
| **Family: Thorectidae** | |
| *Cacospongia mollior* Schmidt, 1862 | 1,3 |
| *Fasciospongia cavernosa* (Schmidt, 1862) | 1,3 |
| *Scalarispongia scalaris* (Schmidt, 1862) | 3,14 |
| **Family: Spongiidae** | |
| *Hippospongia communis* (Lamarck, 1814) | 3 |
| *Spongia (Spongia) officinalis* Linnaeus, 1759 | 3,6,8,9,10,11,14 |
| *Spongia (Spongia) nitens* (Schmidt, 1862) | 14 |
| **Family: Aplysinidae** | |
| *Aplysina aerophoba* Nardo, 1843 | 3,7,14 |
| **Family: Darwinellidae** | |
| *Aplysilla sulfurea* Schulze, 1878 | 14 |

1: Colombo (1885), 2: Ostroumoff (1894), 3: Ostroumoff (1896), 4: Demir (1952–1954), 5: Caspers (1968), 6:Okuş (1989), 7: Bayhan et al. (1989), 8. Yüksek (1989), 9: Balkıs (1994), 10:Eryılmaz (1997), 11:Topaloğlu (2001a), 12: Uysal et al. (2002) 13:Topaloğlu et al. (2014), 14: Topaloğlu et al. (2016), PS: Present Study.


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# ANTHOZOANS OF THE SEA OF MARMARA

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## 1. Introduction

Anthozoans are a class within the phylum Cnidaria, which lack the stage of medusa in their development and describe radially symmetrical polyps in solitary or colonial forms. Anthozoans are exclusively sessile marine organisms and cover morphologically distinct groups that are anemones, stony corals, soft corals, sea pens and gorgonians. The primary difference between the two main subclasses of the class Anthozoa is based on either six or eight fold symmetry of the polyps. Octocoral polyps possess eight tentacles while hexacoral polyps possess six or multiples of six tentacles. The "order" Ceriantharia, within the subclass Hexacorallia, was recently classified also as a subclass (Hoeksema 2016) based on molecular analysis (Stampar *et al.* 2014). The subclass Octocorallia include sea pens (Pennatulacea), soft corals and gorgonians (Alcyonacea) and the blue corals (Helioporacea). Hexacorals comprises sea anemones (Actiniaria), encrusting anemones (Zoantharia), stony corals (Scleractinia), black corals (Antipatharia) and corallimorpharians (Corallimorpharia). The subclass Ceriantharia includes tube-dwelling anemones. From here onwards, the two subclasses Hexacorallia and Ceriantharia will be referred as "hexacorals" for practical purpose.

Ecologically, there are two general types among anthozoans that are called as hermatypic and ahermatypic corals. Hermatypic corals, also termed as the reef-forming species, are known as the primary builders of coral reefs and responsible of forming reef-like structures in the subtropics. Ahermatypic corals are the non-reef forming species and are more abundant than hermatypic ones in the seas and oceans. Although they are not capable of forming real reef structures, some taxa among this group of anthozoans such as gorgonians play a key role as reef-like assemblages and contribute to biodiversity in marine environment. These species build more significant communities in deep waters. (Barnes and Hughes 1999; Veron 2000).

In the Mediterranean Sea, 164 anthozoan species were recorded, 51 of which are octocorals and 131 are hexacorals (Vafidis in Coll *et al.* 2010: Table S13). In the Black Sea, only seven anthozoans were recorded, of which, one species is an octocoral (Vafidis *et al.* 1994, 1997; Grebelnyi and Kovtun 2013). In the Sea of Marmara, where the Mediterranean meets the Black Sea, 59 anthozoan species were recorded so far, with 35 hexacorals and 24 octocorals (with e new record in this study, Table I). An important number of these records are rather recent, and more new records might be expected with more research efforts, focusing particularly at depths greater than the regular scuba diving limits.

The particular oceanography of the Sea of Marmara – where the brackish waters originated form the Black Sea flow in the upper layer, and the Mediterranean-originated saline waters flow in the lower layer – is the primary factor that determines the distribution of anthozoans in this semi-enclosed sea. The brackish waters of the upper layer allows only some anemone species to be present, but the lower layer presents diverse and dense assemblages of both hexacorals and octocorals (Demir 1954; Topçu and Öztürk 2015; Özalp and Ateş 2015a; Özalp and Alparslan 2016). Solitary anemones dominate in the upper layer, sometimes forming large aggregations; whereas encrusting anemones, hard corals and all octocorals are restricted to the lower layer. The depth layer of the permanent halocline and the salinity of the surface waters differ between the northern and southern parts of the basin and depend on seasons (Beşiktepe *et al.* 2000), which leads to different depth distribution of species between the northern and southern parts. Octocorals and hexacorals other than anemones cannot be seen above approximately 20 m in the northern Marmara Sea (Topçu and Öztürk 2015), while in the Çanakkale Strait some species are present as from 12 m (Özalp and Ateş 2015b). As a matter of fact, salinity increases rapidly in the Çanakkale Strait from 24-28 psu at the surface to 32-36 psu at 10 m, particularly in the southeast region of the strait, where the lower layer is attained at much shallower depths than that in the north (Ünlüata *et al.* 1990; Türkoğlu *et al.* 2006; Gökaşan *et al.* 2008). In the southeast region of Çanakkale Strait, continuous *Posidonia oceanica* beds can be seen at 1 m (Özalp 2005; Meinesz *et al.* 2009) and *Cladocora caespitosa* colonies at 10 m (Özalp and Alparslan 2011).

The high food availability in the mesotrophic-eutrophic Sea of Marmara allows anthozoans to thrive all over the basin and be common and abundant macrobenthic organisms in some communities. In coralligenous habitats of the oligotrophic Eastern Mediterranean, sponges, bryozoans and small hexacorals dominate animal assemblages in general (Ballesteros 2006). In the Sea of Marmara, gorgonians and false black coral *Savalia savaglia* form dense assemblages in the coralligenous communities, comparable to those in the western Mediterranean Sea; however their densities seem to be in continuous decrease since the 1980's, due to very strong anthropogenic pressure (Topçu and Öztürk 2014, 2015). Unfortunately, there are very few studies that report density/distribution data in space and time or that deal with the demographics of the species, which restrains comparisons to previous states.

## 2. Octocorals of the Sea of Marmara

Octocorals recorded so far in the Sea of Marmara comprises 4 stoloniferans (Suborder Stolonifera), 5 soft corals (Suborder Alcyoniina), 7 gorgonians (Suborder Holaxonia) and 8 sea pens (Order Pennatulacea) (Table I). *Gorgonia flabellum* Linnaeus, 1758 reported by Demir 1954 (as *Rhipidigorgia flabellum*) was not included in the list because the species has a distribution in the Gulf of Mexico and the Caribbean Sea, has never been reported from the Mediterranean Sea or been signalled again from the Sea of Marmara. The specimen was found by Demir between materials of the Hydrobiology research Institute of Istanbul University and was considered by mistake as a Marmara sample (Topaloğlu B. pers. comm.).

*Pteroeides griseum* (Linnaeus, 1767) (*Penna grisea* Bohadsch, 1761; *Pteroeides griseum* Kükenthal and Broch, 1911; Kükenthal, 1915) was not included in the list because it is accepted as an invalid name by Gili and Pages (1987) and Williams (1995). Despite this, due to its historically common usage in the Mediterranean literature, several references continue using *P. griseum*, sometimes as a synonym of *P. spinosum* (Vafidis *et al.* 1994; Vafidis in Coll *et al.* 2010: Table S13; Aguilar *et al.* 2013; Topçu and Öztürk 2015).

Another species with queries is *Alcyonium coralloides* which was first reported in Ostroumoff 1894. Tixier-Durivault (1961) reported *Alcyonium bosphorense* from the Istanbul Strait (as *Parerythropodium bosphorense*), which was later considered as *A. coralloides* in Vafidis *et al.* (1994). As a matter of fact, *A. coralloides* is a species that exhibits considerable variation in colony growth form, colour, habitat and life history across a broad geographic range (Groot and Weinberg 1982; Mcfadden 1999). Groot and Weinberg (1982) suggested that all morphotypes of *A. coralloides* belong to one variable species, based on morphological and colour variants. However, based on genetic investigations, Mcfadden (1999) proposed five morphotypes that belong to four distinct species. These results point out that the specimens reported in Tixier-Durivault (1961) and those in Topçu and Öztürk (2013, 2015) seem similar to the morphotype M2 in Mcfadden 1999 (Mcfadden, pers. comm.), -a distinct species from *A. coralloides*- but further genetic analyses are necessary to accurately identify it.

Due to the particular oceanography of the Sea of Marmara, octocorals are present only below the permanent halocline, in the lower layer formed by the Mediterranean-originated water mass at approximately 20 m depth, except in the Çanakkale Strait where they can be at shallower depths due to higher salinities. Octocorals are present in various habitats in the Sea of Marmara, of which the high food availability allows them to form relatively dense populations (Topçu and Öztürk 2015).

Sea pens, particularly *Veretillum cynomorium,* are common and abundant on soft substrates as from 20 m (Demir 1954; Topçu and Öztürk 2015). Fully expanded colonies can be seen day and night due probably to high turbidity. Their densities around Prince Islands and Southern Marmara Islands vary from 0.2 to 4.2 colonies.m$^{-2}$ (Topçu and Öztürk 2015).

Soft corals are common along the northern and southern islands coasts of the Sea of Marmara, *Alcyonium palmatum* in particular is common on several types of substrates, as scattered solitary colonies and does not form dense patches (Demir 1954; Topçu and Öztürk 2015). *A. acaule* on the other hand, seems rare but can form relatively dense patches at a few locations between 30 – 40 m (Topçu and Öztürk 2015). *Paralcyonium spinulosum* is particularly common in the northern islands, forming patches with densities up to 7 colonies.m$^{-2}$. *A. coralloides*, present all over the Sea of Marmara, including both straits (Tixier-Durivault 1961 and Box I), might be in both encrusting and lobular forms and can cover gorgonians, shells, polychaete tubes and other bioconcretions. *Maasella edwardsii* was reported so far only from the Çanakkale Strait where it can form dense patches, particularly attached to the roots and leaves of *Posidonia oceanica* (Özalp and Ateş 2015b).

Rocky bottoms of the islands in the Sea of Marmara present two main octocoral communities: – (1) the group of *Paralcyonium spinulosum*, *Paramuricea macrospina* and *Spinimuricea klavereni*; – (2) *Eunicella cavolini* dominated assemblages where occasional *Spinimuricea klavereni, P. clavata* and/or *P. macrospina* colonies are present (Topçu and Öztürk 2015). The latter prefers mainly vertical walls or large rocks on steep bottoms, while the first, large/medium size boulders on a slightly steep or flat bottom. The group of *P. spinulosum*, *P. macrospina* and *S. klavereni* is also common on detritic/muddy bottoms covered with pebbles, shells and small rocks.

*Spinimuricea klavereni* is a Mediterranean endemic gorgonian occurring on hard and muddy substrates, generally attached to stones or shells. In the Western Mediterranean, the species is rather rare and occurs between 50 and 80 m depth (Carpine and Grasshoff 1975). In the north-eastern Sea of Marmara, it is rather a common species that forms relatively dense populations (Topçu and Öztürk 2016a). Similarly, *P. macrospina*, not very common in the Western Mediterranean, occurs on rocks, detritic or sandy/muddy bottoms, mainly at depths of 40 to 200 m (Carpine and Grasshoff 1975). In the north-eastern Sea of Marmara, it is one of the most common gorgonians as from 20 m depth on rocky, detritic or sandy/muddy bottoms (as attached to shells/pebbles). In fact, the particular oceanography of the Sea of Marmara, coupled to high anthropogenic pressures, seem to cause unusual depth distribution for some species (Topçu and Öztürk 2015). The Mediterranean-originated subhalocline waters possess nearly constant temperature (14–15 °C), salinity (up to 38.5 psu) and density all year round and throughout the basin (Beşiktepe *et al.* 1994). Therefore, conditions similar to deeper Mediterranean waters are created as from 20 m, with low irradiance and year-round cool waters. On the other hand, there are several anthropogenic disturbances in the Sea of Marmara that can stress or harm corals, such as pollution and fishing nets. Abandoned fishing nets were found in more than half of the investigated stations in Prince Islands region where octocorals are common (Topçu and Öztürk 2015). These disturbances are particularly affecting species with slow dynamics such as *P. clavata,* while species with relatively higher dynamics could be favoured. As a matter of fact, *S. klavereni* seems to display low necrosis, relatively high growth rates and non-seasonal reproductive pattern with high male and female fecundities year-round (in the Sea of Marmara), indicating an opportunistic behaviour for this species (Topçu and Öztürk 2016a, 2016b). Colonies of *S. klavereni* can grow on horizontal surfaces of rocks, sandy/muddy bottoms as attached to a shell or pebble and on abandoned fishing nets in the Sea of Marmara, therefore able to colonize more space than other substrate-selective gorgonians. Similarly, *P. macrospina* was observed on horizontal natural and artificial surfaces, suggesting that its larvae and juveniles might be resistant to sedimentation, and the colonies able to grow with supposedly high growth rates, differing from what is usually reported for its congeneric *Paramuricea clavata* (Bo *et al.* 2010, 2012). Therefore, relatively fast dynamics and plasticity in habitat preferences of these gorgonians can explain their widespread distribution in the Sea of Marmara, particularly in the northeast region, whereas other typical Mediterranean gorgonians with slow dynamics are either rare and scarce (such as *P. clavata* or *E. singularis*) or might form dense patches but restricted to few small areas (such as *E. cavolini*) (Topçu and Öztürk 2015). For example, *P. clavata* colonies form relatively dense patches at some locations in the Çanakkale Strait. The wreck Captain Franco, between 35 and 47 m depths, particularly the board parts of it, is the largest habitat of the species in the region, where the mean colony density is around 8 individuals per $m^{-2}$ at some points (Özalp B. pers. obs.). Although the species is found at both sides of the strait, the deepest colonies are commonly observed on the Anatolian side, at depths over 35 m.

### 3. Hexacorals of the Sea of Marmara

Hexacorals recorded so far in the Sea of Marmara comprise 15 sea anemones (Actiniaria) with a new report in this study (Box 1), 3 encrusting anemones (Zoantharia), 2 tube dwelling anemones (Ceriantharia), 13 stony corals (Scleractinia) and one species of black coral (Antipatharia) (Table 1). The number of hexacorals recorded in the Sea of Marmara (35) seem low in comparison to that in the Aegean Sea [62 (Vafidis in Coll *et al.* 2010: Table S13)] and that in the Mediterranean Sea [131 (Vafidis in Coll *et al.* 2010: Table S13)]. As a matter of fact, studies on Anthozoans in the Sea of Marmara were more concentrated on octocorals. A significant number of hexacoral reports are very recent and concentrated to the Çanakkale Strait/Southern region where research efforts are lately focused on species living at depths between 2 and 50 m (e.g. Özalp and Ateş 2015a; Özalp and Alparslan 2015; Özalp and Alparslan 2016). This situation shows that more hexacoral records can be expected from the Sea of Marmara as extensive surveys will expand to other regions and at greater depths.

Hexacorals represent coral species with a multiple of six paired mesenteries. Being colonial, clonal or solitary, some hexacorals are the commonly known builders of benthos especially in the tropical reef systems. In the Mediterranean Sea, the colonial members (Scleractinia) are capable of forming reef-like structures and complex coral facies associated to the coralligenous bioconcretions, sponges and calcareous algae. Although some species such as black corals (Anthipatharians) also favor the development of hard substrates and special habitats in marine life, the order Scleractinia, which represents stony corals, comprise the most diversified ecosystems and is believed to have the main reef forming specimens in the subtropics and tropics (Fautin *et al.* 2000; Reimer *et al.* 2014). In the Sea of Marmara, stony corals are generally in solitary forms, but in the Çanakkale Strait, reef-like colonies of *Cladocora caespitosa*, *Polycyathus muellerae* and *Madracis pharensis,* and in less frequency, of *Caryophyllia smithii*, *Caryophyllia inornata*, *Paracyathus pulchellus*, *Leptopsammia pruvoti*, *Balanophyllia europaea* and *Phyllangia mouchezii* are present (Özalp and Alparslan 2016).

The Çanakkale Strait, connecting the Sea of Marmara to the Aegean Sea, differs from both seas by oceanographic features and constitutes a particular ecosystem. While the northern section of the strait until Nara Pass is more similar in physicochemical parameters to the Sea of Marmara; in the southern section, the interface rises and the upper layer becomes thinner and more saline implying enhanced mixing processes in this part of the strait (Ünlüata *et al.* 1990). Consequently, both species composition and distribution of corals in the strait differs from that in the Sea of Marmara. Therefore particular research efforts were focused to the Çanakkale Strait, and more precisely on hexacorals. Although information regarding the ecology of species in the Sea of Marmara is still scarce, the strait has been one of the most studied area basically on Scleractinian diversity. The Çanakkale Strait is rich of both colonial and solitary individuals of stony coral fauna. The anemone species are also commonly found at some localities.

*Cladocora caespitosa*, also defined as the only reef-forming coral of the Mediterranean Sea, is present at both sides of the strait. The highest occurrence of the species is at Dardanos location and thus is the main living area in the region. Lately, there have been revealed over 80 healthy and well-developed colonies between 4 and 7 m depths of the location (Özalp 2014a). This spot is the most important *Cladocora* facies of the strait due to the similarity of colony formation and corallite structure compared to the bioconstruction of the Columbretes Islands (Spain, NW Mediterranean) and Mljet Bank, Adriatic Sea (Kružić and Požar-Domac 2003; Kersting and Linares

2012). This special habitat in the Çanakkale Strait, which has been monitoring for 3 years, was also referred in the last IUCN red list reports (Casado de Amezua *et al.* 2015). The second commonly found species in the strait is *P. muellerae*. Eceabat region is the largest living area and the abundance at some localities may result in over 104 colonies. The species, and also another rare colonial coral *P. mouchezii*, are commonly observed around some parts of the rocky substrates mainly associated with dense coralligenous and calcareous formations. So that, the corallites of both species are hardly developed and fully covered at some spots due to the over-growing of coralline algae especially around the dimly-lit rocky holes. *P. muellerae* is also the only colonial coral revealed during the last BASI coral surveys carried out in the southern of the Sea of Marmara. *Madracis pharensis* is the most abundant colonial coral around the coralligenous habitats in the strait. Occurring up to 39 m depth on rocky holes, overhangs and ceiling of dimly lit crevices (Özalp and Alparslan 2015), it forms very strong and complicated facies among the calcareous bioconcretions. Solitary hard corals are also present, some of them highly populated among calcareous formations, in the strait. *C. smithii* and *B. europaea* may be seen and abundant on rocks, hard-shingly substrates, sponges and *Posidonia* roots, while *C. inornata*, *L. pruvoti* and *P. pulchellus* are mainly occurred in coralligenous assemblages and fully associated to calcareous algae at some localities. *C. smithii* is one of the significant members of Scleractinian fauna in the southern of the Sea of Marmara (Karabiga). The abundance was found high and the investigated specimens were much bigger in size and developed than those observed in the strait. *L. pruvoti* is another solitary species distributed on dark and dimly lit rocky substrates in the same region at depths deeper than 30 m (Özalp 2013). So far, only three Scleractinian species, one of which is colonial, were discovered at the southern part of the Sea of Marmara and the number of surveyed area regarding the Anthozoan presence in marine surveys was limited. Despite the current status, it can be said that the newly started investigations (BKUZEYS marine surveys), supported by TUBITAK, focusing to discover the Scleractinian ecology and demographical features along the coasts of Marmara Islands and the central Marmara Sea will advance the distributional patterns and update the data on Anthozoan fauna of Turkey.

The Çanakkale Strait constitutes a suitable living habitat also for other hexacoral species such as anemones, black corals, Zoantharian and Ceriantharian species. At depths shallower than 10 m on both sides of the strait, Actiniarians *Condylactis aurantiaca*, *Actinia equina*, *Anemonia sulcata* and *Cereus pedunculatus* are the most abundant species on sandy and rocky substrates. The occurrence of *C. aurantiaca*, the most common anemone among them, may reach over nine individuals per square meter, especially around the harbour region. It is also commonly found at some locations in the southern Marmara Sea. The species' body is used as an important shelter by some exotic anemone-associated shrimps (Duris *et al.* 2013). More rare species such as *Aiptasia mutabilis*, *Andresia partenopea*, *Epizoanthus couchii*, *Calliactis parasitica* and *Alicia mirabilis* can be found as isolated individuals at some parts of rocky habitats.

Differently from other species given above, *E. couchii* may exceptionally be seen as dense colonies inhabiting on dark and dimly lit ceilings and crevices in the Çanakkale Strait mainly below 20 m depth. Zoanthids *Savalia savaglia* and *Parazoanthus axinellae* are the commonly present hexacorals and occur in the circalittoral hard substrates in the Çanakkale Strait and the Sea of Marmara. Although it has not been investigated in a large scale, *S. savaglia* also recorded as a near-threatened gorgonian by IUCN, is among the key species in the strait forming special hotspot mainly at depths deeper than 39 m. In some areas at the northern entrance points of the strait (Nara sector) exposed to strong surface currents that are effective throughout the year, there may be seen well-developed and larger facies between 40-65 m depths and some colonies bigger than 1 m in height. Such areas in the region are called coral forest by local fishermen. Occurring from 15 m depth on hard bottoms, *P. axinellae* is another colony forming species in the strait's habitat.

## 4. Threats and Conservation Priorities

Pollution, sedimentation, over-frequentation by divers, biological invasions, mass mortalities following thermal anomalies, destructive fishing activities and the synergistic effects of these stress sources were defined as the main threats to key engineering species in the Mediterranean Sea (Giakoumi *et al.* 2013). The Sea of Marmara, a semi-enclosed sea surrounded by seven cities, is a highly disturbed environment. Anthropogenic inputs in the Sea of Marmara are of various origins including riverine discharges, but a major fraction comes from Istanbul, one of the most populated cities in the world (Tuğrul and Polat 1995). The Sea of Marmara is also an important fishing ground, from where around 10 % of the Turkish fishery catches are obtained (Ulman *et al.* 2013). As a matter of fact, abandoned fishing nets covering gorgonians or their habitats were found in more than half of the investigated stations in Prince Islands region (Topçu and Öztürk 2015).

Therefore, there are several threats to corals in the Sea of Marmara and their effects were already seen destructive at some localities. The disturbances in the Sea of Marmara raised in the last 30 years, due to rapid population growth and industrial revolution in the surrounding region (Burak 2008) and in parallel to the catastrophic degradation period in the Black Sea (Bakan and Büyükgüngör 2000). These degradations were coupled to increased fishing efforts, overfishing and illegal fishing (Öztürk and Öztürk 1996). As a result of these disturbances, the distribution of species with slow dynamics such as *Paramuricea clavata* and *Savalia savaglia* – now restricted to few locations - were probably decreased while the rocky habitats were occupied by species with higher growth rates, responding faster to damages by fisheries practices and more tolerant to sedimentation (Topçu and Öztürk 2015). *S. savaglia* itself was in fact fished in the 1990’s for jewelry making from its skeleton (Öztürk and Bourguet 1990). The abundance of large colonies with thick skeleton seem to have highly decreased, still not recovered due probably to slow radial growth rates of the genus (Roark *et al.* 2009) but also the decrease of host gorgonians.

Also in the Çanakkale Strait, a unique area where *Cladocora* colonies are found in the Sea of Marmara, fishing nets cause sometimes colony damages by turning the colonies upside down (Özalp 2014a). In that case, the colony corallites running out of the sun light after being overturned, bleach and die because the symbiotic zooxanthellae algae cannot survive. The fishing also cause the break of entire colonies or corallites periodically. Some invasive algae species observed recently in the Çanakkale Strait has been another risk factor for healthy colonies of *C. caespitosa*. At some locations, *Caulerpa racemosa* causes partial death of polyps or entire colony. According to the last investigations focusing on algae pressure in the strait, a new invasive algae species was discovered at Dardanos region, where the largest communities of *C. caespitosa* are present. The algae severely affects the colonies by covering its surface, which prevents symbiotic zooxanthellae from photosynthesis and conduce to partial or total colony death (Özalp and Çavaş submitted).

Anchoring is also a major threat in the Sea of Marmara, at some locations because of pleasure boats (like Prince Islands) or at others like the Çanakkale Strait because of fishing boats. During the fishing season of *Pomatomus saltatrix*, benthos at both sides of the strait is intensely affected by anchoring. The latest data revealed after the first UNDP-GEF project on coral conservation and monitoring realized in 2013 around Scleractinian habitats of Çanakkale showed that the total number of daily fishing boats increased up 70 at only one station, where the coral colonies are present in a large scale. Aiming to catch blue fish during the migration season, all boats at some locations (Dardanos, Soğandere, Eceabat, Nara,) use anchor and damage the natural communities of the species *C. caespitosa*, *Polycyathus muellerae* and *Phyllangia mouchezii*. *P. muellerae*, which have dense colonies at some areas, is the most affected colony species among others. *P. clavata* and *S. savaglia* facies are also severely threatened due to anchorage done by the amateur fishermen (Özalp, 2014b). Although a recent national project "Conservation of Marine Biodiversity in the Çanakkale Strait" supported by Çanakkale Mayor developed a monitoring plan for the colonial Scleractinian communities, anchoring is still a problematic issue especially at the largest coral habitats in the region (Özalp 2015).

A series of thermal anomalies recently affected Mediterranean benthic assemblages, causing mass mortalities at some locations, and corals were among the most affected organisms (Cerrano *et al.* 2000; Garrabou *et al.* 2009). In the Sea of Marmara, temperature variances below 20 m are very low and the temperature is generally about 15°C. Since most corals in the Sea of Marmara are found in the lower layer, temperature anomalies in result of climate change might not affect Marmara corals. Despite that, in the Çanakkale Strait where salinity profile allows some corals to be present at shallower depths, monitoring studies showed that there were several bleaching events of *C. caespitosa* in the Çanakkale Strait and the relations of the events to temperature values are being investigated (Özalp B. unpubl. data). Previous studies have already reported bleached colonies following positive thermal anomalies, from the nearby north-eastern Aegean Sea (Güreşen *et al.* 2015). On the other hand, in the north-eastern Sea of Marmara, Prince Islands region, a recent mass mortality of benthic suspension feeders (including corals) was recorded, however this event was not related to temperature anomalies but to other local sedimentation issues (Topçu E. unpubl. data).

To sum up; pollution, sedimentation and destructive fisheries activities seem to be the main but not unique threats to corals in the Sea of Marmara. Bottom trawling has been banned in the Sea of Marmara since 1971, but illegal bottom trawling for shrimp is prevalent to this day (Ulman *et al.* 2013). Recently, purse seine fisheries were prohibited in the northern area of Prince Islands however, the vulnerable coral assemblages are abundant at the south of the islands, where there is no ban. In Turkey, the only regional or national legislation for the protection of corals and gorgonians is the complete prohibition of fisheries of *Corallium rubrum* and *S. savaglia*, according to the Statements 2012/66 and 2012/65. In order to ensure the conservation of coral assemblages in the basin, we suggest some specific measures stated below, but other general measures for the improvement of the environmental health state of the Sea of Marmara, including the control of all kind of pollution loads are also necessary.

- No-take zones over coral assemblages should be created or the existing ones should be enlarged by taking into account coral distribution in the area. Alternatively, marine protected areas to be created might be designed also by taking into account coral distribution.
- Prohibition of anchoring and placement of mooring buoys at some locations where scleractinian and/or arborescent corals are present.

**Table I.** Species list of anthozoans from the Sea of Marmara**.** Substrate types: R: rocks; S: sandy/muddy substrates; M: combination of pebbles, shells and small rocks on a muddy bottom; P: polychaete tubes; Sp: sponges; Co: coralligenous; Bc: Bioconcretions; Po: Posidonia beds; Sh: shells carried by the hermit crabs. Distribution: NM: Northern Sea of Marmara; SM: Southern Sea of Marmara; ÇS: Çanakkale Strait DBM: deep basins of the Sea of Marmara.

| Species | Substrate type | Distribut. | Refer. |
|---|---|---|---|
| **Subclass Octocorallia** | | | |
| **Order Alcyonacea** | | | |
| **Suborder: Stolonifera** | | | |
| *Cornularia cornucopiae* (Pallas, 1766) | R | NM | 1 |
| *Clavularia crassa* (Milne Edwards, 1848) | R; Co; Bc | NM | 2 |
| *Sarcodictyon catenatum* Forbes, 1847 | R; Co; Bc | NM; SM | 3 |
| *Sarcodictyon roseum* (Philippi, 1842) | R; Co; Bc | NM; ÇS | 4; 5a |
| **Suborder: Alcyoniina** | | | |
| *Alcyonium palmatum* Pallas, 1766 | R; M | NM; SM; ÇS | 6; 3 |
| *Alcyonium acaule* Marion, 1878 | R; Co | NM; SM; ÇS | 7; 3; 5a |
| *Alcyonium coralloides* (Pallas, 1766) * | R; Co; Bc | NM; SM; ÇS | 4; 7; 3; ps |
| *Maasella edwardsii* (de Lacaze-Duthiers, 1888) | Po | ÇS | 5b |
| *Paralcyonium spinulosum* (Delle Chiaje, 1822) | R; M; Co | NM; SM | 7; 3 |
| **Suborder: Holaxonia** | | | |
| *Bebryce mollis* Philippi, 1842 | R | NM | 8 |
| *Paramuricea clavata* (Risso, 1826) | R; Co | NM; SM | 9; 3 |
| *Paramuricea macrospina* (Koch, 1882) | R; M; Co | NM; SM | 8; 3 |
| *Spinimuricea klavereni* Carpine & Grasshoff, 1975 | R; M; Co | NM; SM | 8; 3 |
| *Eunicella singularis* (Esper, 1791) | R; Co | SM | 10; 3 |
| *Eunicella cavolini* (Koch, 1887) | R; Co | NM; SM | 10; 3 |
| *Eunicella verrucosa* (Pallas, 1766) | R; Co | SM | 2; 3 |
| **Order Pennatulacea** | | | |
| *Veretillum cynomorium* (Pallas, 1766) | S | NM; SM | 4; 3 |
| *Cavernularia pusilla* (Philippi, 1835) | S | NM; SM | 11 |
| *Kophobelemnon leucharti* Cecchini, 1917 | S | NM | 2 |
| *Funiculina quadrangularis* (Pallas, 1766) | S | NM; SM | 8; 3; 12 |
| *Virgularia mirabilis* (Müller, 1776) | S | NM | 1 |
| *Pennatula phosphorea* Linnaeus, 1758 | S | ÇS | 6; 12 |
| *Pennatula rubra* Ellis, 1761 | S | SM | 12 |
| *Pteroeides spinosum* (Ellis, 1764) | S | NM; SM | 6; 2; 3 |
| **Subclass Hexacorallia** | | | |
| **Order Actiniaria** | | | |
| **Suborder Nynantheae** | | | |
| *Actinia equina* (Linnaeus, 1758) | R; M | NM; ÇS | 2; 5a |
| *Anemonia viridis* (Forskål, 1775) | R; M | NM | 2 |
| *Condylactis aurantiaca* (Delle-Chiaje, 1825) | S | M; ÇS | 13; 5a |
| *Aiptasia mutabilis* (Gravenhorst, 1831) | R; C; Bc; S | M; ÇS | 13; 5a |
| *Aiptasiogeton pellucidus* (Hollard, 1848) | R; Bc | NM | 17 |
| *Calliactis parasitica* (Couch, 1842) | R; Bc; M; Sh | SM, ÇS | 5a |
| *Alicia mirabilis* Johnson, 1861 | R; M; Co; Bc; S | ÇS | ps |
| *Cereus pedunculatus* (Pennant, 1777) | R; M; S | ÇS | 5a |
| *Sagartia elegans* (Dalyell, 1848) | R; Bc | M | 13 |

| | | | |
|---|---|---|---|
| *Sagartiogeton laceratus* (Dalyell, 1848) | R | NM | 17 |
| *Sagartiogeton undatus* (Müller, 1778) | R | NM | 17 |
| *Sagartiogeton viduatus* (Müller, 1776) | S | NM | 8 |
| *Peachia cylindrica* (Reid, 1848) | S | NM | 1 |
| *Andresia partenopea* (Andrès, 1883) | S | ÇS | 5a |
| *Bunodeopsis strumosa* Andrès, 1881 | R; Bc; S | ÇS | 17 |
| **Order Antipatharia** | | | |
| *Parantipathes larix* (Esper, 1788) | S | NM | 8 |
| **Order Scleractinia** | | | |
| **Family Astrocoeniidae** | | | |
| *Madracis pharensis* (Heller, 1868) | R; Co; Bc | ÇS | 14 |
| **Family Scleractinia incertae sedis** | | | |
| *Cladocora caespitosa* (Linnaeus, 1767) | R, P | ÇS | 15 |
| **Family Caryophylliidae** | | | |
| *Caryophyllia (Caryophyllia) cyathus* (Ellis & Solander, 1786) | R | ÇS | 6 |
| *Caryophyllia (Caryophyllia) smithii* Stokes & Broderip, 1828 | R; M; P | NM; SM; ÇS | 8; 16 |
| *Caryophyllia (Caryophyllia) inornata (*Duncan, 1878) | R; Co; Bc | ÇS | 15 |
| *Coenocyathus anthophyllites* Milne Edwards & Haime, 1848 | S | SM | 8 |
| *Desmophyllum dianthus* (Esper, 1794) | R | DBM | 18 |
| *Paracyathus pulchellus* (Philippi, 1842) | R; Sp; Co; Bc | NM, ÇS | 2, 16 |
| *Polycyathus muellerae* (Abel, 1959) | R; Sp; Co; Bc | ÇS | 16 |
| *Phyllangia americana mouchezii* (Lacaze-Duthiers, 1897) | R, Co | ÇS | 16 |
| **Family Dendrophylliidae** | | | |
| *Balanophyllia (Balanophyllia) europaea* (Risso, 1826) | R; Co; Po | NM; SM; ÇS | 8; 16 |
| *Dendrophyllia ramea (*Linnaeus, 1758) | S | SM | 8 |
| *Leptopsammia pruvoti* Lacaze-Duthiers, 1897 | R; Sp; Co; Bc | ÇS | 16 |
| **Order Zoanthidea** | | | |
| **Suborder Macrocnemina** | | | |
| *Epizoanthus couchii* (Johnston in Couch, 1844) | R; Co; Bc | ÇS | 5a |
| *Savalia savaglia* (Bertoloni, 1819) | R; Co | NM; SM; ÇS | 9; 3; 19 |
| *Parazoanthus axinellae* (Schmidt, 1862) | R; Co; Sp | SM; ÇS | 8; 5a |
| **Order Corallimorpharia** | | | |
| *Corynactis viridis* Allman, 1846 | R; Co | NM | 17 |
| **Subclass Ceriantharia** | | | |
| **Order Spirularia** | | | |
| *Cerianthus membranaceus* (Spallanzani, 1784) | S; M | SM | 8 |
| *Pachycerianthus solitarius* (Rapp, 1829) | S | NM | 2 |

* Recorded as *Parerythropodium bosphorense* by Tixier-Durivault 1961. See discussion on the species in the 2nd section.

1: Uysal *et al.* 2002; 2: Demir 1954; 3: Topçu and Öztürk 2015; 4: Ostroumoff 1894; 5a: Özalp and Ateş 2015a; 5b: Özalp and Ateş 2015b; 6: Colombo 1885; 7: Topçu and Öztürk 2013; 8: Ostroumoff 1896; 9: Öztürk and Bourguet 1990; 10: Öztürk *et al.* 2004; 11: Sezgin and Yüksek 2015; 12: Topaloğlu *et al.* 2004; 13: Gözcelioğlu 2011; 14: Özalp and Alparslan 2015; 15: Özalp and Alparslan 2011; 16: Özalp and Alparslan 2016; 17: Çınar *et al.* 2014; 18: Taviani *et al.* 2011; 19: Özalp 2014b; ps: present study (Box I and II).

**Box I**

***Alcyonium coralloides* (Pallas, 1766)**

Notes: Encrusting forms were observed on rocky surface. Coenenchyme was reddish with yellow polyps. Polyps up to 6 mm high.

Distribution: In the Çanakkale Strait, it was found at Nara Region (close to the Marmara Sea entrance of the strait), at 26 m on a rocky surface. The species is distributed along the Mediterranean (Groot and Weinberg 1982) and the northeastern Atlantic (Vafidis *et al.* 1994; Mcfadden 1999).

**Figure I.1** A macro photo of *Alcyonium coralloides* at 26 m depth in the Çanakkale Strait (Özalp, 2013)

**1**

**Box II**

***Alicia mirabilis* Johnson, 1861Notes: The specimen was expanded, translucent white in colour, about 30 cm high.**

**Distribution: Not commonly observed. The individual was recorded during night dive, in the Çanakkale Strait, at Güzelyalı Region (close to the Aegean Sea entrance of the strait), at 37 m depth on mussels. The species has an Atlanto-Mediterranean distribution (Vafidis in Coll *et al.* 2010: Table S13).**

**Figure II.1 A night time photo of A. mirabilis at 37 m depth in the Çanakkale Strait (Özalp, 2016).**

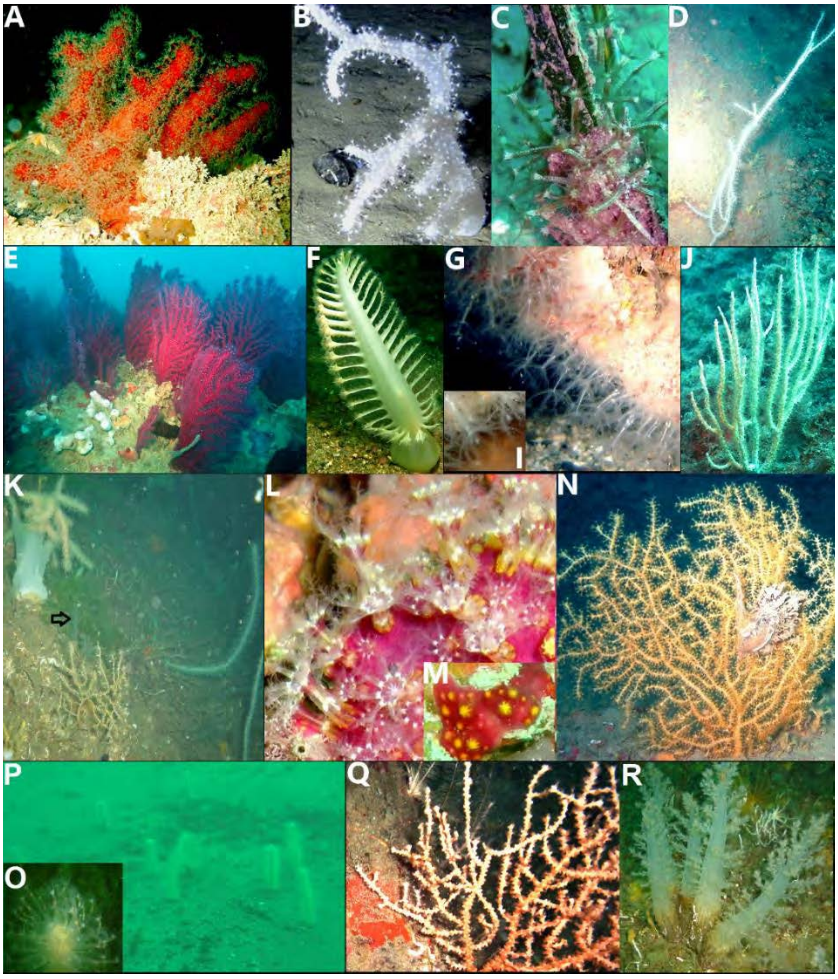

**Figure 1.** Examples to octocoral species in the Sea of Marmara and Çanakkale Strait. A: *Alcyonium acaule*; B: *Alcyonium palmatum*; C: *Maasella edwardsi*; D: *Spinimuricaea klavereni*; E: *Paramuricea clavata*; F: *Pteroeides spinosum*; G: *Sarcodictyon roseum*; I: Macro photo of *S. roseum* polyp; J: *Eunicella singularis*; K: a community of *A. palmatum*, *P. spinulosum* (marked by arrow), *S. klavereni* and *P. macrospina*; L: *Alcyonium coralloides*; M: Macro photo of polyps of *A. coralloides* (polyps retracted); N: *Paramuricea macrospina*; O: Macro photo of *Veretillum cynomorium*; P: An assemblage of *V. cynomorium*; Q: *Eunicella cavolini*; R: *Paralcyonium spinulosum*

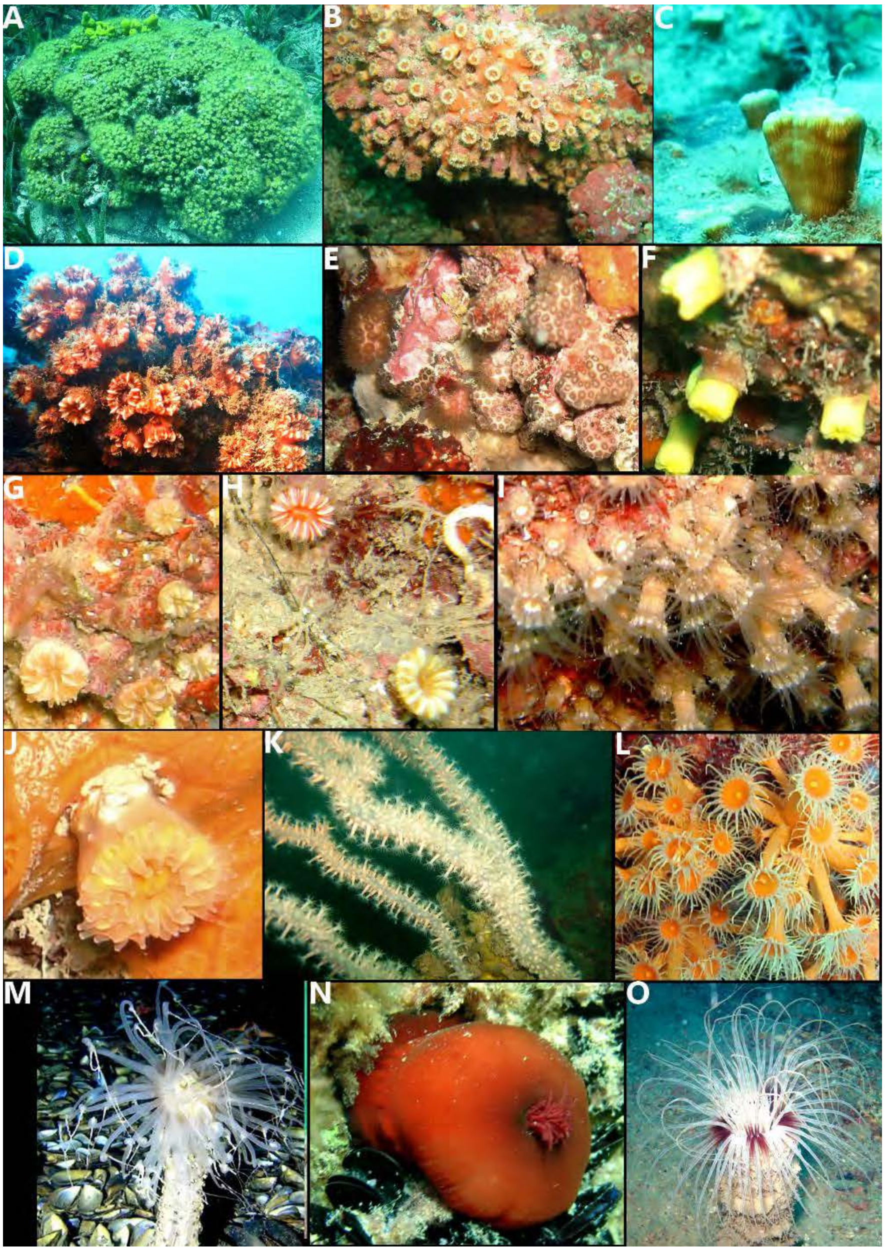


**Figure 2.** Examples to hexacoral species in the Sea of Marmara and Çanakkale Strait. A: *Cladocora caespitosa*; B: *Polycyathus muellerae*; C: *Balanophyllia europaea*; D: *Phyllangia mouchezii*; E: *Madracis pharensis*; F: *Leptopsammia pruvoti*; G: *Caryophyllia inornata*; H: *Caryophyllia smithii*; I: *Epizoanthus couchii*; J: *Paracyathus pulchellus*; K: *Savalia savaglia*; L: *Parazoanthus axinellae*; M: *Alicia mirabilis*; N: *Actinia equina*; O: *Cerianthus membranaceus*.

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**BRYOZOANS OF THE SEA OF MARMARA**

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## 1. Introduction

Bryozoans are sessile and colonial organisms living mostly at hard substrate of marine habitats. Their colonies may be uni or polymorphic and in many different shapes (Demir 1952). Bryozoan diversity varies according to mainly habitat and substrate (Lombardi *et al*. 2008). The relationship between the bryozoan associations and water depth, water energy, sedimentation rate, and substrate type was revealed by Amini *et al*. (2004).

About 5000 bryozoan species were recorded worldwide and approximately 10% of them are known from the Mediterranean. Although Forbes (1844) firstly reported bryozoan species from the Turkish seas in the Aegean Sea, first records about Bryozoa fauna of the Sea of Marmara belongs to Ostroumoff (1894 and 1896), Colombo (1885) and Marion (1898). Afterwards, species of this Phylum were mentioned in general faunistic studies such as by Demir (1952), Pınar (1974), Okuş (1989), Yüksek (1989), Balkıs (1992), Eryılmaz (1997), Balkıs and Albayrak (2001) and finally by Özalp (2016). Studies covering only bryozoan species were carried out by Ünsal (1975) and Unsal and d'Hondt (1978-1979) who studied all Turkish seas including the Sea of Marmara, by Aslan-Cihangir (2007), Koçak (2008) and Koçak and Aydın-Önen (2014a) who studied in the Aegean Sea. The only new bryozoan species described from Turkish seas is *Cleidochasmidra canakkalense* by Unsal and d'Hondt (1978-1979) in the Aegean Sea. Koçak and Aydın-Önen (2014b) prepared a check-list of Bryozoa fauna of Turkish coasts reporting a total of 185 species and indicated the Black Sea as poorest with 8 species, the Aegean Sea as richest with 139 species, while the Sea of Marmara and the Levantine Sea took place between them with 89 and 66 species, respectively. However, our review of literatures brought about changes in species number of the Aegean Sea and the Sea of Marmara due to some taxonomical arrangement, new species records after the year 2014 and replacing some species indicated in Aslan-Cihangir (2007), erroneously noted for the Sea of Marmara in above mentioned check-list, from the Sea of Marmara to the Aegean Sea. Proper species numbers should be 142 for the Aegean Sea and 83 for the Sea of Marmara.

A total of eight bryozoan species, reported by Ostroumoff (1894 and 1896), were excluded from the list because of taxonomical problems. These species are *Alecto repens* Busk, *Bowerbankia densa*, *Lepralia foraminifera* Hell., *Membranipora reticulum* L., *Membranipora rostrata* Hell., *Polytrema corallinum* Risso, *Radiopora hispida* Hcks., *Schizoporella reticulata*. Valid bryozoan species recorded from the Sea of Marmara were presented in List 1 where families and genera within families were exihibited in alphabetical order. The classification of species was based on WoRMS (World Register of Marine Species), besides, Novosel (2005), Rosso & Martino (2016) and web site of IBA (International Bryozoology Association) were also utilized for some species to check valid nomenclature.

**List 1.** Species belonging to Bryozoa fauna of the Sea of Marmara

**Phylum: Bryozoa**

**Family: Adeonidae**
*Adeonella lichenoides* (Lamarck, 1816)
*Reptadeonella violacea* (Johnston, 1847)
**Family: Aeteidae**
*Aetea anguina* (Linnaeus, 1758)
*Aetea sica* (Couch, 1844)
*Aetea truncata* (Landsborough, 1852)
**Family: Alcyonidiidae**
*Alcyonidium mamillatum* Alder, 1857
**Family: Beaniidae**
*Beania magellanica* (Busk, 1852)
**Family: Bitectiporidae**
*Pentapora fascialis* (Pallas, 1766)
*Schizomavella auriculata* (Hassal, 1842)
*Schizomavella linearis* (Hassall, 1841)
**Family: Bryocryptellidae**
*Porella concinna* (Busk, 1854)
**Family: Bugulidae**
*Bugula flabellata* (Thompson, in Gray, 1848)
*Bugula plumosa* (Pallas, 1766)
*Bugula simplex* Hincks, 1886
**Family: Calloporidae**
*Aplousina gigantea* Canu & Bassler, 1927
*Callopora dumerilii* (Audouin, 1826)
*Copidozoum tenuirostre* (Hincks, 1880)
**Family: Candidae**
*Caberea boryi* (Audouin, 1826)
*Cradoscrupocellaria bertholletii* (Audouin, 1826)
*Cradoscrupocellaria reptans* (Linnaeus, 1758)
*Scrupocaberea maderensis* (Busk, 1860)
*Scrupocellaria scrupea* Busk, 1852
*Scrupocellaria scruposa* (Linnaeus, 1758)
**Family: Cellariidae**
*Cellaria salicornioides* Lamouroux, 1816
**Family: Celleporidae**
*Cellepora pumicosa* (Pallas, 1766)
*Celleporina boryi* (Audoin, 1826)
*Celleporina caminata* (Waters, 1879)
*Celleporina costata* (MacGillivray, 1869)
**Family: Chorizoporidae**
*Chorizopora brongniartii* (Audouin, 1826)
**Family: Cribrilinidae**
*Corbulipora tubulifera* (Hincks, 1881)
*Puellina gattyae* (Landsborough, 1852)
**Family: Crisiidae**

*Crisidia cornuta* (Linnaeus, 1758)
*Crisia denticulata* (Lamarck, 1816)
*Crisia eburnea,* (Linnaeus, 1758)
*Crisia fistulosa* (Heller, 1867)
**Family: Cryptosulidae**
*Cryptosula pallasiana* (Moll, 1803)
**Family: Diastoporidae**
*Diplosolen obelia* (Johnston, 1838)
**Family: Electridae**
*Conopeum seurati* (Canu, 1928)
*Electra pilos*a (Linnaeus, 1767)
*Electra posidoniae* Gautier, 1954
**Family: Entalophoridae**
*Mecynoecia delicatula* (Busk, 1875)
*Mecynoecia proboscidea* (Milne-Edwards, 1838)
**Family: Escharinidae**
*Escharina dutertrei* (Audouin, 1826)
*Escharina vulgaris* (Moll, 1803)
*Phaeostachys spinifera* (Johnston, 1847)
**Family: Exochellidae**
*Escharoides coccinea* (Abildgaard, 1805)
**Family: Flustridae**
*Securiflustra securifrons* (Pallas, 1766)
**Family: Frondiporidae**
*Frondipora verrucosa* (Lamouroux, 1821)
**Family: Hippothoidae**
*Hippothoa flagellum* Manzoni, 1870
**Family: Lacernidae**
*Arthropoma cecilii* (Audouin, 1826)
**Family: Lichenoporidae**
*Lichenpora verrucaria* (Fabricius, 1780)
*Patinella radiata* (Audouin, 1826)
**Family: Microporellidae**
*Diporula verrucosa* (Peach, 1868)
*Fenestrulina malusii* (Audouin, 1826)
*Microporella ciliata* (Pallas, 1766)
**Family: Microporidae**
*Calpensia nobilis* (Esper, 1796)
*Mollia circumcincta* (Heller, 1867)
**Family: Mimosellidae**
*Bantariella verticillata* (Heller, 1867)
*Mimosella gracilis* Hincks, 1851
**Family: Myriaporidae**
*Myriapora truncata* (Pallas, 1766)
**Family: Phidoloporidae**
*Reteporella grimaldii* (Jullien, 1903)
*Schizotheca fissa* (Busk, 1856)
**Family: Phoceanidae**
*Phoceana tubulifera* (Heller, 1867)
**Family: Plagioeciidae**
*Plagioecia patina* (Lamarck, 1816)
**Family: Savignyellidae**
*Savignyella lafontii* (Audouin, 1826)
**Family: Schizoporellidae**
*Schizoporella dunkeri* (Reuss, 1848)
*Schizoporella magnifica* (Hincks, 1886)
*Schizoporella unicornis* (Johnston in Wood, 1844)
**Family: Scrupariidae**
*Scruparia chelata* (Linnaeus, 1758)
**Family: Smittinidae**
*Smittina cervicornis* (Pallas, 1766)
*Smittina landsborovii* (Johnston, 1847)
*Smittoidea marmorea* (Hincks, 1877)
*Smittoidea reticulata* (MacGillivray, 1842)
**Family: Tendridae**
*Tendra zostericola* Nordman, 1839
**Family: Terviidae**
*Tervia irregularis* (Meneghini, 1844)
**Family: Triticellidae**
*Triticella flava* Dalyell, 1848
**Family: Tubuliporidae**
*Platonea stoechas* Harmelin, 1976
*Tubulipora liliacea* (Pallas, 1766)
**Family: Vesiculariidae**
*Amathia imbricata* (Adams, 1798)
*Amathia pruvoti* Calvet, 1911

*Amathia semiconvoluta* Lamouroux, 1824

*Bowerbankia citrina* (Hincks, 1877)

**Family: Walkeriidae**

*Walkeria uva* (Linnaeus, 1758)

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# RECENT OSTRACODA SPECIES OF THE SEA OF MARMARA WITH ÇANAKKALE (DARDANELLES) AND ISTANBUL STRAIT (BOSPHORUS): A REVIEW

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## Introduction

The Sea of Marmara is situated in the northwestern part of Turkey, connected to the Black Sea and Aegean Sea through the Bosphorus (or Bosporus) and Dardanelles, respectively, and features a narrow continental shelf at the northern end and a wide continental shelf in the southern. Related studies on ostracod assemblages were performed on the continental shelf of the Sea of Marmara. According to the results of these studies, ostracod species diversity is rich there. The hydrography of the Sea of Marmara is essentially determined by the exchange through the two straits. Three topographic depressions in the northern part of the Sea of Marmara are seaward extensions of the well-known North Anatolian Fault Zone spanning the Anatolian peninsula (Beşiktepe *et al*. 1994). The bathypelagic and bathyal zones are the presented zones of the Sea of Marmara. The less saline water of the Black Sea surface flows via the Bosphorus, the Marmara, and the Dardanelles to the Aegean Sea. A counter movement of more saline water also flows from the Aegean Sea, via the Dardanelles, the Marmara, and the Bosphorus to the Black Sea. The Sea of Marmara is a small basin (size: ~70 km x 250 km, surface area: 11500 km$^2$, maximum depth 1390 m) located between the continents of Europe and Asia, which connects with the Mediterranean Sea and the Black Sea, respectively through the Dardanelles (length:60 km , width: 1.3–7.0 km) and the Bosphorus (length: ~30 km, width: 0.7–3.5 km) straits. The straits and the Sea of Marmara together constitute the Turkish Straits System. (Beşiktepe *et al*. 1994).

Ostracods are small bivalve aquatic crustaceans that are widely distributed in different aquatic habitats, from freshwater to deep marine environments. Marine ostracods have adopted both benthic and pelagic lifestyles, but most marine ostracods live in benthic habitats and most commonly reproduce sexually. They were first identified in the eighteenth century. Earlier studies on them concerned simple collections and taxonomy, but later studies have focused on ecological, paleoeclogical, and geochemical aspects (Holmes and Chivas 2002). Ostracods have a pair of carapax containing calcium carbonate and thus leave behind fossils, which become important materials for paleontological and paleoecological studies. The distribution and diversity of ostracod species are affected by several environmental and sedimentological factors like salinity, depth, mud percentage, wave actions, dentritus type, algal compositon etc.

According to recent studies, ostracod samples were collected from 1 m$^2$ of surface sediment at varying depths, from shallow littoral zones to deep sea levels, by hand nets (200 µm mesh size) or Van Veen Grab. Four hundred ml of surface sediment were collected from each sediment in bottles that included 70% alcohol or formaldehyde. Species were separated from mud and detritus using standard sieves (1 mm, 250–160 µm, and 80 µm mesh sizes) under pressurized tap water. The washed materials were preserved in 70% ethanol. Generic and specific features of the carapace and soft parts were examined for species identification. Resulting materials were taken into micro-paleontological slights or 1:1 70% ethanol and glycerin.

An updated checklist of the marine and coastal brackish waters of Ostracoda in Turkey was presented by Perçin-Paçal *et al.* (2015). The distributions of the publications were stable between 1989 and 2016 (Figure 1).

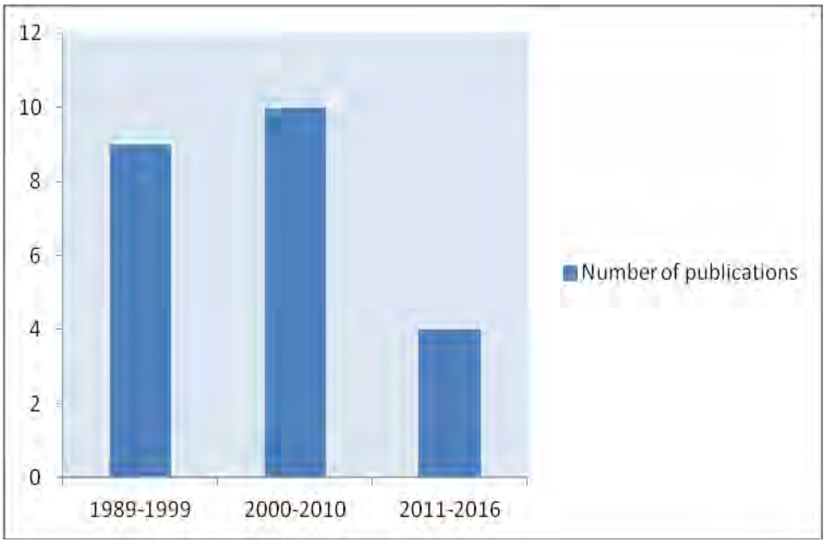


**Figure 1.** Distribution of Ostracoda publications by years.

Recent studies are about ostracoda distribution and diversity from Dardanelles Kubanç and Kılınçarslan (2001); Atay and Tunoğlu (2002); Meriç *et al*. (2009); from Bosphorus Gülen *et al*. (1990a, b), Nazik *et al*. (1999); Meriç *et al*. (2000); Kerey *et al.* (2004); from The Sea of Marmara Kubanç (1989); Gülen *et al*. (1995); Tunoğlu (1996a, b); Kubanç *et al.* (1999); Tunoğlu (1999); Nazik (2001); Kubanç (2002); Kubanç

(2005); Meriç *et al*. (2005); Kubanç *et al*. (2008); Perçin-Paçal and Balkıs (2012); Artüz *et al*. (2013); Perçin- Paçal and Balkıs (2015a); Perçin-Paçal and Balkıs (2015b).

Up to date totally 210 ostracoda species were recorded from the Sea of Marmara [184 species (88%), with the Dardanelles (63 species (30%)) and Bosphorus (54 species (26%) (Table 1)]. The higest number of species was found in Genus *Loxoconcha* with 23 species in the Sea of Marmara. An updated systematic of the Ostracoda is given below according to WoRMS (Worlds register of marine species) taxon detailes (Worms 2015).

Regnum: Animalia

Filum: Arthropoda

Subfilum: Crustacea

Superclass: Oligostraca

Class: Ostracoda

**Table 1:** The list of ostracoda species that observed from the Sea of Marmara, Çanakkale and Istanbul Straits

| | **Dardanelles; The Sea of Marmara; Bosphorus** |
|---|---|
| **OSTRACODA (Class)** | |
| **MYODOCOPA (Subclass)** | |
| **HALOCYPRİDA (Order)** | |
| *Polycope reticulata* G.W. Müeller, 1894 | Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| **PODOCOPA (Subclass)** | |
| **PLATYCOPİDA (Order)** | |
| *Cytherella alvearium* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Cytherella lata* Brady, 1880 | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Cytherella maremensis* Artüz, Gülen & Kubanç, 2013 | Artüz *et al*. 2013; Perçin-Paçal *et al*. 2015 |
| *Cytherella vandenboldi* Sissingh, 1972 | Nazik 2001; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Cytherella vulgata* Ruggieri, 1962 | Meriç *et al*. 2009; Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytherelloidea sordida* (Müller, 1894) | Meriç *et al*. 2009; Perçin-Paçal *et al*. 2015 |
| **PODOCOPİDA (Order)** | |
| *Acantocythereis ascolii* (Puri 1963) | Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Acantocythereis (Cythereis) dunelmensis* (Norman, 1865) | Kubanç 1989; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |
| *Acantocythereis (Trachyleberis) hystrix* (Reuss, 1850) | Meriç *et al*. 2009; Kubanç 1989, Kubanç 2005; Kubanç *et al*. 2008; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Aglaiocypris (Paracypris) complanata* Brady & Robertson, 1869 | Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal *et al*. 2015 |
| *Aglaiocypris rara* G. W. Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |

| | |
|---|---|
| *Argilloecia acuminata* Müller, 1894 | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Argilloecia conoidea* Sars, 1923 | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Argilloecia minor* G.W. Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Argilloecia robusta* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Aurila amygdala* (Stephenson, 1944) | Gülen *et al*. 1990a; Gülen *et al*. 1990b; Perçin-Paçal *et al*. 2015 |
| *Aurila convexa* (Baird, 1850) | Kubanç and Kılınçarslan 2001; Meriç *et al*. 2009; Kubanç 1989; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Kerey *et al*. 2004; Nazik *et al*. 1999 |
| *Aurila prasina* Barbeito-Gonzalez, 1971 | Kubanç 2005; Kubanç *et al*. 2008, Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Aurila speyeri* (Brady, 1868) | Kubanç 2005; Kubanç *et al*. 2008, Perçin-Paçal *et al*. 2015 |
| *Aurila woodwardii* (Brady, 1868) | Kubanç 2005; Perçin-Paçal *et al*. 2015 |
| *Bairdia (Neonesidea) corpulenta* (Müller, 1894) | Meriç *et al*. 2005; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Bairdia (Neonesidea) longevaginata* Müller, 1894 | Kubanç 2005; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Bairdia (Neonesidea) mediterranea* Müller, 1894 | Nazik 2001; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Kerey *et al*. 2004, Meriç *et al*. 2000 |
| *Bairdia (Triebelina) raripila* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Bairdoppilata (Bairdia) supradentata* (Terquem, 1878) Sissingh, 1972 | Meriç *et al*. 2009; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Basslerites berchoni* (Brady, 1869) | Meriç *et al*. 2009; Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal *et al*. 2015 |
| *Bosquetina carinella* (Reuss, 1957) | Meriç *et al*. 2009; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Bosquetina dentata* (Müller, 1894) | Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999 |
| *Buntonia giesbrechti* (Müller, 1894) | Kubanç and Kılınçarslan 2001; Kubanç 1989; Kubanç 2002; Nazik 2001; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Buntonia subulata* Ruggieri, 1954 | Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Buntonia sublatissima* (Neviani, 1906) | Meriç *et al*. 2009; Meriç *et al*. 2005; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Bythocythere (Bythocypris) minima* Bonaduce, Ciampo & Masoli, 1976 | Meriç *et al*. 2009; Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Bythocythere turgida* Sars, 1866 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Bythocypris obtusata* (Sars, 1866) | Perçin-Paçal *et al*. 2015 |
| *Callistocythere adriatica* Masoli, 1968 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; 24 |
| *Callistocythere crispata* (Brady, 1868) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; |

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| | Perçin-Paçal *et al*. 2015 |
| *Callistocythere diffusa* (Müller, 1894) | Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Callistocythere elena* Barbeito-Gonzalez, 1971 | Gülen *et al*. 1995, Kubanç *et al*. 1999, Perçin-Paçal *et al*. 2015 |
| *Callistocythere intricatoides* Ruggieri, 1953 | Meriç *et al*. 2009; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Callistocythere littoralis* (G.W. Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Kerey *et al*. 2004, Meriç *et al*. 2000 |
| *Callistocythere lobiancoi* (Müller, 1894) | Kubanç and Kılınçarslan 2001; Kubanç 1989; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |
| *Callistocythere mediterranea* (Müller, 1894) | Meriç *et al*. 2005; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Callistocythere montana* Doruk, 1973 | Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Callistocythere pallida* (Müller, 1894) | Meriç *et al*. 2009; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al* 2015; Nazik *et al*. 1999 |
| *Callistocythere vexata* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Candona (Candona) burdurensis* Freels, 1980 | Gülen *et al*., 1995, Kubanç *et al*., 1999, Perçin-Paçal *et al*., 2015 |
| *Candona candida* (O.F. Müller, 1776) | Atay and Tunoğlu, 2002, |
| *Candona (Caspiolla) fastigata* Freels 1980 | Gülen *et al*., 1995, Kubanç *et al*., 1999, Perçin-Paçal *et al*., 2015 |
| *Candona neglecta* Sars, 1887 | Atay and Tunoğlu, 2002; Gülen *et al*., 1995, Kubanç *et al*., 1999, Perçin-Paçal *et al*., 2015 |
| *Candona parallela pannocica* (Zalanyi 1959) Syn: *Pseudocandona albicans* (Brady, 1864) | Atay and Tunoğlu, 2002, Gülen *et al*., 1995, Kubanç *et al*., 1999, Perçin-Paçal *et al*., 2015; Nazik *et al*., 1999 |
| *Carinocythereis antiquata* (Baird, 1850) | Kubanç and Kılınçarslan 2001; Gülen *et al*. 1995; Kubanç, 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Gülen *et al*. 1990a; Nazik *et al*. 1999. |
| *Carinocythereis carinata* (Roemer, 1838) | Kubanç and Kılınçarslan 2001; Gülen *et al*. 1995; Kubanç *et al*. 1999; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999; Nazik *et al*. 1999. |
| *Carinocythereis meulenkampi* Sissingh 1972 | Meriç *et al*. 2005; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999 |
| *Carinocythereis quadridentata* (Baird 1850) | Kubanç and Kılınçarslan 2001, Meriç *et al*. 2009; Gülen *et al*. 1995, Kubanç 1989, Kubanç *et al*. 1999, Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |
| *Carinocythereis rhombica* Stambolidis, 1982 | Meriç *et al*. 2009; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Celtia quadridentata* (Baird, 1850) | Nazik 2001; Perçin-Paçal *et al*. 2015 |

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| *Costa batei* (Brady 1866) | Meriç *et al*. 2009; Gülen *et al*. 1995; Kubanç 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Costa edwardsii* (Roemer, 1838) | Meriç *et al*. 2009; Gülen *et al*. 1995, Kubanç 1989, Kubanç *et al*. 1999, Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999; Gülen *et al*., 1990a |
| *Costa punctatissima* Ruggieri, 1962 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Costa tricostata* Reuss, 1850 | Meriç *et al*. 2005; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999 |
| *Cuneocythere semipunctata* (Brady, 1868) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytheretta adriatica* Ruggieri, 1952 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytheretta jurinei* (von Munster 1830) | Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Cytheretta subradiosa* (Roemer, 1836) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Cytherois frequens* Müller,1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytheroma karadagiensis* Dubowsky, 1939 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Cytheroma variabilis* Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytheropteron alatum* Sars, 1866 | Kubanç 1989, Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Cytheropteron latissimum* (Norman, 1865) | Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Cytheropteron latum* Müller, 1894 | Meriç *et al*. 2009<br>Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Cytheropteron punctatum* Brady, 1868 | Kubanç 1989, Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |
| *Cytheropteron rotundatum* Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytheropteron ruggierii* Pucci, 1955 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cytheropteron vespertilio* (Reuss, 1850) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Cyprideis dardanallesensis* Atay 2002 | Atay and Tunoğlu 2002; Perçin-Paçal *et al*. 2015 |
| *Cyprideis pannonica* (Mehes, 1908) | Atay and Tunoğlu 2002; Perçin-Paçal *et al*. 2015 |
| *Cyprideis sohni* Bassiouni, 1979 | Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999 |
| *Cyprideis sorbyana* (Jones, 1856) | Gülen *et al*. 1995; Kubanç *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Cyprideis torosa* (Jones, 1850) | Atay and Tunoğlu 2002; Meriç *et al*. 2009; Gülen *et al*. 1995; Kubanç 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; |

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| | Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu, 1999; Gülen *et al*. 1990a, Gülen *et al*. 1990b; Kerey *et al*. 2004, Meriç *et al*. 2000; Nazik *et al*. 1999. |
| *Cyprideis quadrituberculata* Krstic 1968 | Atay and Tunoğlu 2002, Perçin-Paçal *et al*. 2015 |
| *Cyprideis trituberculata* Krstic, 1968 | Atay and Tunoğlu 2002; Kubanç 2005; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Cythereis tuberculata* Sars, 1865 Syn: *Robertsonites tuberculatus* (Sars, 1865) | Atay and Tunoğlu 2002; Kubanç 1989, Kubanç 2002; Perçin-Paçal *et al*. 2015 |
| *Cytheridea acuminata* (Bosquet, 1952) | Meriç *et al*. 2009; Perçin-Paçal *et al*. 2015 |
| *Cytheridea neapolitana* Kolmann, 1960 | Kubanç and Kılınçarslan 2001, Meriç *et al*. 2009; Gülen *et al*. 1995, Kubanç *et al*. 1999, Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999 |
| *Cytheridea papillosa* Bosquet, 1852 | Gülen *et al*. 1995; Kubanç *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Cytheroma karadagiensis* Dubowsky, 1939 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Cytheroma variabilis* Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Darwinula cylindrica* (Straub, 1952) | Nazik, 2001; Perçin-Paçal *et al*., 2015 |
| *Darwinula stevensoni* (Brady & Robertson, 1870) | Atay and Tunoğlu 2002, |
| *Echinocythereis laticarina* (Brady, 1868) | Kubanç 2005; Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Euxinocythere lopatici* (Schornikov, 1964) | Kerey *et al*. 2004, Meriç *et al*. 2000; Perçin-Paçal *et al*. 2015 |
| *Falunia (Hitermannicythere) emaciata* (Brady, 1867) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Falunia plicatula* (Reuss 1850) | Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999; Kerey *et al*. 2004, Meriç *et al*. 2000; Perçin-Paçal *et al*. 2015 |
| *Falunia quadridentata* Baird, 1850 | Nazik *et al*. 1999. |
| *Falunia (Hiltermanicythere) rugosa* (Costa 1853) Sissingh, 1972 | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Hemicytherura bulgarica* Klie, 1937 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Hemicytherura cellulosa* (Norman, 1865) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Hemicytherura videns* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Henryhowella sarsi* (Müller, 1894) | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Heterocypris kilitbahirensis* Atay& Tunoğlu 2002 | Atay and Tunoğlu, 2002 |
| *Heterocypris salina* (Brady, 1868) Syn: *Cyprinotus salinus* | Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal *et al*., 2015 |
| *Heterocythereis albomaculata* (Baird, 1838) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Hiltermannicythere (Carinocythereis) rubra* (Müller, 1894) | Meriç *et al*. 2009; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Hiltermannicythere turbida* (Müller, 1894) | Meriç *et al*. 2009; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Ilyocypris bradyi* G.O. Sars, 1890 | Atay and Tunoğlu, 2002, |
| *Ilyocypris gibba* (Ramdohr, 1808) | Atay and Tunoğlu, 2002, Perçin-Paçal *et al*. 2015; |

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| | Tunoğlu, 1999 |
| *Krithe reniformis* (Brady, 1868) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Krithe similis* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Leptocythere bisulcata* Stancheva, 1964 | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Leptocythere castanea* (Sars, 1866) | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Leptocythere histriana* Caraion, 1964 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Leptocythere lacertosa* (Hirschmann, 1912) | Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Leptocythere levis* (Müller, 1894) | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Leptocythere macella* Ruggieri, 1975 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Leptocythere multipunctata* (Seguenza, 1942) | Atay and Tunoğlu 2002; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Leptocythere pellucida* (Baird, 1850) | Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999 |
| *Leptocythere (Amnicythere) pirsagatica* (Livental 1949) | Kerey *et al*. 2004; Meriç *et al*. 2000; Perçin-Paçal *et al*. 2015 |
| *Leptocythere psammophila* Guillaume, 1976 | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Leptocythere rara* (Müller, 1894) | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Leptocythere rastrifera* Ruggieri 1953 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Nazik *et al*., 1999 |
| *Loxoconcha agilis* Ruggieri, 1967 | Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999 |
| *Loxoconcha alata* Brady, 1868 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha ancilla* Stancheva, 1964 | Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha bairdi* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha bulgarica* Caraion, 1961 | Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha exagona* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha gibberosa* Terquem, 1878 | Gülen *et al*. 1995; Kubanç *et al*. 1999; Perçin-Paçal *et al*., 2015 |
| *Loxoconcha gibboides* Livental, 1949 | Kerey *et al*. 2004, Meriç *et al*. 2000; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha granulata* Sars, 1866 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Gülen *et al*. 1990a |
| *Loxoconcha lepida* Stepanaitys, 1962 | Kerey *et al*. 2004; Meriç *et al*. 2000; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha littoralis* G. W. Muller 1894 | Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha mediterranea* Müller, 1894 | Nazik 2001; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Loxoconcha minima* Müller, 1894 | Kubanç 2005; Kubanç *et al*., 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha napoliana* Puri, 1963 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha nea* Barbeito & Gonzales, 1971 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and |

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| | Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha obliquata* Sequenza 1880 | Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Kerey *et al*. 2004, Meriç *et al*. 2000; |
| *Loxoconcha (Phlyctocythere) pellucida* Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha pontica* Klie, 1937 | Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha rhomboidea* (Fischer, 1855) | Atay and Tunoğlu 2002, Kubanç and Kılınçarslan 2001; Meriç *et al*. 2009; Gülen *et al*. 1995; Kubanç 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999. |
| *Loxoconcha stellifera* Müller, 1894 | Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Loxoconcha tumida* Chapman, 1902 | Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999 |
| *Loxoconcha turbida* Müller, 1912 | Meriç *et al*. 2009 |
| *Loxoconcha versicolor*, Muller, 1900 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Macrocypris adriatica* (Breman, 1975) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Mediocypris candonaeformis* (Straub 1952) | Perçin-Paçal *et al*., 2015; Tunoğlu, 1999 |
| *Microcytherura angulosa* (Seguenza, 1880) | Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Microcytherura fulva* (Brady & Robertson, 1874) | Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Microcytherura nigrescens* Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Monoceratina mediterranea* Sissingh, 1972 | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Monoceratina oblita* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Neonesidea frequens* (Müller, 1894) | Meriç *et al*. 2009; Perçin-Paçal *et al*. 2015 |
| *Orionina bireticulata* Doruk 1974 | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Paracypris sklira* Barbeito-Gonzales, 1971 | Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal *et al*. 2015 |
| *Paracytheridea bilocunosa* (Speyer 1863) | Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Paracytheridea depressa* Müller, 1894 | Meriç *et al*. 2009; Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999. |
| *Paracytheridea parallia* Barbeito-Gonzales, 1971 | Kubanç and Kılınçarslan 2001; Gülen *et al*. 1995; Kubanç 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Paracytherois ensiforme* (Brady, 1868) | Gülen *et al*. 1995; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |

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| *Paracytherois mediterranea* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Paradoxostoma ensiforme* Brady, 1868 | Kubanç 1989, Kubanç *et al*. 1999; Kubanç 2002; Perçin-Paçal *et al*. 2015 |
| *Paradoxostoma fuscum* G.W. Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Paradoxostoma simile* G.W. Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Kerey *et al*. 2004, Meriç *et al*. 2000 |
| *Paradoxostoma taeniatum* G.W. Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Paradoxostoma triste* G.W. Müller, 1894 | Meriç *et al*. 2009; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Pontocypris (Erythrocypris) acuminata* Ulrich, 1891 | Meriç *et al*., 2009; Meriç *et al*.,2005; Nazik, 2001; Perçin-Paçal *et al*., 2015; Tunoğlu, 1999 |
| *Pontocythere (Cushmanidea) elongata* (Brady, 1868) Oertli, 1956 | Gülen *et al*. 1995, Kubanç *et al*. 1999, Nazik *et al*. 1999Meriç *et al*., 2009; Meriç *et al*. 2005; Nazik 2001;, Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal and Balkıs, 2015b; Perçin-Paçal *et al*., 2015 |
| *Pontocythere turbida* Müller, 1894 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Propontocypris dispar* G.W. Müller, 1894 | Kubanç and Kılınçarslan, 2001; Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal and Balkıs, 2015b; Perçin-Paçal *et al*., 2015; Nazik *et al*., 1999 |
| *Propontocypris pirifera* (G.W. Müller, 1894) | Perçin-Paçal and Balkıs, 2012; Perçin-Paçal and Balkıs, 2015a; Perçin-Paçal *et al*., 2015; Tunoğlu, 1999; Nazik *et al*., 1999 |
| *Pseudocandona (Candona) rostrata* (Brady & Norman, 1889) | Gülen *et al*., 1995, Kubanç *et al*., 1999, Perçin-Paçal *et al*.,2015 |
| *Pseudocytherura calcarata* (Seguenza, 1880) | Meriç *et al*. 2009; Gülen *et al*. 1995, Kubanç 1989; Kubanç *et al*. 1999, Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Pseudocytherura pontica* Dubovsky, 1939 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Pseudopsammocythere similis* (G.W. Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Pterygocythereis ceratoptera* (Bosquet, 1852) | Meriç *et al*. 2009; Nazik 2001; Perçin-Paçal and Balkıs 2012;, Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999 |
| *Pterygocythereis (Cythereis) jonesii* (Baird, 1850 ) | Meriç *et al*. 2009; Gülen *et al*. 1995, Kubanç 1989, Kubanç *et al*. 1999, Kubanç 2002; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1996a; Tunoğlu 1996b; Tunoğlu 1999; Gülen *et al*. 1990a, Perçin-Paçal *et al*. 2015 |

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| *Sclerochilus contortus* (Norman, 1862) | Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999 |
| *Semicytherura acuminata* (Müller, 1894) | Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Semicytherura acuta* (Müller, 1912) | Meriç *et al*. 2009; Meriç *et al*. 2005; Perçin-Paçal *et al*. 2015 |
| *Semicytherura acuticostata* (Sars, 1866) | Gülen *et al*. 1995, Kubanç *et al*. 1999, Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015<br>Nazik *et al*. 1999 |
| *Semicytherura amorpha* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Semicytherura cribiformis* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Semicytherura diafora* Barbeito-Gonzalez, 1971 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Semicytherura incongruens* (Müller, 1894) | Kubanç and Kılınçarslan 2001; Gülen *et al*. 1995; Kubanç 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Semicytherura inversa* (Seguenza, 1880) | Meriç *et al*. 2009; Kubanç 2005; Kubanç *et al*. 2008; Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Semicytherura paradoxa* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |
| *Semicytherura rarecostata* Bonaduce, Ciampo & Masoli, 1976 | Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Semicytherura ruggierii* (Pucci, 1956) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999. |
| *Semicytherura stilifera* Bonaduce, Ciampo & Masoli, 1976 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Semicytherura sulcata* (Müller, 1894) | Meriç *et al*. 2009; Kubanç 2005; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999. |
| *Semicytherura tergestina* Masoli, 1968 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Tegmenia (Falunia) rugosa* (Costa, 1853) | Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Tenedocythere (Quadracythere) prava* (Baird, 1850) | Meriç *et al*. 2009; Kubanç 2005; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal *et al*. 2015 |
| *Trachyleberis (Acantocythereis) hystrix* (Reuss, 1849) | Gülen *et al*. 1995; Kubanç *et al*. 1999; Kubanç 2002; Meriç *et al*. 2005; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Tyrrhenocythere amnicola* (Sars 1887) | Tunoğlu 1999; Kerey *et al*. 2004, Meriç *et al*. 2000; Nazik *et al*. 1999; Perçin-Paçal *et al*. 2015 |
| *Urocythereis britannica* Athersuch, 1977 | Kubanç and Kılınçarslan 2001; Gülen *et al*. 1995; Kubanç 1989; Kubanç *et al*. 1999; Kubanç 2002; Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Gülen *et al*. 1990a; Gülen *et al*. 1990b |
| *Urocythereis crenulosa* (Terquem 1878) | Meriç *et al*. 2009; Perçin-Paçal *et al*. 2015 |

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|---|---|
| *Urocythereis favosa* (Roemer, 1838) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999; |
| *Urocythereis margaritifera* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999. |
| *Urocythereis oblonga* (Brady, 1866) | Meriç *et al*. 2009; Perçin-Paçal *et al*. 2015 |
| *Urocythereis neapolitana* Athersuch, 1977 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Xestoleberis aurantia* (Baird, 1838) | Atay and Tunoğlu 2002; Kubanç *et al*. 2008; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal *et al*. 2015; Nazik *et al*. 1999 |
| *Xestoleberis communis* (Müller, 1894) | Meriç *et al*. 2009; Kubanç 2005; Meriç *et al*. 2000; Meriç *et al*. 2005; Nazik 2001; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Nazik *et al*. 1999 |
| *Xestoleberis cornelii* Caraion, 1963 | Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal *et al*. 2015 |
| *Xestoleberis decipiens* G.W. Müller, 1894 | Kubanç 2005; Kubanç *et al*. 2008; Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Xestoleberis depressa* Sars, 1866 | Meriç *et al*. 2009; Nazik 2001; Perçin-Paçal *et al*. 2015, Nazik *et al*. 1999 |
| *Xestoleberis dispar* Müller, 1894 | Meriç *et al*. 2009; Perçin-Paçal *et al*. 2015; Tunoğlu 1999; Kerey *et al*. 2004; Meriç *et al*. 2000; |
| *Xestoleberis margaritea* (Brady, 1866) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Xestoleberis margaritopsis* Rome, 1942 | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015 |
| *Xestoleberis pellucida* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal and Balkıs 2015b; Perçin-Paçal *et al*. 2015 |
| *Xestoleberis plana* (Müller, 1894) | Perçin-Paçal and Balkıs 2012; Perçin-Paçal and Balkıs 2015a; Perçin-Paçal *et al*. 2015; Tunoğlu 1999 |

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## CRUSTACEA MALACOSTRACA IN THE SEA OF MARMARA: A CHECKLIST

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### 1. Introduction

The Sea of Marmara, together with its two long and narrow straits, the Dardanelles and the Bosphorus, forming the so-called Turkish Straits System, is the only connection between the Black Sea and the Mediterranean. This relatively small inland sea hosts a unique ecosystem formed by its peculiar biological, physiographical and hydrological characteristics (see *e.g.*, Ünlüata *et al.* 1990; Beşiktepe *et al.* 1994; Özsoy *et al.* 1996; Öztürk and Öztürk 1996). It constitutes a transition zone between the Black Sea and the Aegean, and plays crucial role in the hydrology, and thus the biology of these seas. It acts both as a biological barrier, limiting the distribution of some species of both Mediterranean and Black Sea origin, and as a biological corridor, enabling some others to penetrate the Black Sea from the Aegean Sea or vice versa (Öztürk and Öztürk 1996; Öztürk 2002).

Coasts of the Sea of Marmara have undergone tremendous environmental degradation over the last decades, resulting mainly from rapid population growth, urbanization and industrialization. As by far the most populated and industrialized part of Turkey, housing nearly half of the total number of industrial establishments and more than one-fourth of the total population, the marine ecosystem of the Sea of Marmara is subjected to continuing human-induced pressures such as dredging, reclamation, industrial and sewage effluents, brine water discharge from desalination plants, and oil pollution (Ozhan *et al.* 2005; Şekercioğlu *et al.* 2011). Although the knowledge on long-term impacts of these anthropogenic stressors on marine ecosystem in the Sea of Marmara is still limited, it is not difficult to presume that they have led to a drastic decline in the biodiversity of the sea.

This checklist provides an up-to-date list of malacostracan crustaceans of the Sea of Marmara, based on records published from 1775 to 2016, aiming to contribute to the answer of the question "how much do we know about the diversity of invertebrates in this sea, whose biodiversity is under threat?". Records from grey literature such as unpublished research reports and theses were not included in the list. All species names were checked and updated to reflect the current taxonomy, according to the World Register of Marine Species (WoRMS) database. The classification followed in the present checklist is also based on the WoRMS database (WoRMS Editorial Board 2016).

## 2. Results

A review of the relevant literature revealed that 418 species in nine orders of malacostracan crustaceans have hitherto been reported from the Sea of Marmara (Table). Amphipoda with 195 species and Decapoda with 140 species are by far the most diverse orders, which together account for about 80% of the total number of species, followed by Isopoda (42 spp.), Cumacea (18 spp.), Mysida (12 spp.), Tanaidacea (7 spp.), Stomatopoda (2 spp.), Leptostraca (1 sp.), and Euphausiacea (1 sp.).

Of the reported species, six are here considered of doubtful occurrence in the Sea of Marmara. These are the leptostracan *Nebalia bipes* (Fabricius), the amphipod *Byblis gaimardii* (Krøyer), the tanaidacean *Leptognathia propontiaca* Ostroumoff, and the decapods *Eusergestes arcticus* (Krøyer), *Portunus segnis* (Forskål), and *Spinolambrus macrochelos* (Herbst) (Table). Among them, *S. macrochelos* was reported only by Demir (1952-1954) in his book, derived from his doctoral dissertation, "Boğaz ve Adalar Sahillerinin Omurgasız Dip Hayvanları" [*Invertebrate Bottom Animals of the Bosphorus and the Islands*]. The author stated that he had found this species among material collected previously by old Fisheries Institute (operated between 1931 and 1937), but not in the material collected by himself from the Bosphorus Strait and Prince's Islands. Locality of collection of the material in which this species had been found was not mentioned by Demir, probably because it was unknown and may not be in the Sea of Marmara. Opinions on the dubious presence of other five species have been provided by Bakır *et al.* (2014).

The present work provides an updated picture of the status of malacostracan diversity in the Sea of Marmara. Although a number of species are known only from historical records (Table), malacostracan fauna of the Sea of Marmara appears to be diverse, representing about one-third of the Mediterranean malacostracan fauna, recently estimated to number at least 1286 species (Coll *et al.* 2010). Indeed, there is still much to learn about this diverse group of crustaceans in this sea from future faunal surveys and taxonomic efforts.

**Table.** Checklist of Malacostraca (Crustacea) known from the Sea of Marmara. Question marks indicate species with dubious presence and doubtful records.

| SPECIES | REFERENCES |
|---|---|
| **Order LEPTOSTRACA** | |
| ? *Nebalia bipes* (Fabricius, 1780) | Demir (1952-1954) |
| **Order STOMATOPODA** | |
| *Erugosquilla massavensis* (Kossmann, 1880) | Katağan *et al.* (2004) |
| *Squilla mantis* (Linnaeus, 1758) | Demir (1952-1954) |
| **Order MYSIDA** | |
| *Boreomysis arctica* (Krøyer, 1861) | Katağan and Kocataş (1995) |
| *Diamysis cymodoceae* Wittmann & Ariani, 2012 | Wittman and Ariani (2012) |
| *Diamysis mesohalobia heterandra* Ariani & Wittmann, 2000 | Arianni and Wittmann (2000) |
| *Gastrosaccus sanctus* (Van Beneden, 1861) | Bakır (2012) |
| *Haplostylus normani* (G.O. Sars, 1877) | Colosi (1922), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Leptomysis truncata* (Heller, 1863) | Demir (1952-1954) |
| *Lophogaster typicus* M. Sars, 1857 | Colosi (1922) |
| *Mesopodopsis slabberi* (Van Beneden, 1861) | Demir (1952-1954) |
| *Mysidopsis gibbosa* G.O. Sars, 1864 | Bakır (2012) |
| *Paramysis* (*Occiparamysis*) *agigensis* Bacescu, 1940 | Wittman and Ariani (2012) |
| *Paramysis proconnesia* Colosi, 1922 | Colosi (1922) |

**Table.** (Continued).

| | |
|---|---|
| *Siriella jaltensis* Czerniavsky, 1868 | Demir (1952-1954) |
| **Order AMPHIPODA** | |
| *Ampelisca brevicornis* (Costa, 1853) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Ampelisca dalmatina* Karaman, 1975 | Mülayim *et al.* (2015a) |
| *Ampelisca diadema* (Costa, 1853) | Sowinsky (1897), Caspers (1968), Balkıs and Albayrak (1994), Okuş (1989), Uysal *et al.* (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Ampelisca gibba* Sars, 1883 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Ampelisca jaffaensis* Bellan-Santini & Kaim-Malka, 1977 | Bakır (2012), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampelisca ledoyeri* Bellan-Santini & Kaim-Malka, 1977 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Ampelisca multispinosa* Bellan-Santini & Kaim-Malka, 1977 | Bakır *et al.* (2016) |
| *Ampelisca planierensis* Bellan-Santini & Kaim-Malka, 1977 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Ampelisca pseudosarsi* Bellan-Santini & Kaim-Malka, 1977 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampelisca pseudospinimana* Bellan-Santini & Kaim-Malka, 1977 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampelisca rubella* A. Costa, 1864 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampelisca ruffoi* Bellan-Santini & Kaim-Malka, 1977 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |

**Table.** (Continued).

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|---|---|
| *Ampelisca sarsi* Chevreux, 1888 | Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampelisca spinipes* Boeck, 1861 | Mülayim *et al.* (2015a), Bakır *et al.* (2016) |
| *Ampelisca tenuicornis* Lilljeborg, 1855 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampelisca typica* (Bate, 1856) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Ampelisca unidentata* Schellenberg, 1936 | Bakır *et al.* (2016) |
| *Amphilochus brunneus* Della Valle, 1893 | Bakır (2012), Bakır *et al.* (2016) |
| *Ampithoe gammaroides* (Bate, 1856) | Demir (1952-1954) |
| *Ampithoe helleri* Karaman, 1975 | Kalkan *et al.* (2007), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Ampithoe ramondi* Audin, 1826 | Demir (1952-1954), Topaloğlu and Kihara (1993), Balkıs and Albayrak (1994), Erkan Yurdabak (2004), Kalkan *et al.* (2006), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Ampithoe riedli* Krapp-Schickel, 1968 | Mülayim *et al.* (2015b) |
| *Ampithoe rubricata* (Montagu, 1808) | Sowinsky (1897) |
| *Aora gracilis* (Bate,1857) | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Aora spinicornis* Afonso, 1976 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Apherusa alacris* Krapp-Schickel, 1969 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Apherusa bispinosa* (Bate, 1857) | Demir (1952-1954), Erkan Yurdabak (2004), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Apherusa chiereghinii* Giordani-Soika, 1949 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Apherusa mediterranea* Chevreux, 1911 | Mülayim *et al.* (2015a, 2015b) |
| *Apherusa vexatrix* Krapp-Schickel, 1979 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |

**Table.** (Continued).

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|---|---|
| *Apocorophium acutum* (Chevreux, 1908) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Apohyale prevostii* (Milne Edwards, 1830) | Sowinsky (1897) |
| *Apolochus neapolitanus* (Della Valle, 1893) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Apolochus picadurus* (J.L. Barnard, 1962) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Atylus guttatus* (A. Costa, 1851) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Atylus massiliensis* Bellan-Santini, 1975 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Atylus vedlomensis* (Bate & Westwood, 1862) | Bakır *et al.* (2016) |
| *Autonoe karamani* (Myers, 1976) | Bakır (2012) |
| *Autonoe viduarum* (Myers, 1974) | Bakır *et al.* (2016) |
| *Bathyporeia elegans* Watkin, 1938 | Mülayim *et al.* (2015b) |
| *Bathyporeia guilliamsoniana* (Bate, 1857) | Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Bathyporeia phaiophthalma* Bellan-Santini, 1973 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| ? *Byblis gaimardii* (Krøyer, 1846) | Ostroumoff (1894) |
| *Caprella acanthifera* Leach, 1814 | Ostroumoff (1896), Demir (1952-1954), Okuş (1989), Yüksek (1989), Balkıs (1992), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b) |
| *Caprella danilevskii* Czerniavskii, 1868 | Caspers (1968), Balkıs and Albayrak (1994), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Caprella equilibra* Say, 1818 | Balkıs and Albayrak (1994), Bakır *et al.* (2016) |
| *Caprella liliput* Say, 1818 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |

**Table.** (Continued).

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|---|---|
| *Caprella liparotensis* Haller, 1879 | Demir (1952-1954), Balkıs and Albayrak (1994), Kalkan *et al.* (2006), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Caprella mitis* Mayer, 1890 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b) |
| *Caprella rapax* Mayer, 1890 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b) |
| *Caprella scaura* Templeton, 1836 | Bakır *et al.* (2016) |
| *Carangoliopsis spinulosa* Ledoyer, 1970 | Bakır *et al.* (2016) |
| *Ceradocus* (*Ceradocus*) *orchestiipes* Costa, 1853 | Bakır *et al.* (2016) |
| *Cerapopsis longipes* Della Valle, 1893 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Cheirocratus monodontis* G. Karaman, 1977 | Mülayim *et al.* (2015a) |
| *Cheirocratus sundevalli* (Rathke, 1843) | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Chelura terebrans* Philippi, 1839 | Demir (1952-1954), Bakır *et al.* (2016) |
| *Colomastix pusilla* Grube, 1861 | Bakır *et al.* (2016) |
| *Corophium cylindricum* (Say, 1818) | Caspers (1968) |
| *Corophium volutator* (Pallas, 1766) | Topaloğlu and Kihara (1993) |
| *Crassicorophium bonellii* (Milne Edwards, 1830) | Ostroumoff (1894) |
| *Crassicorophium crassicorne* (Bruzelius, 1859) | Sowinsky (1897) |
| *Cryptorchestia cavimana* (Heller, 1865) | Mülayim *et al.* (2015b) |
| *Cymadusa crassicornis* (Costa, 1853) | Demir (1952-1954), Erkan Yurdabak (2004), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Deflexilodes acutipes* (Ledoyer, 1983) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |

**Table.** (Continued).

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|---|---|
| *Deflexilodes gibbosus* (Chevreux, 1888) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Deflexilodes griseus* (Della Valle, 1893) | Ateş *et al.* (2012), Bakır *et al.* (2016) |
| *Deflexilodes subnudus* (Norman, 1889) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Dexamine spiniventris* (Costa, 1853) | Okuş (1989), Balkıs (1992), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Dexamine spinosa* (Montagu, 1813) | Sowinsky (1897), Demir (1952-1954), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Dexamine thea* Boeck, 1861 | Demir (1952-1954), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Echinogammarus olivii* (Milne Edwards, 1830) | Sowinsky (1897), Demir (1952-1954), Balkıs and Albayrak (1994), Kalkan *et al.* (2006, 2007), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Elasmopus brasiliensis* (Dana, 1855) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Elasmopus pocillimanus* (Bate, 1862) | Erkan Yurdabak (2004), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Elasmopus rapax* Costa, 1853 | Okuş (1989), Balkıs (1992), Soyal Eryılmaz (1997), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Ericthonius brasiliensis* (Dana, 1852) | Sowinsky (1897), Uysal *et al.* (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Ericthonius difformis* Milne Edwards, 1830 | Bakır *et al.* (2016) |
| *Ericthonius punctatus* (Bate, 1857) | Sowinsky (1897), Demir (1952-1954), Balkıs and Albayrak (1994), Uysal *et al.* (2002), Kalkan *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Eriopisa elongata* (Bruzelius, 1859) | Bakır (2012), Bakır *et al.* (2016) |
| *Gammarella fucicola* (Leach, 1814) | Sowinsky (1897), Topaloğlu and Kihara (1993), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Gammarellus angulosus* (Rathke, 1843) | Balkıs and Albayrak (1994), Kalkan *et al.* (2006) |

**Table.** (Continued).

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| *Gammarellus homari* (Fabricius, 1779) | Demir (1952-1954) |
| *Gammaropsis maculata* (Johnston, 1828) | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Gammaropsis ostroumowi* Sowinski, 1898 | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Gammaropsis palmata* (Stebbing & Robertson, 1891) | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Gammarus aequicauda* (Martynov, 1931) | Okuş (1989), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a) |
| *Gammarus crinicornis* Stock, 1966 | Mülayim *et al.* (2015a, 2015b) |
| *Gammarus insensibilis* Stock, 1966 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Gammarus locusta* (Linneaus, 1758) | Ostroumoff (1894), Sowinsky (1897), Okuş (1989), Soyal Eryılmaz (1997) |
| *Gammarus subtypicus* Stock, 1966 | Erkan Yurdabak (2004), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Gitana sarsi* Boeck, 1871 | Bakır *et al.* (2016) |
| *Guernea* (*Guernea*) *coalita* (Norman, 1868) | Bakır *et al.* (2016) |
| *Harpinia agna* Karaman, 1987 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Harpinia crenulata* (Boeck, 1871) | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Harpinia dellavallei* Chevreux, 1910 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Harpinia pectinata* G.O. Sars, 1891 | Bakır *et al.* (2016) |
| *Hippomedon massiliensis* Bellan-Santini, 1965 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Hyale crassipes* (Heller, 1866) | Erkan Yurdabak (2004), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Hyale grimaldii* Chevreux, 1891 | Bakır (2012) |
| *Hyale perieri* (Lucas, 1849) | Sowinsky (1897), Demir (1952-1954), Balkıs and Albayrak (1994), Uysal *et al.* (2002), Kalkan *et al.* (2006, 2007), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |

**Table.** (Continued).

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|---|---|
| *Hyale pontica* Rathke, 1837 | Sowinsky (1897), Demir (1952-1954), Balkıs and Albayrak (1994), Kalkan *et al.* (2007) |
| *Hyale schmidti* (Heller, 1866) | Okuş (1989), Balkıs (1992), Soyal Eryılmaz (1997), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Iphimedia gibbula* Ruffo & Schiecke, 1979 | Bakır *et al.* (2016) |
| *Iphimedia minuta* G.O. Sars, 1883 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Ischyrocerus inexpectatus* Ruffo, 1959 | Bakır *et al.* (2016) |
| *Jassa marmorata* Holmes, 1905 | Sowinsky (1897), Demir (1952-1954), Topaloğlu and Kihara (1993), Balkıs and Albayrak (1994), Kalkan *et al.* (2006, 2007), Demir (1952-1954), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Jassa ocia* (Bate, 1862) | Sowinsky (1897), Demir (1952-1954), Balkıs and Albayrak (1994), Kalkan *et al.* (2006, 2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Laetmatophilus tuberculatus* Bruzelius, 1859 | Sowinsky (1897) |
| *Lembos websteri* Bate, 1857 | Bakır *et al.* (2016) |
| *Leptocheirus guttatus* (Grube, 1864) | Bakır *et al.* (2016) |
| *Leptocheirus mariae* Karaman, 1973 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Leptocheirus pectinatus* (Norman, 1869) | Caspers (1968), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Leptocheirus pilosus* Zaddach, 1844 | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Leucothoe crassimana* Kossmann, 1880 | Sowinsky (1897) |
| *Leucothoe incisa* (Robertson, 1892) | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Leucothoe lilljeborgi* Boeck, 1861 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |

**Table.** (Continued).

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|---|---|
| *Leucothoe oboa* Karaman, 1971 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Leucothoe occulta* Krapp-Schickel, 1975 | Bakır *et al.* (2016) |
| *Leucothoe spinicarpa* (Abildgaard, 1789) | Demir (1952-1954), Yüksek (1989), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Liljeborgia dellavallei* Stebbing, 1906 | Ateş *et al.* (2012), Bakır *et al.* (2016) |
| *Liljeborgia psaltrica* Krapp-Schickel, 1975 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Lysianassa costae* (Milne Edwards, 1830) | Bakır (2012), Bakır *et al.* (2016) |
| *Lysianassina longicornis* (Lucas, 1846) | Ritt *et al.* (2010) |
| *Maera grossimana* (Montagu, 1808) | Sowinsky (1897), Balkıs and Albayrak (1994), Uysal *et al.* (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Maera sodalis* Karaman & Ruffo, 1971 | Ateş *et al.* (2012) |
| *Medicorophium affine* (Bruzelius, 1859) | Sowinsky (1897) |
| *Medicorophium rotundirostre* (Stephensen, 1915) | Ateş *et al.* (2012), Mülayim *et al.* (2015a) |
| *Medicorophium runcicorne* (Della Valle, 1893) | Sowinsky (1897), Bakır *et al.* (2016) |
| *Medicorophium minimum* (Schiecke, 1978) | Bakır *et al.* (2016) |
| *Megaluropus massiliensis* Ledoyer, 1976 | Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Megamphopus brevidactylus* Myers, 1976 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Megamphopus cornutus* Norman, 1869 | Bakır *et al.* (2016) |
| *Megamphopus katagani* Bakır, Sezgin & Myers, 2011 | Bakır *et al.* (2011), Bakır *et al.* (2016) |
| *Melita hergensis* Reid, 1939 | Mülayim *et al.* (2015b) |

**Table.** (Continued).

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|---|---|
| *Melita palmata* (Montagu, 1804) | Sowinsky (1897), Demir (1952-1954), Topaloğlu and Kihara (1993), Balkıs and Albayrak (1994), Kalkan *et al.* (2006), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a), Bakır *et al.* (2016) |
| *Melphidippella macra* (Norman, 1869) | Aslan-Cihangir *et al.* (2009), Bakır *et al.* (2016) |
| *Metaphoxus simplex* (Bate, 1857) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Microdeutopus algicola* Della Valle, 1893 | Kalkan *et al.* (2006), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Microdeutopus anomalus* (Rathke, 1843) | Sowinsky (1897), Balkıs and Albayrak (1994), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Microdeutopus bifidus* Myers, 1977 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Microdeutopus chelifer* (Bate, 1862) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Microdeutopus gryllotalpa* Costa, 1853 | Sowinsky (1897), Demir (1952-1954), Topaloğlu and Kihara (1993), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Microdeutopus obtusatus* Myers, 1973 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Microdeutopus stationis* Della Valle, 1893 | Sowinsky (1897), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Microdeutopus versiculatus* (Bate, 1856) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Çağlar and Albayrak (2012), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Microjassa cumbrensis* (Stebbing & Robertson, 1891) | Sowinsky (1897) |
| *Microprotopus maculatus* Norman, 1867 | Sowinsky (1897) |
| *Monocorophium acherusicum* (Costa, 1853) | Sowinsky (1897), Demir (1952-1954), Çağlar and Albayrak (2012), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |

**Table.** (Continued).

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|---|---|
| *Monocorophium insidiosum* (Crawford, 1937) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Monocorophium sextonae* (Crawford, 1937) | Aslan-Cihangir *et al.* (2009), Bakır *et al.* (2016) |
| *Monoculodes carinatus* ( Bate, 1857) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Nototropis guttatus* A. Costa, 1853 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Orchestia gammarellus* (Pallas, 1766) | Sowinsky (1897), Okuş (1989), Balkıs (1992), Soyal Eryılmaz (1997) |
| *Orchestia mediterranea* Costa, 1853 | Demir (1952-1954) |
| *Orchestia montagui* Audouin, 1826 | Sowinsky (1897), Bakır *et al.* (2016) |
| *Orchestia stephenseni* Cecchini, 1928 | Bakır *et al.* (2016) |
| *Orchomene grimaldii* Chevreux, 1890 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Orchomene humilis* (Costa, 1853) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Othomaera schmidti* (Stephensen, 1915) | Bakır (2012), Bakır *et al.* (2016) |
| *Paracentromedon crenulatus* (Chevreux, 1900) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Paralysianopsis parthenopeia* (Ruffo, 1971) | Bakır *et al.* (2016) |
| *Parametaphoxus fultoni* (Scott, 1890) | Mülayim *et al.* (2015b) |
| *Paraphoxus oculatus* (G.O. Sars, 1879) | Sowinsky (1897), Demir (1952-1954), Okuş (1989), Balkıs (1992), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a), Bakır *et al.* (2016) |
| *Parhyale aquilina* (Costa, 1857) | Demir (1952-1954), Balkıs and Albayrak (1994) |
| *Parvipalpus linea* Mayer, 1890 | Bakır *et al.* (2016) |
| *Peramphithoe spuria* (Krapp-Schickel, 1978) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |

**Table.** (Continued).

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| *Perioculodes aequimanus* (Korssman, 1880) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a), Bakır *et al.* (2016) |
| *Perioculodes longimanus longimanus* (Bate & Westwood, 1868) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Photis longicaudata* (Bate & Westwood, 1862) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Photis longipes* (Della Valle, 1893) | Bakır *et al.* (2016) |
| *Phoxocephalus aquosus* Karaman, 1985 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Phtisica marina* Slabber, 1769 | Ostroumoff (1894), Sowinsky (1897), Demir (1952-1954), Caspers (1968), Okuş (1989), Balkıs and Albayrak (1994), Soyal Eryılmaz (1997), Uysal *et al.* (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015b), Bakır *et al.* (2016) |
| *Platorchestia platensis* (Krøyer, 1845) | Demir (1952-1954) |
| *Podocerus variegatus* Leach, 1814 | Topaloğlu and Kihara (1993) |
| *Pontocrates arenarius* (Bate, 1858) | Mülayim *et al.* (2015a) |
| *Pseudolirius kroyeri* (Haller, 1897) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Pseudoprotella phasma* (Montagu, 1804) | Ostroumoff (1894), Sowinsky (1897), Demir (1952-1954), Okuş (1989), Balkıs and Albayrak (1994), Kalkan *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Quadrimaera inaequipes* (A. Costa, 1857) | Bakır *et al.* (2016) |
| *Siphonoecetes* (*Centraloecetes*) *dellavallei* Stebbing, 1899 | Bakır (2012), Bakır *et al.* (2016) |
| *Stenothoe bosphorana* Sowinsky, 1898 | Sowinsky (1897), Caspers (1968), Bakır *et al.* (2016) |
| *Stenothoe elachista* Krapp-Schickel, 1975 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a, 2015b) |
| *Stenothoe marina* (Bate, 1856) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |

**Table.** (Continued).

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|---|---|
| *Stenothoe monoculoides* (Montagu, 1815) | Sowinsky (1897), Demir (1952-1954), Balkıs and Albayrak (1994), Kalkan *et al.* (2007), Mülayim *et al.* (2015a, 2015b), Bakır *et al.* (2016) |
| *Stenothoe tergestina* Nebeski, 1881 | Kalkan *et al.* (2006), Mülayim *et al.* (2015a), Bakır *et al.* (2016) |
| *Sunamphitoe pelagica* (Milne Edwards, 1830) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Synchelidium haplocheles* (Grube, 1864) | Bakır (2012), Bakır *et al.* (2016) |
| *Synchelidium longidigitatum* Ruffo, 1947 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Talitrus saltator* (Montagu, 1808) | Okuş (1989), Balkıs (1992) |
| *Tritaeta gibbosa* (Bate, 1862) | Okuş (1989), Yüksek (1989), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Tryphosa nana* (Krøyer, 1846) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a) |
| *Tryphosella simillima* Ruffo, 1985 | Bakır *et al.* (2016) |
| *Urothoe elegans* (Bate, 1857) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Urothoe intermedia* Bellan-Santini & Ruffo, 1986 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Urothoe pulchella* (Costa, 1853) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Bakır *et al.* (2016) |
| *Westwoodilla rectirostris* (Della Valle, 1893) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Mülayim *et al.* (2015a), Bakır *et al.* (2016) |
| **Order ISOPODA** | |
| *Anilocra physodes* (Linnaeus, 1758) | Demir (1952-1954) |
| *Anthura gracilis* (Montagu, 1808) | Okuş (1989), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Astacilla dilatata* (G.O. Sars, 1883) | Okuş (1989) |
| *Athelges paguri* (Rathke, 1843) | Sowinsky (1897) |

**Table.** (Continued).

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|---|---|
| *Bopyrus squillarum* Latreille, 1802 | Demir (1952-1954) |
| *Carpias stebbingi* (Monod, 1933) | Erkan Yurdabak (2004) |
| *Ceratothoa italica* Schiödte & Meinert, 1883 | Öktener and Trilles (2004) |
| *Ceratothoa oestroides* (Risso, 1816) | Öktener and Trilles (2004) |
| *Ceratothoa parallela* (Otto, 1828) | Öktener and Trilles (2004) |
| *Cleantis prismatica* (Risso, 1826) | Demir (1952-1954) |
| *Cymodoce emarginata* Leach, 1818 | Sowinsky (1897) |
| *Cymodoce tattersalli* Torelli, 1929 | Ostroumoff (1894) |
| *Cymodoce tuberculata* Costa in Hope, 1851 | Ostroumoff (1896), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Cymothoa oestrum* (Linnaeus, 1758) | Demir (1952-1954) |
| *Dynamene bicolor* (Rathke, 1837) | Sowinsky (1897) |
| *Dynamene bidentata* (Adams, 1800) | Demir (1952-1954), Soyal Eryılmaz (1997), Kalkan *et al.* (2006) |
| *Emetha audouini* (H. Milne Edwards, 1840) | Öktener and Trilles (2004) |
| *Eurydice spinigera* Hansen, 1890 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Gnathia maxillaris* (Montagu, 1804) | Sowinsky (1897), Demir (1952-1954), Okuş (1989), Balkıs (1992) |
| *Gnathia oxyuraea* (Lilljeborg, 1855) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Gnathia vorax* (Lucas, 1849) | Ostroumoff (1896) |
| *Idotea balthica* (Pallas, 1772) | Demir (1952-1954), Topaloğlu and Kihara (1993), Kalkan *et al.* (2006) |
| *Idotea linearis* (Linnaeus, 1766) | Okuş (1989) |
| *Idotea metallica* Bosc, 1802 | Ostroumoff (1896), Demir (1952-1954), Okuş (1989) |
| *Jaera* (*Jaera*) *nordmanni* (Rathke, 1837) | Demir (1952-1954), Kalkan *et al.* (2006) |
| *Janira maculosa* Leach, 1814 | Demir (1952-1954), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |

**Table.** (Continued).

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|---|---|
| *Joeropsis brevicornis brevicornis* Koehler, 1885 | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Joeropsis brevicornis littoralis* Amar, 1949 | Uysal *et al.* (2002) |
| *Ligia italica* Fabricius, 1798 | Demir (1952-1954), Okuş (1989), Yüksek (1989), Balkıs (1992) |
| *Limnoria lignorum* (Rathke, 1799) | Demir (1952-1954) |
| *Limnoria tuberculata* Sowinsky, 1884 | Sowinsky (1897) |
| *Livoneca punctata* (Uljannin, 1872) | Öktener and Trilles (2004) |
| *Natatolana hirtipes* (H. Milne Edwards, 1840) | Colombo (1885) |
| *Nerocila bivittata* (Risso, 1816) | Demir (1952-1954) |
| *Paragnathia formica* (Hesse, 1864) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Rocinela ophthalmica* Milne Edwards, 1840 | Ostroumoff (1896) |
| *Sphaeroma serratum* (Fabricius, 1787) | Colombo (1885), Demir (1952-1954), Topaloğlu and Kihara (1993), Uysal *et al.* (2002), Okuş (1989), Yüksek (1989), Uysal *et al.* (2002), Kalkan *et al.* (2006), Çağlar and Albayrak (2012) |
| *Stenosoma capito* (Rathke, 1837) | Ostroumoff (1894), Sowinsky (1897), Demir (1952-1954), Kalkan *et al.* (2006), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Stenosoma lancifer* (Miers, 1881) | Ostroumoff (1896) |
| *Synischia hectica* (Pallas, 1772) | Demir (1952-1954), Yüksek (1989) |
| *Tylos latreillei* Audouin, 1826 | Demir (1952-1954) |
| *Uromunna petiti* (Amar, 1948) | Erkan Yurdabak (2004) |
| **Order TANAIDACEA** | |
| *Apseudopsis acutifrons* (Sars, 1882) | Caspers (1968) |

**Table.** (Continued).

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|---|---|
| *Apseudopsis latreillii* (Milne Edwards, 1828) | Ostroumoff (1896), Uysal *et al.* (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011b), Çağlar and Albayrak (2012) |
| *Chondrochelia dubia* (Krøyer, 1842) | Demir (1952-1954), Caspers (1968) |
| *Chondrochelia savignyi* (Krøyer, 1842) | Ostroumoff (1896), Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| ? *Leptognathia propontiaca* Ostroumoff, 1896 | Ostroumoff (1896) |
| *Paradoxapseudes intermedius* (Hansen, 1895) | Aslan-Cihangir and Pancucci-Papadopoulou (2011b) |
| *Tanais dulongii* (Audouin, 1826) | Sowinsky (1897), Demir (1952-1954), Topaloğlu and Kihara (1993), Kalkan *et al.* (2006, 2007) |
| **Order CUMACEA** | |
| *Bodotria arenosa mediterranea* (Steuer, 1938) | Ateş *et al.* (2014) |
| *Campylaspis glabra* G.O. Sars, 1878 | Băcescu (1982) |
| *Campylaspis macrophthalma* G.O. Sars, 1878 | Aslan-Cihangir and Pancucci-Papadopolou (2011b) |
| *Cumella* (*Cumella*) *limicola* G.O. Sars, 1879 | Bakır (2012) |
| *Cumopsis goodsir* (Van Beneden, 1861) | Ateş *et al.* (2014) |
| *Diastylis rugosa* G.O. Sars, 1865 | Bakır (2012) |
| *Diastyloides serratus* (G.O. Sars, 1865) | Ritt *et al.* (2010) |
| *Diastyloides bosphorica* (Băcescu, 1982) | Băcescu (1982) |
| *Eudorella truncatula* (Bate, 1856) | Băcescu (1982) |
| *Iphinoe douniae* Ledoyer, 1965 | Aslan-Cihangir and Pancucci Papadopolou (2011b) |

**Table.** (Continued).

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|---|---|
| *Iphinoe elisae* Băcescu, 1950 | Băcescu (1982) |
| *Iphinoe rhodaniensis* Ledoyer, 1965 | Băcescu (1982) |
| *Iphinoe tenella* G.O. Sars, 1878 | Aslan-Cihangir and Pancucci-Papadopolou (2011b) |
| *Nannastacus longirostris* G.O. Sars, 1879 | Băcescu (1982), Bakır (2012) |
| *Nannastacus turcicus* Băcescu (1982) | Băcescu (1982) |
| *Nannastacus unguiculatus* (Bate, 1859) | Băcescu (1982), Bakır (2012) |
| *Pseudocuma* (*Pseudocuma*) *longicorne* (Bate, 1858) | Ateş *et al.* (2014) |
| *Vaunthompsonia cristata* Bate, 1858 | Băcescu (1982), Bakır (2012) |
| **Order EUPHAUSIACEA** | |
| *Meganyctiphanes norvegica* (M. Sars, 1857) | Demir (1959) |
| **Order DECAPODA**<br>**Suborder DENDROBRANCHIATA** | |
| ? *Eusergestes arcticus* (Krøyer, 1855) | Ostroumoff (1896) |
| *Gennadas elegans* (Smith, 1882) | Stephensen (1923), Kocataş and Katağan (2003) |
| *Penaeus japonicus* Spence Bate, 1888 | Zaitsev and Öztürk (2001) |
| *Parapenaeus longirostris* (Lucas, 1846) | Ostroumoff (1896), Stephensen, 1923, Demir (1952-1954), Kocataş (1981), Yüksek (1989), Balkıs (1998-1999b), Kocataş and Katağan (2003), Topaloğlu *et al.* (2004), Bayhan (2005), Altuğ *et al.* (2011) |
| *Penaeus kerathurus* (Forskål, 1775) | Demir (1952-1954), Kocataş (1981), Balkıs (1992), Kocataş and Katağan (2003) |
| *Penaeus semisulcatus* De Haan, 1844 [in De Haan, 1833-1850] | Altuğ *et al.* (2011) |
| *Sergia robusta* (Smith, 1882) | Kocataş and Katağan (2003), Topaloğlu (2014) |

**Table.** (Continued).

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|---|---|
| *Solenacera membranacea* (Risso, 1816) | Stephensen (1923), Balkıs (1998-1999b), Kocataş and Katağan (2003) |
| **Suborder PLEOCYEMATA**<br>**Infraorder CARIDEA** | |
| *Aegaeon cataphractus* (Olivi, 1792) | Colombo (1885) |
| *Alpheus dentipes* Guérin, 1832 | Colombo (1885), Ostroumoff (1896), Demir (1952-1954), Kocataş (1981), Kocataş and Katağan (2003), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Alpheus glaber* (Olivi, 1792) | Stephensen (1923), Demir (1952-1954), Caspers (1968), Okuş (1989), Balkıs (1998-1999b) |
| *Alpheus macrocheles* (Hailstone, 1835) | Ateş *et al.* (2011), Bakır (2012) |
| *Ascidonia flavomaculata* (Heller, 1864) | Colombo (1885) |
| *Athanas nitescens* (Leach, 1813 [in Leach, 1813-1814 ]) | Colombo (1885), Ostroumoff (1896), Demir (1952-1954), Caspers (1968), Kocataş (1981), Müller (1985), Okuş (1989), Balkıs (1992), Kocataş and Katağan (2003), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011), Bakır (2012) |
| *Chlorotocus crassicornis* (A. Costa, 1871) | Balkıs (1998-1999b), Kocataş and Katağan (2003) |
| *Crangon crangon* (Linnaeus, 1758) | Ninni (1923), Devedjian (1926), Demir (1952-1954), Kocataş (1981), Okuş (1989), Balkıs (1998-1999b), Kocataş and Katağan (2003), Ateş *et al.* (2011) |
| *Eualus cranchii* (Leach, 1817 [in Leach, 1815-1875]) | Ostroumoff (1896), Demir (1952-1954), Kocataş (1981), Müller (1986), Kocataş and Katağan (2003), Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011) |
| *Gnathophyllum elegans* (Risso, 1816) | Colombo (1885) |
| *Hippolyte holthuisi* Zariquiey Álvarez, 1953 | Demir (1952-1954), Okuş (1989) |
| *Hippolyte inermis* Leach, 1816 | Demir (1952-1954), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011) |
| *Hippolyte leptocerus* (Heller, 1863) | Colombo (1885), Ostroumoff (1896), Kocataş (1981), Balkıs (1992), Kocataş and Katağan (2003), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |

**Table.** (Continued).

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|---|---|
| *Lysmata seticaudata* (Risso, 1816) | Demir (1952-1954) |
| *Palaemon adspersus* Rathke, 1837 | Ninni (1923), Demir (1952-1954), Kocataş (1981), Okuş (1989), Balkıs (1998-1999b), Kocataş and Katağan (2003), Bakır (2012) |
| *Palaemon elegans* Rathke, 1837 | Ostroumoff (1896), Ninni (1923), Demir (1952-1954), Holthuis (1961), Kocataş (1981), Okuş (1989), Yüksek (1989), Kocataş and Katağan (2003) |
| *Palaemon longirostris* H. Milne Edwards, 1837 [in H. Milne Edwards, 1834-1840] | Demir (1952-1954) |
| *Palaemon serratus* (Pennant, 1777) | Heller (1863), Ostroumoff (1896), Marion (1898), Ninni (1923), Devedjian (1926), Demir (1952-1954), Kocataş (1981), Balkıs (1998-1999b), Kocataş and Katağan (2003), Bakır (2012) |
| *Palaemon xiphias* Risso, 1816 | Colombo (1885) |
| *Pandalina brevirostris* (Rathke, 1843) | Okuş (1989), Balkıs (1992), Kocataş and Katağan (2003) |
| *Pandalina profunda* Holthuis, 1946 | Kocataş and Katağan (2003) |
| *Pasiphaea sivado* (Risso, 1816) | Stephensen (1923), Kocataş and Katağan (2003) |
| *Periclimenes aegylios* Grippa & d'Udekem d'Acoz, 1996 | Ďuriš *et al.* (2013) |
| *Periclimenes amethysteus* (Risso, 1827) | Ďuriš *et al.* (2013) |
| *Periclimenes scriptus* (Risso, 1822) | Colombo (1885), Ďuriš *et al.* (2013) |
| *Philocheras bispinosus bispinosus* (Hailstone, 1835) | Ateş *et al.* (2011) |
| *Philocheras fasciatus* (Risso, 1816) | Ateş (2007), Ateş *et al.* (2011) |
| *Philocheras trispinosus* (Hailstone in Hailstone & Westwood, 1835) | Kocataş (1981), Kocataş and Katağan (2003) |
| *Plesionika heterocarpus* (A. Costa, 1871) | Ostroumoff (1896), Balkıs (1998-1999b), Kocataş and Katağan (2003) |

**Table.** (Continued).

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|---|---|
| *Plesionika narval* (Fabricius, 1787) | Altuğ *et al.* (2011) |
| *Processa edulis edulis* (Risso, 1816) | Ostroumoff (1896), Demir (1952-1954), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Bakır (2012) |
| *Processa canaliculata* Leach, 1815 [in Leach, 1815-1875] | Okuş (1989), Yüksek (1989), Uysal *et al.* (2002), Kocataş and Katağan (2003) |
| *Processa macrophthalma* Nouvel & Holthuis, 1957 | Ateş *et al.* (2011) |
| *Processa nouveli nouveli* Al-Adhub & Williamson, 1975 | Balkıs (1998-1999b), Kocataş and Katağan (2003), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Typton spongicola* O.G. Costa, 1844 | Colombo (1885), Ostroumoff (1896), Demir (1952-1954) |
| **Infraorder ASTACIDEA** | |
| *Homarus gammarus* (Linnaeus, 1758) | Thompson (1912), Ninni (1923), Devedjian (1926), Demir (1952-1954), Kocataş (1981), Balkıs (1992), Kocataş and Katağan (2003) |
| *Nephrops norvegicus* (Linnaeus, 1758) | Kocataş and Katağan (2003) |
| **Infraorder AXIIDEA** | |
| *Calliax lobata* (de Gaillande & Lagardère, 1966) | Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Calocaris macandreae* Bell, 1853 | Balkıs (1998-1999a), Uysal *et al.* (2002), Kocataş and Katağan (2003), Topaloğlu *et al.* (2004), Topaloğlu (2014) |
| *Pestarella tyrrhena* (Petagna, 1792) | Erkan Yurdabak (2004) |
| **Infraorder GEBIIDEA** | |
| *Jaxea nocturna* Nardo, 1847 | Balkıs (1998-1999a) |
| *Upogebia pusilla* (Petagna, 1792) | Demir (1952-1954), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011) |

**Table.** (Continued).

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|---|---|
| **Infraorder ACHELATA** | |
| *Palinurus elephas* (Fabricius, 1787) | Thompson (1912), Ninni (1923), Devedjian (1926), Demir (1952-1954) |
| *Scyllarus arctus* (Linnaeus, 1758) | Stephensen (1923), Demir (1952-1954) |
| **Infraorder POLYCHELIDA** | |
| *Polycheles typhlops* (Heller, 1862) | Balkıs (1998-1999a), Kocataş and Katağan (2003), Topaloğlu *et al.* (2004), Altuğ *et al.* (2011), Topaloğlu (2014) |
| **Infraorder ANOMURA** | |
| *Anapagurus bicorniger* A. Milne-Edwards & Bouvier, 1892 | Müller (1986), Balkıs (2002) |
| *Anapagurus chiroacanthus* (Liljeborg, 1856) | Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Anapagurus laevis* (Bell, 1845) | Koçak *et al.* (2001), Balkıs (2002) |
| *Anapagurus petiti* Dechancé & Forest, 1962 | Ateş *et al.* (2011) |
| *Calcinus tubularis* (Linnaeus, 1767) | Ostroumoff (1896) |
| *Cestopagurus timidus* (Roux, 1830) | Müller (1986), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Clibanarius erythropus* (Latreille, 1818) | Ostroumoff (1896), Marion (1898), Demir (1952-1954), Kocataş (1981), Okuş (1989), Koçak *et al.* (2001), Balkıs (2002), Kocataş and Katağan (2003) |
| *Dardanus arrosor* (Herbst, 1796) | Demir (1952-1954) |
| *Diogenes pugilator* (Roux, 1829) | Colombo (1885), Ostroumoff (1896), Demir (1952-1954), Holthuis (1961), Kocataş (1981), Balkıs (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011), Bakır (2012) |
| *Galathea dispersa* Bate, 1859 | Marion (1898) |
| *Galathea intermedia* Lilljeborg, 1851 | Demir (1952-1954), Aslan-Cihangir and Pancucci- Papadopoulou (2011a) |
| *Galathea nexa* Embleton, 1834 | Ostroumoff (1896), Marion (1898) |

**Table.** (Continued).

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|---|---|
| *Galathea squamifera* Leach, 1814 | Colombo (1885), Demir (1952-1954), Okuş (1898), Balkıs (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Galathea strigosa* (Linnaeus, 1767) | Demir (1952-1954) |
| *Munida rugosa* (Fabricius, 1775) | Colombo (1885), Ostroumoff (1896) |
| *Munida tenuimana* G.O. Sars, 1872 | Ostroumoff (1896) |
| *Paguristes eremita* (Linnaeus, 1767) | Colombo (1885), Ostroumoff (1896), Marion (1898), Müller (1986), Balkıs (2002), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Paguristes syrtensis* de Saint Laurent, 1971 | Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Pagurus alatus* Fabricius, 1775 | Colombo (1885), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Pagurus anachoretus* Risso, 1827 | Colombo (1885), Balkıs (2002) |
| *Pagurus cuanensis* Bell, 1845 | Colombo (1885), Ostroumoff (1896), Marion (1898), Balkıs (2002), Ateş *et al.* (2011) |
| *Pagurus excavatus* (Herbst, 1791) | Balkıs (2002) |
| *Pagurus forbesii* Bell, 1845 | Ostroumoff (1896), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Pagurus prideaux* Leach, 1815 | Colombo (1885), Marion (1898), Balkıs (2002), Ateş *et al.* (2011) |
| *Pisidia bluteli* (Risso, 1816) | Topaloğlu and Kihara (1993), Koçak *et al.* (2001), Balkıs (2002), Erkan Yurdabak (2004), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Bakır (2012) |
| *Pisidia longicornis* (Linnaeus, 1767) | Demir (1952-1954), Caspers (1968), Okuş (1989), Yüksek (1989), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Pisidia longimana* (Risso, 1816) | Holthuis, 1961, Kocataş, 1981, Koçak *et al.* (2001), Balkıs (2002), Kocataş and Katağan (2003), Kalkan *et al.* (2006), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011), Bakır (2012) |
| *Porcellana platycheles* (Pennant, 1777) | Ostroumoff (1896), Demir (1952-1954), Kocataş (1981), Müller (1985), Koçak *et al.* (2001), Balkıs (2002), Kocataş and Katağan (2003) |

**Table.** (Continued).

| **Infraorder BRACHYURA** | |
|---|---|
| *Acanthonyx lunulatus* (Risso, 1816) | Demir (1952-1954) |
| *Achaeus cranchii* Leach, 1817 | Colombo (1885), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Achaeus gracilis* (Costa, 1839) | Ateş *et al.* (2007) |
| *Atelecyclus rotundatus* (Olivi, 1792) | Demir (1952-1954) |
| *Bathynectes longipes* (Risso, 1816) | Ostroumoff (1896) |
| *Brachynotus sexdentatus* (Risso, 1827) | Ostroumoff (1894), Müller (1986), Balkıs (1994), Ateş *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Calappa granulata* (Linnaeus, 1758) | Müller (1986), Çelik *et al.* (2007) |
| *Callinectes sapidus* Rathbun, 1896 | Tuncer and Bilgin (2008) |
| *Carcinus aestuarii* Nardo, 1847 | Ostroumoff (1894, 1896), Rathbun (1930), Demir (1952-1954), Holthuis (1961), Kocataş (1981), Kocataş and Katağan (1983), Okuş (1989), Yüksek (1989), Balkıs (1992), Balkıs (1994), Soyal Eryılmaz (1997), Palaz *et al.* (2001), Kocataş and Katağan (2003), Erkan Yurdabak (2004), Ateş *et al.* (2007), Çelik *et al.* (2007), Palaz and Colakoglu (2009), Ateş *et al.* (2011), Bakır (2012) |
| *Coleusia signata* (Paul'son, 1875) | Artüz (2007) |
| *Derilambrus angulifrons* (Latreille, 1825) | Ostroumoff (1894), Marion (1898), Çelik *et al.* (2007) |
| *Dromia personata* (Linnaeus, 1758) | Ostroumoff (1896), Demir (1952-1954), Çelik *et al.* (2007), Palaz and Colakoglu (2009) |
| *Ebalia cranchii* Leach, 1817 | Ostroumoff (1896) |
| *Ebalia edwardsii* Costa, 1838 | Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Ebalia tuberosa* (Pennant, 1777) | Colombo (1885) |
| *Eriphia verrucosa* (Forskål, 1775) | Forskål (1775), Demir (1952-1954), Holthuis and Gottlieb (1958), Holthuis (1961), Kocataş (1981), Okuş (1989), Balkıs (1994), Palaz *et al.* (2001), Uysal *et al.* (2002), Kocataş and Katağan (2003), Çelik *et al.* (2007), Palaz and Colakoglu (2009) |

**Table.** (Continued).

| | |
|---|---|
| *Ethusa mascarone* (Herbst, 1785) | Ateş *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Eurynome aspera* (Pennant, 1777) | Colombo (1885), Ostroumoff (1896), Marion (1898), Okuş (1989), Balkıs (1994) |
| *Geryon longipes* A. Milne-Edwards, 1882 | Ostroumoff (1896) |
| *Goneplax rhomboides* (Linnaeus, 1758) | Demir (1952-1954), Balkıs (1994), Kocataş and Katağan (2003), Çelik *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Herbstia condyliata* (Fabricius, 1787) | Tortonese (1959) |
| *Ilia nucleus* (Linnaeus, 1758) | Ostroumoff (1894, 1896), Demir (1952-1954), Palaz *et al.* (2001), Çelik *et al.* (2007), Palaz and Colakoglu (2009), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Inachus communissimus* Rizza, 1839 | Ateş *et al.* (2007) |
| *Inachus dorsettensis* (Pennant, 1777) | Colombo (1885), Ostroumoff (1896), Demir (1952-1954), Balkıs (1994), Çelik *et al.* (2007) |
| *Inachus leptochirus* Leach, 1817 | Ostroumoff (1896) |
| *Inachus phalangium* (Fabricius, 1775) | Ďuriš *et al.* (2013) |
| *Inachus thoracicus* Roux, 1830 | Colombo (1885), Ostroumoff (1896), Marion (1898), Yüksek (1989) |
| *Liocarcinus corrugatus* (Pennant, 1777) | Forskål (1775), Colombo (1885), Ostroumoff (1896), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Liocarcinus depurator* (Linnaeus, 1758) | Ostroumoff (1896), Marion (1898), Demir (1952-1954), Tortonese (1959), Okuş (1989), Yüksek (1989), Balkıs (1992), Balkıs (1994), Palaz *et al.* (2001), Uysal *et al.* (2002), Kocataş and Katağan (2003), Ateş *et al.* (2007), Çelik *et al.* (2007), Palaz and Colakoglu (2009), Altuğ *et al.* (2011), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011), Bakır (2012) |
| *Liocarcinus maculatus* (Risso, 1827) | Ateş *et al.* (2011) |
| *Liocarcinus marmoreus* (Leach, 1814) | Ateş *et al.* (2011) |

**Table.** (Continued).

| | |
|---|---|
| *Liocarcinus navigator* (Herbst, 1794) | Colombo (1885), Ostroumoff (1894), Ostroumoff (1896), Marion (1898), Demir (1952-1954), Caspers (1968), Müller (1985), Okuş (1989), Yüksek (1989), Balkıs (1992), Balkıs (1994), Ateş *et al.* (2007), Bakır (2012) |
| *Liocarcinus vernalis* (Risso, 1827) | Ostroumoff (1894, 1896) ?, Kocataş (1981), Balkıs (1994), Uysal *et al.* (2002), Kocataş and Katağan (2003), Ateş *et al.* (2007), Çelik *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Bakır (2012) |
| *Lissa chiragra* (Fabricius, 1775) | Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Macropodia czernjawskii* (Brandt, 1880) | Demir (1952-1954), Ďuriš *et al.* (2013) |
| *Macropodia longirostris* (Fabricius, 1775) | Colombo (1885), Ostroumoff (1896), Demir (1952-1954), Okuş (1989), Yüksek (1989), Balkıs (1994), Palaz *et al.* (2001), Ateş *et al.* (2007), Çelik *et al.* (2007), Palaz and Colakoglu (2009), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Macropodia rostrata* (Linnaeus, 1761) | Colombo (1885), Ostroumoff (1896), Kocataş (1981), Okuş (1989), Yüksek (1989), Balkıs (1994), Kocataş and Katağan (2003), Çelik *et al.* (2007) |
| *Maja crispata* Risso, 1827 | Colombo (1885), Ostroumoff (1896), Ninni (1923), Demir (1952-1954), Okuş (1989), Balkıs (1994), Palaz *et al.* (2001), Çelik *et al.* (2007), Palaz and Colakoglu (2009) |
| *Maja squinado* (Herbst, 1788) | Ninni (1923), Holthuis and Gottlieb (1958), Okuş (1989), Yüksek (1989) |
| *Medorippe lanata* (Linnaeus, 1767) | Demir (1952-1954), Balkıs (1994), Kocataş and Katağan (2003), Çelik *et al.* (2007) |
| *Monodaeus couchii* (Couch, 1851) | Ostroumoff (1896), Balkıs (1994), Kocataş and Katağan (2003) |
| *Monodaeus guinotae* Forest, 1976 | Artüz *et al.* (2014) |
| *Nepinnotheres pinnotheres* (Linnaeus, 1758) | Forskål (1775), Demir (1952-1954) ?, Balkıs (1994) |
| *Pachygrapsus marmoratus* (Fabricius, 1787) | Stimpson (1861), Ostroumoff (1896), Demir (1952-1954), Holthuis and Gottlieb (1958), Holthuis (1961), Kocataş (1981), Balkıs (1994), Palaz *et al.* (2001), Kocataş and Katağan (2003), Çelik *et al.* (2007) |

**Table.** (Continued).

| | |
|---|---|
| *Parthenopoides massena* (Roux, 1830) | Colombo (1885), Ostroumoff (1896), Tortonese (1959), Müller (1986), Ateş *et al.* (2007), Ateş *et al.* (2011) |
| *Pilumnus hirtellus* (Linnaeus, 1761) | Colombo (1885), Ostroumoff (1894, 1896), Marion (1898) ?, Demir (1952-1954), Tortonese (1959) ?, Holthuis (1961), Caspers (1968), Kocataş (1981), Okuş (1989), Yüksek (1989), Topaloğlu and Kihara (1993), Balkıs (1994), Kocataş and Katağan (2003), Erkan Yurdabak (2004), Kalkan *et al.* (2006), Ateş *et al.* (2007), Çelik *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011) |
| *Pilumnus spinifer* H. Milne Edwards, 1834 | Colombo (1885), Aslan-Cihangir and Pancucci-Papadopoulou (2011a) |
| *Pinnotheres pisum* (Linneaus, 1767) | Ostroumoff (1896), Demir (1952-1954) ?, Balkıs (1994), Çelik *et al.* (2007) |
| *Pirimela denticulata* (Montagu, 1808) | Kocataş (1981), Kocataş and Katağan (2003) |
| *Pisa armata* (Latreille, 1803) | Colombo (1885), Ostroumoff (1896), Demir (1952-1954) |
| *Pisa hirticornis* (Herbst, 1804) | Ostroumoff (1896) |
| *Pisa nodipes* Leach, 1815 | Demir (1952-1954) |
| *Pisa tetraodon* (Pennant, 1777) | Ostroumoff (1894), Ostroumoff (1896), Demir (1952-1954), Çelik *et al.* (2007), Palaz and Colakoglu (2009) |
| *Portumnus latipes* (Pennant, 1777) | Müller (1986) |
| ? *Portunus segnis* (Forskål, 1775) | Altuğ *et al.* (2011) |
| *Sirpus zariquieyi* Gordon, 1953 | Kocataş (1981), Kocataş (1982), Kocataş and Katağan (2003), Ateş *et al.* (2011) |
| ? *Spinolambrus macrochelos* (Herbst, 1790) | Demir (1952-1954) |
| *Xantho pilipes* A. Milne-Edwards, 1867 | Balkıs (1994), Ateş *et al.* (2007), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Ateş *et al.* (2011) |

**Table.** (Continued).

| | |
|---|---|
| *Xantho poressa* (Olivi, 1792) | Heller (1863), Ostroumoff (1894, 1896), Marion (1898), Demir (1952-1954), Holthuis and Gottlieb (1958), Holthuis (1961), Caspers (1968), Kocataş (1981), Okuş (1989), Yüksek (1989), Balkıs (1992), Balkıs (1994), Palaz *et al.* (2001), Kocataş and Katağan (2003), Erkan Yurdabak (2004), Kalkan *et al.* (2006), Ateş *et al.* (2007), Çelik *et al.* (2007), Palaz and Colakoglu (2009), Aslan-Cihangir and Pancucci-Papadopoulou (2011a), Bakır (2012) |

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**MOLLUSCA FAUNA OF THE SEA OF MARMARA**

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## 1. Introduction

Term mollusc simply means invertebrate animals with soft body, lacking an articulated internal skeleton, whether secreting a shell or not. To draw a standart mollusc form is impossible since it possesses extremely different body types such as whelk, mussel, ship-worm or octopus. Molluscs has a quite ancient origin as Cambrian period that is about 545 million years from the day. They originated in the sea, spread to fresh water and its largest class Gastropoda successfully survived even at terrestrial habitats (Powell 1979).

Phyllum Mollusca is of eight classes namely Caudofoveata, Solenogastres, Monoplacophora, Polyplacophora, Gastropoda, Bivalvia, Scaphopoda and Cephalopoda. It is one of the largest phyllums of marine invertebrate fauna in terms of species number by having about 50.000 species (Bouchet 2006).

Early records of this well-studied phyllum from Turkish seas belong to Forsskal (1775), Forbes (1844), Colombo (1885), Ostroumoff (1894, 1896), Sturany (1895) and Marion (1898). Following researches were focused to the Sea of Marmara in the first half of $20^{th}$ century and to the Aegean Sea especially after 1970s. Despite few studies from the Black Sea and Levantine Sea, interest to alien species triggered new researches in the Levantine Sea.

Molluscan species reported from Turkish seas were gathered firstly in a checklist by Öztürk and Çevik (2000). Noteworthy study of Demir (2003) reported new species and closed gaps between seas by indicating new distributional data. Yokeş (2009) mentioned about opisthobranches and Albayrak (2011) about bivalves of Turkish seas. Finally, Öztürk *et al*. (2014) published a new checklist by adding the findings from last studies.

Öztürk *et al*. (2014) notified a total of 1.065 molluscan species from the seas surrounding Turkey of which 706 (66.29 %) belonged to Gastropoda, 279 (26.20 %) to Bivalvia, 50 (4.69 %) to Cephalopoda, 17 (1.60 %) to Polyplacophora, 10 (0.93 %) to Scaphopoda, 2 (0.19 %) to Caudofoveata and 1 (0.09 %) to Solenogastres. Our review of literatures (please follow huge literatures present in above mentioned checklists) about molluscs of the Sea of Marmara revealed totally 598 molluscan species of which 362 (60.54 %) belonging to Gastropoda, 200 (33.44 %) to Bivalvia, 18 (3.01 %) to Cephalopoda, 11 (1.84 %) to Polyplacophora, 5 (0.84 %) to Scaphopoda and 2 (0.33 %) to Caudofoveata (Figs. 1 and 2). One Solenogastres species (*Eleutheromenia carinata* Salvini-Plawen and Öztürk, 2006) was recorded from the Aegean Sea but not from the Sea of Marmara. No Monoplacophora species was indicated from any seas surrounding Turkey. The classification of species was based on CLEMAM (Check List of European Marine Mollusca) except placing genera in alphabetical order within families, WoRMS (World Register of Marine Species) was also utilized for some species to check valid nomenclature. All 598 molluscan species of the Sea of Marmara are presented in List 1.

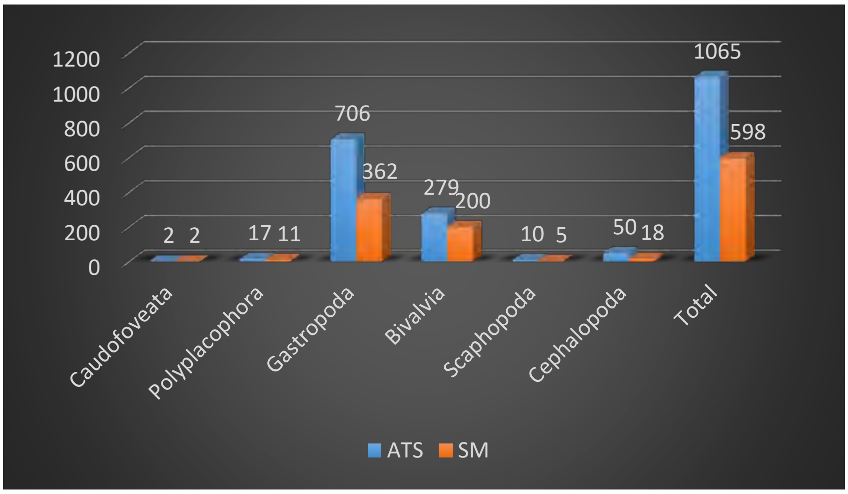
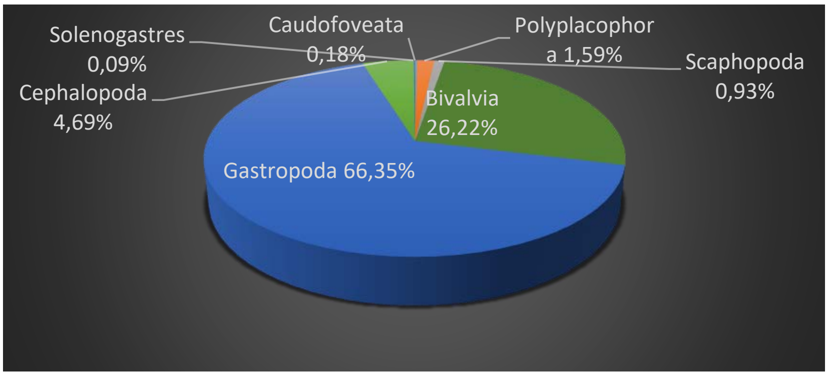
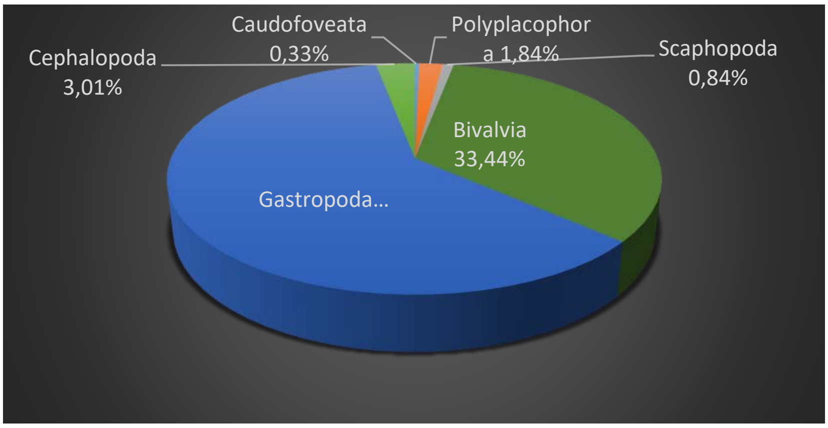



**Figure 1.** Species number of six molluscan classes reported from the Sea of Marmara. ATS: All Turkish Seas, SM: the Sea of Marmara

Seven (1.17 %) of 598 species are aliens. Those are *Rapana venosa* (Valenciennes, 1846) and *Aplysia parvula* Mörch, 1863 from Gastropoda; *Anadara kagoshimensis* (Tokunaga, 1906), *Chama asperella* Lamarck, 1819, *Ruditapes philippinarum* (Adams and Reeve, 1850), *Mya arenaria* Linnaeus, 1758 and *Teredo navalis* Linnaeus, 1758 from Bivalvia. *A. parvula* and *T. navalis* are cryptogenic, other 5 species are established.




a




b

**Figure 2.** Percentages of species in the classes within total Mollusca fauna. a: All Turkish Sea, b: the Sea of Marmara

A total of 20 molluscan species were excluded from the list because of several reasons such as being misidentification, doubtful or invalid records. These species are *Patella rustica* Linnaeus, 1758, *Diodora ruppellii* (Sowerby, G.B. I, 1835), *Anatoma aspera* (Philippi, 1844), *Setia lacourti* (Verduin, 1984), *Caecum glabrum* (Montagu, 1803), *Murex exigua* (without author name), *Trophonopsis barvicensis* (Johnston, 1825), *Fusinus labronicus* (Monterosato, 1884), *Raphitoma contigua* (Monterosato, 1884), *Chrysallida* cf. *monozona* (Brusina, 1869), *Ringicula minutula* Locard, 1897, *Atys brocchii* (Michelotti, 1847), *Doris tuberculata* (Cuvier, 1804) from Gastropoda; *Mytilus edulis* Linnaeus, 1758, *Crassostrea gigas* (Thunberg, 1793), *Galeomma politum* Deshayes, 1855, *Cerastoderma edule* (Linnaeus, 1758), *Cardium ostroumovi* Mil. and *Chamelea striatula* (da Costa, 1778) from Bivalvia; *Antalis novemcostata* (Lamarck, 1818) from Scaphopoda. Species from some checklists, not indicated in original paper, were not mentioned in List 1.

List 1. Marine molluscan species of the Sea of Marmara. *: Alien species

**CAUDOFOVEATA**

**Chaetodermatidae**
*Falcidens gutturosus* (Kowalewsky, 1901)
**Prochaetodermatidae**
*Prochaetoderma raduliferum* (Kowalewsky, 1901)

**POLYPLACOPHORA**

**Leptochitonidae**
*Lepidopleurus cajetanus* (Poli, 1791)
*Leptochiton africanus* (Nierstrasz, 1906)
*Leptochiton cancellatus* (Sowerby, G. B.II, 1840)
*Leptochiton cimicoides* (Monterosato, 1879)
**Callochitonidae**
*Callochiton septemvalvis* (Montagu, 1803)
**Chitonidae**
*Chiton corallinus* (Risso, 1826)
*Chiton olivaceus* Spengler, 1797
**Lepidochitonidae**
*Lepidochitona caprearum* (Scacchi, 1836)
*Lepidochitona cinerea* (Linneaus, 1767)
**Acanthochitonidae**
*Acanthochitona crinita* (Pennant, 1777)
*Acanthochitona fascicularis* (Linnaeus, 1767)

**GASTROPODA**

**Patellidae**
*Patella caerulea* Linnaeus, 1758
*Patella ulyssiponensis* Gmelin, 1791
**Lottiidae**
*Tectura virginea* (Müller, O.F., 1776)
**Fissurellidae**
*Diodora gibberula* (Lamarck, 1822)
*Diodora graeca* (Linnaeus, 1758)
*Diodora italica* (Defrance, 1820)
*Emarginula adriatica* Costa, O. G., 1829
*Emarginula rosea* Bell, T., 1824
*Emarginula sicula* Gray, J.E., 1825
**Scissurellidae**
*Anatoma crispata* (Fleming, 1828)
*Scissurella costata* d'Orbigny, 1824
**Lepetellidae**
*Lepetella laterocompressa* (de Rayneval and Ponzi, 1854)
**Trochidae**
*Clanculus corallinus* (Gmelin, 1791)
*Clanculus cruciatus* (Linnaeus, 1758)
*Clelandella miliaris* (Brocchi, 1814)
*Gibbula adansonii* (Payraudeau, 1826)
*Gibbula adriatica* (Philippi, 1844)
*Gibbula albida* (Gmelin, 1791)
*Gibbula ardens* (Salis Marschlins, 1793)
*Gibbula deversa* Milaschewitsch, 1916
*Gibbula divaricata* (Linnaeus, 1758)
*Gibbula fanulum* (Gmelin, 1791)
*Gibbula guttadauri* (Philippi, 1836)
*Gibbula magus* (Linneaus, 1758)
*Gibbula philberti* (Récluz, 1843)
*Gibbula racketti* (Payraudeau, 1826)
*Gibbula rarilineata* (Michaud, 1829)
*Gibbula spratti* (Forbes, 1844)
*Gibbula turbinoides* (Deshayes, 1835)
*Gibbula umbilicaris* (Linnaeus, 1758)
*Gibbula varia* (Linnaeus, 1758)
*Jujubinus exasperatus* (Pennant, 1777)
*Jujubinus montagui* (Wood, W., 1828)
*Jujubinus striatus* (Linnaeus, 1758)
*Phorcus articulatus* (Lamarck, 1822)
*Phorcus mutabilis* (Philippi, 1846)
*Phorcus richardi* (Payraudeau, 1826)
*Phorcus turbinatus* (Born, 1778)
**Calliostomatidae**
*Calliostoma conulus* (Linnaeus, 1758)
*Calliostoma granulatum* (Born, 1778)
*Calliostoma laugieri* (Payraudeau, 1826)
*Calliostoma virescens* Coen, 1933
*Calliostoma zizyphinum* (Linnaeus, 1758)
**Turbinidae**
*Bolma rugosa* (Linnaeus, 1767)

**Chilodontidae**
*Danilia tinei* (Calcara, 1839)
**Calliotropidae**
*Putzeysia wiseri* (Calcara, 1842)
**Phasianellidae**
*Tricolia pullus pullus* (Linnaeus, 1758)
*Tricolia speciosa* (Megerlevon Mühlfeld, 1824)
*Tricolia tenuis* (Michaud, 1829)
**Colloniidae**
*Homalopoma sanguineum* (Linnaeus, 1758)
**Neritidae**
*Smaragdia viridis* (Linnaeus, 1758)
**Cerithiidae**
*Bittium lacteum* (Philippi, 1836)
*Bittium latreillii* (Payraudeau, 1826)
*Bittium reticulatum* (da Costa, 1778)
*Bittium submamillatum* (de Rayneval and Ponzi, 1854)
*Cerithium alucastrum* (Brocchi, 1814)
*Cerithium protractum* Bivona, Ant in Bivona, And., 1838
*Cerithium renovatum* Monterosato, 1884
*Cerithium vulgatum* Bruguière, 1792
**Siliquariidae**
*Tenagodus obtusus* (Schumacher, 1817)
**Turritellidae**
*Turritella communis* Risso, 1826
*Turritella turbona* Monterosato, 1877
**Triphoridae**
*Marshallora adversa* (Montagu, 1803)
*Metaxia metaxa* (Delle Chiage, 1828)
*Monophorus perversus* (Linnaeus, 1758)
**Cerithiopsidae**
*Cerithiopsis barleei* Jeffreys, 1867
*Cerithiopsis fayalensis* Watson, 1880
*Cerithiopsis minima* (Brusina, 1865)
*Cerithiopsis scalaris* Locard, 1892
*Cerithiopsis tubercularis* (Montagu, 1803)
*Dizoniopsis coppolae* (Aradas, 1870)
**Aclididae**
*Aclis ascaris* (Turton, 1819)
*Aclis minor* (Brown, 1827)
**Epitoniidae**
*Acirsa subdecussata* (Cantraine, 1835)
*Epitonium algerianum* (Weinkauff, 1866)
*Epitonium clathratulum* (Kanmacher, 1798)
*Epitonium clathrus* (Linnaeus, 1758)
*Epitonium muricatum* (Risso, 1826)
*Epitonium pulchellum* (Bivona, Ant.,1832)
*Epitonium turtonis* (Turton, 1819)
*Gyroscala lamellosa* (Lamarck, 1822)
**Eulimidae**
*Curveulima devians* (Monterosato, 1884)
*Eulima bilineata* Alder, 1848
*Eulima glabra* (da Costa, 1778)
*Melanella polita* (Linnaeus, 1758)
*Sabinella bonifaciae* (Nordsieck, 1974)
*Vitreolina antiflexa* (Monterosato, 1884)
*Vitreolina curva* (Monterosato, 1874)
*Vitreolina incurva* (Bucquoy, Dautzenberg and Dollfus, 1883)
*Vitreolina philippi* (de Rayneval and Ponzi, 1854)
**Littorinidae**
*Melarhaphe neritoides* (Linnaeus, 1758)
**Cingulopsidae**
*Eatonina ochroleuca* (Brusina, 1869)
**Rissoidae**
*Alvania beanii* (Hanley in Thorpe, 1844)
*Alvania cancellata* (da Costa, 1778)
*Alvania cimex* (Linnaeus, 1758)
*Alvania cimicoides* (Forbes, 1844)
*Alvania discors* (Allan, 1818)
*Alvania geryonia* (Nardo, 1847)
*Alvania hispidula* (Monterosato, 1884)
*Alvania lactea* (Michaud, 1830)
*Alvania lanciae* (Calcara, 1845)
*Alvania lineata* Risso, 1826
*Alvania punctura* (Montagu, 1803)
*Alvania rudis* (Philippi, 1844)
*Alvania testae* (Aradas and Maggiore, 1884)
*Crisilla semistriata* (Montagu, 1808)

*Manzonia crassa* (Kanmacher, 1798)
*Obtusella intersecta* (Wood, S., 1857)
*Pusillina inconspicua* (Alder, 1844)
*Pusillina lineolata* (Michaud, 1830)
*Pusillina marginata* (Michaud, 1830)
*Pusillina philippi* (Aradas and Maggiore, 1844)
*Pusillina radiata* (Philippi, 1836)
*Pusillina sarsii* (Lovén, 1846)
*Rissoa auriscalpium* (Linnaeus, 1758)
*Rissoa guerinii* Récluz, 1843
*Rissoa membranacea* (Adams, J., 1800)
*Rissoa monodonta* Philippi, 1836
*Rissoa parva* (da Costa, 1778)
*Rissoa similis* Scacchi, 1836
*Rissoa splendida* Eichwald, 1830
*Rissoa ventricosa* Desmarest, 1814
*Rissoa violacea* Desmarest, 1814
*Rissoina bruguieri* (Payraudeau, 1826)
*Setia valvatoides* (Milaschewitsch, 1909)
**Caecidae**
*Caecum auriculatum* de Folin, 1868
*Caecum subannulatum* de Folin, 1870
*Caecum trachea* (Montagu, 1803)
*Parastrophia asturiana* de Folin, 1870
**Elachisinidae**
*Laeviphitus verduini* van Aartsen, Bogi and Giusti, 1989
**Hydrobiidae**
*Ecrobia ventrosa* (Montagu, 1803)
*Hydrobia acuta* (Draparnaud, 1805)
**Iravadiidae**
*Ceratia proxima* (Forbes and Hanley, 1850)
*Hyala vitrea* (Montagu, 1803)
**Tornidae**
*Circulus striatus* (Philippi, 1836)
*Tornus subcarinatus* (Montagu, 1803)
**Truncatellidae**
*Truncatella subcylindrica* (Linnaeus, 1767)
**Vermetidae**
*Dendropoma cristatum* (Biondi, 1859)
*Petaloconchus glomeratus* (Linnaeus, 1758)
*Thylacodes arenarius* (Linnaeus, 1758)
*Thylaeodus semisurrectus* (Bivona-Bernardi, 1832)
*Vermetus granulatus* (Gravenhorst, 1831)
*Vermetus triquetrus* Bivona-Bernardi,1832
**Aporrhaidae**
*Aporrhais pespelecani* (Linnaeus, 1758)
*Aporrhais serresianus* (Michaud, 1828)
**Calyptraeidae**
*Calyptraea chinensis* (Linnaeus, 1758)
*Crepidula moulinsii* Michaud, 1829
*Crepidula unguiformis* Lamarck, 1822
**Capulidae**
*Capulus ungaricus* (Linnaeus, 1758)
**Triviidae**
*Erato voluta* (Montagu, 1803)
*Trivia levantina* Smriglio, Mariottini and Buzzurro, 1998
*Trivia monacha* (da Costa, 1778)
**Cypraeidae**
*Erosaria spurca* (Linnaeus, 1758)
**Ovulidae**
*Pseudosimnia adriatica* (Sowerby, G.B. I, 1828)
*Pseudosimnia carnea* (Poiret, 1789)
**Naticidae**
*Euspira fusca* (de Blainville, 1825)
*Euspira guilleminii* (Payraudeau, 1826)
*Euspira intricata* (Donovan, 1804)
*Euspira macilenta* (Philippi, 1844)
*Euspira nitida* (Donovan, 1804)
*Natica stercusmuscarum* (Gmelin, 1791)
*Neverita josephinia* Risso, 1826
*Notocochlis dillwynii* (Payraudeau, 1826)
*Tectonatica sagraiana* (d'Orbigny, 1842)
**Cassidae**
*Galeodea echinophora* (Linnaeus, 1758)
**Ranellidae**
*Monoplex corrugatus* (Lamarck, 1816)
**Pterotracheaidae**
*Pterotrachea coronata* Forsskål in Niebuhr, 1775

**Atlantidae**
*Atlanta peronii* Lesueur, 1817
**Muricidae**
*Bolinus brandaris* (Linnaeus, 1758)
*Coralliophila squamosa* (Bivona Ant. in Bivona, And., 1838)
*Hadriania craticulata* Bucquoy, Dautzenberg and Dollfus, 1882
*Hexaplex trunculus* (Linnaeus, 1758)
*Muricopsis cristata* (Brocchi, 1814)
*Ocenebra erinaceus* (Linnaeus, 1758)
*Ocinebrina aciculata* (Lamarck, 1822)
*Ocinebrina edwardsii* (Payraudeau, 1826)
**Rapana venosa* (Valenciennes, 1846)
*Trophonopsis breviata* (Jeffreys, 1882)
*Trophonopsis muricata* (Montagu, 1803)
*Typhinellus labiatus* (de Cristofori and Jan, 1832)
**Marginellidae**
*Granulina marginata* (Bivona, Ant., 1832)
**Cystiscidae**
*Gibberula miliaria* (Linnaeus, 1758)
**Costellariidae**
*Vexillum ebenus* (Lamarck, 1811)
*Vexillum granum* (Forbes, 1844)
*Vexillum tricolor* (Gmelin, 1791)
**Buccinidae**
*Chauvetia brunnea* (Donovan, 1804)
*Chauvetia mamillata* (Risso, 1826)
*Engina leucozona* (Philippi, 1844)
*Euthria cornea* (Linnaeus, 1758)
*Pisania striata* (Gmelin, 1791)
*Pollia dorbignyi* (Payraudeau, 1826)
**Nassariidae**
*Cyclope neritea* (Linnaeus, 1758)
*Cyclope pellucida* Risso, 1826
*Nassarius corniculum* (Olivi, 1792)
*Nassarius cuvierii* (Payraudeau, 1826)
*Nassarius incrassatus* (Stroem, 1768)
*Nassarius nitidus* (Jeffreys, 1867)
*Nassarius pygmaeus* (Lamarck, 1822)
*Nassarius reticulatus* (Linnaeus, 1758)

**Columbellidae**
*Columbella rustica* (Linnaeus, 1758)
*Mitrella gervillii* (Payraudeau, 1826)
*Mitrella scripta* (Linnaeus, 1758)
**Fasciolariidae**
*Fusinus pulchellus* (Philippi, 1844)
*Fusinus rostratus* (Olivi, 1792)
*Fusinus syracusanus* (Linnaeus, 1758)
**Conidae**
*Conus mediterraneus* Hwass in Bruguière, 1792
**Drilliidae**
*Crassopleura maravignae* (Bivona Ant. in Bivona And., 1838)
**Horaiclavidae**
*Haedropleura septangularis* (Montagu, 1803)
**Clathurellidae**
*Comarmondia gracilis* (Montagu, 1803)
**Mitromorphidae**
*Mitromorpha olivoidea* (Cantraine, 1835)
**Mangeliidae**
*Bela cycladensis* (Reeve, 1845)
*Bela fuscata* (Deshayes, 1835)
*Bela menkhorsti* van Aartsen, 1988
*Bela nebula* (Montagu, 1803)
*Bela taprurensis* (Pallary, 1904)
*Bela zenetouae* (van Aartsen, 1988)
*Bela zonata* (Locard, 1892)
*Mangelia attenuata* (Montagu, 1803)
*Mangelia barashi* (van Aartsen and Fehr de Wal, 1978)
*Mangelia brusinae* van Aartsen and Fehr-de Wal, 1978
*Mangelia costata* (Pennant, 1777)
*Mangelia costulata* Risso, 1826
*Mangelia melitensis* Cachia and Mifsud, 2008
*Mangelia multilineolata* (Deshayes, 1835)
*Mangelia nuperrima* (Tiberi, 1855)
*Mangelia paciniana* (Calcara, 1839)
*Mangelia pontica* Milaschewitsch, 1908
*Mangelia scabrida* Monterosato, 1890
*Mangelia sicula* Reeve, 1846
*Mangelia stosiciana* Brusina, 1869
*Mangelia striolata* Risso, 1826

*Mangelia taeniata* (Deshayes, 1835)
*Mangelia unifasciata* (Deshayes, 1835)
*Mangelia vauquelini* (Payraudeau, 1826)
*Sorgenfreispira brachystoma* (Philippi, 1844)

**Raphitomidae**

*Raphitoma aequalis* (Jeffreys, 1867)
*Raphitoma alternans* (Monterosato, 1884)
*Raphitoma concinna* (Scacchi, 1836)
*Raphitoma cordieri* (Payraudeau, 1826)
*Raphitoma echinata* (Brocchi, 1814)
*Raphitoma leufroyi* (Michaud, 1828)
*Raphitoma linearis* (Montagu, 1803)
*Raphitoma papillosa* (Pallary, 1904)
*Raphitoma philberti* (Michaud, 1829)
*Raphitoma pruinosa* (Pallary, 1906)
*Raphitoma pupoides* (Monterosato, 1884)
*Raphitoma purpurea* (Montagu, 1803)
*Teretia teres* (Reeve, 1844)

**Architectonicidae**

*Heliacus fallaciosus* (Tiberi, 1872)
*Pseudotorinia architae* (Costa, O.G., 1841)

**Omalogyridae**

*Ammonicera fischeriana* (Monterosato, 1869)
*Omalogyra atomus* (Philippi, 1841)

**Pyramidellidae**

*Auristomia erjaveciana* (Brusina, 1869)
*Brachystomia eulimoides* (Hanley, 1844)
*Brachystomia scalaris* (MacGilivray, 1843)
*Chrysallida excavata* (Philippi, 1836)
*Chrysallida fenestrata* (Jeffreys, 1848)
*Chrysallida intermixta* (Monterosato, 1884)
*Eulimella acicula* (Philippi, 1836)
*Eulimella scillae* (Scacchi, 1835)
*Eulimella ventricosa* (Forbes, 1844)
*Euparthenia bulinea* (Lowe, 1841)
*Euparthenia humboldti* (Risso, 1826)
*Megastomia conoidea* (Brocchi, 1814)
*Noemiamea dolioliformis* (Jeffreys, 1848)
*Odostomella doliolum* (Philippi, 1844)
*Odostomia acuta* Jeffreys, 1848
*Odostomia plicata* (Montagu, 1803)
*Odostomia striolata* Forbes and Hanley, 1850
*Odostomia turrita* Hanley, 1844
*Odostomia unidentata* (Montagu, 1803)
*Ondina warreni* (Thompson, 1845)
*Parthenina clathrata* (Jeffreys, 1848)
*Parthenina emaciata* (Brusina, 1866)
*Parthenina flexuosa* (Monterosato, 1874)
*Parthenina indistincta* (Montagu, 1808)
*Parthenina interstincta* (Adams, J., 1797)
*Parthenina suturalis* (Philippi, 1844)
*Parthenina terebellum* (Philippi, 1844)
*Spiralinella incerta* (Milaschewitsch, 1916)
*Turbonilla acuta* (Donovan, 1804)
*Turbonilla acutissima* Monterosato, 1884
*Turbonilla gradata* Bucquoy, Dautzenberg and Dollfus, 1883
*Turbonilla jeffreysii* (Jeffreys, 1848)
*Turbonilla lactea* (Linnaeus, 1758)
*Turbonilla micans* (Monterosato, 1875)
*Turbonilla pusilla* (Philippi, 1844)
*Turbonilla rufa* (Philippi, 1836)
*Turbonilla striatula* (Linnaeus, 1758)

**Amathinidae**

*Clathrella clathrata* (Philippi, 1844)

**Murchisonellidae**

*Ebala nitidissima* (Montagu, 1803)
*Ebala pointeli* (de Folin, 1868)

**Acteonidae**

*Acteon tornatilis* (Linnaeus, 1758)

**Ringiculidae**

*Ringicula auriculata* (Ménard de la Groye, 1811)
*Ringicula conformis* Monterosato, 1877

**Haminoeidae**

*Atys jeffreysi* (Weinkauff, 1866)
*Haminoea hydatis* (Linnaeus, 1758)
*Haminoea navicula* (da Costa, 1778)
*Weinkauffia turgidula* (Forbes, 1844)

**Philinidae**

*Hermania scabra* (Müller, O.F., 1784)
*Philine catena* (Montagu, 1803)
*Philine monterosati* Monterosato, 1874
*Philine quadrata* (Wood, S., 1839)
*Philine quadripartita* Ascanius, 1772
**Cylichnidae**
*Cylichna cylindracea* (Pennant, 1777)
**Scaphandridae**
*Roxania utriculus* (Brocchi, 1814)
*Scaphander lignarius* (Linnaeus, 1758)
**Gastropteridae**
*Gastropteron rubrum* (Rafinesque, 1814)
**Retusidae**
*Cylichnina laevisculpta* (Granata-Grillo, 1877)
*Cylichnina umbilicata* (Montagu, 1803)
*Pyrunculus hoernesii* (Weinkauff, 1866)
*Retusa mammillata* (Philippi, 1836)
*Retusa minutissima* (Monterosato, 1878)
*Retusa pellucida* (Sars G. O., 1878)
*Retusa truncatula* (Bruguière, 1792)
*Volvulella acuminata* (Brugière, 1792)
**Cavoliniidae**
*Cavolinia tridentata* (Forsskål in Niebuhr, 1775)
**Creseidae**
*Creseis acicula* Rang, 1828
*Creseis virgula* Rang, 1828
**Plakobranchidae**
*Elysia viridis* (Montagu, 1804)
**Limapontiidae**
*Limapontia capitata* (Müller, O.F., 1774)
**Umbraculidae**
*Umbraculum umbraculum* (Lightfoot, 1786)
**Akeridae**
*Akera bullata* Müller, O.F., 1776
**Aplysiidae**
*Aplysia depilans* Gmelin, 1791
**Aplysia parvula* Mörch, 1863
*Aplysia punctata* (Cuvier, 1803)
**Pleurobranchidae**
*Berthella aurantiaca* (Risso, 1818)
*Berthella plumula* (Montagu, 1803)
*Pleurobranchus membranaceus* (Montagu, 1816)
**Pleurobranchaeidae**
*Pleurobranchaea meckeli* (de Blainville, 1825)
**Discodorididae**
*Peltodoris atromaculata* Bergh, 1880
*Rostanga rubra* (Risso, 1818)
*Thordisa filix* Pruvot-Fol, 1951
**Chromodorididae**
*Felimare orsinii* (Vérany, 1846)
*Felimare tricolor* (Cantraine, 1835)
*Felimare villafranca* (Risso, 1818)
*Felimida purpurea* (Risso in Guérin, 1831)
**Phyllidiidae**
*Phyllidia flava* Aradas, 1847
**Dendrodorididae**
*Dendrodoris limbata* (Cuvier, 1804)
**Goniodirididae**
*Trapania maculata* Haefelfinger, 1960
**Polyceridae**
*Limacia clavigera* (Müller, O.F., 1776)
*Polycera quadrilineata* (Müller, O.F., 1776)
**Tritoniidae**
*Marionia blainvillea* (Risso, 1818)
**Arminidae**
*Armina tigrina* Rafinesque, 1814
**Dotidae**
*Doto coronata* (Gmelin, 1791)
**Proctonotidae**
*Janolus cristatus* (Delle Chiaje, 1841)
**Aeolidiidae**
*Aeolidiella alderi* (Cocks, 1852)
**Facelinidae**
*Cratena peregrina* (Gmelin, 1791)
*Dondice banyulensis* Portmann and Sandmeier, 1960
*Facelina annulicornis* (Chamisso and Eysenhardt, 1821)
*Facelina bostoniensis* (Couthouy, 1838)
*Facelina dubia* Pruvot-Fol, 1948
*Pruvotfolia pselliotes* (Labbé, 1923)
**Flabellinidae**
*Calmella cavolini* (Vérany, 1846)
*Flabellina affinis* (Gmelin, 1791)

*Flabellina ischitana* Hirano and Thompson, 1990
*Flabellina lineata* (Lovén, 1846)
*Flabellina pedata* (Montagu, 1815)
**Tergipedidae**
*Tergipes tergipes* (Forsskål in Niebuhr, 1775)
**Siphonariidae**
*Williamia gussoni* (Costa, O.G., 1829)
**Ellobiidae**
*Auriculinella bidentata* (Montagu, 1808)
*Myosotella myosotis* (Draparnaud, 1801)

**BIVALVIA**

**Nuculidae**
*Ennucula aegeensis* (Forbes, 1844)
*Ennucula tenuis* (Montagu, 1808)
*Nucula hanleyi* Winckworth, 1931
*Nucula nitidosa* Winckworth, 1930
*Nucula nucleus* (Linnaeus, 1758)
*Nucula sulcata* Bronn, 1831
**Nuculanidae**
*Nuculana pella* (Linnaeus, 1767)
*Saccella commutata* (Philippi, 1844)
**Yoldiidae**
*Yoldiella striolata* (Brugnone, 1876)
**Arcidae**
*Anadara corbuloides* (Monterosato, 1880)
**Anadara kagoshimensis* (Tokunaga, 1906)
*Anadara polii* (Mayer, 1868)
*Arca noae* Linnaeus, 1758
*Arca tetragona* Poli, 1795
*Barbatia barbata* (Linnaeus, 1758)
*Bathyarca pectunculoides* (Scacchi, 1835)
*Bathyarca philippiana* (Nyst, 1848)
**Noetiidae**
*Striarca lactea* (Linnaeus, 1758)
**Glycymerididae**
*Glycymeris bimaculata* (Poli, 1795)
*Glycymeris glycymeris* (Linnaeus, 1758)
*Glycymeris nummaria* (Linnaeus, 1758)
**Mytilidae**
*Dacrydium hyalinum* (Monterosato, 1875)
*Gibbomodiola adriatica* (Lamarck, 1819)
*Lithophaga lithophaga* (Linnaeus, 1758)
*Modiolarca subpicta* (Cantraine, 1835)
*Modiolula phaseolina* (Philippi, 1844)
*Modiolus barbatus* (Linnaeus, 1758)
*Musculus costulatus* (Risso, 1826)
*Mytilaster lineatus* (Gmelin, 1791)
*Mytilaster minimus* (Poli, 1795)
*Mytilus galloprovincialis* Lamarck, 1819
**Pinnidae**
*Atrina fragilis* (Pennant, 1777)
*Pinna nobilis* Linnaeus, 1758
**Pteriidae**
*Pteria hirundo* (Linnaeus, 1758)
**Propeamussiidae**
*Parvamussium fenestratum* (Forbes, 1844)
*Similipecten similis* (Laskey, 1811)
**Pectinidae**
*Aequipecten opercularis* (Linnaeus, 1758)
*Delectopecten vitreus* (Gmelin, 1791)
*Flexopecten flexuosus* (Poli, 1795)
*Flexopecten glaber* (Linnaeus, 1758)
*Flexopecten hyalinus* (Poli, 1795)
*Manupecten pesfelis* (Linnaeus, 1758)
*Mimachlamys varia* (Linnaeus, 1758)
*Palliolum incomparabile* (Risso, 1826)
*Palliolum striatum* (Müller O.F., 1776)
*Pecten jacobeus* (Linnaeus, 1758)
*Pseudamussium clavatum* (Poli, 1795)
*Talochlamys multistriata* (Poli, 1795)
*Talochlamys pusio* (Linnaeus, 1758)
**Spondylidae**
*Spondylus gaederopus* Linnaeus, 1758
*Spondylus gussonii* Costa O.G., 1829
**Anomiidae**
*Anomia ephippium* Linnaeus, 1758
*Heteranomia squamula* (Linnaeus, 1758)

*Monia patelliformis* (Linnaeus, 1761)
*Monia squama* (Gmelin, 1791)
**Limidae**
*Lima lima* (Linnaeus, 1758)
*Limaria hians* (Gmelin, 1791)
*Limaria loscombi* (Sowerby G.B. I, 1823)
*Limaria tuberculata* (Olivi, 1792)
*Limatula subauriculata* (Montagu, 1808)
**Ostreidae**
*Ostrea edulis* Linnaeus, 1758
**Gryphaeidae**
*Neopycnodonte cochlear* (Poli, 1795)
**Lucinidae**
*Ctena decussata* (Costa O.G., 1829)
*Loripes lucinalis* (Lamarck, 1818)
*Loripinus fragilis* (Philippi, 1836)
*Lucinella divaricata* (Linnaeus, 1758)
*Lucinoma borealis* (Linnaeus, 1767)
*Lucinoma kazani* Salas and Woodside, 2002
*Myrtea amorpha* (Sturany, 1896)
*Myrtea spinifera* (Montagu, 1803)
**Thyasiridae**
*Axinulus eumyarius* (Sars M., 1870)
*Thyasira biplicata* (Philippi, 1836)
*Thyasira flexuosa* (Montagu, 1803)
*Thyasira granulosa* (Monterosato, 1874)
**Ungulinidae**
*Diplodonta brocchii* (Deshayes, 1850)
*Diplodonta rotundata* (Montagu, 1803)
**Chamidae**
**Chama asperella* Lamarck, 1819
*Chama circinata* Monterosato, 1878
*Chama gryphoides* Linnaeus, 1758
*Pseudochama gryphina* (Lamarck, 1819)
**Galeommatidae**
*Galeomma turtoni* Turton, 1825
**Kelliidae**
*Bornia sebetia* (Costa O.G., 1829)
*Kellia suborbicularis* (Montagu, 1803)
**Lasaeidae**
*Hemilepton nitidum* (Turton, 1822)
*Lepton squamosum* (Montagu, 1803)
**Montacutidae**
*Kurtiella bidentata* (Montagu, 1803)
*Mancikellia parrussetensis* (Giribet and Penas, 1999)
*Tellimya ferruginosa* (Montagu, 1808)
**Neoleptonidae**
*Neolepton sulcatulum* (Jeffreys, 1859)
**Sportellidae**
*Sportella recondita* (Fischer P. in de Folin, 1872)
**Carditidae**
*Cardita calyculata* (Linnaeus, 1758)
*Centrocardita aculeata* (Poli, 1795)
*Glans trapezia* (Linnaeus, 1767)
**Astartidae**
*Astarte fusca* (Poli, 1791)
*Astarte sulcata* (da Costa, 1778)
*Gonilia calliglypta* (Dall, 1903)
**Cardiidae**
*Acanthocardia aculeata* (Linnaeus, 1758)
*Acanthocardia deshayesii* (Payraudeau, 1826)
*Acanthocardia echinata* (Linnaeus, 1758)
*Acanthocardia paucicostata* (Sowerby G.B.II., 1834)
*Acanthocardia spinosa* (Lightfoot, 1786)
*Acanthocardia tuberculata* (Linnaeus, 1758)
*Cerastoderma glaucum* (Bruguiere, 1789)
*Laevicardium crassum* (Gmelin, 1791)
*Laevicardium oblongum* (Gmelin, 1791)
*Papillicardium papillosum* (Poli, 1791)
*Parvicardium exiguum* (Gmelin, 1791)
*Parvicardium minimum* (Philippi, 1836)
*Parvicardium pinnulatum* (Conrad, 1831)
*Parvicardium scabrum* (Philippi, 1844)
**Mactridae**
*Mactra glauca* Born, 1778
*Mactra stultorum* (Linnaeus, 1758)

*Spisula subtruncata* (da Costa, 1778)
**Mesodesmatidae**
*Donacilla cornea* (Poli, 1791)
**Solenidae**
*Solen marginatus* Pulteney, 1799
**Pharidae**
*Ensis ensis* (Linnaeus, 1758)
*Ensis minor* (Chenu, 1843)
*Ensis siliqua* (Linnaeus, 1758)
*Pharus legumen* (Linnaeus, 1758)
*Phaxas pellucidus* (Pennant, 1777)
**Tellinidae**
*Arcopagia balaustina* (Linnaeus, 1758)
*Gastrana fragilis* (Linnaeus, 1758)
*Macoma cumana* (Costa O.G., 1829)
*Tellina albicans* Gmelin, 1791
*Tellina distorta* Poli, 1791
*Tellina donacina* Linnaeus, 1758
*Tellina fabula* Gmelin, 1791
*Tellina incarnata* Linnaeus, 1758
*Tellina planata* Linnaeus, 1758
*Tellina pulchella* Lamarck, 1818
*Tellina pygmaea* Loven, 1846
*Tellina serrata* Brocchi, 1814
*Tellina tenuis* da Costa, 1778
**Donacidae**
*Capsella variegata* (Gmelin, 1791)
*Donax trunculus* Linnaeus, 1758
*Donax venustus* Poli, 1795
**Psammobiidae**
*Gari costulata* (Turton, 1822)
*Gari depressa* (Pennant, 1777)
*Gari fervensis* (Gmelin, 1791)
**Semelidae**
*Abra alba* (Wood W., 1802)
*Abra longicallus* (Scacchi, 1835)
*Abra nitida* (Müller O.F., 1776)
*Abra prismatica* (Montagu, 1808)
*Abra segmentum* (Recluz, 1843)
*Scrobicularia plana* (da Costa, 1778)
**Solecurtidae**
*Azorinus chamasolen* (da Costa, 1778)
*Solecurtus scopula* (Turton, 1822)
*Solecurtus strigilatus* (Linnaeus, 1758)
**Kelliellidae**
*Kelliella miliaris* (Philippi, 1844)
**Vesicomyidae**
*Isorropodon perplexum* Sturany, 1896
**Trapezidae**
*Coralliophaga lithophagella* (Lamarck, 1819)
**Glossidae**
*Glossus humanus* (Linnaeus, 1758)
**Veneridae**
*Callista chione* (Linnaeus, 1758)
*Chamelea gallina* (Linnaeus, 1758)
*Clausinella fasciata* (da Costa, 1778)
*Dosinia exoleta* (Linnaeus, 1758)
*Dosinia lupinus* (Linnaeus, 1758)
*Globivenus effossa* (Philippi, 1836)
*Gouldia minima* (Montagu, 1803)
*Irus irus* (Linnaeus, 1758)
*Mysia undata* (Pennant, 1777)
*Petricola lithophaga* (Retzius, 1788)
*Pitar mediterraneus* (Aradas and Benoit, 1872)
*Pitar rudis* (Poli, 1795)
*Polititapes aureus* (Gmelin, 1791)
*Polititapes rhomboides* (Pennant, 1777)
*Ruditapes decussatus* (Linnaeus, 1758)
**Ruditapes philippinarum* (Adams and Reeve, 1850)
*Timoclea ovata* (Pennant, 1777)
*Venerupis corrugata* (Gmelin, 1791)
*Venus casina* Linnaeus, 1758
*Venus nux* Gmelin, 1791
*Venus verrucosa* Linnaeus, 1758
**Myidae**
**Mya arenaria* Linnaeus, 1758
*Sphenia binghami* Turton, 1822
**Corbulidae**
*Corbula gibba* (Olivi, 1792)
*Lentidium mediterraneum* (Costa O.G., 1829)
**Gastrochaenidae**
*Gastrochaena dubia* (Pennant, 1777)
**Hiatellidae**
*Hiatella arctica* (Linnaeus, 1767)
*Hiatella rugosa* (Linnaeus, 1767)
**Basterotiidae**
*Saxicavella jeffreysi* Winckworth, 1930
**Pholadidae**
*Barnea candida* (Linnaeus, 1758)

*Pholas dactylus* Linnaeus, 1758
**Teredinidae**
*Bankia carinata* (Gray J.E., 1827)
*Lyrodus pedicellatus* (de Quatrefages, 1849)
*Nototeredo norvagica* (Spengler, 1792)
*Teredo navalis* Linnaeus, 1758
**Xylophagaidae**
*Xylophaga dorsalis* (Turton, 1819)
**Thraciidae**
*Thracia convexa* (Wood W., 1815)
*Thracia corbuloidea* de Blainville, 1827
*Thracia distorta* (Montagu, 1803)
*Thracia phaseolina* (Lamarck, 1818)
*Thracia pubescens* (Pulteney, 1799)
**Pandoridae**
*Pandora inaequivalvis* (Linnaeus, 1758)
*Pandora pinna* (Montagu, 1803)
**Poromyidae**
*Poromya granulata* (NystandWestendorp, 1839)
**Cuspidariidae**
*Cardiomya costellata* (Deshayes, 1835)
*Cuspidaria cuspidata* (Olivi, 1792)
*Cuspidaria rostrata* (Spengler, 1793)
*Tropidomya abbreviata* (Forbes, 1843)

**SCAPHOPODA**

**Dentaliidae**
*Antalis dentalis* (Linnaeus, 1758)
*Antalis inaequicostata* (Dautzenberg, 1891)
*Antalis vulgaris* (da Costa, 1778)
**Fustiariidae**
*Fustiaria rubescens* (Deshayes, 1825)
**Entalinidae**
*Entalina tetragona* (Brocchi, 1814)

**CEPHALOPODA**

**Sepiidae**
*Sepia elegans* Blainville, 1827
*Sepia officinalis* Linnaeus, 1758
*Sepia orbignyana* Ferrussac, 1826
**Sepiolidae**
*Rondeletiola minor* (Naef, 1912)
*Sepietta neglecta* Naef, 1916
*Sepietta obscura* Naef, 1916
*Sepietta oweniana* d'Orbigny, 1841
*Sepiola rondeletii* Leach, 1817
**Loliginidae**
*Alloteuthis media* (Linnaeus, 1758)
*Loligo vulgaris* Lamarck, 1798
**Ommastrephidae**
*Illex coindetii* (Vérany, 1839)
*Todarodes sagittatus* (Lamarck, 1798)
*Todaropsis eblanae* (Ball, 1841)
**Chiroteuthidae**
*Chiroteuthis veranii* (Férussac, 1835)
**Octopodidae**
*Callistoctopus macropus* (Risso, 1826)
*Eledone cirrhosa* (Lamarck, 1798)
*Eledone moschata* (Lamarck, 1798)
*Octopus vulgaris* Cuvier, 1797

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## ECHINODERM FAUNA OF THE SEA OF MARMARA, TURKEY

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### 1. Introduction

Echinoderms play a vital role in the marine ecosystems since they are globally distributed in almost all depths, latitudes and environments in the ocean and it has been estimated that they capture and sequester about 0.1 gigatonnes of carbon per year as calcium carbonate, making them important contributors in the global carbon cycle (Lebrato *et al.* 2010). They are relatively large invertebrates and could form dense aggregations. They play numerous ecological roles since they exhibit greatly different modes of feeding. Crinoids and some ophiuroids are suspension feeders; other ophiuroids can be scavengers, detritivore or voracious carnivores. Majority of starfish are active hunters and they are the keystone predators on the mussel banks. Most sea urchins are grazers. Sand dollars and sea cucumbers are deposit feeders; they burrow into the sand and actively feed on organic material in the sediment (Brusca and Brusca 2003; Pawson 2007).

The effects of nutrient enrichment, also known as eutrophication, are the greatest threat to the Sea of Marmara ecosystem. Undesirable effects of eutrophication are related to human activities that give rise to increased nutrient loads, dominance of gelatinous zooplankton (jellyfish) over crustacean zooplankton, increased sedimentation of organic matter to the seafloor, near-seafloor oxygen depletion, ultimately resulting in hypoxia or anoxia, and loss of higher life forms, including fish and bottom invertebrates (Morkoç *et al.* 1997; Klein and Perera 2002; Turkoglu 2013). Dense aggregations and high abundances of some echinoderm species observing in the Sea of Marmara can be interpreted as a consequence of the altering benthic biota and response of the ecosystem to the eutrophication.

### 2. Studies on the echinoderms in the Turkish Straits System (TSS)

According to the available literature (Table 1), the echinoderm species in the TSS were first reported by Colombo (1885), Ostroumoff (1894, 1896) and Marion (1898). More comprehensive studies were then conducted by Demir (1952) and Tortonese and Demir (1960) reporting 27 and 44 species, respectively. In the '90s, the reported number of echinoderm species increased to 58 with the contributions of the studies by Artüz (1967, 1968), Caspers (1968), Balkıs (1992), Özaydın *et al.* (1995) and Albayrak (1996).

The exotic species, *Asterias rubens* Linnaeus, 1758 in the Sea of Marmara was first reported by Albayrak (1996) and then by several other studies (Yüce and Sadler 2000; Altuğ *et al.* 2011; Aslan-Cihangir and Pancucci Papadopoulou 2012) and aslo from the Black Sea (Karhan *et al.* 2008). Later in the following ten years, although some studies reported echinoderm species (Uysal *et al.* 2002; Topaloğlu *et al.* 2004; Yazıcı 2004; Bayhan *et al.* 2006; Kalkan 2006; Çağlar 2008; Zengin and Akyol 2009), there was no addition to the number of species. The main contribution to our knowledge in these years was the quantitative data of some the echinoderms reported by Topaloğlu *et al.* (2004), Yazıcı (2004), Bayhan *et al.* (2006), and Zengin and Akyol (2009). Özgür and Öztürk (2010) reviewed the studies on the echinoderm fauna in the Sea of Marmara and the Istanbul Strait. After this date, seven species were added to the list by Altuğ *et al.* (2011), and Aslan-Cihangir and Pancucci Papadopoulou (2012).

The check-list of the echinoderm fauna of Turkey firstly was reported by Özaydın *et al.* (1995). Özgür *et al.* (2008) and Özgür-Özbek (2013) reviewed the list with the new findings from the Gulf of Antalya (E Mediterranean Sea). Recently the list was reviewed again by Öztoprak *et al.* (2014).

Later, Artüz *et al.* (2014), and Acarlı and Ayaz (2015) reported some echinoderm species from their samplings and Dereli *et al.* (2015), and Çulha *et al.* (2016) also contributed to the knowledge on *Holothuria tubulosa* in the TSS.

None of the studies realized in the TSS has investigated the temporal and spatial fluctuations of the echinoderms except for Aslan-Cihangir and Pancucci Papadopoulou (2012) in the Çanakkale Strait. So the knowledge on the abundance, biomass and distribution as well as the environmental factors affecting them is very scarce for the other regions in the TSS.

## 3. Echinoderms in the Turkish Straits System

Turkey is surrounded by four seas with different hydrographical characteristics and TSS (Çanakkale Strait, Sea of Marmara and İstanbul Strait) serve both as a biological corridor and barrier between the Aegean and Black Seas (Öztürk and Öztürk, 1996). Among the 92 echinoderm species (two Crinoidea, 24 Asteroidea, 24 Ophiuroidea, 20 Echinoidea and 22 Holothuroidea) reported from Turkey, 65 (two Crinoidea, 17 Asteroidea, 17 Ophiuroidea, 18 Echinoidea and 11 Holothuroidea) were reported from the TSS. The number of echinoderm species in the coasts of the TSS also varies due to the different biotic environments. There are 36 echinoderm species (two Crinoidea, 9 Asteroidea, 14 Ophiuroidea, 5 Echinoidea and 6 Holothuroidea) reported from the Çanakkale Strait, 58 (two Crinoidea, 17 Asteroidea, 12 Ophiuroidea, 18 Echinoidea and 9 Holothuroidea) from the Sea of Marmara, and 19 species (one Crinoidea, 4 Asteroidea, 4 Ophiuroidea, 4 Echinoidea and 6 Holothuroidea) from the İstanbul Strait. Most echinoderms cannot tolerate marked changes in salinity, temperature, and light intensity and tend to move away from areas where the salinity is below 15‰ (Binyon 1966). The low number of echinoderm species reported in the İstanbul Strait is probably related to the low salinity and high seasonal alterations in the hydrographical conditions. However, lower number of species reported from the Çanakkale Strait comparing to the Sea of Marmara, could possibly be related to the limited scientific efforts in this area.

Zoogeographical categories to which the echinoderm species are assigned are also presented in Table 1. The dominant components of the echinoderm fauna, in terms of number of species are the Atlanto-Mediterranean species accounting for 71.0% followed by the Mediterranean endemics (18%), the Cosmopolitan (2.9%) and the Indo-Pacific ones (1.4%). However, the record of the only Indo-Pacific species, *Asterias amurensis* Lutken, 1871 by Altuğ *et al.* (2011) should be considered as doubtful due to the possible confusion with the different color varieties of *A. rubens.*

**Table 1.** The list of studies on the echinoderm fauna of the Turkish Straits System [Çanakkale Strait (Ç.S.), Marmara Sea (M.S.) and Istanbul Strait (I.S.)]. Origin: Atlanto-Mediterranean (AM), endemic (E), cosmopolit (C), Indo-Pacific (IP).

| Reference No | G.O. | Ç.S. | M.S. | İ.S. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Crinoidea** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Antedon mediterranea* (de Lamarck, 1816) | E | + | + | + | + | | | | + | + | | | | + | | | | | + | | | | | + | | | |
| *Leptometra phalangium* (Müller, 1841) | E | + | + | | | | + | | | | | | | + | | | | | | | | | | | + | | |
| **Total** | | **2** | **2** | **1** | **1** | **0** | **1** | **0** | **1** | **1** | **0** | **0** | **0** | **2** | **0** | **0** | **0** | **0** | **1** | **0** | **0** | **0** | **0** | **1** | **1** | **0** | **0** |
| **Ophiuroidea** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Amphipholis squamata* (Delle Chiaje, 1829) | C | + | + | + | | + | | | + | + | | | | | + | | | | | | + | | | | + | | |
| *Amphiura cherbonnieri* Guille, 1972 | E | + | | | | | | | | | | | | | | | | | | | | | | | + | | |
| *Amphiura chiajei* Forbes, 1843 | AM | + | + | + | + | | + | | | + | | | | + | + | | + | | | | | | | | + | | |
| *Amphiura filiformis* (O.F. Müller, 1776) | AM | + | + | | | | + | | | + | | | + | | | | | | | | | | | | + | + | |
| *Amphiura lacazei* Guille, 1976 | E | + | | | | | | | | | | | | | | | | | | | | | | | + | | |
| *Amphiura* (*Ophiopeltis*) *securigera* (Düben & Koren, 1846) | AM | + | | | | | | | | | | | | | | | | | | | | | | | + | | |
| *Ophiacantha setosa* (Bruzelius, 1805) | AM | + | | | + | | | | | | | | | | | | | | | | | | | | | + | |
| *Ophiocten abyssicolum* (Forbes, 1843) | AM | | + | | | | + | | | | | | | | | | | | | | | | | | | | |
| *Ophioderma longicauda* (Bruzelius, 1805) | AM | + | + | | + | | | | | + | | | | | | | | | | | | | | | | | |
| *Ophiomyxa pentagona* (de Lamarck, 1816) | AM | + | + | | + | | | | + | + | | | | | | | | | | | | | | | + | + | |
| *Ophiopsila annulosa (M. Sars, 1859)* | AM | + | | | | | | | | | | | | | | | | | | | | | | | + | | |
| *Ophiopsila aranea* Forbes, 1845 | AM | + | + | | | | + | | | + | | | | | | | | | | | | | | | + | | |
| *Ophiothrix fragilis* (Abildgaard, in O.F. Müller, 1789) | AM | + | + | + | | | + | | + | + | | | | | + | | | | | | | | | | + | | |
| *Ophiothrix quinquemaculata* (D.Chiaje, 1828) | E | | + | | | | | | | | | | | + | | | | | | | | | | | | | |
| *Ophiura albida* Forbes, 1839 | AM | + | + | | + | | + | | + | + | | | + | | | | | | | + | | | | | + | | |
| *Ophiura grubei* Heller, 1863 | AM | | + | | | | | | | + | | | | | | | | | | | | | | | | | |
| *Ophiura ophiura* (Linnaeus, 1758) | AM | + | + | + | + | | + | | + | + | | | | + | + | | | | | | | | + | | + | + | |
| **Total** | | **14** | **12** | **4** | **6** | **1** | **7** | **0** | **5** | **10** | **0** | **0** | **2** | **3** | **4** | **0** | **1** | **0** | **0** | **1** | **1** | **0** | **1** | **0** | **12** | **4** | **0** |
| **Asteroidea** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Anseropoda placenta* (Pennant, 1777) | AM | + | + | | + | | | | | + | + | | + | + | | | | | | + | | | | | | + | |
| *Asterias amurensis* Lutken, 1871 | IP | | + | | | | | | | | | | | | | | | | | | | | | + | | | |

**Table 1.** continues

| Reference No | G.O. | Ç.S. | M.S. | İ.S. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Asterias rubens* Linnaeus, 1758 | AM | + | + | + | | | | | | | | | | | + | + | | | | | | | | + | + | | |
| *Asterina gibbosa* (Pennant, 1777) | AM | + | + | + | | | | | + | + | + | | | | + | | | | | | | | | | + | | |
| *Asterina pancerii* (Gasco, 1870) | E | + | + | | + | | | | | + | | | | | | | | | | | | | | | | | |
| *Astropecten aranciacus* (Linnaeus, 1758) | AM | | + | | | | | | | + | + | | | + | | | | + | | | | | | + | | | |
| *Astropecten bispinosus* (Otto, 1823) | AM | + | + | | + | | + | | + | + | + | | | | | | | | | | | | | | | + | |
| *Astropecten irregularis* (Pennant, 1777) | AM | + | + | + | | | + | | | + | + | | | + | + | | | + | | + | | | + | | + | | |
| *Astropecten jonstoni* (Delle Chiaje, 1827) | E | | + | | | | | | + | + | | | | | | | | | | | | | | | | | |
| *Astropecten platyacanthus* (Philippi, 1837) | E | + | + | | | + | | | | + | | | | | | | | | | | | | | | + | | |
| *Astropecten spinulosus* (Philippi, 1837) | E | | + | | | | | | + | + | + | | | | | | | + | | | | | | | | + | |
| *Coscinasterias tenuispina* (de Lamarck, 1816) | AM | | + | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Echinaster (Echinaster) sepositus* (Retzius, 1783) | AM | + | + | | + | | + | | + | + | | | | + | | | | + | | + | | | | + | | | |
| *Hacelia attenuata* Gray, 1840 | AM | + | + | | | | | | + | + | | | | + | | | | | | | | | + | | | | |
| *Luidia ciliaris* (Philippi, 1837) | AM | | + | | | | | | + | + | + | | | | | | | | | | | | | | | | |
| *Marthasterias glacialis* (Linnaeus, 1758) | AM | | + | + | | + | | + | + | + | + | | + | + | + | | | + | + | + | | + | + | + | | + | + |
| *Peltaster placenta* (J. Müller & Troschel, 1842) | AM | | + | | | | | | + | + | + | | | | | | | + | | | | | | | | | |
| **Total** | | **9** | **17** | **4** | **4** | **2** | **3** | **1** | **9** | **14** | **9** | **0** | **3** | **6** | **4** | **1** | **0** | **6** | **1** | **4** | **0** | **1** | **3** | **5** | **4** | **4** | **1** |
| **Echinoidea** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Arbacia lixula* (Linnaeus, 1758) | AM | | + | | | + | + | | | | | | | | | | | | | | | | | | | | |
| *Brissopsis lyrifera* (Forbes, 1841) | AM | | + | | | | + | | + | + | | + | | + | | | | | | | | | + | | | | |
| *Brissopsis atlantica mediterranea* Mortensen, 1913 | AM | | + | | | | | | | | | | | | | | | | | | | | | + | | | |
| *Brissus unicolor* (Leske, 1778) | AM | | + | | | | | | | | | | + | | | | | | | | | | | | | | |
| *Centrostephanus longispinus* (Philippi, 1845) | AM | | + | | | | | | + | + | | + | | | | | | | | | | | | | | | |
| *Cidaris cidaris* (Linnaeus, 1758) | AM | | + | | | | + | | | | | | | | | | | + | | | | | | | | | |
| *Echinocardium cordatum* (Pennant, 1777) | C | | + | | | | + | + | | | | | | | | | | | | | | | | | | | |
| *Echinocardium mediterraneum* (Forbes, 1844) | AM | | + | | | | | | | + | | | | | | | | | | | | | | | | | |
| *Echinocyamus pusillus* (O.F. Müller, 1776) | AM | + | + | + | | + | + | | + | + | | + | | | | | | | | | | | | | + | | |
| *Echinus melo* Lamarck, 1816 | AM | | + | | | | | | + | | | | | | | | | | | | | | | | | | |
| *Genocidaris maculata* A. Agassiz, 1869 | AM | + | + | | | | | | | + | | | | | | | | | | | | | | | + | | |

**Table 1.** continues

| Reference No | G.O. | Ç.S. | M.S. | İ.S. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Gracilechinus acutus* (Lamarck, 1816) | AM | | + | + | | | | | + | + | | + | | | | | | | | | | | | | | | |
| *Ova canaliferus* (Lamarck, 1816) | E | | + | | | | + | + | + | + | | | | | | | | | | | | | | | | | |
| *Paracentrotus lividus* (de Lamarck, 1816) | AM | + | + | + | | + | | | + | + | | + | + | | + | | | | | | | | | | + | | + |
| *Psammechinus microtuberculatus* (de Blainville, 1825) Heller, 1868 | E | + | + | + | + | | | + | | + | | + | | + | | | | | | | | | | | + | + | |
| *Spatangus purpureus* (O.F. Müller, 1776) | AM | | + | | | | + | | | + | | + | | | | | | + | | + | | | | | | + | |
| *Sphaerechinus granularis* (de Lamarck, 1816) | AM | + | + | | + | | + | | + | + | | + | | | | | | | | | | | | | | | |
| *Stylocidaris affinis* (Philippi, 1845) | AM | | + | | | | | | + | + | | + | | | | | | | | | | | | | | | |
| **Total** | | **5** | **18** | **4** | **2** | **3** | **8** | **3** | **9** | **12** | **0** | **9** | **2** | **2** | **1** | **0** | **0** | **2** | **0** | **1** | **0** | **0** | **1** | **1** | **4** | **2** | **1** |
| **Holothuroidea** | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| *Holothuria (Holothuria) tubulosa* Gmelin, 1791 | AM | + | + | + | + | | | | + | + | | | | | | | | | + | | | | + | | | | + |
| *Oestergrenia digitata* (Montagu, 1815) | AM | | + | + | | + | | | | + | | | | | | | | | | | | | | | | | |
| *Leptopentacta elongata* (Düben & Koren, 1846) | AM | | + | + | | | + | | | + | | | | | + | | | | | | | | | | | | |
| *Leptopentacta tergestina* (M. Sars, 1857) | AM | + | + | | | | | | | + | | | | + | | | | | | | | | + | | + | + | |
| *Leptosynapta inhaerens* (O.F. Müller, 1776) | AM | + | + | + | | | | | + | + | | | | | | | | | | | | | | | + | | |
| *Pseudocnus dubiosus koellikeri* (Semper, 1868) | AM | + | + | | | | | | | | | | | + | | | | | | | | | | | | | |
| *Ocnus planci* (Brandt, 1835) | AM | | + | + | | | + | | + | + | | | + | | | | | + | | | | | | + | | + | |
| *Parastichopus regalis* (Cuvier, 1817) | AM | + | + | | + | | | | | + | | | + | + | | | | + | | + | | | | + | | | |
| *Phyllophorus (Phyllophorus) urna* Grube, 1840 | E | | + | | | | + | | | | | | + | | | | | | | | | | | | | | |
| *Stereoderma kirchsbergii* (Heller, 1868) Panning, 1949 | AM | | | + | | + | | | | | | | | | + | | | | | | | | | | | | |
| *Thyone fusus* (O.F. Müller, 1776) | E | + | | | | | | | | | | | | | | | | | | | | | | | + | | |
| **Total** | | **6** | **9** | **6** | **2** | **2** | **3** | **0** | **3** | **7** | **0** | **0** | **3** | **3** | **2** | **0** | **0** | **2** | **1** | **1** | **0** | **0** | **2** | **2** | **3** | **2** | **1** |
| **Overall Total** | **65** | **36** | **58** | **19** | **15** | **8** | **22** | **4** | **27** | **44** | **9** | **9** | **10** | **16** | **11** | **1** | **1** | **11** | **3** | **7** | **1** | **1** | **7** | **9** | **24** | **12** | **3** |

References in the Table 1: **1)** Colombo (1885), **2)** Ostroumoff (1894), **3)** Ostroumoff (1896), **4)** Marion (1898), **5)** Demir (1952), **6)** Tortonese and Demir (1960), **7)** Artüz (1967), **8)** Artüz (1968), **9)** Balkıs (1992), **10)** Özaydın *et al.* (1995), **11)** Albayrak (1996), **12)** Yüce and Sadler (2000), **13)** Uysal *et al.* (2002), **14)** Topaloğlu *et al.* (2004), **15)** Yazıcı (2004), **16)** Bayhan *et al.* (2006), **17)** Kalkan (2006), **18)** Çağlar (2008), **19)** Zengin and Akyol (2009), **20)** Altuğ *et al.* (2011), **21)** Aslan Cihangir and Pancucci Papadopoulou (2012), **22)** Artüz *et al.* (2014), **23)** Acarlı and Ayaz (2015)

## 4. Abundance and biomass data of the echinoderms in the Turkish Straits System

According to the results of 12 trawl hauls conducted between the depths of 33-298 m in the Sea of Marmara, 3270 individuals of thirteen echinoderm species were sampled. Among them, *Spatangus purpureus* (1856 ind.) had the highest number of individuals, following by *Astropecten spinulosus* (940 ind.), *Astropecten irregularis* (164 ind.), *Ophiura* sp. (161 ind.), *Marthasterias glacialis* (58 ind.), *Parastichopus regalis* (37 ind.), *Ocnus planci* (18 ind.), Asteroidea (sp.) (18 ind.), *Antedon mediterranea* (8 ind.), *Cidaris cidaris* (6 ind.), *Astropecten aranciacus* (2 ind.), *Echinaster sepositus* (1 ind.), and *Peltaster placenta* (1 ind.) (Topaloğlu *et al.* 2004).

According to the results of 23 beam-trawl hauls conducted at the depths of 42-86 m in the South of the Sea of Marmara, 1351 individuals of seven echinoderm species constitutes 4.94% of the total number of individuals of the by-catch. The echinoderm species with the highest individual number was reported as *P. regalis* (606 ind.), following by *A. irregularis* (576 ind.), *E. sepositus* (66 ind.), *S. purpureus* (47 ind.), *Anseropoda placenta* (29 ind.), *M. glacialis* (21 ind.) and *Ophiura albida* (6 ind.) (Bayhan *et al.* 2006).

According to the results of 32 beam-trawl hauls at the depths between 44-110 m in the Sea of Marmara, 1714 individuals of seven echinoderm species with a total weight of 12.31 kg constitutes 10.08% of the total number of individuals and 6.80% of the total weight of the by-catch. The echinoderm species with the highest individual number was reported as *A. irregularis* (1360 ind., 2.97 kg), following by *Brissopsis lyrifera* (222 ind., 7.12 kg) and *M. glacialis* (91 ind., 2.02 kg) (Zengin and Akyol 2009).

According to the van Veen grab samples collected from the Çanakkale Strait, the abundance of 25 echinoderm species was calculated as1636 ind.$m^{-2}$ (Ophiuroidea (970 ind. $m^{-2}$), Echinoidea (603 ind. $m^{-2}$), Asteroidea (51 ind. $m^{-2}$), Holothuroidea (9 ind. $m^{-2}$), and Crinoidea (3 ind. $m^{-2}$) and the biomass as 1714.98 g $m^{-2}$. The most important species were reported as *Echinocyamus pusillus* (484 ind. $m^{-2}$), *Amphipholis squamata* (390 ind. $m^{-2}$), *and Ophiothrix fragilis* (294 ind. $m^{-2}$), representing 71% of the total abundance (Aslan-Cihangir and Pancucci Papadopoulou 2012).

According to the beam-trawl sampling at 53 m depth realized in a hydrothermal vent site in Gemlik Bay, 93 individuals of twelve echinoderm species with a total weight of 1845 g were collected by Artüz *et al.* (2014). *M. glacialis* (26 ind., 432 g) had the highest number of individuals, following by *Astropecten bispinosus* (15 ind., 210 g) and *S. purpureus* (13 ind., 342 g).

Photos of the echinoderm species taken both from the trawl and beam-trawl samplings and the scientific underwater surveys in the TSS were given below (Photo 1-20). Underwater photos were taken from the hard substrates and Mediterranean mussel banks (*Mytilus galloprovincialis*) in 2007, during the TUBITAK Project no. 105Y039 and the results were published by Altuğ *et al.* (2011). *O. fragilis*, *A. rubens*, *M.glacialis,* and *P. lividus* were observed to form dense aggregations on the Mediterranean mussel banks and *H. tubulosa* was also present near the banks. *A. mediterranea* beds were observed above rocky substrates at the depths between 30-45 m, and *E. melo* and *E. sepositus* were also present at this depth level. Photo of the *S. purpureus* from the catch of the trawl in the Gulf of Izmit were taken during the survey of R/V Yunus (Istanbul University) in 2001 and the results of the survey were published by Topaloğlu *et al.* (2004). Photos from the catch of the beam-trawl taken during the TAGEM Project, in 2012 were provided by Mukadder Arslan İhsanoğlu and as reported by the previous studies, *S. purpureus, Astropecten* sp., *Ophiura* sp., *M.glacialis,* and *P. regalis* were seen to be the most abundant echinoderm species in the soft substrates of TSS.

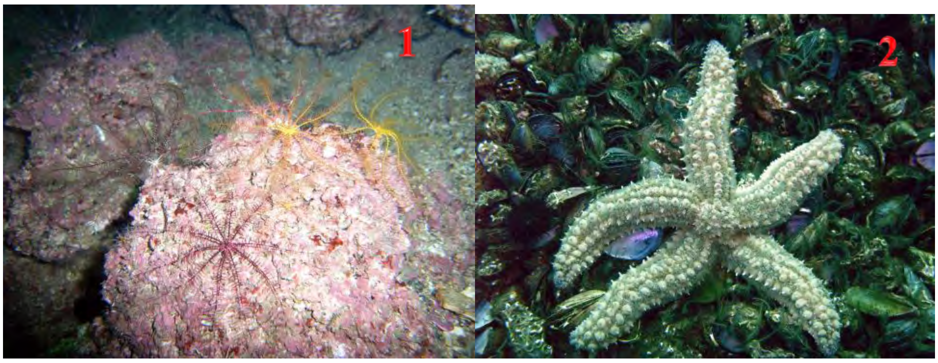


**Photo 1.** *Antedon mediterranea* in Fener Adası, 2007 by Elif ÖZGÜR ÖZBEK (EÖÖ)

**Photo 2.** High abundance of *Ophiothrix fragilis*, together with *Marthasterias glacialis* on a Mediterranean mussel bank (*Mytilus galloprovincialis*) in Marmara Island, 2007 by EÖÖ

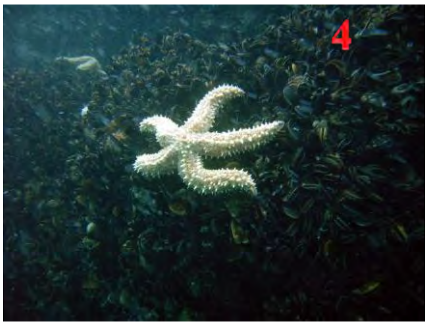


**Photo 3.** High abundance of *M. glacialis* on a Mediterranean mussel bank (*M. galloprovincialis*) in Fener Island, 2007 by EÖÖ

**Photo 4.** *M. glacialis* on a Mediterranean mussel bank (*M. galloprovincialis*) in Koyun Island, 2007 by EÖÖ


**Photo 5.** High abundance of *O. fragilis* and *Paracentrotus lividus* together with *M. glacialis* on a Mediterranean mussel bank (*M. galloprovincialis*) in Marmara Island, 2007 by EÖÖ

**Photo 6.** *M. glacialis* and *P. lividus* on a Mediterranean mussel bank (*M. galloprovincialis*) in Fener Island, 2007 by EÖÖ



**Photo 7.** *Asterias rubens* and *M. glacialis* on a Mediterranean mussel bank (*M. galloprovincialis*) in Yassıada Island, 2007 by EÖÖ

**Photo 8.** High abundance of *O. fragilis* together with *P. lividus* and *A. rubens* on a Mediterranean mussel bank (*M. galloprovincialis*) in Marmara Island, 2007 by EÖÖ



**Photo 9.** *A. rubens* and *P. lividus* in the Sea of Marmara by Ateş EVİRGEN

**Photo 10.** High abundance of *O. fragilis* together with *A. rubens* on a Mediterranean mussel bank (*M. galloprovincialis*) in Fener Island, 2007 by EÖÖ



**Photo 11.** *Echinaster sepositus, M. glacialis*, and *P. lividus* in Fener Adası, 2007 by Bülent TOPALOĞLU

**Photo 12.** *P. lividus* in Fener Adası, 2007 by Bülent TOPALOĞLU


**Photo 13.** *Echinus melo* in Fener Adası, 2007 by EÖÖ
**Photo 14.** *Holothuria (Holothuria) tubulosa* in Marmara Adası, 2007 by EÖÖ


**Photo 15.** *Spatangus purpureus* from the catch of trawl in the Gulf of İzmit, 2001 by EÖÖ
**Photo 16.** *S.purpureus* from the catch of beam-trawl in Kumbağ- Barbaros, 2012 by Mukadder Arslan İhsanoğlu (MAİ)


**Photo 17.** *S.purpureus* from the catch of beam-trawl in Ambarlı, 2012 by MAİ
**Photo 18.** *Astropecten* sp. from the catch of beam-trawl in Kapıdağ Peninsula, 2012 by MAİ


**Photo 19.** *Astropecten* sp., *M. glacialis*, *Ophiura* sp., and *S. purpureus* from the catch of beam-trawl in Bursa, 2012 by MAİ

**Photo 20.** *Parastichopus regalis* from the catch of beam-trawl in the Sea of Marmara, 2012 by MAİ

## 5. Conclusion

The echinoderm species are increasingly becoming a subject of study in the Mediterranean Sea because of their ecological roles in the ecosystem and usage as indicator organisms for monitoring the alterations in the ecosystem (Francour *et al.* 1994, Hereu Fina 2004, Sala 2004, Tuya *et al.* 2004, Hereu *et al.* 2005, Tuya *et al.* 2006, Dupon *et al.* 2010). From the results of the present studies, it can be understood that the echinoderms constitute an important role and amount in the TSS marine ecosystem. However, there is a big gap in our knowledge on their spatio-temporal distribution of abundance, biomass and the factors affecting them. Thus, long-term and holistic approaches are required to monitor the TSS marine ecosystem to evaluate and predict the consequences of various anthropogenic impacts on TSS.

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# SEABIRDS IN THE SEA OF MARMARA

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## 1. Introduction

Turkey is an important biodiversity hotspot due to its location that forms a bridge between different continents. Bird diversity in Turkey is therefore very high (Kirwan *et al*. 2008). Just as the country itself, the Sea of Marmara connects the Black Sea and the Mediterranean through two narrow straits and providing a passageway for the seabirds.

The Marmara region is internationally recognized for its importance for migratory soaring birds such as raptors and storks, which use the narrow land bridge to travel from Europe to Africa without having to cross the Mediterranean Sea. Perpendicular to the migration of landbirds, seabirds travel through the Sea of Marmara to reach either the Black Sea or to the Mediterranean Sea, but the information on and interest in seabirds in the region is poor. Seabirds are marine top predators; they exploit a wide variety of marine organisms in the food web and therefore reflect the dynamics of marine environment (Camphuysen 2006). We can use such information to set management priorities for sustainable use of our seas. This chapter aims at gathering the available information on the current status of seabirds in the Sea of Marmara as well as providing broad information on seabirds and their biology.

### 1.1. What is a seabird?

There is not a single definition of seabirds. Very often seabirds are defined as birds that depend completely or partly on marine resources for living (Schreiber and Burger 2002). Seabirds are also described as birds that spend some time in the offshore marine environment rather than just wading into it, as do shorebirds (Furness and Monaghan 1987). They breed on offshore islands or coastal zones that are related with the marine environment.

Seabirds are grouped under eight major orders (Croxall *et al*. 2012) of which Turkey hosts at least one group except Penguins and Tropicbirds (Table 1).

**Table 1:** The major orders and seabird groups belonging to these orders

| Order | Type of Seabirds |
|---|---|
| Anseriformes | Sea ducks |
| Gaviiformes | Divers |
| Sphenisciformes | Penguins |
| Procellariiformes | Albatrosses, Petrels, Shearwaters |
| Podicipediformes | Grebes |
| Phaethontiformes | Tropicbirds |
| Pelecaniformes | Pelicans |
| Suliformes | Frigatebirds, Gannets, Boobies, Cormorants |
| Charadriiformes | Phalaropes, Gulls, Terns, Skuas, Auks |

### 1.2. Adaptations to Marine Life

Seabirds display a huge variation in size, general appearance, and life style. For instance, a streamlined wandering albatross with its 3-4m wingspan has little similarity to a plump, flightless sea duck species. Despite this diversity, seabirds share common features as they all have adapted to living at least partly in the marine environment.

Life at sea is not easy; the salt water, dynamic and rather unpredictable distribution of resources and vastness are just a few challenges that seabirds face when compared to terrestrial birds. Feeding in the marine environment requires adaptations to deal with high salt loads. Seabirds cope with this problem through salt glands. These glands are located in the eye orbit and act as an additional kidney to take the excess salt out of the body by secreting solutions with high sodium chloride (NaCl) content (Goldstein 2002). This secretion then drips from the narrow tubes located on the beak. Seabirds also limit their salt-water intake by getting most of the water from the fresh food they eat such as fish with high water content.

Although the distribution of resources at sea is not completely unpredictable to seabirds (Weimerskirch 2007) they mostly need to travel long distances to exploit rich resource patches such as upwelling areas. To cope with the cost of flying some species use the vertical gradient of wind velocity (wind shear) that forms over the water surface and soar without flapping their wings (Alexander 2004). These species have long and narrow wings that allow them to use the wind shear. By climbing the vertical wind gradient and gliding back into the surface these birds can travel long distances with minimum energy (Weimerskirch *et al.* 2000). This flight strategy is called dynamic soaring and it is common among albatrosses and some large shearwaters such as Scopoli’s shearwater, which can be seen soaring in the Aegean and the Mediterranean Seas.

Most seabirds also have waterproof plumage, which facilitates the life in marine environment. Through a gland on the upper base of the tail that secretes waxes and fats, these species can spread wax across the feathers regularly to keep them waterproof. Some groups such as cormorants and shags do not have these glands so they have to air-dry their feathers by frequently returning to land.

Seabirds have adaptations for swimming and diving. Wing and body shape have evolved to be aerodynamic in species that obtain their food by diving. Webbed feet to swim on water, hooked beaks to help catching fish or squid, a bullet shaped body to dive efficiently and black-white (dull) colouring to prevent predation while being less conspicuous to prey are other examples of adaptations to marine life (Schreiber and Burger 2002).

### 1.3. Seabird Feeding and Breeding

Seabirds spend most of their lives at sea but they are bound to land during the breeding season. This dual existence in marine and terrestrial environment has shaped the foraging and breeding behaviour of seabirds.

The rich habitat diversity in marine environments provide diverse food options and seabirds have evolved a wide variety of foraging strategies at sea. Beside this diversity, some species take benefit of fisheries to feed on discards while some others exploit domestic waste products. The differences in seabird foraging strategies can broadly be attributed to the variation in body size, flight and diving capacity and location of breeding colonies (e.g. offshore islands, coastal areas). Among the sources of food for seabirds the most common are fish, squid, crustaceans, krill and plankton (Furness and Monaghan 1987; Shealer 2002).

Some examples of foraging strategies of the species in Turkish seas are described below. Cormorants dive from the surface and pursue their prey by using their feet for propulsion under water (pursuit diving), while shearwaters do the same but use their wings for propulsion. Gannets and terns make a quick dive from 2 - 40 m above the water surface to catch prey up to 5 m under water using gravity to accelerate as they lack the ability of propulsion under water (surface plunging). Scaups and eiders dive and feed on the bottom of the sea in coastal waters (bottom feeding). Shearwaters see the prey and dive either from the surface or air to pursue it in offshore waters (pursuit plunging). Storm petrels patter with their long legs and webbed feet on the surface to stay above the water and locate the planktonic prey on the surface (pattering). Skuas are kleptoparasites; they chase other seabirds such as gulls or terns to rob their prey (aerial pursuit) (Ashmole 1971).

With the recent increase in fishing activities some seabirds have adapted to feed on fisheries waste products. Some gull and shearwater species can be seen following fishing boats to benefit from discards. Although shearwaters can dive down to 55 meters to pursue their prey (Shoji *et al.* 2016) feeding on discards is common in areas where fishing activities are high (Bartumeus *et al*. 2010).

During the breeding season seabirds commute between land and sea; they need to balance the cost of travelling as they need to carry food to the chicks, therefore species' foraging range are different in breeding and non-breeding seasons (Thaxter *et al*. 2012). Seabirds often prefer coastal areas or offshore islands and islets for nesting, mostly because these islands used to be safe from predators before humans transported mammals to various islands.

Seabirds are long-lived organisms. They start breeding very late and spend several non-breeding "bachelor" years to gaining experience on foraging for resources with patchy distribution. Once they start breeding they produce very few offspring at once; most seabirds lay a single egg per season. The incubation and chick rearing period takes several months in most seabird species. For some of the largest species raising a single chick takes so long (>12 months) that they can only breed every two years.

Because seabirds are long-lived, and adult survival rates are generally very high, they have relatively constant population sizes that fluctuate much less than for smaller birds with high fecundity and low adult survival. The seabird population size is greatly regulated by adult survival rather than fecundity (Oro *et al*. 2004). Low reproductive potential, combined with high site fidelity and monogamy (mating for a season or for life) makes seabirds one of the most vulnerable groups to global change.

## 2. Seabirds in the Sea of Marmara

Marmara is the most developed and populated socio-economic region in Turkey. As a result, the Sea of Marmara is under tremendous anthropogenic pressure and its biodiversity is heavily affected by this pressure (Beauchard *et al*. 2014). Seabirds are at the upper level of the marine food web and one of the most informative indicators about the health of the marine environment. However due to little interest and expertise, there is no detailed study available on the seabird populations in the Sea of Marmara. Most of the information in this chapter is gathered from records on eBird; a database where bird watchers upload their sightings (eBird 2012). These data is biased, as there is a strong bias in birdwatcher density towards large cities, and it is limited to the coastal area. To fill the gap in offshore data, personal observations from cargo ships travelling between the north and south coast of the Sea of Marmara are used. However, these are not truly representative as the spatio-temporal range of these observations is very narrow. Seabird taxonomy is also controversial. Several lists classifying different species as seabirds are available. The most current seabird list, which is published by Croxall *et al*. (2012) used in this chapter. The taxonomy in this list is accepted by International Ornithologists' Committee (IOC) (Gill and Donsker 2016).

The Sea of Marmara is a passageway between the Black Sea and the Mediterranean Sea. The majority of Seabird species use the area during passage or wintertime. A total of 46 seabird species has been recorded in the Sea of Marmara; 6 species as breeding; 3 as resident but non-breeder; 21 as winter visitors; 6 as passage migrants and 8 species have only been recorded as vagrants. Family level details on these species are given below for the full list please refer to the table under the "Checklist" section.

### 2.1. Wildfowl (Anatidae)

Seabirds in the wildfowl family consist of ducks that prefer the marine environment at least in one stage of their life cycle. These ducks generally breed at higher latitudes. Most of them visit the Sea of Marmara during wintertime and use estuarine habitats such as Büyükçekmece Lagoon, Kocaçay Delta and İzmit Bay. Some routinely winter at sea such as common eider and velvet scoter. Although most wildfowl is gregarious during winter, the groups visiting the Sea of Marmara are rather loose, consisting of few individuals, because the core winter distribution of these species is in more northerly regions.

Members of this group feed in shallow waters, and collect their food by diving. Therefore all species can be seen in coastal waters. On the other hand there isn't too much at sea observation in the Sea of Marmara during winter months. Therefore a knowledge gap exists on the at sea distribution of wildfowl. Wildfowl species in the Sea of Marmara are listed in the table under "Checklist" section.

### 2.2. Divers (Gaviidae)

Divers (or Loons) are large water birds with long body, long neck and pointed beak. They are good at swimming and diving but they are unable to walk on land as their feet are placed on the very back of the body. They rarely approach land outside their breeding grounds in sub-arctic and arctic latitudes. Three species from this family has recorded in the Sea of Marmara. Red-throated diver (*Gavia stellata*) and black-throated diver (*Gavia arctica*) regularly visit the region during winter months and great northern diver (*Gavia immer*) has only historical records (Kirwan *et al*. 2008). These species feed predominantly on fish and are very sensitive to disturbance by ships. They prefer inshore waters with sheltered coasts away from shipping lanes. The majority of the records in the area is from coastal lagoons or wetlands.

### 2.3. Tubenoses (Procellariidae)

Members of the Tubenoses family are exclusively seabirds with a strong adaptation to feed on pelagic marine organisms. Two members of this family occur in the Sea of Marmara; the Yelkouan shearwater (*Pufinus yelkouan*) and the Scopoli's shearwater (*Calonectris diomedea*). The Scopoli's shearwater is mostly a vagrant that infrequently enters the Marmara Sea from its breeding grounds in the Aegean and the Mediterranean Sea. On the other hand, the Yelkouan shearwater uses the Turkish Straits intensively, and the world's largest concentrations of this species have been observed in the Bosporus. Groups of Yelkouan shearwaters commute nonstop between the Black Sea and the Aegean Sea during the day.

The Yelkouan shearwater is endemic to the Mediterranean Basin and its conservation status is under discussion due to the fact that there is no data on the species from the eastern Mediterranean. A large proportion of the global Yelkouan shearwater population congregates in the Turkish Straits in February –especially in the Bosporus – and therefore the Turkish Strait System is of critical importance in the conservation of the species (Şahin and Oppel, *in litt*).

### 2.4. Grebes (Podicipedidae)

Grebes are small to medium-sized diving birds and greatly related with freshwater. They use marine habitats; namely estuaries and coastal inshore waters during winter. Three members of the family visit the Sea of Marmara and great crested grebes breed in lakes around the Sea of Marmara. Although scarce, threatened horned grebes can be seen in lagoons of the Sea of Marmara during winter months. Grebe species in the Sea of Marmara are listed in the table under "Checklist" section.

### 2.5. Pelicans (Pelecanidae)

Pelicans are large birds with characteristic long beaks and large gular pouches. Two members of the family use the Sea of Marmara; the white pelican (*Pelecanus onocrotalus*) and the Dalmatian pelican (*Pelecanus crispus*). Both are entirely piscivorous; mostly rely on fish in the brackish water or fresh water. The white pelican is recorded in lakes and lagoons of the Sea of Marmara but the Dalmatian pelican is scarcer and more common in the south part of the area. Both species are passage migrants although there is a small breeding colony of the white pelicans in Lake Manyas.

### 2.6. Cormorants and Shags (Phalacrocoracidae)

The members of this family are large and dark birds. They have a long body with long neck and wings. These birds are great divers and chase their prey fish underwater. Their long and thick beaks have a hook at the tip to help catching the fish.

Two members of this family use the Sea of Marmara; the great cormorant (*Phalacrocorax carbo*) and the European shag (*Phalacrocorax aristotelis*). Both species breed in the region. Although using both habitats, the great cormorant is more related to freshwater but the European shag exclusively uses marine habitat. In the region, great cormorants breed in coastal lagoon and deltas while European shags prefer rocky shore adjacent to deep and clear waters.

A sub-species of the European shag (*Phalacrocorax aristotelis desmarestii*) is endemic to the Mediterranean Basin. This population is included in Annex II of the Bern Convention, and listed in Annex I of the Birds Directive 79/409. Local populations in the Mediterranean are mostly sedentary and show high philopatry (Sponza *et al*. 2013).

### 2.7. Gulls and Terns (Laridae)

Gulls are small to large seabirds with grey, white and black colouring when mature. During immature years gulls have darker brown and grey plumage. They have long and strong wings and strong legs that help them to adapt to terrestrial life better than other seabirds. Gulls are highly versatile and can exploit food sources on land and at sea, and few species are strictly marine birds, but terns are almost exclusively reliant on fish.

Gulls are represented with a total of 14 species in the Sea of Marmara. The majority of these species are winter visitors. However the yellow-legged gull is a common breeder in the region.

Terns are similar to gulls but they are smaller and slimmer. Tern species that use the marine environment are mostly pale grey and white colored; have long tail and black caps during breeding season. The little tern (*Sternula albifrons*) and the common tern (*Sterna hirundo*) are breeding in the southern part of the Sea of Marmara. Most of the other species are seen during migration and the sandwich tern (*Thalasseus sandvicensis*) is the only species that occur in the area throughout the year. Gulls and tern species in the Sea of Marmara are listed in the table under “Checklist” section.

### 2.8. Skuas

Skuas are the "pirates" of the seabirds. They chase other seabird species (mainly gulls) and rob their prey. Skuas form a small family and four members of this family can be seen in the Sea of Marmara; the great skua (*Stercorarius skua*); the pomarine skua (*Stercorarius pomarinus*); the parasitic jaeger (*Stercorarius parasiticus*) and the long-tailed jaeger (*Stercorarius longicaudus*). The great skua and the long-tailed jaeger are vagrant species. The pomarine skua and the parasitic jaeger are scarce winter visitors and occur in low numbers mostly during passage from their subarctic and arctic breeding grounds to pelagic wintering areas in the Atlantic Ocean. However as these species are highly pelagic, the coastal observations of the species may not be fully representative for their occurrence in the region.

## 3. Key Habitats to Seabirds in the Sea of Marmara

Despite being under high anthropogenic pressure the Sea of Marmara still holds important habitats for seabirds. BirdLife Turkey identified eight areas in the Marmara Region as important for seabirds (Eken *et al*., 2006). Species that use the Sea of Marmara for wintering predominately use coastal habitats such as estuaries and shores. Breeding species need rocky coasts, offshore islands and islets with minimum human disturbance.

### 3.1. Coastal Habitats

Coastal habitats are used as breeding, feeding and resting/roosting sites by seabirds. The Sea of Marmara provides sandy shores, rocky shores, estuaries and sea grass meadows as coastal habitat. Terns and gulls use sandy shores for feeding, resting or roosting. Shags and gulls use rocky shores for breeding. Cormorants and shags use sea grass meadows for feeding. And ducks, grebes, pelicans, and cormorants use estuarine habitats as feeding, wintering and breeding sites.

### 3.2. Open Sea

The open sea is of critical importance for Yelkouan shearwaters in the Sea of Marmara. Shearwaters feed on pelagic species in offshore waters. Any factor that is limiting the birds' ability to see the prey in the surface such as algal blooms, unexpected circulations due to severe weather and pollution threatens this species. Gulls, shags, skuas and divers also use offshore surface waters for feeding.

### 3.3. Offshore islands and islets

These habitats could provide breeding areas to species like the Yelkouan shearwater, European shag, yellow-legged gull and common tern in the Sea of Marmara. The offshore islands in the region are densely populated by humans and this is probably negatively affecting the breeding seabirds. However there is no information on the breeding seabird populations on these islands.

## 4. Threats to Seabirds in the Sea of Marmara

Seabirds spend their lives in the marine environment but they need to return to land for breeding. This dual life makes seabirds one of the most threatened groups as they face several threats both at sea and on land.

The level of anthropogenic activity in the Sea of Marmara potentially put seabirds under high pressure but because no study has addressed this problem, only potential threats to seabirds in the Sea of Marmara can be listed here. These potential threats are definitely required to be documented.

### 4.1. Threats on Land

The species breeding around the Sea of Marmara such as European shag, yellow-legged gull, great crested grebe, great cormorant and common terns use rocky and sandy shores and estuaries. Wintering birds also use similar habitats in the region. These species are potentially vulnerable to introduced predators, habitat loss and human disturbance as these habitats are limited and mostly in the vicinity of urban areas in the region.

Habitat loss simply eliminates available land to breeding and migrating birds. The development rate in the cities around the Sea of Marmara and inadequate coastal zone management are probably contributing to the loss of valuable seabird breeding and stopover habitats in the area.

Human activity such as picnics, tourism, artisanal fishing and hunting in seabird nesting and roosting areas may cause birds to abandon the area. Moderate human activity in the breeding season may cause seabirds to leave the nest frequently for longer time than usual and therefore the eggs to overexpose to solar radiation and the embryo to die. For instance the European shag has strong preference for rocky coast and islands and is known to be negatively affected by human activity around breeding colonies (Gallo-orsi 2003).

Introduced predators such as rats and cats reduce the breeding success by predating on eggs and chicks of breeding seabirds. Rats are especially widespread invasive species and they have negative impact on seabird populations globally (Jones et al., 2008). The impact of introduced species on the breeding seabird populations in the Marmara Region is unknown.

### 4.2. Threats at Sea

Seabirds utilize highly productive areas when foraging at sea. Fisheries also target the same areas. This interaction may cause seabirds to suffer from overfishing and from mortality from incidental capture by fishing gear. Amongst the seabirds in the Sea of Marmara, Yelkouan shearwater feeds on commercial pelagic fish *(Bourgeois et al.* 2011). Although the diet of the species in the Sea of Marmara is not known, overfishing of Clupeids, Engraulids and Scombrids may affect the survival of the Yelkouan shearwaters in the region if their diet is similar as in French Mediterranean waters.

Incidental capture by fishing gear (by-catch) is an important threat to seabirds as it causes adult mortality. The sporadic nature of seabird by-catch leads to the perception that it is not greatly impacting seabird populations. But for most seabird species, adult survival is regulating the population and this unnecessary mortality in fishing lines is causing rapid declines in the populations as in the case of the critically endangered Balearic shearwater in the western Mediterranean (Genovart *et al.* 2016). Although seabird by-catch is mostly observed in long-line fisheries, the mortality rates in other fishing gears is not known. Yelkouan shearwater, European shag and yellow-legged gull are the most vulnerable species to by-catch in the Sea of Marmara.

Ship traffic is another factor affecting the foraging activities of seabirds. Velando and Munilla (2011) found that European shags reduced their foraging activities in areas where boats are present. More importantly boats caused birds to be excluded from rich areas, which resulted with congregations of more birds in poorer areas where the boat activity is less pronounced. Commercial vessel activity in offshore waters also has an impact on seabird distributions. Schwemmer et al. (2011) found that loons showed clear avoidance of areas with high shipping intensity.

During migration season the Bosporus and the Dardanelles serve as a stopover area to many seabird species such as Mediterranean gulls, Caspian terns, lesser black-backed gulls. Several thousands of Yelkouan shearwaters congregate in these areas during winter. Any disturbance in the area such as high vessel activity or threat such as oil spills would impact the global population of the Yelkouan seharawers.

Pollution is a significant but overlooked threat to seabirds. The Sea of Marmara is a centre of industrial activity and has a dense human population. Many chemicals used in industry and homes are discharging into the Sea of Marmara. Seabirds are exposed to these chemicals as they spend most of their lives at sea. Inhalation, ingestion of food and external contact to water is the main source of contamination for seabirds. The major pollutants of concern for seabirds are metals, petroleum products, plastics and chlorinated hydrocarbons (Wilcox *et al.* 2015).

Some seabirds are more vulnerable to pollutants because of their foraging method, prey or nesting habitat. For instance cormorants, shags, gulls and terns may be more vulnerable as they nest near the shore and therefore close to the discharge areas. The impact of pollution on seabirds is not fully understood due to difficulties in measurement of pollutants; identifying thresholds; conducting comparable studies and conducting long-term studies (Rochman *et al*. 2016).

Climate change is another major threat not only to seabirds but whole marine life. Extreme and frequent weather conditions; change in the productivity due to change in water temperature (Veit *et al.* 1997) and acidification are known to be affecting seabirds (Frederiksen and Haug, 2015).

## 5. Conclusions and Recommendations for Future Seabird Studies in the Sea of Marmara

The Sea of Marmara has been under pressure from human exploitation and from pollution. As a result its biodiversity is under stress (Şekercioğlu *et al.* 2011). Long-term monitoring studies are important if we are to protect this valuable ecosystem. And before long-term studies we need to have a good understanding of the biodiversity in the area; the ecology of the species, the interaction among them and species that can be used as indicator for the changes in the Sea of Marmara.

Seabirds depend on marine resources and spend most of their lives at sea but they need to return to land to breed. This dual life provides an advantage to use them as indicator species for the changes in the marine environment. In most cases, seabirds breed in multi-species colonies where different species might be using resources from different levels of food web. In such colonies, monitoring more than one species and therefore gaining insight into multiple levels in the marine food web is relatively easier and cheaper. For example, an island where shearwater, storm petrel and gull species are breeding one can cover planktonic species, pelagic fish and coastal fish at the same time. Also the high philopatry in seabirds -that is returning to the same area to breed each year- make the monitoring even easier. Despite these advantages, there has been little interest in seabirds in Turkey. Even the basic knowledge such as the distribution of breeding colonies and the at sea distribution of species is poor in Turkey.

Seabird diversity in the Sea of Marmara is not very high but includes threatened species such as the Yelkouan shearwater and the European shag. In the case of

Yelkouan shearwater the Sea of Marmara holds critical importance. Breeding Mediterranean populations of this species migrate to the Black Sea after the breeding season and as they do not fly over land they use the Turkish Straits during migration (Militão *et al*. 2013; Raine *et al*. 2013). Any threat in the region would impact the global population of this species. To protect the species; its movements in the Turkish Strait System, the breeding status in the region and threats to this species should be addressed urgently.

European shag is another threatened species that breeds in the region. As the Mediterranean population of this species shows high site fidelity, protection of local breeding colonies is important (Gallo-orsi 2003). Eken *et al.* (2006) defined some areas as important for the breeding population of the species but updated information on the distribution of breeding colonies in the region should be collected. Then monitoring programmes for these populations should be started to understand the health of these populations.

As seabirds travel vast distances at sea, the nesting, foraging and resting locations might be different. Locating breeding colonies is not enough if we are to understand the lives of the resident species in the Sea of Marmara. Therefore the at sea distribution of seabirds and spatio-temporal variations in these distributions should be clearly understood in the Sea of Marmara. This also applies for wintering and migratory species. In the case of passage migrants the conditions in stopover areas impact the survival of the species.

Most other species winter in the Sea of Marmara. For these species estuarine habitats are important. However the health of these habitats and the magnitude of human disturbance to these species in these habitats should be documented.

The Sea of Marmara is also important for passage migrant species. Some species such as lesser black backed gulls and Caspian tern migrates over Turkey and the Sea of Marmara provides important stopover sites to these species. Conservation of these species depend equally on the conservation in breeding, migration and wintering areas, therefore the Sea of Marmara should not be considered only with breeding seabirds.

It is for certain that ecosystem based approach provides benefit to multiple groups of marine organisms. For instance coastal protection areas that are identified for terrestrial species are beneficial for seabirds. Such approach should be taken when protecting the biodiversity in the Sea of Marmara. And seabirds as top predators would provide protection to the lower level organisms in the food web.

## 6. Checklist of Seabirds in the Sea of Marmara

The information in the checklist is gathered from Bacak *et al*. (2015); eBird (2012); Güçlüsoy *et al*. (2014); Kirwan *et al.* (2008).

| Family Name | Latin Name | Common Name | Turkish Name | Status in the Region |
|---|---|---|---|---|
| Anatidae | *Aythya marila* | Greater Scaup | Karabaş Patka | Scarce winter visitor |
| | *Somateria mollissima* | Common Eider | Pufla | Scarce winter visitor |
| | *Melanitta fusca* | Velvet Scoter | Kadife Ördek | Scarce winter visitor |
| | *Bucephala clangula* | Common Goldeneye | Altıngöz | Winter visitor |
| | *Mergellus albellus* | Smew | Sütlabi | Winter visitor |
| | *Mergus merganser* | Common Merganser | Büyük Tarakdiş | Irregular winter visitor |
| | *Mergus serrator* | Red-breasted Merganser | Tarakdiş | Winter visitor |
| Gaviidae | *Gavia stellata* | Red-throated Diver | Kızılgerdanlı Dalgıç | Winter visitor |
| | *Gavia arctica* | Black-throated Diver | Karagerdanlı Dalgıç | Winter visitor |
| | *Gavia immer* | Great Northern Diver | Buz Dalgıcı | Vagrant |
| Procellariidae | *Calonectris diomedea* | Scopoli's Shearwater | Boz Yelkovan | Vagrant |
| | *Puffinus yelkouan* | Yelkouan Shearwater | Yelkovan | Resident |
| Podicipedidae | *Podiceps cristatus* | Great Crested Grebe | Bahri | Breeding resident |
| | *Podiceps auritus* | Horned Grebe | Kulaklı Batağan | Scarce winter visitor |
| | *Podiceps nigricollis* | Black-necked Grebe | Kara Boyunlu Batağan | Winter visitor |
| Pelecanidae | *Pelecanus onocrotalus* | Great White Pelican | Ak Pelikan | Local breeder |
| | *Pelecanus crispus* | Dalmatian Pelican | Tepeli Pelikan | Passage migrant |
| Phalacrocoracidae | *Phalacrocorax aristotelis* | European Shag | Tepeli Karabatak | Breeding resident |
| | *Phalacrocorax carbo* | Great Cormorant | Karabatak | Breeding resident |
| Scolopacidae | *Phalaropus lobatus* | Red-necked Phalarope | Deniz Düdükçünü | Vagrant |
| Laridae | *Rissa tridactyla* | Black-legged Kittiwake | Kara Ayaklı Martı | Scarce winter visitor |
| **Family Name** | **Latin Name** | **Common Name** | **Turkish Name** | **Status in the Region** |

| | | | | |
|---|---|---|---|---|
| Laridae (continued) | Chroicocephalus genei | Slender-billed Gull | İnce Gagalı Martı | Scarce winter visitor |
| | Chroicocephalus ridibundus | Black-headed Gull | Karabaş Martı | Resident |
| | Hydrocoloeus minutus | Little Gull | Küçük Martı | Winter visitor |
| | Ichthyaetus audouinii | Audouin's Gull | Ada Martısı | Breeding resident |
| | Ichthyaetus melanocephalus | Mediterranean Gull | Akdeniz Martısı | Resident |
| | Ichthyaetus ichthyaetus | Pallas's Gull | Büyük Karabaş Martı | Scarce winter visitor |
| | Larus canus | Mew Gull | Küçük Gümüş Martı | Winter visitor |
| | Larus marinus | Great Black-backed Gull | Büyük Kara Sırtlı Martı | Scarce winter visitor |
| | Larus cachinnans | Caspian Gull | Hazar Martısı | Winter visitor |
| | Larus michahellis | Yellow-legged Gull | Gümüş Martı | Breeding resident |
| | Larus argentatus | European Herring Gull | Kuzey Gümüş Martısı | Vagrant |
| | Larus armenicus | Armenian Gull | Van Gölü Martısı | Vagrant |
| | Larus fuscus | Lesser Black-backed Gull | Kara Sırtlı Martı | Winter visitor |
| | Gelochelidon nilotica | Gull-billed Tern | Gülen Sumru | Passage migrant |
| | Hydroprogne caspia | Caspian Tern | Hazar Sumrusu | Passage migrant |
| | Thalasseus sandvicensis | Sandwich Tern | Karagagalı Sumru | Winter visitor |
| | Sternula albifrons | Little Tern | Küçük Sumru | Summer visitor |
| | Sterna hirundo | Common Tern | Sumru | Summer visitor |
| | Sterna paradisaea | Arctic Tern | Kutup Sumrusu | Vagrant |
| | Chlidonias leucopterus | White-winged Tern | Ak Kanatlı Sumru | Passage migrant |
| | Chlidonias niger | Black Tern | Kara Sumru | Passage migrant |
| Stercorariidae | Stercorarius skua | Great Skua | Büyük Korsanmartı | Vagrant |
| | Stercorarius pomarinus | Pomarine Skua | Küt Kuyruklu Korsanmartı | Scarce winter visitor |
| | Stercorarius parasiticus | Parasitic Jaeger | Korsanmartı | Passage migrant |
| | Stercorarius longicaudus | Long-tailed Jaeger | Uzun Kuyruklu Korsanmartı | Vagrant |

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# THE TURKISH STRAITS SYSTEM AS A PHYLOGEOGRAPHIC BOUNDARY – A LITERATURE REVIEW

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## 1. Introduction

Phylogeography was described by Avise (1998) as "the field of study concerned with the principles and processes governing the geographical distributions of genealogical lineages, especially those at the intraspecific level". This field has proven highly successful in explaining how historical geological and climatic events, which occurred thousands or millions of years ago, have affected animal and plant range distributions (Beebee and Rowe 2004). Phylogeographic inference operates on the basic premise that populations separated by greater distance or by geological obstacles will exhibit a greater degree of genetic difference, reflecting the accumulation of mutations acquired during long periods of isolation from one another (Hewitt 2001; Beebee and Rowe 2004). Physical barriers that lead to reproductive isolation between populations can result in some instances in allopatric speciation (Mayr 1942).

Allopatry can lead to speciation if the populations are separated long enough to establish barriers to reproduction, but if contact is re-established before reproductive barriers have evolved, then gene flow may resume. In this case, genetic differences may be the only way to detect a past history of isolation and divergence. Phylogeographic boundaries, specific locations delineating breaks in the genetic lineages of multiple taxa, represent zones of major genetic change reflecting historical and ongoing physical or biological barriers to gene flow (Beebee and Rowe 2004). In the marine environment, organisms with large geographic ranges may in fact be assemblages of multiple populations that previously diverged and re-established contact, or which remain isolated from each other by currents or other hydrographic barriers. Numerous well supported phylogeographic boundaries for marine species occur, often where historically isolated bodies of water are now connected through narrow waterways with limited water exchange, strong currents, or steep environmental clines. These include the Indo-Pacific, Baltic Sea, and Strait of Gibraltar/Almería-Oran Front (Patarnello *et al.* 2007).

The Turkish Straits System (TSS) consists of the bodies of water that connect the Black Sea to the Aegean and separate the continents of Europe and Asia. The TSS consists of the Dardanelles Strait, the Sea of Marmara, and the Bosphorus Strait. Both the marine environment and biodiversity change dramatically from the Black Sea to the Aegean. Geologically and hydrologically the TSS is likely to be a marine phylogeographic boundary, yet few studies have examined the role of the TSS in shaping the distributions of species either by facilitating, preventing or reducing the gene flow between populations in the Black Sea and Aegean Sea. The studies that have been conducted have primarily looked at the extent of genetic differentiation between the Black Sea and the Mediterranean, without a closer examination of the TSS region itself.

These studies include population surveys spanning the northeast Atlantic Ocean, the Mediterranean Sea (west and east) and the Black Sea for three seagrass species, *Zostera marina* Linnaeus 1753, *Z. noltei* Hornemann 1832 and *Posidonia oceanica* (Linnaeus) Delile 1813 (Olsen *et al.* 2004; Coyer *et al.* 2004; Meinesz *et al.* 2009, respectively); eight invertebrates, *Calanus helgolandicus* (Claus 1863) and *C. euxinus* Hulsemann 1991 (Papadopoulos *et al.* 2005; Yebra *et al.* 2011), *Chthamalus stellatus* (Poli 1791) and *C. montagui* Southward 1976 (Shemesh *et al.* 2009), *Palaemon elegans* Rathke 1837 (Reuschel *et al.* 2010; Kalkan *et al.* 2013a; Kalkan and Bilgin 2016), *Pachygrapsus marmoratus* (Fabricius 1787) (Kalkan *et al.* 2013b; Çetin *et al.* 2015; Fratini *et al.* 2016), *Mytilus galloprovincialis* Lamarck 1819 (Ladoukakis *et al.* 2002; Kalkan *et al.* 2011; Kalkan and Bilgin 2016), and *Parasagitta setosa* (J. Müller 1847) (Peijnenburg *et al.* 2004, 2006); six fishes, *Engraulis encrasicolus* (Linnaeus 1758) (Magoulas *et al.* 1996, 2006; Erdoğan *et al.* 2009), *Trachurus mediterraneus* (Steindachner 1868) (Turan *et al.* 2009a), *T. trachurus* (Linnaeus 1758) (Turan *et al.* 2009b), *Mugil cephalus* Linnaeus 1758 (Durand *et al.* 2013), *Pomatomus saltatrix* (Linnaeus 1766) (Pardiñas *et al.* 2010; Miralles *et al.* 2014), and *Sarda sarda* (Bloch 1793) (Roberti *et al.* 1993; Turan 2015; Turan *et al.* 2015); and one mammal, *Phocoena phocoena* (Linnaeus 1758) (Viaud-Martínez *et al.* 2007; Tonay *et al.* 2016). In many of these cases some genetic differentiation is observed between the Black Sea and Mediterranean, yet rarely is the sampling conducted at a scale that can reveal the effect of the TSS in determining population structure or speciation.

## 2. Literature Overview and Key Findings on the Phylogeographic Patterns of Species

### 2.1. Phylogeography of Seagrasses

The only marine plants whose phylogeography has been evaluated at a large scale across the Mediterranean and Black Sea are three seagrasses, *Zostera marina*, *Z. noltei*, and *Posidonia oceanica*. The most detailed of these was the phylogeographic analysis of eelgrass, *Z. marina*, using three different genetic markers (rDNA-ITS, chloroplast *mat*K-intron, and nine microsatellite loci) throughout its global range, including the temperate waters of the North Pacific and North Atlantic, the Mediterranean and the Black Sea (Olsen *et al.* 2004). Using rDNA-ITS and *mat*K-intron sequences, the authors found no genetic differentiation among populations ranging from the western N. Atlantic to the Black Sea; however, the microsatellite data revealed differences among geographically distinct populations. Neighbor joining (NJ) analysis showed four major biogeographic groups (eastern N. Atlantic-Baltic, western N. Atlantic, eastern N. Pacific, and Portugal-Mediterranean-Black Sea). Within the Portugal-Mediterranean-Black Sea regional group, the Black Sea populations were genetically distinct from Mediterranean and Portugal populations but did not follow a pattern of isolation by distance (Olsen *et al.* 2004). Importantly, in this study the Mediterranean population was represented by samples from a single location, Thau Lagoon at the eastern coast of Spain. This one sampling location is unlikely to represent the genetic profile of *Z. marina* throughout the Mediterranean Sea, particularly in the eastern Mediterranean and the Aegean. Because the Strait of Sicily represents a phylogeographic boundary for many Mediterranean species (Patarnello *et al.* 2007), population structure may exist between western and eastern basins of the sea for *Z. marina*. Therefore, the location of the genetic break between Mediterranean and Black Sea populations of *Z. marina* remains to be determined through increased sampling in the Eastern Mediterranean, Aegean and the TSS.

In a microsatellite-based study of dwarf eelgrass, *Zostera noltei*, Coyer *et al.* (2004) detected three well-resolved genetic groups corresponding to northern Europe, Mauritania and the Black Sea/Azov Sea. The population in Mauritania appears to be an ancestral population that survived in a refugium during the last glacial maximum, after which the species expanded its distribution northward and into the Mediterranean. It is suggested that the species colonized the Black Sea after the Bosphorus Strait opened, flooded with marine water and became a suitable habitat for *Z. noltei*. Today, *Z. noltei* is found to have a high genetic diversity in the Black/Azov Sea regions (Coyer *et al.* 2004).

The third study of a seagrass, Neptune grass, *Posidonia oceanica* by Meinesz *et al.* (2009) is the only marine plant study to specifically investigate the population genetic structure in the Sea of Marmara (including in the Dardanelles) and the Aegean Sea. Using thirteen polymorphic microsatellite loci, this study showed that the Sea of Marmara *P. oceanica* population has genetic characteristics indicating isolation from the Aegean population; these include low clonal diversity, a higher number of heterozygotes than other populations, and low allelic diversity with a significant Wilcoxon test, suggesting the existence of genetic bottleneck. The authors hypothesized that the Sea of Marmara population has been functioning as a separate population since the Middle Holocene (approx. 12,000 years ago), before the intrusion of brackish Black Sea water into the Sea of Marmara through the Bosphorus Strait (between 10,000 and 5,300 years ago; Aksu *et al.* 2002). While the Sea of Marmara appears to lack input of gene flow from other populations, genotypes likely to have originated in the Sea of Marmara were found in the Aegean Sea. This recent unidirectional gene flow pattern is most likely due to the surface currents of the TSS flowing towards the Aegean Sea and permitting movement from Sea of Marmara to Aegean, but preventing the buoyant fruits of Aegean *P. oceanica* from entering into the Sea of Marmara.

### 2.2. Phylogeography of Invertebrates

Among the invertebrates whose phylogeography has been studied in the Black Sea and Mediterranean, three species, two copepods (*Calanus helgolandicus* and *C. euxinus*) and one chaetognath (*Parasagitta setosa*), are holoplanktonic, spending their entire life cycle as plankton in the water column. The other invertebrate species have bipartite life cycles of a planktonic larval phase followed by a benthic adult phase. For two chthamalid barnacle species, *Chthamalus stellatus* and *C. montagui*, and a bivalve mollusk, *Mytilus galloprovincialis*, dispersal is restricted to the pelagic larval stage, after which the adult phase is sessile. For two decapod species, a caridean shrimp, *Palaemon elegans,* and a brachyuran crab, *Pachygrapsus marmoratus*, a planktonic larval stage is followed by a mobile benthic adult stage in which relatively limited movement is possible.

Holoplanktonic species can potentially travel over large distances, but both copepod and chaetognath groups studied in the Mediterranean-Black Sea region were found to have range and gene flow limitations that suggest migration is restricted by currents and other environmental factors. Papadopoulos *et al.* (2005) constructed a phylogeny based on cytochrome c oxidase (COI) and combined COI-CytB (cytochrome B) data for two species of calanoid copepod, the North Atlantic and Mediterranean species *Calanus helgolandicus* and the Black Sea species *C. euxinus*. North Atlantic samples for *C. helgolandicus* were obtained from Denmark and the United Kingdom, and Adriatic samples were obtained from Italy. Black Sea samples of *C. euxinus* were obtained from Bulgaria. Population genetic analyses indicate significant population genetic structure among the three Seas; however, no samples were obtained from the eastern Mediterranean, Aegean or Levantine Seas, so a precise geographic boundary between these populations/species could not be located from these data. One presumably-ancestral COI haplotype was shared by samples from all three locations, probably due to incomplete lineage sorting rather than ongoing gene flow. In a follow-up study, Yebra *et al.* (2011) expanded the number of sampling locations and revealed finer-scale phylogenetic structures. Their sampling, which included one location in the Aegean, indicated little-to-no ongoing gene flow between the Black Sea and the Aegean, either due to physical or environmental barriers.

Previous studies of these copepods based on morphology had estimated allopatric divergence of the two species during the last glacial maximum, approximately 7,000 years ago, and a comparable, or even older date of divergence (18,000 years ago) for the N. Atlantic and Mediterranean populations of *C. helgolandicus* (Fleminger and Hulsemann 1987). However, COI data presented by Papadopoulos *et al.* (2005) suggest a much earlier divergence between Black Sea and Adriatic populations of 290,000-690,000 years ago, and a divergence of N. Atlantic and other populations between 500,000 years ago and more than 1 million years ago.

Peijnenburg *et al.* conducted two studies (2004 and 2006) evaluating the phylogeography of the holoplanktonic chaetognath *Parasagitta* (=*Sagitta*) *setosa* in the North Atlantic, Mediterranean, and Black Sea. The initial study used mtDNA COII sequences and revealed four geographically-structured mtDNA clades: N. Atlantic, Western Mediterranean, Adriatic Sea and Black Sea. The Black Sea haplotypes formed a monophyletic clade, with Adriatic haplotypes being a sister group. Together, Black Sea, Adriatic and Western Mediterranean haplotypes were highly divergent from those in the N. Atlantic. Because of the low sample size (11-32 individuals per group) and use of a single genetic marker, a follow-up study was conducted (Peijnenburg *et al.* 2006) using a large sample size (n>1700) and both mitochondrial DNA (COII RFLP) and nuclear DNA (four microsatellite markers). The mtDNA results of this study support the separation of the N. Atlantic clade from the Mediterranean and Black Sea, and a monophyletic group containing the majority of Black Sea samples, indicating ongoing isolation of this population. However, in this study, an additional clade (Clade A) was also found containing a small number of N. Atlantic (7) and Black Sea (2) haplotypes and no Mediterranean haplotypes. The authors suggest that Clade A represents an ancestral lineage, and that since the N. Atlantic and Black Sea haplotypes within this group separate into subclades, their similarity does not represent recent dispersal events. As with the divergence time estimates of the copepod species, the authors calculated a divergence time of ~ 400,000 years ago for Black Sea and Adriatic populations of *P. setosa*, suggesting isolation of these groups began much earlier than the most recent glacial cycles.

The microsatellite data supported differentiation among the N. Atlantic, Mediterranean and Black Sea, but not within the Mediterranean. Additionally, common microsatellite genotypes were found in individuals with Clade A haplotypes, indicating a mito-nuclear discordance. Overall, the combined data do point to significant isolation of the Black Sea population from the Mediterranean, suggesting an ongoing barrier to gene flow; however, due to a lack of sampling locations within the eastern Mediterranean and Aegean it cannot be determined whether the phylogeographic break occurs through the TSS, Aegean, or other location within the Mediterranean.

Sessile invertebrates with planktonic larvae also show range-related and genetic breaks between Mediterranean and Black Sea populations. Phylogeography and population genetics for three species of chthamalid barnacles were evaluated in the North Atlantic, Mediterranean and Black Sea (Shemesh *et al.* 2009). For two of the species, three loci were sequenced: COI mtDNA and two nuclear markers, elongation factor 1$\alpha$ (EF-1$\alpha$) and ITS. For the third species, only COI was sequenced. COI, the most variable locus, and EF-1$\alpha$ were the focus of the results. Two of the three species were widely sampled enough to give a good idea of the population genetics within their ranges. One species, *Chthamalus montagui* was sampled in the N. Atlantic, Mediterranean, Aegean, Sea of Marmara and Black Sea, while the other, *C. stellatus*, though also sampled extensively, was not found in the Black Sea.

The COI haplotype network for *C. montagui* showed clear structuring of N. Atlantic, Mediterranean, and Aegean/Marmara/Black Sea haplotypes into clusters. Each of the Aegean, Marmara and Black Seas contained its own set of haplotypes that were not shared with each other, but which radiated from the same central haplotype found in the Black Sea. Significant population genetic structure was found between Mediterranean and Black Sea/Aegean groups, but because the Black Sea and Aegean Sea samples were grouped for the analysis, resolution between populations separated by the TSS is not discussed. We can presume some differentiation for the COI locus, because different haplotypes were found in Black Sea, Sea of Marmara, and Aegean Sea. Lower haplotype diversity at the EF-1$\alpha$ locus still resulted in significant population genetic structure for *C. montagui* between Mediterranean and Aegean/Black Sea, although one ancestral haplotype was shared. One common haplotype was only found in the Sea of Marmara and Black Sea samples and not in the Aegean, supporting isolation of a Black Sea/Marmara population from the Mediterranean in *C. montagui*. This population is probably separated from the Aegean through the Dardanelles strait, and the Black Sea and Marmara populations may also be isolated more recently from one another through the Bosphorus strait, as suggested by the COI data.

*C. stellatus* was not found in the Black Sea, and the only sample within the TSS was a single Büyükada (Prince's Islands, NE Sea of Marmara) sample, which had a distinct COI haplotype and was not included in the EF-1$\alpha$ haplotype network. The Aegean/Marmara and Mediterranean were significantly different for COI (no haplotypes were shared between these populations), but not for EF-1$\alpha$, since two common EF-1$\alpha$ haplotypes were shared. More sampling is needed for this species, but these results, including the absence of *C. stellatus* in the Black Sea, suggest the TSS could be a barrier to gene flow. One of the three species, *Euraphia depressa* had a very small sample size and was only analyzed for COI, which was unable to detect any population genetic structure (probably due to too few samples).

In one of the earliest studies of invertebrate phylogeography of the region, Ladoukakis *et al.* (2002) investigated mtDNA variation in Mediterranean mussel, *Mytilus galloprovincialis*, from the Black Sea, the Mediterranean, and the Spanish Atlantic coast. They found geographically-structured genetic differentiation within *M. galloprovincialis*, despite the species' ability to disperse during its planktonic larval stage. Significant genetic differentiation was detected between populations of the Mediterranean (Adriatic, Ionian, and southern, middle and northern Aegean) and the northern Black Sea (Sevastopol, Ukraine); however, a sampling gap between northern Aegean and Ukraine prevented determining where the actual genetic break occurs. The authors suggested that genetic differentiation between Aegean and Black Seas may be due to the TSS and hydrological barriers restricting migration.

Subsequently, to determine if the genetic differentiation detected between the Aegean and the Black Seas was due to the Bosphorus Strait, Kalkan *et al.* (2011) analyzed the mtDNA COIII region and six nuclear microsatellite loci of specimens collected from the prebosphoric region of the Black Sea, the Bosphorus Strait and the Sea of Marmara. However, across the Bosphorus region, no genetic differentiation was detected in either mitochondrial or nuclear DNA, failing to confirm the Bosphorus Strait as a hydrological barrier to gene flow in this species. A more comprehensive study of *M. galloprovincialis* was performed by Kalkan and Bilgin (2016) involving an intensive sampling strategy along the coasts of Turkey, Bulgaria, Ukraine and Russia, and examining both the mitochondrial COIII gene and five microsatellite loci. Their mtDNA results confirmed the genetic differentiation detected by Ladoukakis *et al.* (2002) and detected two different haplogroups: one predominantly found in the Black Sea-TSS (common haplogroup) and the other almost exclusively found in the Aegean. However, microsatellite results did not support genetic differentiation between Black Sea-TSS and Aegean populations.

To explain these results, Kalkan and Bilgin (2016) suggest a scenario where the two divergent mtDNA clades of *M. galloprovincialis* differentiated during the last ice age within isolated populations in the Black Sea and the Aegean. Following the re-connection of the Black Sea and the Aegean, planktonic mussel larvae with Black Sea haplotypes were able to colonize the Sea of Marmara and the Aegean Sea through the TSS; whereas, larvae from the Aegean could not colonize the Sea of Marmara and the Black Sea in the reverse direction, due to the current regime of the TSS. The observed discrepancy between mtDNA and nuclear markers was explained as the mussel populations (representing common and Aegean haplogroups) not having established complete reproductive isolation.

In another geographically broad study, Reuschel *et al.* (2010) determined the degree of population genetic differentiation of the rockpool prawn, *Palaemon elegans*, from a wide range of sampling locations (Baltic Sea, Norwegian Sea, North Sea, eastern N. Atlantic, Mediterranean Sea, Black Sea and Caspian Sea) using two mitochondrial genes; 16S rRNA and COI. Their results supported the existence of three geographically-distributed haplotype groups found in the Atlantic and Alboran Sea (Type I), in the Mediterranean only (Type II) and in the Baltic Sea, Caspian Sea and the Black Sea, as well as the Mediterranean (Type III). Surprisingly, COI sequences that comprised Type III were separated by over 50 mutation steps from individuals with the other haplotypes (Type I and Type II). In the light of this finding, the authors proposed that the Type III haplogroup could represent a cryptic species, formed due to an isolation event dating to the Messinian Salinity Crisis.

The Mediterranean Sea was isolated from the world ocean during the Messinian Crisis between 5.96 and 5.33 million years ago in the late Miocene (Krijgsman *et al.* 1999; Duggen *et al.* 2003) when the sea level of the Mediterranean dramatically and a series of saline lakes were formed. According to Reuschel *et al.* (2010)'s proposed scenario, during this time a Type III ancestral population was isolated in the Mediterranean and diverged from the Atlantic populations. After the connection was reestablished with the Atlantic Ocean, genetically distinct *P. elegans* from the Atlantic entered the Mediterranean but remained reproductively isolated from the local Type III population. These newcomers became isolated from the Atlantic and differentiated due to effects such as isolation by distance and limited gene flow, ultimately evolving the haplotypes observed as Type II in the Mediterranean. This study showed that the contemporary migration between Atlantic and Mediterranean remains restricted to the Alboran Sea, with further expansion limited by the Almería-Oran Front. Regarding movement between the Mediterranean and Black Sea, the authors inferred that the TSS historically acted as a corridor through which Type III larvae colonized the Black Sea from the Mediterranean about 6800-9630 years ago when the Black Sea was flooded through the TSS. On the other hand, dispersal of the Mediterranean Type II haplotypes to the Black Sea has been prevented by the currents of the TSS that form a present-day barrier for larval dispersal.

To specifically investigate the effects of the TSS on *P. elegans*, Kalkan *et al.* (2013a) used COI sequences to evaluate population genetic structure of the species in the Black Sea, the TSS, and the eastern basin of the Mediterranean. Two genetically distinct haplogroups were found that supported the presence of two cryptic taxa within a *P. elegans* complex, as suggested by Reuschel *et al.* (2010). To clarify the issue of a cryptic species complex, Kalkan and Bilgin (2016) conducted a follow-up study in which some ambiguous COI haplotypes were re-sequenced and re-analyzed, and the nuclear histone-3 (H3) gene was sequenced to detect nuclear divergence that might suggest speciation. The two main mtDNA haplogroups (Type II, dominated by Mediterranean specimens and Type III, mixture of Black Sea, TSS and Mediterranean specimens) were again recovered for the COI gene in the haplotype network and were differentiated from each other by 13 mutations. The high frequency of Type III haplotypes in the Black Sea, and lower frequency in the Aegean (and *vice versa* for Type II) suggests unidirectional gene flow from the Black Sea to the Aegean. When combined with the results of Reuschel *et al.* (2010), these results also suggest unidirectional gene flow to the rest of the Mediterranean. In contrast, neither differentiation nor cryptic speciation was supported by the nuclear H3 gene (Kalkan and Bilgin 2016). The discordance between mtDNA and nuclear DNA suggest that isolation between the Black Sea and the Mediterranean populations of the species resulted in the formation of two mitochondrial entities, but the isolation did not last long enough to promote nuclear differentiation and reproductive isolation.

In a study of the marbled crab, *Pachygrapsus marmoratus*, across a broad geographic range, Fratini *et al.* (2016) examined COI sequences from a total of 587 specimens sampled from 51 populations from the Atlantic to the Black Sea. In total, they analyzed 238 sequences from the western Mediterranean and Atlantic (Fratini *et al.* 2011), 98 sequences from North Africa and Turkey (Deli *et al.* 2016) and five sequences from the Azores (Matzen da Silva *et al.* 2011). They found that the Black Sea population was genetically differentiated from populations in the Mediterranean Sea and Atlantic Ocean, which was attributed to the biogeographic barrier between the Aegean and Black Seas.

For *P. marmoratus*, Kalkan *et al.* (2013b) investigated the population genetic structure along the Turkish coasts and through the TSS, with dense geographical sampling, using cytochrome COI sequences. High genetic similarity among the Black Sea, the TSS and the Mediterranean populations were found; however, analysis of the geographic distribution pattern of COI haplotypes suggested a weak restriction of gene flow from the Mediterranean to the Black Sea. Population genetics of *P. marmoratus* in Turkey was re-investigated by Çetin *et al.* (2015) using a combination of nuclear microsatellites and COI sequences and an increased sample size and geographic range. mtDNA data supported the findings of Kalkan *et al.* (2013b), but the microsatellite data indicated two genetically distinct populations: one distributed all around the Turkish coasts, and another found only on the Mediterranean coast, from the northern Aegean to the eastern Levantine coast. For *P. marmoratus*, the surface current of the TSS likely prevents gene flow from the Mediterranean into the TSS, effectively restricting the Mediterranean population from entering the Sea of Marmara and Black Sea. In their work, the authors suggested that the retention of ancestral polymorphism in the COI haplotypes is the most likely reason for the cytonuclear discordance in *P. marmoratus*.

### 2.3. Phylogeography of Fishes

In two studies of European anchovy (*Engraulis encrasicolus*) using mtDNA RFLP, Magoulas *et al.* (1996, 2006) helped to define the connectivity of its populations in the region around Greece and Turkey (1996), as well as throughout the greater Mediterranean and eastern N. Atlantic (2006). In the earlier study, samples from 10 sites in the Black Sea, the Aegean, the Mediterranean and the Bay of Biscay to the north of France in the Atlantic, Magoulas *et al.* (1996) revealed the presence of two genetic clades (or phylads as described by authors) with some separation across the TSS. One of the phylads (A) was found in the Black Sea with high frequency (almost 100%), with decreasing frequencies in the Aegean (85%), and the Mediterranean and the Bay of Biscay, and *vice versa* for phylad B. This pattern of genetic diversity, along with the starlike phylogeny of the phylad A haplotypes suggests that the Black Sea population evolved in isolation from the rest of the sampled populations, and subsequently expanded unidirectionally into the Aegean when the connection through the TSS was established during the interglacial period. Unidirectional gene flow through the TSS or natural selection was proposed as mechanisms that may have prevented phylad B haplotypes from colonizing the Black Sea.

In the follow-up study by Magoulas *et al.* (2006), additional *E. encrasicolus* samples were added to the analyses from the western Mediterranean and Atlantic at either side of the Gibraltar Strait, the western coasts of France, and the northwestern coast of Africa as south as Dakar, Senegal. This study revealed the importance of extensive geographic coverage in elucidating species' evolutionary histories, since rather than the expected high frequency of phylad B, phylad A was predominant in these newly samples sites. Based on this new evidence, the authors suggested that the refugium for phylad A could have been in the western coast of Africa, with a relatively recent subsequent dispersal into the Mediterranean, as well as the Black Sea, whereas phylad B had a more continuous, historical presence in the Mediterranean. Considering the effect of the TSS on gene flow and dispersal, the study shows how increased geographical sampling for a species can unveil an unexpected scenario, in this case opposite to the hypothesis proposed based on findings in a narrower geographic range (Magoulas *et al.* 1996). In the earlier study, historical dispersal of phylad A was hypothesized to have originated in the Black Sea, then expanded southwards into the Mediterranean; whereas, Magoulas *et al.* (2006) concluded that the Black Sea was populated by phylad A from the Mediterranean and ultimately the Atlantic. A more recent paper using two allozyme loci (Erdoğan *et al.* 2009) was unable to clarify the populations genetics across the TSS due to low variability of the markers, although some differences were observed between Eastern and Western Black Sea populations, suggesting that geographic or reproductive barriers may exist within the Black Sea for this species.

A second fish species for which the TSS appears to act as a barrier to gene flow is the flathead grey mullet, *Mugil cephalus*, whose population genetic structure was evaluated using mtDNA cytB sequences and seven nuclear markers, including six microsatellites and an intron of the prolactin 1 gene locus (prl-1) (Durand *et al.* 2013). In this species, population genetic differentiation was found between Black Sea and Mediterranean populations for both mtDNA and nuclear loci. Interestingly, for this species, the authors estimated a higher rate of migration from Aegean to Black Sea, against the dominant current regime of the TSS. This may be possible for a fish that is not dependent on passive dispersal during a larval stage.

For the Atlantic bonito, *Sarda sarda*, an early study comparing cytochrome b sequences between populations in the Marmara, Aegean, and Ionian Seas found that the Sea of Marmara was genetically differentiated from the others (Roberti *et al.* 1993). Turan (2015) and Turan *et al.* (2015) used mtDNA D-loop sequences and five microsatellite loci to evaluate population genetics of *S. sarda* from five locations in the Black Sea, two locations in the northeast Mediterranean (Antalya and Iskenderun Bay) as well as single locations in the Bosphorus Strait, Sea of Marmara (Bandirma), Aegean Sea (Izmir Bay) and Adriatic Sea. Both mtDNA and microsatellite data revealed a similar pattern of three genetically distinct and geographically-defined groups. The Black Sea, Bosphorus Strait and Sea of Marmara were not significantly different from each other, but were significantly different from the second group that included Aegean and northeastern Mediterranean samples. The Adriatic Sea sample was significantly different from the other two genetic groupings. These findings suggest that Black Sea and Sea of Marmara populations migrate and interact through the Bosphorus Strait, while being isolated from the Aegean and Mediterranean populations. Yet, the pattern of low frequency alleles also indicates that the Black Sea and the TSS (Bosphorus Strait and Sea of Marmara) populations are not a single homogeneous unit. The relatively high genetic differentiation between Black Sea-Sea of Marmara and Aegean-Mediterranean groups indicates that either the current regime through the Dardanelles, or other environmental factors, act as a barrier to gene flow. The genetic differentiation between these populations is an important finding, considering that the Black Sea and Sea of Marmara have been hypothesized to be spawning grounds for the eastern Mediterranean *S. sarda* stocks (Pujolar *et al*. 2001). Both mitochondrial and nuclear DNA data indicate such migrations for reproduction either do not occur or do not result in homogenization of the gene pools.

In other fish species, there is little evidence that the TSS plays a role as a phylogeographic barrier. Pardiñas *et al.* (2010) and Miralles *et al.* (2014) investigated the evolutionary history of the bluefish, *Pomatamus saltatrix*, with samples from western Atlantic, Atlantic side of the Gibraltar Strait, western Mediterranean, Black Sea (near Istanbul) and the TSS (Dardanelles Strait). They sequenced partial fragments of two mitochondrial genes (cytB and COI), as well as eight nuclear microsatellite loci.

The results showed two barriers to gene flow, corresponding to the Atlantic Ocean and the Mediterranean. Although the authors suggest that Siculo-Tunisian Strait might have contributed to the differentiation in the Mediterranean, they acknowledge that they cannot exactly pinpoint where the break takes place, due to the large gap in sampling between western Mediterranean and the TSS. As there are no samples from the Aegean, it is hard to evaluate the effect of the TSS on the connectivity of the Black Sea and the Aegean populations, even though the similarity of the Black Sea and the TSS samples suggests some ongoing gene flow.

Turan *et al.* (2009a) and (2009b) investigated the evolutionary history the Mediterranean horse mackerel, *Trachurus mediterraneus*, and Atlantic horse mackerel, *T. trachurus*, respectively, around the Turkish coasts, using an mtDNA based RFLP approach. In both species, population genetic structure was found between Black Sea populations, yet none of the observed population differentiation was associated directly with the TSS. For both species, population genetic differentiation was found among an eastern Black Sea population and other populations around the Turkish coasts, and for the Mediterranean horse mackerel, central Black Sea and southeastern Turkey/eastern Mediterranean populations were also differentiated. However, in these pelagic fish species, the TSS itself does not appear to be a phylogeographic boundary.

### 2.4. Phylogeography of a Mammal Species

The effect of the TSS on the genetic diversity of the harbour porpoise, *Phocoena phocoena*, was studied by Viaud-Martínez *et al.* (2007), and subsequently with denser sampling along the Turkish coasts by Tonay *et al.* (2016). The earlier study investigated the genetic of this species considering a wide geographic range including northern France, Gibraltar (Atlantic side), the Aegean, the Sea of Marmara, the Black Sea (three sites from Turkey, and one site from Ukraine), and using sequences of a partial mitochondrial D-loop fragment. Atlantic *P. phocoena* were found to be genetically distinct from those in the Black Sea, and based on the combination of genetic data and skull morphology data, the authors suggested the Black Sea harbour porpoise population should be recognized as the subspecies *Phocoena phocoena relicta.* A follow-up genetic study by Tonay *et al.* (2016) with the additional sampling from the Aegean confirmed the distinctness of the Black Sea population from the Atlantic population, and also showed connectivity between Black Sea, Sea of Marmara and sporadic Aegean populations of harbour porpoise. Interestingly, Tonay *et al.* (2016) also revealed a genetically isolated subpopulation of the harbor porpoise in the Sea of Marmara, suggesting the role of the TSS as an area that can be a refugium for isolated subpopulations.

## 3. Paleoceanography of the TSS

The TSS forms the only connection between the Black Sea and the Mediterranean by way of two relatively narrow straits and an almost completely land-locked sea. The hydrology of the TSS is characterized by strong stratification (halocline and thermocline) and a two-layer current system, in which brackish water from the Black Sea flows to the Aegean above the denser saline Mediterranean waters that flow towards the Black Sea (see *e.g.*, Oğuz *et al.* 1990; Beşiktepe *et al.* 1994; Özsoy *et al.* 1996). These hydrographic properties help to explain the observed phylogeographic patterns. However, in order to understand the phylogeographic and demographic history of the species distributed in Black Sea-Sea of Marmara-Aegean region, the dynamic paleoceanographic history of the TSS must be considered.

During the last ~ 30,000 years, the Sea of Marmara was isolated from both the Black Sea and the Aegean Sea at least two times. This isolation happened because the levels of the Aegean Sea and the Black Sea stayed below the level of the sills of the Bosphorus and the Dardanelles Straits during Quaternary glacial periods. Therefore, the connection between the Black Sea and the Mediterranean was lost and the Sea of Marmara was completely isolated from both the Black Sea and the Aegean (Aksu *et al.* 2002). The isolation of the Sea of Marmara has been suggested as a source of a genetically distinct Marmara population of the seagrass *Posidonia oceanica* (Meinesz *et al.* 2009), and potentially for the harbor porpoise *Phocoena phocoena* (Tonay *et al.* 2016).

In the Holocene, the sea level of the Black Sea and the eastern Mediterranean started to rise, which caused large rivers such as Don, Dnieper, and Dniester to raise the water level in the Black Sea. Subsequently, waters coming from the Black Sea breached the sill in the Bosphorus Strait and flowed through the Sea of Marmara and the Aegean (Aksu *et al.* 2002; Hiscott *et al.* 2007). During this time, the first intrusion of the Mediterranean waters into the Black Sea was dated to approximately 8,400 years ago (Hiscott *et al.* 2007) and the full re-connection and persistent two-way flow between the Black Sea and the Aegean was established approximately 8,000 years ago (Mertens *et al.* 2012). The flooding of the Black Sea from the Mediterranean is cited as the most likely source of colonization of the Black Sea populations, and is supported in some species, including the rockpool prawn, *Palaemon elegans*, by the genetic divergence of Black Sea and Mediterranean clades dating to this approximate time period.

## 4. Phylogeographic Patterns and Interpretations

### 4.1. Discontinuous Distributions and Undersampled Taxa

In multiple instances, there is little known about how the TSS affects the phylogeography of a species due to a lack of data. In seagrasses, genetic differentiation was found between Mediterranean and Black Sea populations, yet no Mediterranean samples were collected east of Spain for *Zostera marina* (Olsen *et al.* 2004), or east of

Italy for *Z. noltei* (Coyer *et al.* 2004). This vast region of unsampled Mediterranean, including the Aegean and Adriatic Seas, leaves the true location of the genetic break as an open question.

Likewise for some invertebrates, a phylogeographic break exists between the Mediterranean and Black Sea, but the involvement of the TSS has not been tested explicitly. This includes both groups of holoplanktonic genera studied. A genetic break occurs between two calanoid copepod species, *Calanus helgolandicus* in the Aegean and *C. euxinus* in the Black Sea (Papadopoulos *et al.* 2005), but due to a low density of sampling locations in relation to the TSS, genetic differentiation may be due to the TSS or other environmental limitations and natural selection. In addition, significant population genetic structure of the chaetognath *Parasagitta setosa* exists between the Black Sea and the Mediterranean, but in this case no sampling was conducted in the Aegean or Levantine Seas. For these groups, when possible additional data collected with a greater sampling density from the Aegean, Sea of Marmara, and prebosphoric region of the Black Sea can elucidate the role of the TSS in generating this genetic differentiation.

### 4.2. Unidirectional Barrier/Corridor

In terms of the overarching patterns for different species, we see the contemporary TSS can be both a corridor and a barrier to gene flow, as has been suggested by Öztürk and Öztürk (1996). In multiple taxa, including the marine plant *Posidonia oceanica*, and invertebrates with pelagic larvae such as the rockpool prawn (*Palaemon elegans*) and the Mediterranean mussel (*Mytilus galloprovincialis*), contemporary gene flow appears to occur in one direction. While Black Sea haplotypes can move from the Black Sea to the Aegean, following the surface currents of the TSS, Aegean haplotypes cannot effectively migrate in the other direction. As described earlier, the current system of the TSS involves two stratified layers that run in opposite directions. The surface current, which is more likely to effectively transport buoyant larvae or pelagic eggs, contains brackish Black Sea water that flows to the Aegean. The bottom current contains higher density saltier Aegean water that remains below the halocline as it moves towards the Black Sea. Larvae originating in the Aegean are likely to float up to the surface, be trapped in the current, and be transported back to the Aegean. The exceptions to this pattern were found in the pelagic fishes *Trachurus mediterraneus*, *T. trachurus* (Turan *et al.* 2009a, b) and the harbour porpoise *Phocoena phocoena* (Tonay *et al.* 2016), which being strong swimmers can potentially migrate against the current to homogenize populations. An additional exception was the fish *Mugil cephalus*, which showed population differentiation, but with the hypothesized direction of gene flow from Aegean to Black Sea (Durand *et al.* 2013).

### 4.3. Geographically Remote Ancestral Clade/Cryptic Speciation

One surprising pattern is the historical connection between some phylogroups in the Black Sea and those in the eastern Atlantic, particularly the West coast of Africa, which have been detected due to broad geographic sampling. Found in anchovy (Magoulas *et al.* 2006) and the chaetognath *Parasagitta setosa* (Peijnenburg *et al.* 2006), some Black Sea and Atlantic individuals are more closely related than they are to the dominant clade sampled in the Mediterranean. Since these similarities represent ancient connections and not modern day gene flow resulting from human-facilitated introduction, they suggest either survival of an ancient clade within the Black Sea or recolonization of the Black Sea by an Atlantic phylogroup that did not become dominant in the Mediterranean.

These studies covering wide geographical ranges are important in demonstrating that small scale patterns may be somewhat misleading. They also reveal that the data from distant locations can provide information about the phylogeographic histories of species around the TSS. Regional data for the anchovy, without including the data from the western coast of Africa, had suggested unidirectional gene flow out of the TSS, a relatively common pattern discussed above. However, the inclusion of the samples from the western coast of Africa in the analyses showed that a more likely scenario was of the TSS being populated from the Mediterranean. On the other hand, the majority of studies found contain extensive geographic sampling in the Mediterranean and the Atlantic, but very little information around the TSS. For instance, in the rockpool prawn, *P. elegans*, without adequate data from the TSS (only one site was sampled in the Black Sea and none in the Aegean), Reuschel *et al.* (2010) had suggested that the Black Sea was populated from the Mediterranean. However, with extensive sampling in and around the TSS, Kalkan and Bilgin (2016) suggest unidirectional gene flow from Black Sea to Aegean, with the implication that the Type III Mediterranean populations of this species could have their origins in the Black Sea. This study shows how a thorough examination of the TSS can contribute to a better understanding of the historical phylogeography of the entire Mediterranean.

## 5. Conclusions

From this review of the literature, we can see that there are diverse marine taxa, including plants, animals, pelagic and benthic organisms, whose phylogeography has been shaped by historical and contemporary differences between the Black Sea and the Mediterranean. We have also shown that the cause of limited gene flow among populations has not definitively been answered and appears to vary among taxa, even closely related ones. Additional sampling employing diverse genetic markers, as well as surveys to detect ranges and habitat availability within the TSS, Black Sea and Aegean Sea can help to clarify the ways in which the ranges of marine taxa are defined throughout this region.

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# BIODIVERSITY OF THE SEA OF MARMARA AND THE AFFECTING FACTORS

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## 1. Introduction

Biodiversity is the variety and the natural order of life forms in an ecosystem, in a simple explanation even though it has many other definitions. The interaction among and within species is also considered to be in the definition of biodiversity. It also includes the variety of the ecosystems and the genes in a region, the species had the mentioned genes, the ecosystem which host the species and the processes bound them (IUCN 2001).

The basic objective about maintaining the biodiversity is to prevent further loss of the diversity of habitats/communities, species and genes at ecologically relevant scales and in deteriorated situations, reaching to the target levels where intrinsic environmental conditions allow (Figure 1) (Groves, C.R. 2003).

In order to manage the life of humans as sustainable, it is needed to have a healthy and constant system which provides productive lands, nourishments and other needs besides clean water, air and energy resources in their environment. The flow of energy is more affective and perpetual in an ecosystem as we mentioned in which the diversity is higher. Unfortunately, previous surveys indicate that 0.6% of the species extinct every year in a word the decrease in biodiversity is incredibly rapid. Still it is a fact that while the new species occurs some of others extinct during the evolution process. However, certain studies verify that the rate of species loss was 10.000 fold higher than the rate of the evolution of new species, following the occurrence of human species. The human population growth rate to be directly proportional with the rate of species loss strengthens this suggestion. It was stated that a theoretical loss would occur in the bioclimatic spread of species in Europe within the ratio of 6-11% in an altered study (Araujo *et al*. 2004) (IUCN, 2008).

Scientists point out that the human activities accelerate the climate change and destroy the food chain (carbon, nitrogen and water cycles). The loss of the biodiversity mentioned above effects human beings existed on the top of the food chain. When the threat started for human race, national and international enforcements in which many countries are stakeholders, have been get off the ground in the leadership of UNDP and these become the controlling factors for the policies of the countries. The aim of UNDP biodiversity studies are to preserve and enhance the advantageous services which were supplied by natural ecosystems which provide; livelihood, nourishment, water and health safety, decrease the vulnerability against climate change, hinder the emission in forests by carbon stocking land use (Dudley *et al*. 2010).

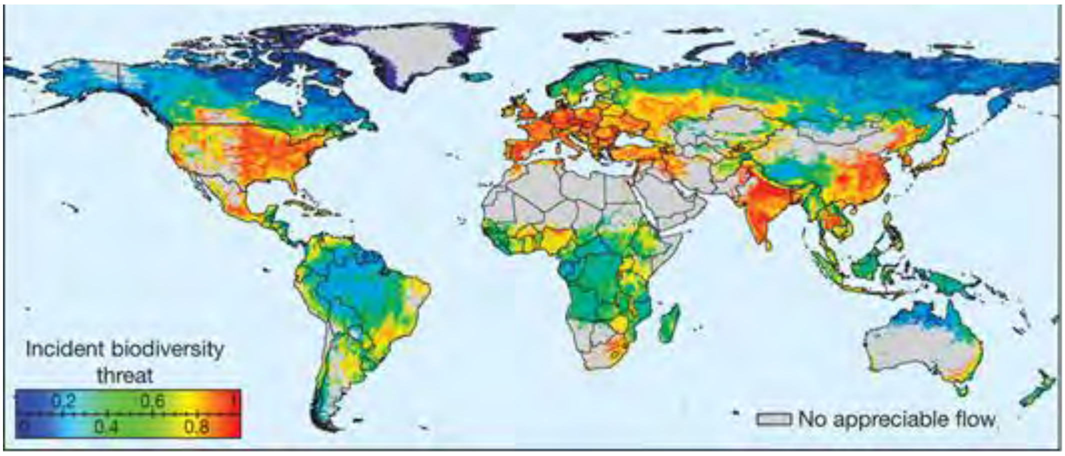


**Figure 1.** Regions where biodiversity is under threat in the World http://www.nature.com/nature/journal/v467/n7315/fig_tab/nature09440_F1.html)

The conventions which Turkey participates as stakeholder are listed below.

EC Habitat Directive (HD)
EC Birds Directive
EC Biodiversity Strategy
EU Water Framework Directive (WFD)
EU Common Fisheries Policy (CFP)
Convention on the Conservation of European Wildlife and Habitats (Bern Convention)
Convention on the Conservation of Migratory Species of Wild Animals (Bonn Convention) (CMS)-ASCOBANS, ACCOBAMS, AEWA
Barcelona Convention (BARCOM)
Bucharest Convention
Ramsar Convention
Convention on Biological Diversity (CBD)

According to these conventions, conservation areas in different status have determined and management plans on protection in some other regions have established across Turkey.

The significance of the Sea of Marmara is that being one of the important migratory routes of sea mammals, birds and many spices that are under protection or commercially valuable fish. Additionally, due to the high level of nutrients and plankton abundance, it is reproduction and growth area of many species. Particularly, it is the most important source of the Black Sea in terms of biodiversity.

In order to determine the current status and to compare it with the past, the results of the dissertations and surveys on water quality, ichthyoplankton and fisheries within the Institute of Marine Sciences and Management of Istanbul University, have been used which conducted between 1991 and 2010. The stations of trawling were given below in Figure 2.

**Figure 2.** Stations of trawling and ichtyoplankton sampling

## 2. ASSESSMENT

### Biodiversity

The Sea of Marmara corresponds the first six criteria of EBSA (Ecologically or Biologically Significant Marine Areas) at “high level”. These are, respectively;

C1) uniqueness or rarity
C2) special importance for life-history stages
C3) importance for threatened, endangered or declining species and/or habitats
C4) vulnerability, fragility, sensitivity, or slow recovery
C5) biological productivity
C6) biological diversity and
C7) naturalness.

Unfortunately, the industrialization and urbanization around the Sea of Marmara region which accommodates 26% of the Turkey's population, caused deviation from criteria 7.

The Sea of Marmara is an important migration route of many species such as marine mammals under protection and commercially valuable fish like *Xiphia gladius* (Sword fish), *Scomber scomberus* (Mackerel), *Sarda sarda* (Bonito), *Pomatamus saltatrix* (Bluefish), *Engraulis encrasicolus* (Anchovy). These species particularly distribute and spend a part of their life among the sea. The Swordfish and Mackerel abovementioned unfortunately, have affected the distribution pattern in the Sea of Marmara due to over fishing recently. Additionally, according to RAMSAR convention in which we participate as stakeholder, it has 2 important conservation areas and 16 important areas for birds.

The high level of plankton in the water column, formalize the sea as a unique pasturage for the larvae of these fish. The fertile waters of the Sea of Marmara has affected also the Black Sea from past to present. The 90% of the fishery of Turkey has carried out in these zones. Although, there is no certain knowledge about the pelagic fish stock of both seas. The distribution zones, population size and status, time of the migrations and routes, and temporal changes of them are still unknown.

According to Red List of Native Mediterranean Marine Fish Species (IUCN, 2012, ), It was stated that 4 of the species were CR (danger of extinction is at critical level) (*Squatina squatina, Oxynotus centrina, Rostroraja alba, Pomatoschistus microps*), 4 of the species were EN (endangered) (*Mustelus mustelus, Mustelus asterias, Squalus acanthias, Thunnus thynnus*), 6 of the species were VU (vulnerable) (*Merluccius merluccius, Labrus viridis, Umbrina cirrosa, Sciaena umbra, Dentex dentex, Pomatoschistus minutus*), 12 of the species were NT (Near threatened ) (*Scyliorhinus stellaris, Dasyatis pastinaca, Raja clavata, Psetta maxima, Pleuronectes platessa, Platichthys flesus, Syngnathus acus, Scomber colias, Hippocampus hippocampus, Syngnathus typhle, Xiphias gladius, Dicentrarchus labrax*) and 26 of the species were LC (Least Concern) (*Scyliorhinus canicula, Raja asterias, Raja miraletus, Raja montagui, Torpedo torpedo, T. mamorata  Atherina boyeri, Belone belone, Sardina pilchardus, Sardinella aurita, Engraulis encrasicolus, Merlangius merlangus, Gadiculus argenteus, Micromesistius poutassou, Gaidropsarus mediterraneus, Lophius piscatorius, Blennius ocellaris, Callionymus lyra, Callionymus maculatus, Trachurus mediterraneus, Trachurus trachurus, Spicara maena, Spicara smaris, Gobius niger, Ctenolabrus rupestris, Coris julis (LC), Symphodus ocellatus (LC)* (endemic)*, Liza species, Mullus surmuletus, M. barbatus, Scomber scombrus, Sarda sarda, Lithognathus mormyrus, Serranus hepatus, S. scriba, S. cabrilla (LC)  Diplodus annularis, D. vulgaris, D. Sargus sargus, Oblada melanura, Sparus aurata, Pagrus pagrus, Pagellus erythrius, Salpa salpa, Sphyraena sphyraena, Uranoscopus scaber, Trachinus draco, Scorpaena scrofa, S. porcus, Trigla lyra, Lepidotrigla cavillone,* *Chelidonichthys lucernus, Eutrigla gurnardus, Maurolicus muelleri, Zeus faber, Solea solea, Microchirus variegatus, Buglossidium luteum, Scophthalmus rhombus, Arnoglossus laterna*) among the Sea of Marmara.

When the distribution of biodiversity has investigated in the Sea of Marmara, the İzmit and Gemlik Bays are the regions where bottom life is under threat because of the hypoxic conditions. The regions where the biodiversity is in its higher status are Erdek Bay, South Marmara archipelago surroundings and south shelf of the sea (Figure 3).

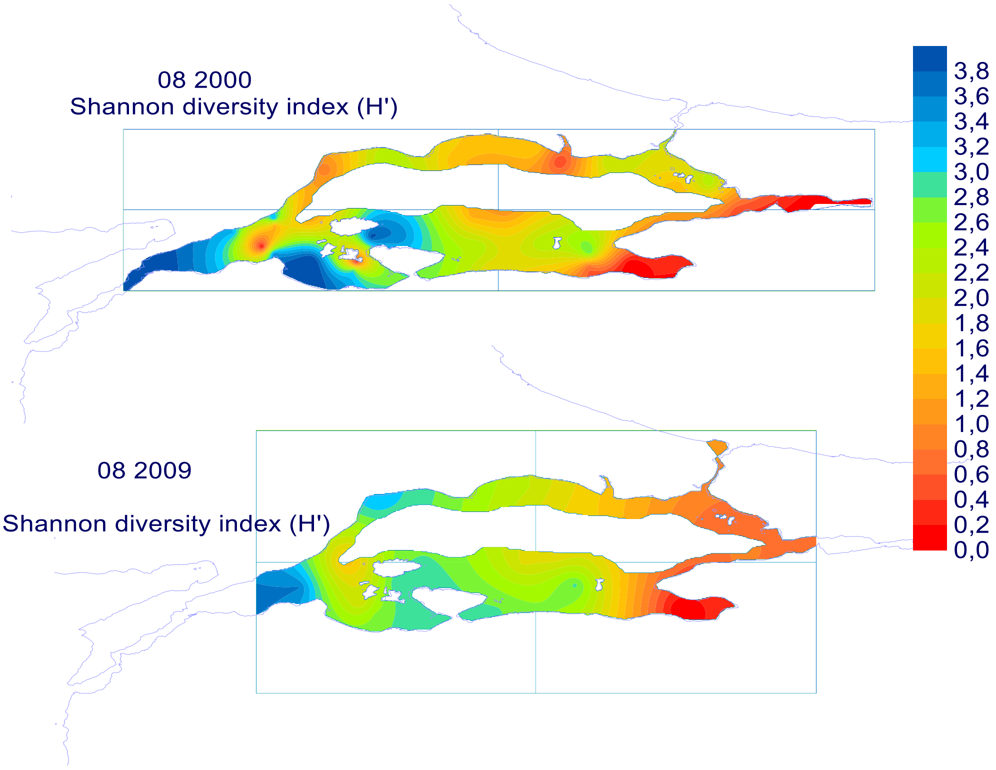


**Figure 3.** The distribution of biodiversity in the Sea of Marmara

There are three important factors affect the species distribution in the Sea of Marmara which is very significant in the terms of biıdiversity. These are;

**The impact factors of the biodiversity**

1. Natural causes ( dissolved oxygen of bottom)
2. Antropogenic pressure
3. Overfishing and inappropriate fisheries policy
4. Marine litter pollution of the seafloor

The Sea of Marmara is a two-layered system. The difference in density between upper and lower layer waters affects the dissolved oxygen of the sea bottom. The richly oxygenated Mediterranean water flows through Dardanelles to the Sea of Marmara, gravitates towards the North following the South coast. Therefore, the level of the dissolved oxygen of the South coast bottom is higher. This situation is a significant factor which affects the biodiversity (Figure 4).

Dissolved oxygen particularly, is a factor of species distribution of the macrozoobenthic communities to be present at low trophic level and which is one of the important components of the ecosystem. When the distribution of macrozoobenthos throughout the Sea of Marmara considered, it is observed that the abundance is high while the diversity is lower in the Northern Marmara. Due to the increased population of the species tolerated to hypoxic conditions this situation appears. According to high concentrations of dissolved oxygen at the South the diversity is higher than the Northern region.

The increasing eutrophication caused by anthropogenic impact induces a further decrease in the concentrations of the bottom DO, species diversity and the population, at the regions had low bottom current like Gemlik and İzmit Bays. As a result of the data in a decade, the values belonging to the year of 2010 have higher levels than the year 2000. This status is based on the renewing of the Mediterranean sourced, highly oxygenated bottom waters. However, it is observed that the hypoxic conditions continue due to the low current system hence longer renewing period, despite all the precautions, in İzmit Bay.

As an indicator of anthropogenic impact when the seasonal variation of chlorofil-a considered, the production is lower in summer while it is higher in spring and winter with high average precipitation (Figure 4). However, it is a problem that the impact of the high level of primary production continues all over the year in İzmit Bay. On the other side, the same problem is observed occasionally in the inner parts of the Bandırma and Gemlik Bays and the regions where close to Yenikapı and Tuzla discharges system.

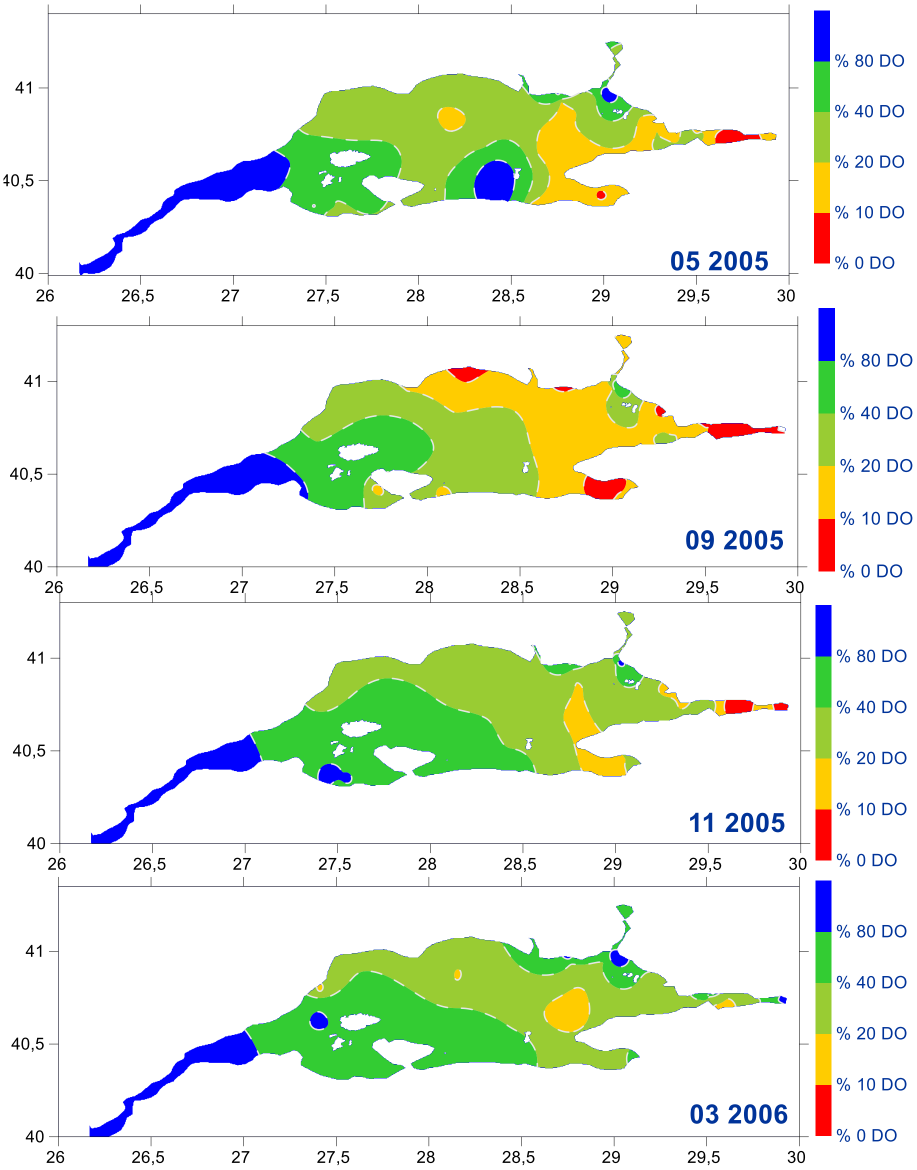


**Figure 4.** The distribution of dissolved oxygen of the bottom water in the Sea of Marmara.

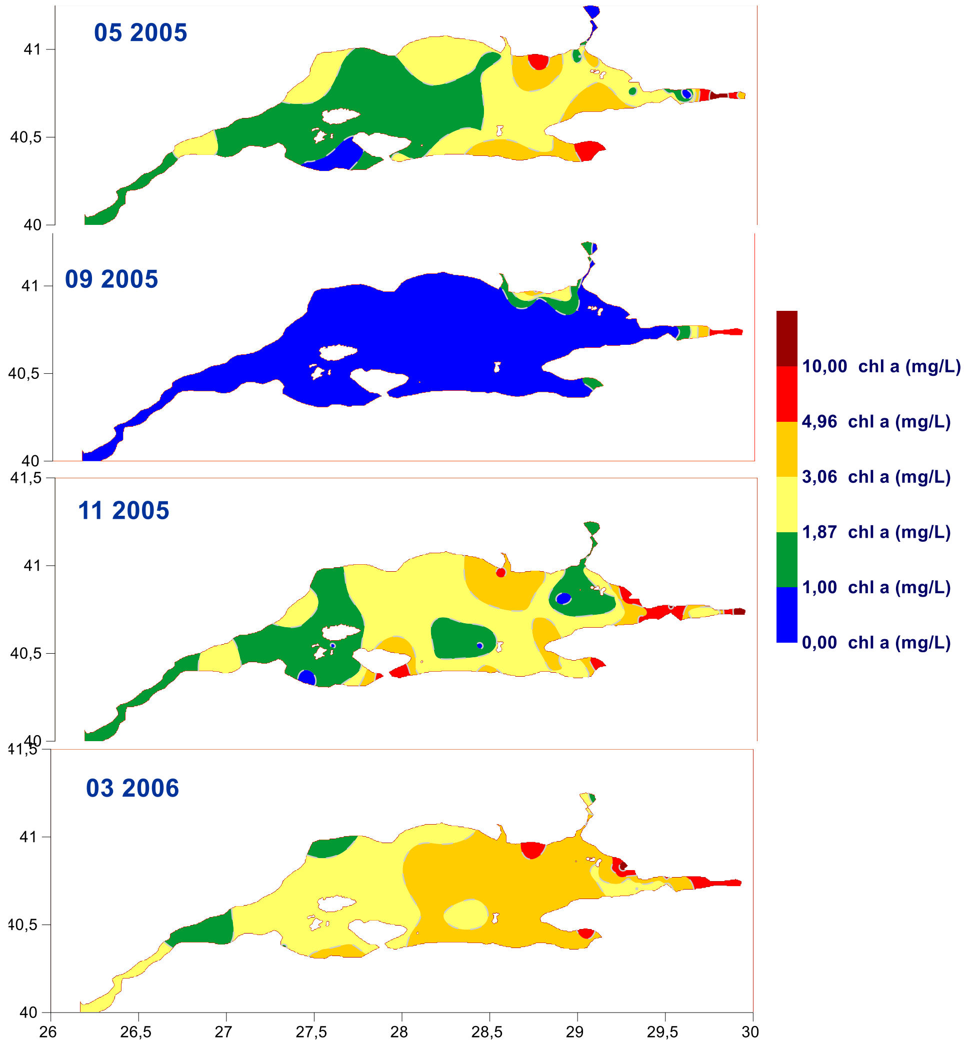


**Figure 5.** The seasonal distribution of Chlorophyl-a

The distribution of marine litter on the seafloor is in line with the distribution of biodiversity in the Sea of Marmara. Marine litter is more dense in the areas where human localization was more affective and the current was slower (Figure 5). These areas have lower biodiversity which shown in Figure.

**Seasonal Variation of Stocks**

The abundance of demersal fishes is higher in the wide shelf between Erdek Bay and Kapıdağ Peninsula- İmralı Island. This distributional composition does not change according to years but dragging destroys the bottom structure. In winter, particularly, larger fish move to shallow waters, spread along İmralı and Prince’s Islands, when their distribution considered in terms of biomass. The 90% of the population is *M. merluccius*.

The distribution of the species according to order of dominance is *M. merluccius* (european hake), *Merlangius merlangus* (whiting), *Mullus barbatus* (red mullet), *Solea solea* (common sole), *Raja calavata* (thornback ray), respectively. Apart from that, *Parapeneus longirostris* (deep water rose shrimp) is one of the most exploited species because of its commercially high value.

Raja clavata is another endangered species which has an important role in the ecosystem of the Sea of Marmara. The distribution of this predator species is wide. İt has supplanted decreased stocks of the species *Mustelus mustelus*, *Dasyatis pastinaca*, *Scyliorhinus canicula* and *Squalus acanthias*, also has had a decreasing stock pattern since 2009. Most widely the distribution areas are Erdek Bay and off Yalova coasts.

A significant depletion has pointed out according to the data of total demersal fish stock of a decade in south shelf of the Sea of Marmara.

As noted above, south shelf of the Sea of Marmara is an area where human pressure and solid waste distribution are lower and has high concentration of dissolved oxygen. However, it is a fact that the reasons of the decrease in the stocks gone down, are overfishing and wrongly implemented fishery techniques. The damage caused by forbidden dragging has affected the species diversity and composition of macrozoobenthic communities.

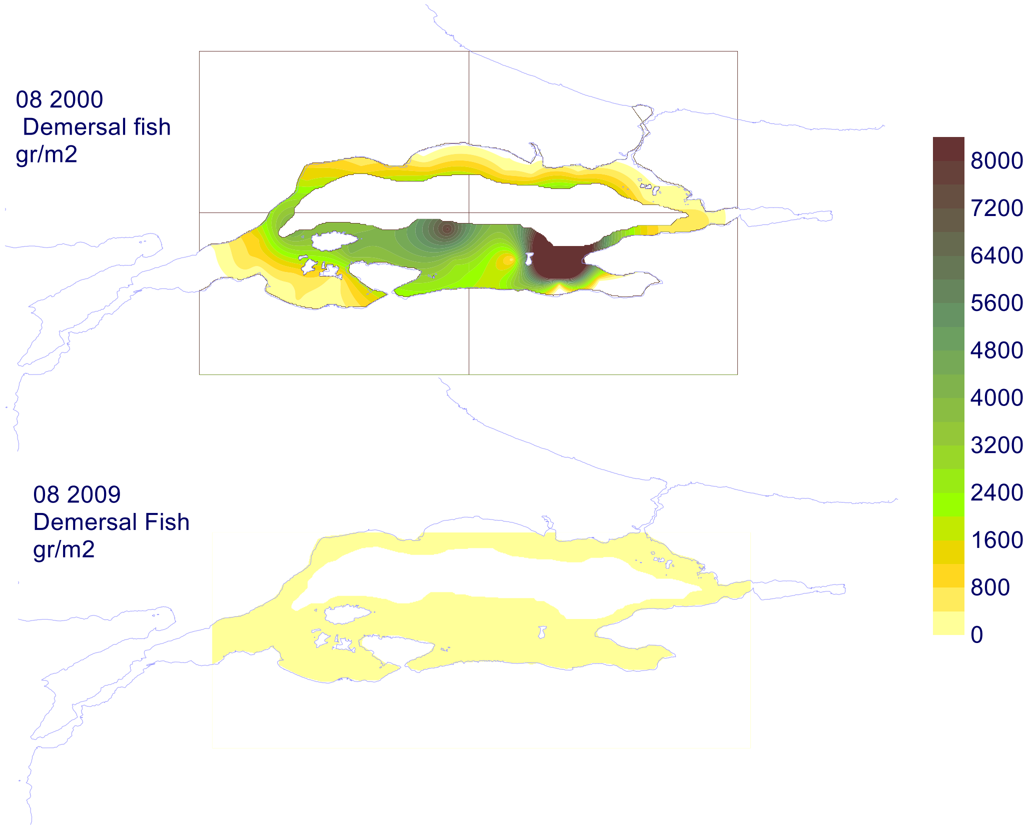


**Figure 6.** The distribution of demersal fish

**Precautions on the terms of sustainability**

The impact of the domestic pressure on the biodiversity is more affective at the points where had low current system as inner parts of the bays. High level of primary production caused by domestic pressure stimulates the hypoxic conditions and negatively affects the biodiversity. Even though the recent environmental policies implemented by local authorities have caused a recovery in pelagic system, the negativities still continue in the demersal system. Also, the results of the rehabilitation studies for Gemlik Bay have not obtained yet. The impact and the rehabilitation processes of the highly populated cities should monitor in particular.

The fishing activities have damaged to bottom structure in south shelf of Marmara where has no significant impact of pollution. Our researches have pointed out that the 80% of demersal fish stock per unit has depleted as a consequence of extreme pressure on stocks and the destruction of habitats.

Although there are many species under protection in the South shelf of the Sea of Marmara, legal arrangements should be improved and implemented against forbidden (such as, dragging, seine fishing with light) and inappropriate fishing activities as soon as possible. Likewise, it is a fact that enhancing the supervisions against forbidden fishing will remove the pressure on habitats and contribute to improving of biodiversity.

Ecosystem is always shifting. System bends to another alteration itself against every pressure. To mention about sustainability in an environment, it is needed to have all the knowledge about the environment and provide the continuity of data. The solution can be achieved under these circumstances only. Unfortunately the monitoring programs on biodiversity, fish stocks and water quality are discontinuous or even there isn't any monitoring program is on progress. Unless we have adequate information on the environment, there is no healthy way to determine a sustainable management plan. Therefore, the continuous knowledge is needed to be provided. Thus,

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# CURRRENT BIODIVERSITY OF SOFT-BOTTOM MACROZOOBENTHOS OF THE GOLDEN HORN

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Golden Horn was one of the most popular residential areas in history because of its clean water and sheltered harbors (Eyice 1975). However, historical data on biological diversity of the estuarine system is not available. Although many fishing activities carried out by purse seines in 1940s, following the 1970s, extreme pollution due to unplanned urbanization around the Golden Horn, has destroyed the ecosystem structure and limited the biological activity just around the Galata Bridge (Güveniriş 1977).

An environmental impact assessment study supported by İSKİ (İstanbul Water and Sewage Adminstration) in 1996 provides a detailed knowledge about the early biological structure of the estuary. Findings of the study showed that species number and diversity decreased towards upper estuary. Phytoplankton abundance followed the same pattern as we mentioned above, and, phytoplankton was rarely detected around Valide Sultan Bridge. Particularly, it was seen that upper estuary had almost no eukaryotic life forms due to hypoxia and heavy sedimentation (Taş *et al.* 2009). Further, benthic life was limited with only one pollution tolerated Polychaeta species (*Nereis caudata*) around the Galata Bridge again. Unfortunately, inner parts of the estuary had azoic sediment conditions but some polychaeta have detected in spray and mediolittoral zone (Okuş *et al.* 1996) (see Figure 1, for the morphology of the estuary).

Eventually, the Rehabilitation Project of the Golden Horn started in 1997. Primarily, the discharges flowing into estuarine were removed and connected to big waste collectors which were delivered to the lower layer of the Bosphorus. Further, $4.25 \times 10^6$ $m^3$ anoxic sediment has removed from totally filled upper estuary thus, 5 m depth was achieved. The turning point for the Golden Horn was the removal of Valide Sultan Bridge which blocked the surface circulation and it was very significant for the surface circulation when an amount of fresh water was released from Alibey Stream into estuary in 2000.

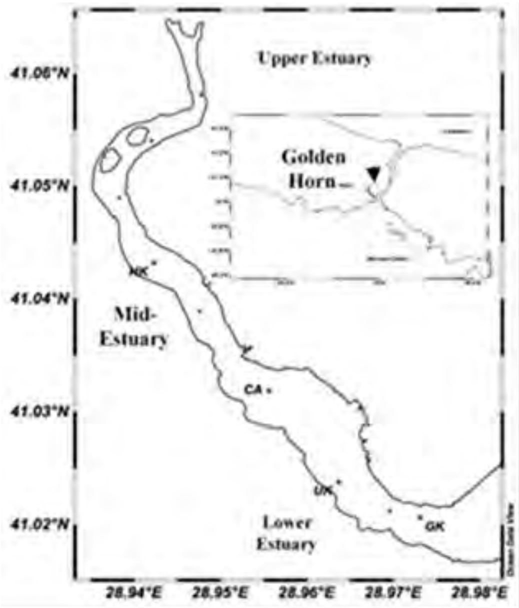


**Figure 1.** The morphology of the Golden Horn

Following all the rehabilitation studies, macrobenthic life particularly increased in 2001 around Galata Bridge; *Mytillus galloprovincialis* from Bivalvia; *Ampelisca diadema*, *Jassa* sp., *Maera* sp, *Erichthonius* sp., *Liocarcinus* sp., *Chthamalus* sp. from Crustacea and *Polycirus* sp., *Nereis* sp., *Eunice* sp. from Polychaeta were determined by Yüksek *et al.* (2006) and they stated that *M. galloprovincialis* facies extended as far as the region between Eyüp and Sütlüce, grab samples of anoxic Camialtı (CA) showed that *Hinia* sp. (Gastropoda) and *Pagurus* sp. (Crustacea) populations existed.

Further, according to the study carried out by Albayrak *et al.* (2010) in 2005, 35 species presented the Golden Horn and the Shannon-Weiver Diversity index were at low values which stated that all the five stations were at bad status, and anoxic conditions were still found at the upper estuary (Albayrak *et al.* 2010).

The monitoring project of water/sediment quality and biodiversity in the Golden Horn supported by İSKİ and carried out by the Institute of Marine Sciences and Management in 2013 showed that there was a recovery for soft-bottom macrozoobenthic life. Even though, the species number decreases towards the upper estuary from 19 species to 4, the rate of sensitive and indifferent species showed an increase meanwhile opportunistic fauna decreased (Table 1 and Figure 3) (Gürkan, 2016).

**Tablo 1.** S, species number; N, individual number; H', Shannon-Weiver diversity index

| Station | S | N | H'($log_2$) | Status |
|---|---|---|---|---|
| GK | 19 | 610 | 2,62 | Moderate |
| UK | 11 | 346 | 1,42 | Poor |
| CA | 9 | 14 | 2,95 | Good |
| HK | 4 | 214 | 0,95 | Poor |

Macrobenthic fauna is more variable in the lower estuary around Galata (GK) and Unkapanı Birdges (UK) while low variety is detected in the upper parts in the terms of common invertebrate groups (Figure 2).

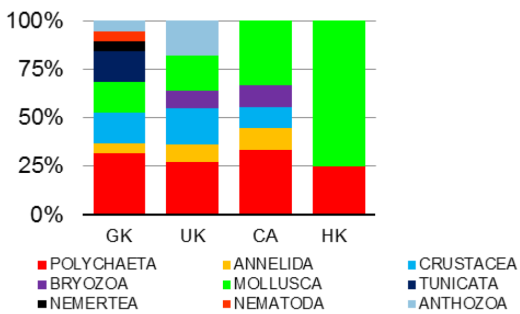


**Figure 2.** Rate of the detected invertebrate groups by stations

Polychaeta, Oligochaeta and Actiniidae are very abundant at the region of Galata Bridge (GK) and they follow the Nematoda, respectively. The most abundant Polychaeta species in the station are *Maloceros fuliginosus* and *Neanthes caudata* which are also known as tolerant species to organic pollution. Otherwise, there is another pattern can be seen; Mollusca abundance shows an increase through the upper estuary while GK has only 3 species of Mollusca which are *Mytilaster* cf. *lineatus*, *Nassarius corniculum* and *Mytillus galloprovincialis.* Additionally, individuals of *M. galloprovincialis* increases at the region of Unkapanı Bridge (UK). The species composition changes along Camialtı (CA) and Haliç Bridge (HK), Polychaeta recedes from the environment and Mollusca becomes dominant. Especially, in the station of HK an indifferent species *Odostomia erjaveciana* is very abundant.

However, diversity doesn't present a gradient

The highest biodiversity values belong to the region close to Galata Bridge and Camialtı stations as the values were 2,62 (Moderate) and 2,95 (Good), respectively

(Table 1). Low biodiversity index values belong to the area around UK and HK. Particularly the HK has the lowest value of all estuary which indicates “poor” status according to Shannon-Weiver diversity index (Table 1). Yet the species composition comprises indifferent species with a high ratio of 76% (Figure 3).

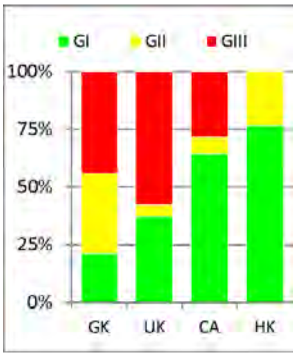


**Figure 3.** Rate of the ecolocigal groups by stations; GI, sensetive and indifferent species; GII, tolerant and GIII, opportunistic species.

These results show that there were two different zones for the marine macrozoobenthos in the estuary. The first zone represents the highly dynamic Bosphorus and the Sea of Marmara systems and the second zone displays a very specific estuarine ecosystem.

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**ALIEN SPECIES IN TURKISH SRAITS SYSTEM (TSS: ISTANBUL STRAIT, SEA OF MARMARA, ÇANAKKALE STRAIT)**

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## 1. Introduction of alien species in the Sea of Marmara

The phenomenon of Alien species and environmental impacts of IAS (Invasive Alien Species) in the Black Sea and Mediterranean Sea have been recorded for several decades. It has speeded up in recent years, with many examples of negative impacts on marine ecosystems, on the local marine fauna and flora, and on socio-economic activities, such as fisheries and tourism. The Black and Mediterranean Seas are interconnected by the Turkish Straits System. These narrow straits act as a biological corridor, a barrier or an acclimatization zone for some marine species (Öztürk and Öztürk 1996), (See map 1).


**Map 1.** The Turkish Straits System

By the opening of Suez Canal, the Mediterranean Sea has been connected to the Red Sea, thus the Indian Ocean. Some Erythrean and Indo-Pacific species have entered and started to colonize in the Black, Marmara, Aegean and Mediterranean Seas. Moreover, ship-transported species, such as *Rapana venosa*, or introduced species, such as *Liza haematochelia*, colonized in the Black Sea and then dispersed to the Sea of Marmara.

Shipping traffic is increasing in the Istanbul Strait and thus poses new risks for the Marmara and Black Seas since shipping is the main vector for alien species in this region. Zaitsev and Ozturk (2001) reported 14 alien species, Cinar *et al.* (2005) reported 48 alien species and Çınar *et al.* (2011) reported 69 alien species in the Sea of Marmara. Öztürk (2002) at present, Sea of Marmara is represented by 95 alien species belonging to 11 different systematic groups (Figure 4). Main vectors is mainly by ships in ballast water, sediment tank or on ship's hull, e.g. *Mnemiopsis leidyi.* Lessepsian species are only a few yet in the Sea of Marmara as it serves as a barrier for many thermophilic fish species. However, the Sea of Marmara is likely to act as a major transitional acclimatization and colonization zone prior to settlement in the Black Sea. For example, Katagan *et al.* (2004); Tuncer *et al.* (2008); Artüz and Kubanc (2015) reported for the first time the settlement of a lessepsian migrant stomatopod shrimp *Erugosquilla massavensis* and fishes *Lagocephalus spadiceus*, *L.sceleratus* in the Sea of Marmara whereas they have not been reported yet in the Black Sea. *Solea senegaelensis* is the only example of the Atlantic Ocean originated alien species in the Sea of Marmara. Besides these, only one intentionally introduced species is found in the Sea of Marmara, having a high commercial value *Marsupenaeus japonicus.*

## 2. Ctenophore, *Mnemiopsis leidyi* and its impacts on the fisheries and fish stocks in the Sea of Marmara

*M. leidyi* made severe negative impacts on the fisheries and this needs to be evaluated in terms of fisheries and fishery stocks in the Sea of Marmara. This species was first introduced to the Black Sea and via the surface current to the Marmara, Aegean and Mediterranean Seas. In October 1992, an extremely vigorous outbreak was recorded in the Sea of Marmara. The abundance of *M. leidyi* was as high as 4.3 kg/m$^2$ near the Istanbul Strait and 9.7 kg/m$^2$ near the Canakkale Strait, mostly in 10-30 m water depth (Shiganova *et al.* 1995). The pelagic fish stocks in the Sea of Marmara declined since these fishes feed mainly on copepods and cladocerans, which are also foraged by *M. leidyi.* Furthermore, *M. leidyi* feeds on fish eggs and larvae, seriously affecting the economically important fishes, such as *Scomber scombrus, Sardina pilchardus, Sprattus sprattus*, *Engraulis encrasicolus*, *Trachurus trachurus* and *Pomatomus saltatrix,*which use the Sea of Marmara as spawning grounds. Isinibilir (2007) reported that the abundance of the *M. leidyi* becomes limited in summer, when *Beroe ovata* is present in Izmit Bay. It means that *B. ovata* managed to control the *M.leidyi* stocks as it did in the Black Sea. After the outburst of *Mnemiopsis* during 1989 in the Black Sea (which could be assumed for the Sea of Marmara as well), the fish catch was increasing steadily until 1999 (up to almost 55,000 tons). As clearly seen in Figure 1, the catch of the main pelagic commercial fish species declined in 1989. Nevertheless, between 1991 and 2000, the decline of the fish stocks and economic loss of fisheries was estimated as 400,000 USD for Turkey only (Ozturk and Ozturk 2000).

Another economic impacts made by *M. leidyi* were also important. The fresh water reservoir of the Istanbul City was invaded by this species and it caused a serious economic loss due to the damage of the pipeline (Ozturk *et al.* 2001). Figure 2 shows the catch of commercial small pelagic fish species in the Sea of Marmara between 2000 and 2013, dominant species were anchovy and horsemackerel and the impact of the *Mnemiopsis* is not recognized at present.

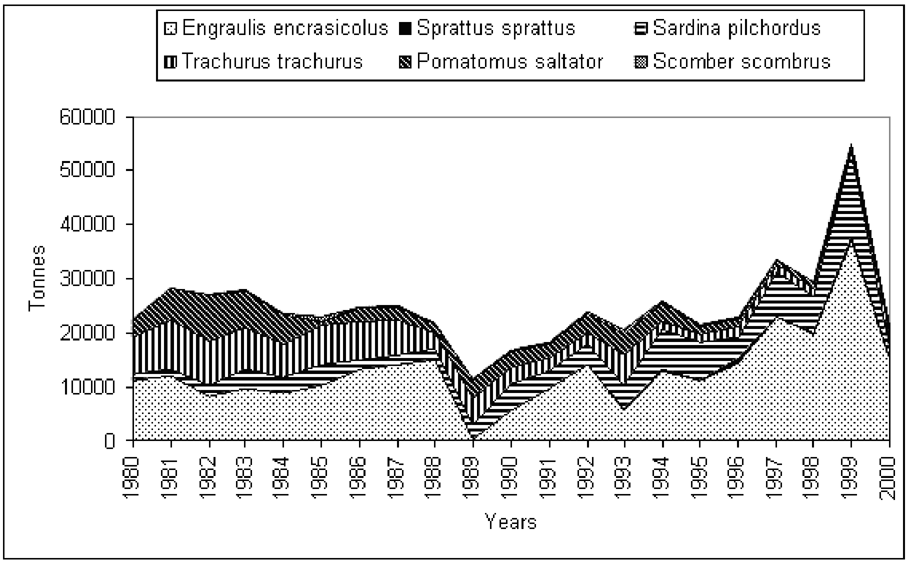


**Figure 1.** Catches of some pelagic fish species in the Sea of Marmara (1980-2000) (from Isinibilir *et al.* 2004)

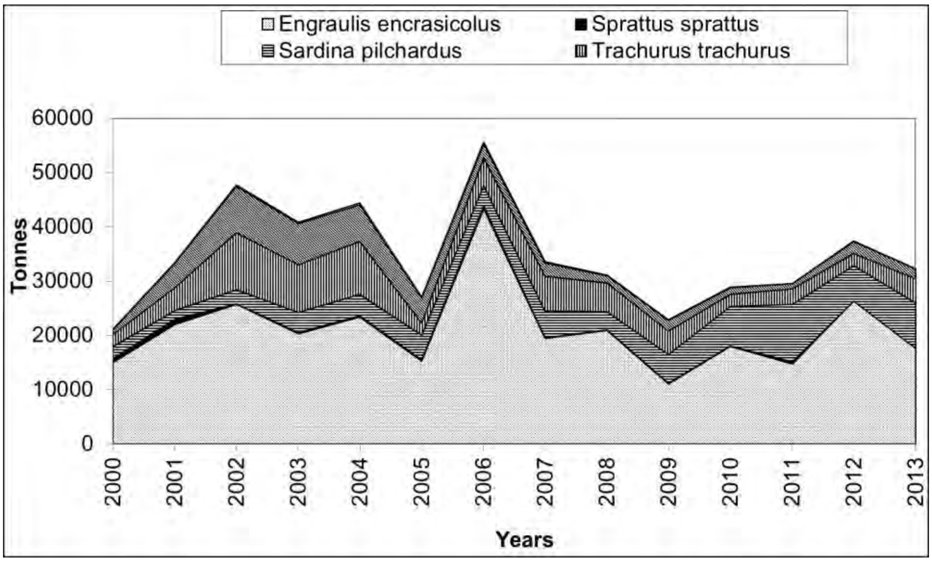


**Figure 2.** Catches of some pelagic fish species in the Sea of Marmara (2000-2013, from TUIK)

### 3. Sea snail, *Rapana venosa*, and its impacts on the fisheries in the Sea of Marmara

*Rapana venosa* is a whelk shell and native to the Sea of Japan. Its possible way of introduction into the Black Sea is by ballast water and eggs attached to ship hulls. *R. venosa* penetrated to the Sea of Marmara in the 1960s and later in the Aegean Sea as well.

*R. venosa* feeds mainly on mussels and oysters on rocky bottoms. In the Sea of Marmara, it is quite abundant at 5-25 m depth (maximum density is 15-20 ind/$m^2$). Due to the high population density of *R. venosa* along the Marmara coasts, oysters and mussels have been exterminated from these areas where the bivalve harvesting used to be commercially important. This gastropod is harvested by diving and by dredging. The dredging method is harmful to benthic ecosystem, as it is a non-selective method, unlike diving. For the first time in 1982, this species gained an economic importance and was exported as *Rapana* meat to Japan.

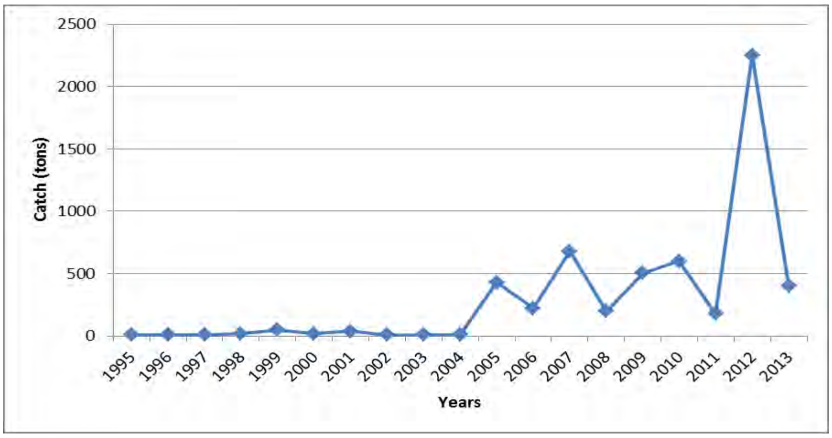


**Figure 3.** *Rapana* catch between 1995 and 2013 in the Sea of Marmara.

### 4. Other alien species and impacts on the fisheries in the Marmara Sea

The Indo-Pacific prawn *Marsupenaeus japonicus* was intentionally introduced to the Sea of Marmara in the late 1960s from Iskenderun Bay on the Turkish coast of the Mediterranean Sea (M. Demir, pers. comm.). However, its population did not increase as much as expected.

Another Indo-Pacific crustacean, *Erugosquilla massavensis*, a mantis shrimp, was found in the central Sea of Marmara in 2004 (Katagan *et al.* 2004). This is the second Indo-Pacific crustacean species reported from the Sea of Marmara. Manthis shrimps do have commercial value in Turkish part of the Mediterranean Sea but no fishing has been made yet in the Sea of Marmara due to its small stock size.

An intentionally inroduced fish, haarder, *Liza haematochelia*, native to the Amu Darya River basin, reached the Turkish Black Sea coast from the Sea of Azov, migrated to the west, reaching the Sea of Marmara and later the coasts of the Aegean Sea. This species has potential commercial importance.

The Indo-Pacific originated *Lagocephalus spadiceus* is one of the most abundant alien puffer fishes of the eastern Mediterranean Sea, distributing along the entire Levantine basin coasts from Port Said to the southern Aegean Sea (Golani *et al*. 2002). It is known to be poisonous to eat. Colonization of this species needs monitoring in terms of fisheries and human health and impacts of native fish fauna in the Sea of Marmara.

Bivalves, *Anadara kagoshimensis* and *Mya arenaria,* are also remarkable alien mollusc species in the Sea of Marmara. These bivalves are found between 3-15 m depth dominantly. *M. arenaria* is preyed on by *Rapana venosa* and demersal fishes, such as turbot, goby and mullet, in the Sea of Marmara. Around the Prince Islands, its average biomass was 1 kg/m$^2$ in 1999. Manila clam also reported by Işmen *et al*. (2010). Çınar *et al.* (2011) reported six alien polychaete species*, Paraprionospio coora, Polydora cornuta, Prionospio (Minuspio) pulchra, Pseudopolydora paucibranchiata, Chaetozone corona* and *Metasychis gotoi.*

Albayrak (2005) reported *Ruditapes philippinarum* from the Sea of Marmara. The alien starfish species *Asterias rubens* was observed in the Sea of Marmara and Istanbul Strait in 1996 (Albayrak 1996). The interaction with mussel community seems to be slow in the Sea of Marmara.

The Sea of Marmara is a link between the Mediterranean and Black Sea, which is the reason why alien species, originally introduced to either of the two seas, are found here. However, for certain species, it serves as a barrier which limits their distribution, while for others, it serves as a corridor for enlarging their distribution ranges. The Istanbul Strait plays a crucial role for dispersion of marine organisms. A permanent plankton runoff from the Black Sea to the Sea of Marmara takes place in the Istanbul Strait due to surface water current, and the Black Sea originated organisms are common in the northern part of the Sea of Marmara, some of them reaching the Aegean Sea. On the other hand, the bottom saline water in the İstanbul Strait transport Mediterranean organisms to the Black Sea, where few of them can survive in low salinity water. The Sea of Marmara is also a small acclimatization area for alien species. Consequently, more detailed investigations and monitoring studies are needed for the alien species and their impacts on the biota and fisheries.

Interestingly, some alien species have turned out to be highly valuable resources, such as *Rapana venosa* and *Liza haematochelia*. On the contrary, some species, such as *Mnemiopsis leidyi*, have turned out to be extremely harmful to the native fauna and flora, creating a considerable economic loss. It is predicted that more alien species will be observed in the near future due to heavy shipping activities between the Mediterranean and Black Sea.

Although the vectors for most species are ships, some species were intentionally introduced to the Black Sea and subsequently settled in the Sea of Marmara. *Marsupenaeus japonicas* and *Liza haematochelia* needs to be monitored due to the possibility of displacement with other native mullet species. A pufferfish species, *Lagocephalus spadicus,is* poisonous and need special attention for public health, biota and impact of fisheries. Special monitoring programs are needed for the toxic phytoplankton species, jellyfish, such as *B. ovata* and *M. leidyi,* due to their important impacts on the fisheries in the entire region. The Sea of Marmara also is exposed to jellyfish invasion because of its trophic structure (Isinibilir *et al.* 2010; Isinibilir 2012). Taşkın (2012) reported alien brown alga *Scytosiphon dotyi* from the Sea of Marmara. Besides Çolakoğlu and Palaz (2014) reported that *Ruditapes philippinarum*, a venerid clam, is a dominant species in the sandy and muddy areas in the coastal waters of the Sea of Marmara. Intensive commercial harvesting of this species is conducted in these regions. In 2015, *Cassiopea andromeda* an alien jellyfish observed during the diving in the entrance of the Çanakkale Strait. An updated list of alien species in the Sea of Marmara was presented in Table 1.

**Table 1.** List of alien species of the Sea of Marmara

| Group/Species | Year of First Record | Establishment Success | References | Pathway | Origin | Potential Impact |
|---|---|---|---|---|---|---|
| **PHYTOPLANKTON** | | | | | | |
| *Rhizosolenia calcar-avis* M. Schultze, 1858 | 1993 | Established | Kocataş *et al.* 1993 | Shipping | Atlantic | |
| **PHYTOBENTHOS** | | | | | | |
| **Rhodophyta** | | | | | | |
| *Acanthophora nayadiformis* (Delile) Papenfuss, 1968 | 1973 | Established | Zeybek and Güner, 1973 | Suez Canal | Red Sea, Indian Ocean | |
| *Acrochaetium codicolum Børgesen, 1927* | 1986 | Established | Zeybek *et al.* 1986 | Shipping | Indopacific-Atlantic | |
| *Asparagopsis armata* Harvey, 1855 | 1986 | Invasive | Zeybek *et al.* 1986 | Shipping | Atlantic-Pacific Ocean | |
| *Bonnemaisonia hamifera* Hariot, 1891 | 1986 | Invasive | Zeybek *et al.* 1986 | Shipping | Indo Pacific | |
| *Chondria collinsiana Howe, 1920* | 1986 | Invasive | Zeybek *et al.* 1986 | Suez Canal | Atlantic-Pacific Ocean | |
| *Chondrophycus papillosus (C. Agardh) Garbary & Harper 1998* | 1957 | Established | Öztığ 1957 | Suez Canal | Red Sea | |
| *Chondria curvilineata* F.S. Collins & Hervey, 1917 | 1984 | Established | Zeybek *et al.* 1986 | Shipping | Atlantic Ocean | |
| *Colaconema codicola* (Borgesen) H.Stegenga, J.J.Bolton, & R.J.Anderson, 1997 | 1984 | Established | Zeybek *et al.* 1986 | Shipping | Atlantic-Pacific Ocean | |
| *Ganonema farinosum* (Lamouroux) Fan & Wang, 1974 | 1899 | Cryptogenic | Fritsch,1899 | Suez Canal | Red Sea-Indo Pacific | Commercial |
| *Gracilaria arcuata* Zanardini 1858 | 1986 | Questionable | Zeybek *et al.* 1986 | Suez Canal | Red Sea-Indo Pacific | Commercial |
| *Griffithsia corallinoides* (Linnaeus) Trevisan, 1845 | 1993 | Established | Aysel *et al.* 1993 | Gibraltar | Atlantic-Indo Pacific | |
| *Hypnea variabilis Okamura, 1909* | 1986 | Established | Zeybek *et al.* 1986 | Shipping | Pacific Ocean | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Radicilingua thysanorhizans (Holmes) Papenfuss, 1956* | 1986 | | Zeybek *et al.* 1986 | Shipping | Atlantic Ocean | |
| *Rhodophysema georgei* Batters, 1900 | 1986 | Casual | Zeybek *et al.* 1986 | Shipping | Atlantic-Pacific Ocean | |
| **Heterokontophyta=Ochrophyta** | | | | | | |
| *Botrytella parva* (Takamatsu) | 2012 | Established | Taşkın and Pedersen 2012 | Shipping | | |
| *Chorda filum* (Linnaeus) Stackhouse 1797 | 1986 | Casual | Zeybek *et al.* 1986 | Shipping | Atlantic-Pacific Ocean | |
| *Cladosiphon zosterae* (J.Agardh) Kylin, 1940 | 1984 | Cryptogenic | Aysel *et al.* 1993 | Shipping | Atlantic Ocean | |
| *Colpomenia peregrina* Sauvageau, 1927 | 1998 | Invasive | Aysel *et al.* 2000 | Shipping | Indo Pacific | |
| *Ectocarpus siliculosus var. hiemalis* (Crouan frat.ex Kjellman) T.Gallardo 1992 | 1899 | Cryptogenic | Fritsch 1899 | Shipping | Atlantic Ocean | |
| *Halothrix lumbricalis* (Kützing) Reinke, 1888 | 1993 | Established | Aysel *et al.* 1993 | Shipping | Atlantic-Pacific Ocean | |
| *Microspongium globosum* Reinke 1888 | 2003 | Questionable | Taşkın *et al.* 2006 | Shipping | AtlanticOcean | |
| *Pylaiella littoralis* (Linnaeus) Kjellman, 1872 | 1993 | Cryptogenic | Aysel *et al.* 1998 | Shipping | Atlantic-Pacific Ocean | |
| *Protectocarpus speciosus Boergesen, 1902* | 1993 | | Aysel *et al.* 1998 | Shipping | Atlantic-Pacific Ocean | |
| *Sargassum (Sargassum) latifolium* (Turner) C.Agardh, 1820 | 1986 | Questionable | Zeybek *et al.* 1986 | Suez Canal | Red Sea | |
| *Scytosiphon dotyi* M.J. Wynne | 2011 | Established | Taşkin, 2012 | Shipping | | |
| *Sphaerotrichia divaricata (Agardh) Kylin, 1940* | 1986 | Established | Zeybek *et al.* 1986 | Shipping | Atlantic-Pacific Ocean | |
| *Ulonema rhizophorum* Foslie 1894 | 2012 | Established | Taşkın, 2013. | Shipping | | |
| **Chlorophyta** | | | | | | |
| Bryopsis pennata Lamouroux, 1809 | 1986 | | Aysel *et al.* 1986 | Shipping | Atlantic-Pacific Ocean | |
| *Codium fragile* subsp. *fragile* (Suringar) Hariot, 1889 | 1998 | Invasive | Okudan *et al.* 2003 | Shipping | Atlantic-Pacific Ocean | Commercial |
| *Ulva fasciata* Delile, 1813 | 1986 | Cryptogenic | Aysel *et al.* 1990 | Shipping/ Suez Canal | Cosmopolitan | Commercial |
| **FORAMINIFERA** | | | | | | |
| *Agglutinella arenata* (Said, 1949) | 2002 | Casual | Kaminski *et al.* 2002 | Shipping | Pacific Ocean | |
| *Amphistegina lobifera* Larsen, 1976 | 2004 | Invasive | Meriç *et al.* 2005 | Suez Canal | Circumtropical | |
| *Cushmanina striatopunctata* (Parker & Jones, 1865) | 2007 | Established | Meriç *et al.* 2009 | Shipping | Tropical Atlantic | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Spiroloculina antillarum* d'Orbigny, 1839 | 2007 | Established | Meriç *et al.* 2008 | Suez Canal | Circumtropical | |
| *Spiroloculina angulata* (Cushman, 1917) | 2001 | Unknown | Avsar *et al.* 2001 | Shipping | | |
| **CNIDARIA** | | | | | | |
| *Coryne eximia* Allman, 1859 | 1952 | Established | Demir 1952 | Shipping | | |
| *Diadumene cincta* Stephenson, 1925 | 2011 | Established | Gökalp, 2011 | Shipping | | |
| *Eudendrium merulum* Watson, 1985 | 1953 | Established | Marques *et al.* 2000 | Shipping | | |
| *Filellum serratum* (Clarke, 1879) | 1981 | Established | Ünsal 1981 | Shipping | | |
| *Sagartiogeton laceratus* (Dalyell, 1848) | 2014 | Established | Çınar *et al.* 2014b | Shipping | | |
| **CTENOPHORA** | | | | | | |
| *Beroë ovata* Mayer 1912 | 2004 | Established | İşinibilir *et al.* 2004 | Shipping | Western Atlantic | Invasive |
| *Mnemiopsis leidyi* (Agassiz, 1865) | 1994 | Invasive | Kıdeyş and Niermann 1994 | Shipping | Western Atlantic | Invasive |
| **CILIOPHORA** | | | | | | |
| *Eutintinnus lususundae* (Entz, 1884) | 2004 | Established | Balkis 2004 | Shipping | | |
| *Eutintinnus apertus* Kofoid & Campbell, 1929 | 2004 | Established | Balkis 2004 | Shipping | | |
| **POLYCHAETA** | | | | | | |
| *Ancistrosyllis rigida* Fauvel, 1919 | 1959 | | Rullier 1963 | Shipping | Red Sea-Indo Pacific | |
| *Capitellethus dispar* (Ehlers, 1907) | 1959 | Questionable | Rullier1963 | Shipping | Red Sea-Indo Pacific | |
| *Chaetozone corona* Berkeley & Berkeley, 1941 | 2010 | Cryptogenic | Çınar *et al.* 2011 | Shipping | Pacific Ocean | |
| *Dasybranchus carneus* Grube, 1870 | 1959 | Questionable | Rullier 1963 | Shipping | Red Sea | |
| *Desdemona ornata* Banse, 1957 | 2005 | Established | Çınar *et al.* 2009 | Shipping | Indo Pacific | |
| *Ficopomatus enigmaticus* (Fauvel, 1923) | 1952 | Invasive | Demir 1952 | Shipping | Subtropical | |
| *Glycera alba adspersa Fauvel, 1939* | 1963 | | Rullier 1963 | Shipping | Indo Pacific | |
| *Hydroides diramphus* Mörch, 1863- | 1894 | Invasive | Ostroumoff 1894 | Shipping | Circumtropical | |
| *Harmothoe boholensis* (Grube, 1878) | 1963 | | Rullier 1963 | Shipping | Red Sea-Indo Pacific | |
| *Harmothoe minuta* (Potts, 1910) | 1963 | | Rullier 1963 | Shipping | Red Sea-Indo Pacific | |
| *Hydroides elegans* (Haswell, 1883) | 2014 | Invasive | Çınar *et al.* 2014a | Shipping | Cosmopolitan | |
| *Lumbrineris debilis Grube, 1878* | 1959 | | Rullier 1963 | Shipping | Indo Pacific | |
| *Lepidonotus carinulatus* (Grube, 1870) | 1959 | Questionable | Rullier 1963 | Shipping | Red Sea-Indo Pacific | |

| | | | | | | |
|---|---|---|---|---|---|---|
| *Loimia medusa* (Savigny in Lamarck, 1818) | 1959 | Questionable | Rullier 1963 | Suez Canal | Red Sea | |
| *Metasychis gotoi* (Izuka, 1902) | 2008 | Established | Çinar *et al.* 2011 | Suez Canal | Red Sea-Indo Pacific | |
| *Nereis persica* Fauvel, 1911 | 1959 | Established | Rullier 1963 | Suez Canal | Red Sea-Indo Pacific | |
| *Notomastus aberans* Day, 1957 | 2014 | Established | Çınar *et al.* 2014a | Shipping | Cosmopolitan | |
| *Paraprionospio coora* Wilson, 1990 | 2008 | Cryptogenic | Yokoyama *et al.* 2010 | Shipping | Indo Pacific | |
| *Polydora cornuta* Bosc, 1802 | 2002 | Invasive | Dağlı and Ergen 2008 | Shipping | Western Atlantic | |
| *Prionospio (Minuspio) pulchra* Imajima 1990 | 2008 | Established | Çınar *et al.* 2011 | Shipping | Indo Pacific | |
| *Pseudopolydora paucibranchiata* Okuda, 1937 | 2008 | Established | Çınar *et al.* 2011 | Shipping | Indo Pacific | |
| *Sigambra constricta* (Southern, 1921) | 1959 | | Rullier 1963 | Shipping | Red Sea-Indo Pacific | |
| *Streblospio gynobranchiata* Rice & Levin, 1998 | 2005 | Invasive | Çinar *et al.* 2009 | Shipping | Western Atlantic | |
| *Timarete anchylochaeta* (Schmarda, 1861) | 1959 | Questionable | Rullier 1963 | Shipping | Indo Pacific | |
| *Timarete dasylophius* (Marenzeller, 1879) | 1959 | Questionable | Rullier 1963 | Shipping | Indo Pacific | |
| **CRUSTACEA** | | | | | | |
| **Copepoda** | | | | | | |
| *Acartia (Acanthacartia) tonsa* Dana, 1849 | 1990 | Established | Ünal *et al.* 2000 | Shipping | Western Atlantic-Indo Pacific | |
| *Acrocalanus longicornis* Giesbrecht, 1888 | 1988 | Established | Ünal *et al.* 2000 | Suez Canal | | |
| *Acrocalanus monachus* Giesbrecht, 1888 | 1998 | Established | Ünal *et al.* 2000 | Suez Canal | | |
| *Calanopia elliptica* (Dana, 1849) | 1998 | Established | Ünal *et al.* 2000 | Suez Canal | | |
| *Centropages furcatus* (Dana, 1846) | 2000 | Established | Ünal *et al.* 2000 | Suez Canal | Red Sea, Indo Pacific | |
| *Parvocalanus elegans* Andronov, 1972 | 2000 | Established | Ünal *et al.* 2000 | Suez Canal | Red Sea-Indo Pacific | |
| *Parvocalanus latus* Andronov, 1972 | 2000 | Established | Ünal *et al.* 2000 | Suez Canal | Indian Ocean | |
| **Amphipoda** | | | | | | |
| *Monocorophium sextonae* (Crawford, 1937) | 2006 | Casual | Cihangir *et al.* 2009 | Shipping | Pacific Ocean | |
| **Decapoda** | | | | | | |
| *Callinectes sapidus* Rathbun, 1896 | 2008 | Invasive | Tuncer and Bilgin 2008 | Shipping | | Commercial |
| *leucosia signata* (Paulson, 1875) | 2006 | Established | Artüz 2007b | Suez Canal | Red Sea | |
| *Marsupenaeus japonicus* (Bate, 1888) | 2001 | Invasive | Zaitsev and Öztürk 2001 | Suez Canal | Indo Pacific | Commercial |
| *Portunus segnis* (Forskål, 1775) | 2011 | Established | Altuğ *et al.* 2011 | Unknown | | Commercial |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Stomatopoda** | | | | | | |
| *Erugosquilla massavensis* (Kossmann, 1880) | 2004 | Invasive | Katağan *et al.* 2004 | Suez Canal | Indo Pacific | Commercial |
| **MOLLUSCA** | | | | | | |
| **Gastropoda** | | | | | | |
| *Rapana venosa* (Valenciennes, 1846) | 1993 | Invasive | Albayrak and Balkıs 1996b | Shipping | Pacific Ocean | Commercial |
| **Bivalvia** | | | | | | |
| *Anadara kagoshimensis (Tokunaga, 1906)*) | 1993 | Invasive Established | Albayrak and Balkıs 1996a | Shipping | Indo Pacific | Commercial |
| *Chama asperella* Lamarck, 1819 | 1990 | Established | Çınar *et al.* 2011 | Shipping | Red Sea-Indo Pacific | |
| *Mya arenaria* Linnaeus, 1758 | 1993 | Invasive | Albayrak and Balkıs 1996a | Shipping | Western Atlantic | Commercial |
| *Ruditapes philippinarum* (Adams & Reeve, 1850) | 2004 | Invasive | Tunçer *et al.* 2004 | Aquacult ure | Pacific Ocean | Commercial |
| *Teredo navalis* Linnaeus, 1758 | 1966 | Invasive | Oberling 1971 | Shipping | Circumtropical | |
| **ECHINODERMATA** | | | | | | |
| *Asterias rubens* Linnaeus, 1758 | 1993 | Established | Albayrak 1996 | Shipping | Atlantic Ocean | |
| Gambusia affinis | Unknow n | Established | Zaitsev and Öztürk 2001 | Intention ally introduce d | America | |
| **PISCES** | | | | | | |
| **Actinopterygii** | | | | | | |
| *Solea senegalensis* Kaup, 1858 | 1942 | Established | Erazi 1942 | Gibraltar | Tropical Atlantic | |
| *Lagocephalus sceleratus* (Gmelin,1789) | 2015 | Unknown | Artüz and Kubanç (2015) | Unknown | Red Sea-Indo pasific | Poisonus |
| *Lagocephalus spadiceus* (Richardson, 1844) | 2007 | Established? | Tuncer *et al.* 2008 | Suez Canal | Red Sea-Indo Pacific | Poisonous |
| *Liza haematocheila* (Temminck & Schlegel, 1845) | 1998 | Established | Kaya *et al.* 1998 | Aquacult ure | Pacific Ocean | Commercial |

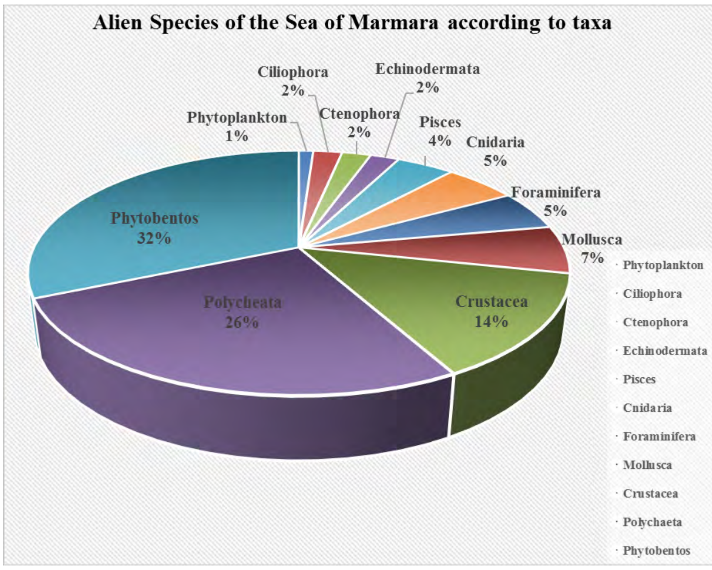


**Figure 4.** shows that the Sea of Marmara represented by 95 species belonging to 11 different systematic groups, of which Phytobenthos had the highest number of species (30 species), followed by Polycheata (25 species), Crustacea (13 species), Molusca (6 species), Cnidaria (5 species), Foraminifera (5 species), Pisces (4 species), Ctenophora (2 species), Ciliophora (2 species), Echinodermata (2 species), Phytoplankton (1).

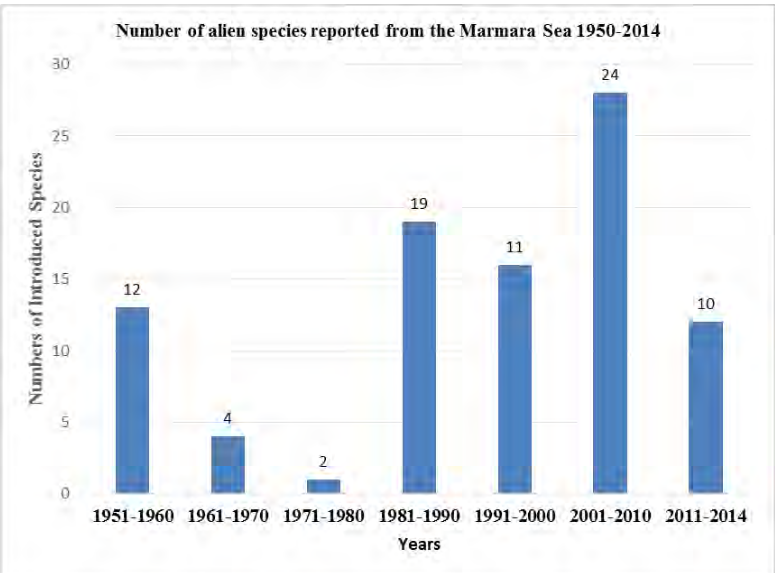


**Figure 5.** shows that since 1950, almost every year at least one alien species has been recorded in the Sea of Marmara. The highest number of alien species were reported between 2001-2010 as 24 species.

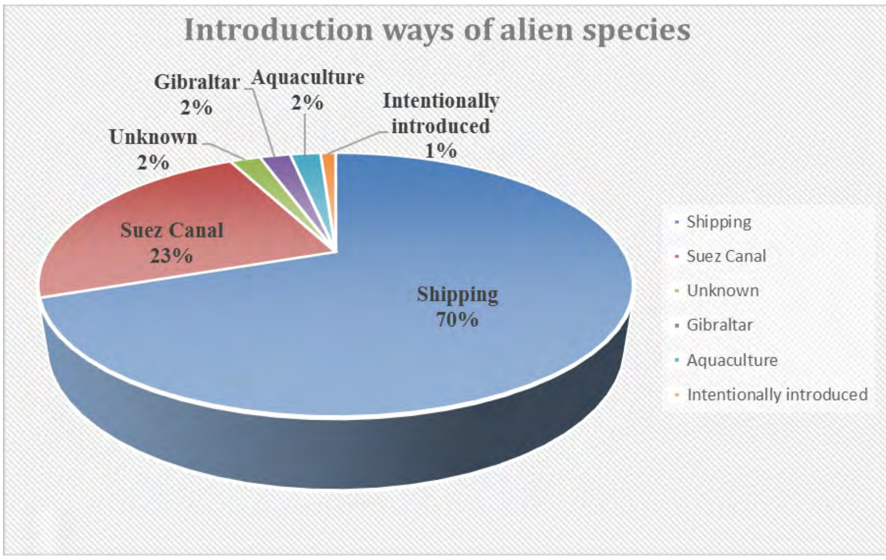


**Figure 6.** shows alien species introduced via shipping (66 species), Suez Canal (22 species), aquaculture (2 species) and Gibraltar (2 species) and unknown way (2 species) Intentionally introduction (1 species).

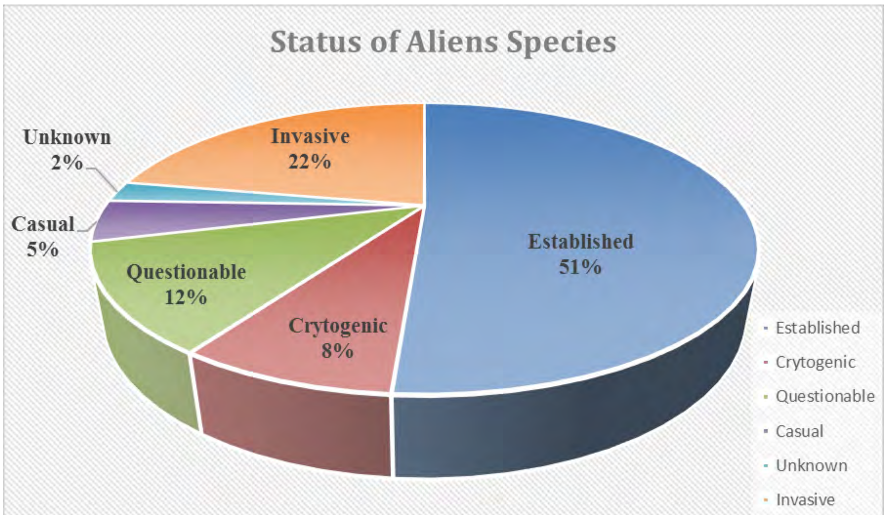


**Figure 7.** shows that 44 species are established, 7 species are cryptogenic, 10 species are questionable, 4 species are casual and 2 species are unknown, 19 species are invasive in the Marmara Sea.

Ballast water exchange is another threat for the Marmara Sea. (Altuğ *et al.* 2012) and Olgun *et al.* (2012) reported that ballast water is inceasing ecological threat. Adoption and ratification of the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM) is urgent task for Turkey.

The Sea of Marmara is a kind of “test laboratory” for alien species and monitoring of these alien species in this sea may help predict the process in the Black and Aegean Seas. To collect new and accurate information on the occurrence of alien species, a reporting and monitoring system is required. In this system, fishermen must report to fisheries cooperatives or relevant fisheries authorities whenever they find unusual organisms in their catch. Besides, other stakeholders such as divers, sailors and harbour authorities also cooperate with scientific institutions for the alien species in the Sea of Marmara.

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**DISTRIBUTION OF THE ICHTHYOPLANKTON IN THE ISTANBUL STRAIT (BOSPHORUS)**

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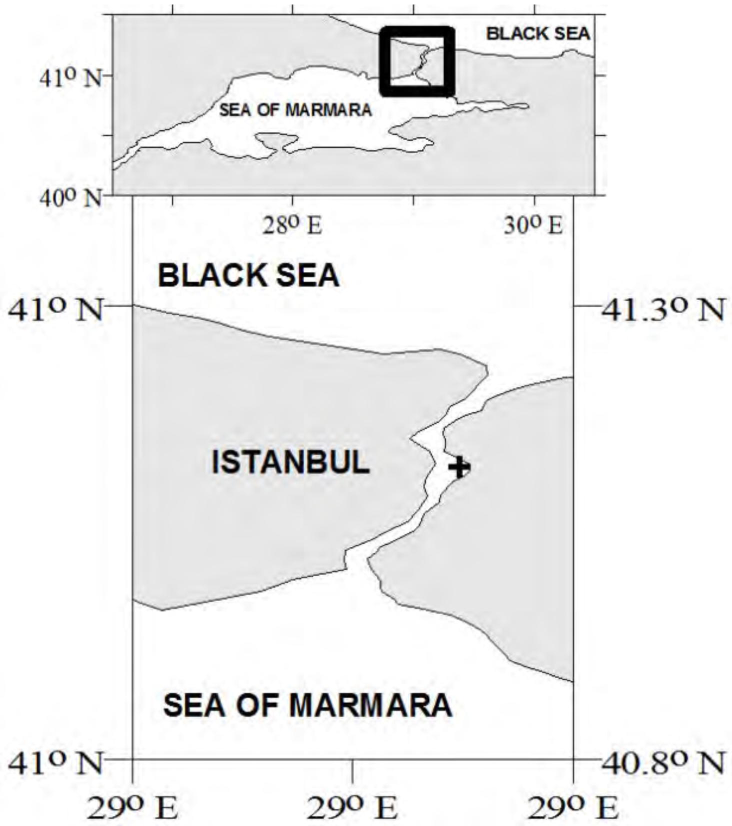
The Istanbul Strait (Bosphorus) is a narrow and locally shallow and serves as a biological corridor between the Aegean and the Black Sea due to its two layered current structure (Öztürk and Öztürk 1996). A negative impact on this biological corridor would adversely affect the biota at the adjacent seas, especially the Black Sea. Two-layered water exchange throughout the strait take role as a biogeographic barrier for marine species, especially for eggs and larvae in the Bosphorus. For example, fish eggs and larvae are brought by the upper layer from the Black Sea to the Sea of Marmara increase the species diversity, while species originated from Mediterranean transported to Black sea via lower layer distribute to a limited area. Hereby, it is significant to study the ichthyoplankton distribution, particularly in an area such narrow where also fast water exchanges prevail like Bosphorus. Existing circumstance is also considered as a critical information not only in terms of biodiversity but also in terms of determination and estimation of the consequences of an adverse impact to the ecosystem particularly originated from potential pollutions caused by ship accidents. It is needed to have knowledge about the distribution of time-dependent eggs and larvae to determine and predict the species to be affected in case of an oil spill.

Although the Bospohorus is a reproduction and nursery area for some fish species (Keskin, 2012) unfortunately the ichthyoplankton studies are rather limited. Thus, the number of such studies must be increased over time. In this research, the role of the Bosphorus connecting two productive seas (Black sea and Sea of Marmara) was considered for the first time as a reproduction area that would affect fish diversity. For this purpose, the aim of this study is to examine the potential transition of fish eggs and larvae between the Sea of Marmara and the Black Sea in terms of number and abundance and to constitute a background for the future ichthyoplankton studies in the Bosphorus.

**Materials and Methods**

Ichthyoplankton samples were obtained with horizontal and vertical hauling via using 500 µm mesh size Nansen net from four stations at both sides of the northern strait. Water surface samplings were performed horizontally for 15 minutes while vertical samplings were started from 50 meters up to surface (See Map 1).




**Map 1.**Sampling Station (Beykoz and Yeniköy)

**Results**

The eggs and larvae belonging to 27 species were obtained as result (Table1, 2). It was reported that the dominant species in the summer season is anchovy (*Engraulis encrasicolus)* while *Sprattus sprattus* takes over dominance in winter. The Bosphorus shares some similarity with Marmara and Black Sea in terms of species dominance. Furthermore, the species show high frequency are; *Diplodus annularis, Engraulis encrasicolus*, *Sprattus sprattus, Trachurus mediterraneus* ve *Gaidropsarus mediterraneus.* Despite anchovy (*Engraulis encrasicolus*), sprat (*Sprattus sprattus*) and horse mackerel (*Trachurus mediterraneus*) present transition between the Black Sea and the Sea of Marmara while the other species determined as settled in the strait. In the light of the above findings, we would like to point out that the Bosphorus, which has a very strong hydrodynamic structure, is not only used by migrating species, but also serves as a specific habitat for some fish species.

Besides, some species such as *E. encrasicolus and T. mediterraneus and S. sprattus* are small pelagic species and has commercial values.

It has been observed that the European Side and the Anatolian Side are similar from the point of species diversity (Table 3,4, Figure 1,. On the both sides, biodiversity is increasing in summer period in parallel with the number of species. (Tables 3 and 4, Figure 1). This situation shows resembles with Black Sea and the Sea of Marmara. In winter, biodiversity and abundance decrease in the Bosphorus (Tables 3and 4). In the adjacent seas, diversity decreases in winter either but the abundance is relatively higher. The reason for this, plantivorous species such as sprat and sardine have reproduction season during winter period and especially, highly distribute in the Sea of Marmara. Furthermore, it has been observed that the density of eggs and larvae on the Anatolian side is higher than the European side, the abundance of eggs and larvae in the unit area increases in July, while the amount of abundance decrease in spring and autumn in both sides (Figures 2 and 3). This is an expected situation because the number of species spawning in spring and autumn are low in adjacent seas. The reason for the reduction in the abundance of eggs and larvae during winter is that the increased hydrodynamical attributes of the strait by the effects of strong winter (northerly) winds and consequently planktonic eggs and larvae accumulate in the coastal zone.

In conclusion, this first research on the ichthyoplankton in the Bosphorus reveals that the strait is a unique ecosystem for the settled species as it constitutes special feeding and spawning areas, especially in the junctions of the strait (Demirel and Yüksek 2013).

**Table 1.** Abundance of eggs and larvae in the unit area (10 $m^2$) in the Anatolian side of the Bosphorus

| | **07/13** | | **08/13** | | **09/13** | | **10/13** | | **11/13** | | **12/13** | | **01/14** | | **02/14** | | **03/14** | | **04/14** | | **05/14** | | **06/14** | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B1** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** |
| *Engraulis encrasicolus* | 3192 | 704 | 563 | 235 | 94 | | | | | | | | | | | | | | | | | | 188 | 47 |
| *Sprattus sprattus* | | | | | | | | | | | 141 | 47 | 986 | 282 | 845 | 516 | 141 | | | | | | | |
| *Merlangius merlangius merlangius* | | | | | | | | | | | | | | | | | 47 | | | | | | | |
| *Gaidropsarus mediterraneus* | | | | | | | | | 47 | | 141 | 47 | 47 | | 282 | 47 | | | | | | | | |
| *Diplodus annularis* | 1127 | | 235 | | 141 | | 47 | | | | | | | | | | | | | | 94 | | | |
| *Diplodus sargus* | 141 | | | | | | | | | | | | | | | | | | | | | | | |
| *Lithognathus mormyrus* | 47 | | | | | | | | | | | | | | | | | | | | | | | |
| *Serranus hepatus* | 47 | 141 | | | | | | | | | | | | | | | | | | | | | 47 | |
| *Trachurus mediterraneus* | | | 188 | 47 | 94 | | | | | | | | | | | | | | | | | | 516 | |
| *Scomber japonicus* | | | | | | | | | | | | | | | | | | | | | 47 | | | |
| *Liza aurata* | 47 | | | | | | | | | | | | | | | | | | | | | | | |
| *Liza saliens* | | | 47 | | | | | | | | | | | | | | | | | | | | | |
| *Mugil cephalus* | 47 | | 94 | | | | | | | | | | | | | | | | | | | | | |
| *Mullus barbatus* | 141 | 94 | | | | | | | | | | | | | | | | | | | | | | |
| *Sciaena umbra* | 47 | | | | | | | | | | | | | | | | | | | | | | | |
| *Callionymus lyra* | | | | | 47 | | | | | | | | | | | | | | | | | | | |
| *Ctenolabrus rupestris* | | | | | 47 | | | | | | | | | | | | | | | | | | 47 | |
| *Symphodus tinca* | | 47 | 47 | | | | | | | | | | | | | | | | | | | | | |
| *Uranoscopus scaber* | 141 | | | | 47 | | | | | | | | | | | | | | | | | | 94 | |
| *Blennius ocellaris* | | | | | | | | | | | | | | | | | | | | | 141 | | | |
| *Gobius niger* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Scorpaena porcus* | 1690 | | 141 | | 188 | | | | | | | | | | | | | | | | | | 329 | |
| *Trachinus draco* | 47 | | | | | | | | | | | | | | | | | | | | | | | |
| *Trigla sp* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Buglossidium luteum* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Solea sp* | | | | | | | | | | | | | | | | | | | | | | | 94 | |
| *Arnoglossus sp.* | 47 | | | | | | | | | | | | | | | | | | | | | | | |

**Tablo 2.** Abundance of eggs and larvae in the unit area (10 $m^2$) in the Anatolian side of the Bosphorus

| | 07/13 | | 08/13 | | 09/13 | | 10/13 | | 11/13 | | 12/13 | | 01/14 | | 02/14 | | 03/14 | | 04/14 | | 05/14 | | 06/14 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **B2** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** | **E** | **L** |
| *Engraulis encrasicolus* | 3146 | 1315 | | | 47 | 376 | | | | | | | | | | | | | | | 141 | | 469 | |
| *Sprattus sprattus* | | | | | | | | | | | | | 188 | | 845 | 282 | 986 | 235 | | | | 47 | | |
| *Merlangius merlangius merlangius* | | | 47 | | | | | | | | | | 47 | | | | | | | | | | | |
| *Gaidropsarus mediterraneus* | | | | | | | | | | | | | | | 94 | | 47 | 47 | | | | | | |
| *Diplodus annularis* | | 423 | 94 | 657 | 141 | | 47 | | | | | | | | | | | | | | 235 | 329 | 47 | |
| *Diplodus sargus* | | | 188 | | | | | | | | | | | | | | | | | | 94 | | 282 | |
| *Lithognathus mormyrus* | 47 | | | | | | | | | | | | | | | | | | | | | | | |
| *Serranus hepatus* | | | 47 | | | | | | | | | | | | | | | | | | | | | |
| *Trachurus mediterraneus* | 423 | 141 | 235 | | 751 | 47 | | | | | | | | | | | | | | | 47 | | | |
| *Scomber japonicus* | | | | | | | | | | | | | | | | | | | | | 47 | | | |
| *Liza aurata* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Liza saliens* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Mugil cephalus* | 47 | | | | | | | | | | | | | | | | | | | | | | | |
| *Mullus barbatus* | 141 | | | | | | | | | | | | | | | | | | | | 188 | | | |
| *Sciaena umbra* | 47 | | 47 | | | | | | | | | | | | | | | | | | | | | |
| *Callionymus lyra* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Ctenolabrus rupestris* | 47 | | | | | | | | | | | | | | | | | | | | 47 | | | |
| *Symphodus tinca* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Uranoscopus scaber* | 94 | | 376 | 94 | | | | | | | | | | | | | | | | | | | | |
| *Blennius ocellaris* | | 94 | 47 | | | | | | | | | | | | | | | | | | | 516 | | 188 |
| *Gobius niger* | | 47 | | 47 | | 47 | | | | | | | | | | | | | | | | 94 | | |
| *Scorpaena porcus* | | | 141 | 5 | | | | | | | | | | | | | | | | | | | | |
| *Trachinus draco* | | | | | | | | | | | | | | | | | | | | | | | | |
| *Trigla sp* | | | | | 94 | | | | | | | | | | | | | | | | | | | |
| *Buglossidium luteum* | | | | | | | | | | | | | | | | | | | | | 141 | | | |
| *Solea sp* | | | | | | | | | | | | | | | | | | | | | 94 | | | |
| *Arnoglossus sp.* | 94 | | 47 | | | | | | | | | | | | | | | | | | 47 | | | |

**Table 3.** Changes in biodiversity indexes of the European side by months (S= number of species, N= number of total eggs and larvae, d= the Margalef diversity index, J'= the Pielou evenness index, H' = the Shannon biodiversity index)

| B1 (European Side) | S | N | d | J' | H'(loge) | H'(log2) |
|---|---|---|---|---|---|---|
| **July 2013** | 14 | 7746 | 1,45 | 0,57 | 1,52 | 2,19 |
| **August 2013** | 7 | 1596 | 0,81 | 0,77 | 1,50 | 2,16 |
| **September 2013** | 7 | 657 | 0,92 | 0,93 | 1,81 | 2,61 |
| **October 2013** | 1 | 47 | 0,00 | **** | 0,00 | 0,00 |
| **November 2013** | 1 | 47 | 0,00 | **** | 0,00 | 0,00 |
| **December 2013** | 2 | 376 | 0,17 | 1,00 | 0,69 | 1,00 |
| **January 2014** | 2 | 1315 | 0,14 | 0,22 | 0,15 | 0,22 |
| **February 2014** | 2 | 1690 | 0,13 | 0,71 | 0,49 | 0,71 |
| **March 2014** | 2 | 188 | 0,19 | 0,81 | 0,56 | 0,81 |
| **April 2014** | 0 | 0 | **** | **** | 0,00 | 0,00 |
| **May 2014** | 3 | 282 | 0,35 | 0,92 | 1,01 | 1,46 |
| **June 2014** | 7 | 1362 | 0,83 | 0,83 | 1,62 | 2,33 |

**Table 4.** Changes in Biodiversity indexes of the Anatolian side by months (S= number of species, N= number of total eggs and larvae, d= the Margalef diversity index, J'= the Pielou evenness index, H' = the Shannon biodiversity index)

| B2 (Anatolian side) | S | N | d | J' | H'(loge) | H'(log2) |
|---|---|---|---|---|---|---|
| **July 2013** | 12 | 6103 | 1,26 | 0,44 | 1,10 | 1,59 |
| **August 2013** | 11 | 2070 | 1,31 | 0,78 | 1,87 | 2,70 |
| **September 2013** | 5 | 1502 | 0,55 | 0,74 | 1,20 | 1,73 |
| **October 2013** | 1 | 47 | 0,00 | **** | 0,00 | 0,00 |
| **November 2013** | 0 | 0 | **** | **** | 0,00 | 0,00 |
| **December 2013** | 0 | 0 | **** | **** | 0,00 | 0,00 |
| **January 2014** | 2 | 235 | 0,18 | 0,72 | 0,50 | 0,72 |
| **February 2014** | 2 | 1221 | 0,14 | 0,39 | 0,27 | 0,39 |
| **March 2014** | 2 | 1315 | 0,14 | 0,37 | 0,26 | 0,37 |
| **April 2014** | 0 | 0 | **** | **** | 0,00 | 0,00 |
| **May 2014** | 13 | 2066 | 1,57 | 0,83 | 2,14 | 3,08 |
| **June 2014** | 4 | 986 | 0,44 | 0,85 | 1,17 | 1,69 |

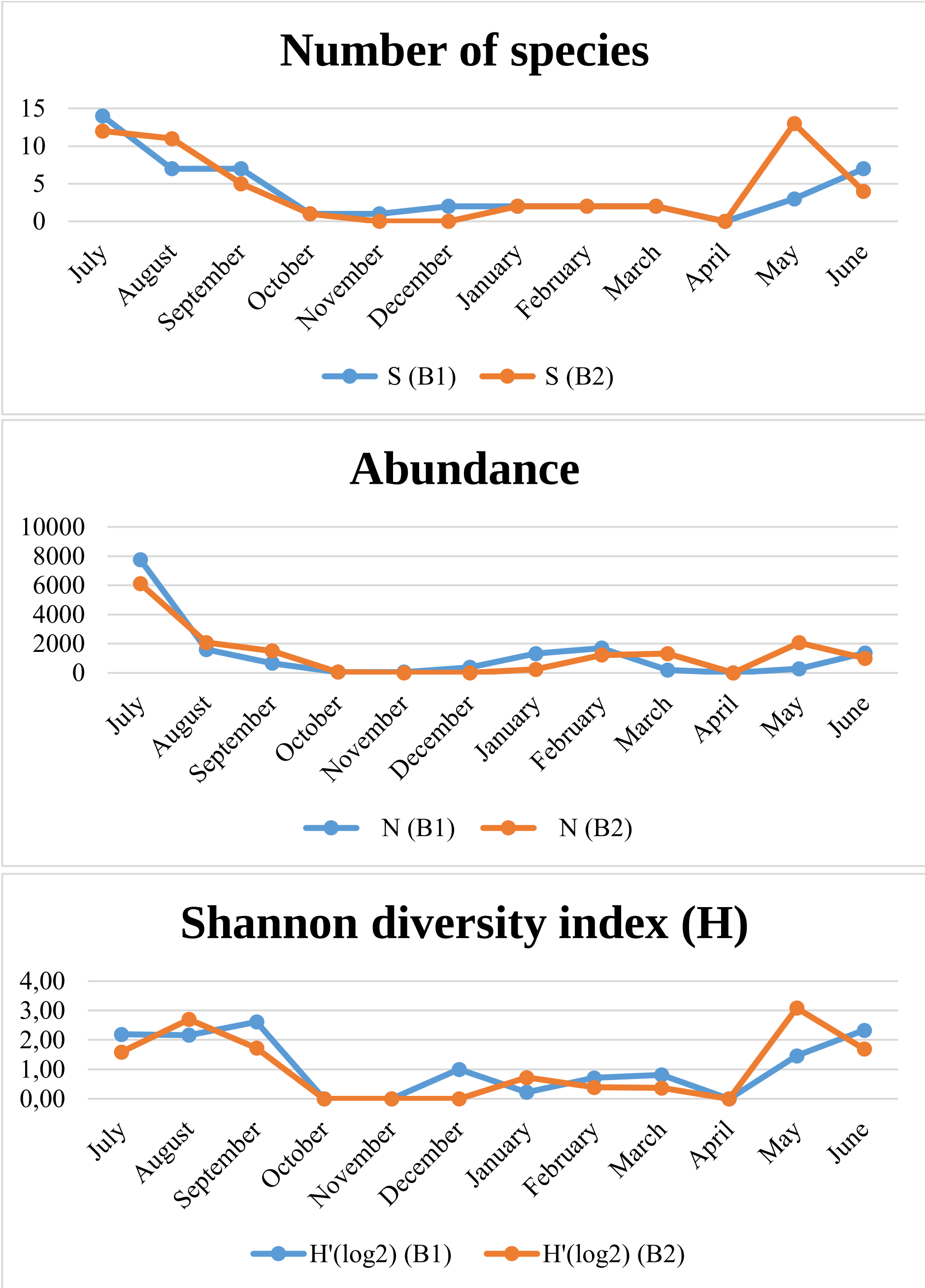



**Figure 1.** Comparison of regional diversity

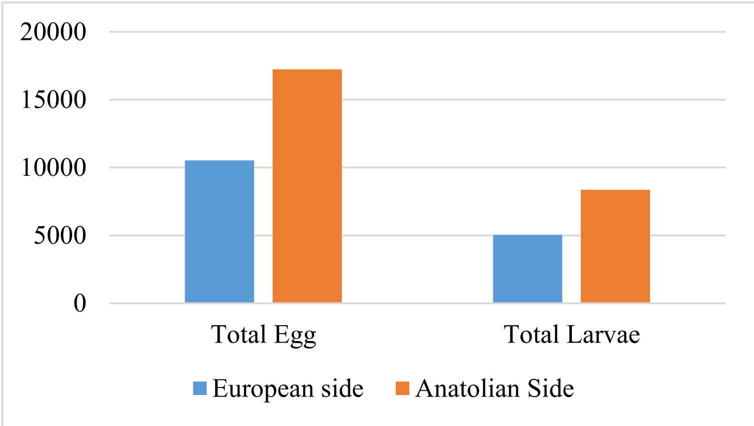



**Figure 2.** Comparison of two regions in terms of Egg and Larval Density

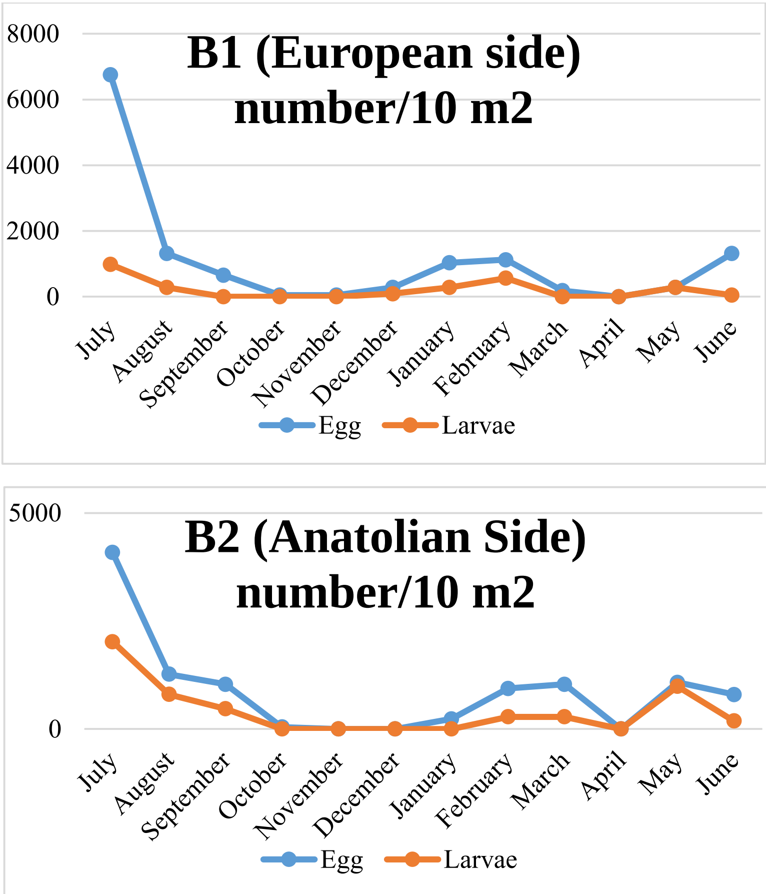



**Figure 3.** Comparison of the abundance of egg and larvae in Europe and Anatolia

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# STATUS OF SMALL PELAGIC FISHES IN THE SEA OF MARMARA

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## 1. Introduction

The first research on fish biodiversity of the Sea of Marmara was performed around 70 years ago by Erazi (1942) with reported 181 fish species. Since then a few number of other researches were also reported 135 species (Slastenenko 1965), 175 species (Geldiay 1969) and in the most recent research with 257 species (Bilecenoğlu *et al.* 2014) in the Sea of Marmara which represents half of the recorded ichthyofauna in Turkish seas (see Appendix Table 1). Of the 257 species, 36 of them are cartilaginous species including 21 sharks, 14 rays and 1 chimeras. The great majority of total fish species are constituted by ray-finned fishes namely teleosteans or bony fishes over 80% percent and chondrosteans namely sturgeons with 5 species.

The term “small pelagics” defines the species live in coastal pelagic zone of the marine environment with schooling behaviour in huge number. Small pelagics are very important component of the marine life with th e close relation to upper and lower trophic levels (Palomera *et al.* 2007). Anchovy, sardine, sprat and herring are the main small pelagic fishes which are the most important for commerical interest around the world.

According to FAO latest review of world fisheries, global capture database includes 1600 harvested species, and only 25 genera including 14 small pelagics represent about 40% and 23% of the total marine catch respectively (Table 1). Those small pelagics widely used as raw material in reduction to meal and oil, and are of low commercial value. The fishery industries of developing countries rely heavily on developed countries both as outlets for their exports and as suppliers of their imports for local consumption (mainly low-priced small pelagics as well as high-value fishery species for emerging economies) or for their processing industries (FAO 2016).

Catch statistics of small pelagics show significant decline for 50 years. In 1960’s, small pelagics constituted 69% percent total catch while it was reported 23% in 2014. Especially the situation in the Mediterranean and Black Sea is alarming as catches have dropped by one-third since 2007, a decrease mainly in small pelagics such as anchovy and sardine but one that has also affected most species groups. The Mediterranean and Black Sea had 59 percent of assessed stocks fished at biologically unsustainable levels and 41 percent fully fished to under fished in 2013 (FAO 2016).

As a global scale, the key responsibility of states was recognized to preserve or rebuild healthy ecosystems for the wellbeing of current and future generations under the subject of conservation of biological diversity (CBD 1992). One of the central themes in this context is the preservation of the marine environment and implementation of precautionary rules for the exploitation of living marine resources (UNFSA 1995).

This chapter, put an effort to understand current situation of small pelagic fishery in the Sea of Marrmara. Catch statistics in years, fishing effort, fish regulation and previous studies for small pelagic fishes have been summarized.

**Table 1.** Marine captures of major species and genera (FAO 2016).

| Scientific name | FAO English name | 2003-2012 | 2013 (Tonnes) | 2014 |
|---|---|---|---|---|
| *Theragra chalcogramma* | Alaska pollock (= walleye pollock) | 2860840 | 3239296 | 3214422 |
| *Engraulis ringens* | Anchoveta (= Peruvian anchovy) | 7329446 | 5674036 | 3140029 |
| *Katsuwonus pelamis* | Skipjack tuna | 2509640 | 2974189 | 3058608 |
| *Sardinella spp.1* | Sardinellas nei | 2214855 | 2284195 | 2326422 |
| *Scomber japonicus* | Chub mackerel | 1804820 | 1655132 | 1829833 |
| *Clupea harengus* | Atlantic herring | 2164209 | 1817333 | 1631181 |
| *Thunnus albacares* | Yellowfin tuna | 1284169 | 1313424 | 1466606 |
| *Decapterus spp.1* | Scads nei | 1389354 | 1414958 | 1456869 |
| *Scomber scombrus* | Atlantic mackerel | 717030 | 981998 | 1420744 |
| *Engraulis japonicus* | Japanese anchovy | 1410105 | 1329311 | 1396312 |
| *Gadus morhua* | Atlantic cod | 897266 | 1359399 | 1373460 |
| *Trichiurus lepturus* | Largehead hairtail | 1311774 | 1258413 | 1260824 |
| *Sardina pilchardus* | European pilchard (= sardine) | 1088635 | 1001627 | 1207764 |
| *Dosidicus gigas* | Jumbo flying squid | 778384 | 847292 | 1161690 |
| *Micromesistius poutassou* | Blue whiting (= poutassou) | 1357086 | 631534 | 1160872 |
| *Scomberomorus spp.1* | Seerfishes nei | 834548 | 941741 | 919644 |
| *Illex argentinus* | Argentine shortfin squid | 446366 | 525402 | 862867 |
| *Nemipterus spp.1* | Threadfin breams nei | 536339 | 581276 | 649700 |
| *Cololabis saira* | Pacific saury | 465032 | 428390 | 628569 |
| *Portunus trituberculatus* | Gazami crab | 356587 | 503868 | 605632 |
| *Acetes japonicus* | Akiami paste shrimp | 580147 | 585433 | 556316 |
| *Strangomera bentincki* | Araucanian herring | 580805 | 236968 | 543278 |
| *Sprattus sprattus* | European sprat | 611525 | 394405 | 494619 |
| *Clupea pallasii* | Pacific herring | 330017 | 510025 | 478778 |

| | | | | |
|---|---|---|---|---|
| *Gadus macrocephalus* | Pacific cod | 373547 | 464367 | 474498 |
| **Total 25 major species and genera** | | **34232526** | **32954012** | **33319537** |

## 2. Catch Statistic (Landings) of small pelagic fishes in the Sea of Marmara

The Sea of Marmara forms the transitional environment between the Black Sea and the Mediterranean Sea. This unique marine environment exchanges waters with the Black Sea through the Istanbul Strait (Bosphorus) and with the Mediterranean Sea through the Dardanelles Strait. In the Bosphorus, this exchange of water is achieved by a surface current entering from the Black Sea and a deep current flowing from the Mediterranean towards the Black Sea (Beşiktepe *et al.* 1994).

Kocatas *et al.* (1993) defined the Sea of Marmara as an enclosed basin where Atlanto-Mediterranean originated commercial pelagic fishes spawn while migrating from the Mediterranean and Aegean Sea to the Black Sea. Besides the well-established importance of the Black Sea fisheries for Turkey, the catches from the Sea of Marmara, despite its small surface area (11,111 km$^2$), constitute a significant fraction of catches in Turkey through 1980's (7%), 1990's (14%) and 2000's (10%). However, dramatic declines in catches were recorded for total fish production in 2015 (8%) for the Sea of Marmara (TÜİK 2015) (Table 2).

**Table 2.** Decadal changes in annual fish production in Turkish waters and in the Sea of Marmara since 1970.

| Years | Sea of Marmara (t) | Turkey (t) | % |
|---|---|---|---|
| 1970 | 17448 | 166080 | 10.5 |
| 1980 | 30365 | 392196 | 7.74 |
| 1990 | 42064 | 297123 | 14.15 |
| 2000 | 46137 | 441690 | 10.44 |
| 2010 | 36529 | 399656 | 9.14 |
| 2015 | 29337 | 345765 | 8.48 |

The catch statistics of the Sea of Marmara have been started to collect since 1967 by Turkish Statistical Institute (formerly known as State Institute of Statistic). The contribution of the Sea of Marmara to the total marine landing of Turkey increased in 39% percent in a decade between 1980 and1990. Increasing of total fish production was mainly the results by new regulations such as high promotion to fishermen provided extending the fishing fleet, by demographic changes and increased population in the Marmara region and industrial development with the establishment of fish meal and fish oil factories in the region. The changes in catch of small pelagics for 50 years period can be seen in Table 3.

**Table 3.** Small pelagic catches (tonnes) in the Sea of Marmara between the years 1967 and 2015.

| Years | Anchovy | Small horse mackerel | Horse mackerel | Sardine | Sprat |
|---|---|---|---|---|---|
| 1967 - 1970 | 1960 | 925 | 434 | 1111.3 | - |
| 1970 - 1979 | 5439 | 2100 | 570 | 980.8 | - |
| 1980 - 1989 | 10258 | 6641 | 1728 | 2330.1 | - |
| 1990 - 1999 | 14857 | 2242.6 | 2276 | 6482 | 297.2 |
| 2000 - 2009 | 21591 | 5907 | 2846.4 | 4576 | 346.1 |
| 2010 - 2015 | 18249 | 2735.1 | 1972.1 | 7209 | 93.5 |

Small pelagics constitutes a high percent of (68%) total fish production in Turkey and any fluctiations in small pelagics catched directly affected Turkish fish production. This fluctuation pattern and its direct effect can be seen clearly in Figure 1.

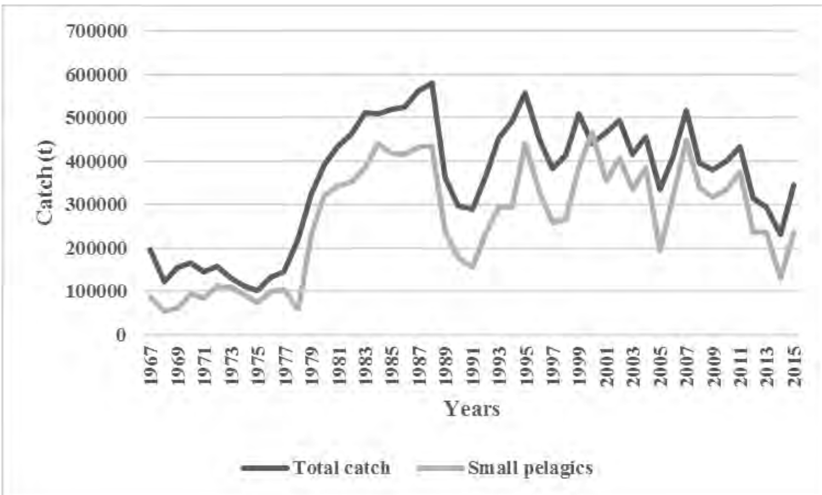


**Figure 1.** Annual total fish production and small pelagics catch statistics in Turkish waters between the years 1967 and 2015 (TUIK 2015).

Fish production in the Sea of Marmara corresponds 8% percent of total fish production in Turkey while 10% percent of small pelagics catch was obtained from this small sea according to the recent catch statistics (TÜİK 2015) (Figure 2). In other words, the fisheries of the Sea of Marmara is mainly dominated by small pelagics. Commercially exploited small pelagic fish species in this sea are: *Engraulis encrasicolus* (anchovy), *Trachurus mediterraneus* (Mediterranean horse mackerel), *Trachurus trachurus* (Atlantic horse mackerel), *Sardina pilchardus* (sardine) and *Sprattus sprattus* (sprat).

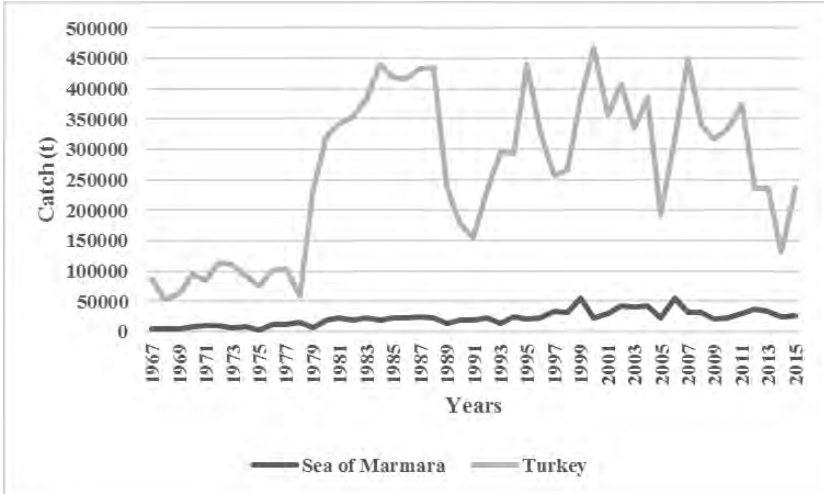


**Figure 2.** The annual small pelagics catches in the Sea of Marmara and in Turkish waters between the years 1967 and 2015.

Anchovy, the most important species of small pelagic fishing, accounts for approximately 61% of the Sea of Marmara fisheries. This commercially important fish species is sensitive to environmental conditions and any fluctuations in its population directly affect commercial fishing in the Sea of Marmara. Anchovy fisheries can be addressed as a good indicator of the chancing environment in the Sea of Marmara due to various reasons such as demographic changes in the region, urbanization and eutrophication, increased fishing activity, alien species in the past 50 years.

Early 1980s, an Atlantic originated ctenephore species *Mnemiopsis lediyi* has been transported via ballast water and widespreaded in the Black Sea before the late 1980s. Dramatic changes in Black Sea anchovy fisheries were observed in 90's due to *Mnemiopsis leidy* invasion. (Kıdeyş 2002). In 1991 the first observation of the invasive ctenophore species was observed in the Sea of Marmara (Artüz 1991). Average abundance of *Mnemiopsis leidy* was determined 4.2 kg.m$^{-2}$ in the surface water of the Sea of Marmara in October 1992 (Shinagova *et al.* 1995). A sharp decline in anchovy catch was recorded in 1993 with only 709 tonnes while it was recorded 13971 ton already in previous year 1991 (TUIK 1992; 1993) (Figure 3).

The latest considerable environmental change was mucilage event in the Sea of Marmara. Mucilage formation was first observed in the Sea of Marmara in October 2007 and dozens of square kilometers area of the sea surface was covered by. It has been caused not only visual pollution also economical damage on fisheries by decreasing fishing production as well as clogging the fishing nets and causing discards.

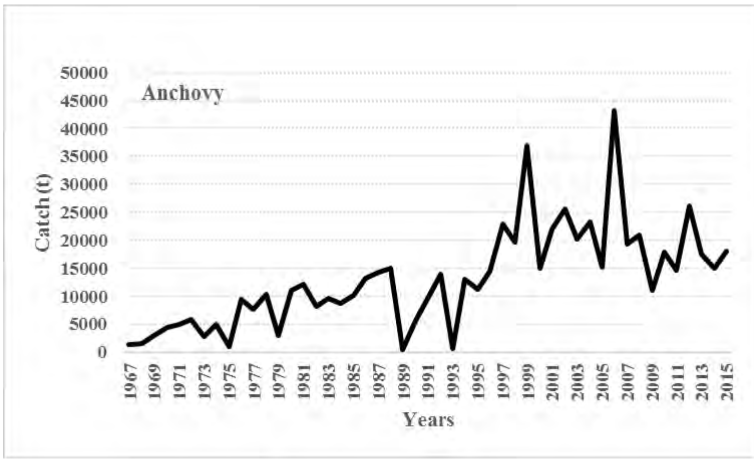


**Figure 3.** The annual anchovy catch statistics in the Sea of Marmara between the years 1967 and 2015.

The other important small pelagic fish species in the Sea of Marmara are Mediterranean horse mackerel and Atlantic horse mackerel. The production of those species were recorded 2256 tonnes for Mediterranean horse mackerel and 794 tonnes for Atlantic horse mackerel in 2015 (TUIK 2015). There is a significant declining trend in horse mackerel productions in the last decade (Figure 4). However, likewise the anchovy fisheries there are no stock assessment studies on those species and poor knowledge on stock status makes it difficult to evaluate maximum sustainable yield, biological reference points and overfishing activity on horse mackerel fisheries both in the Sea of Marmara and in Turkish waters.

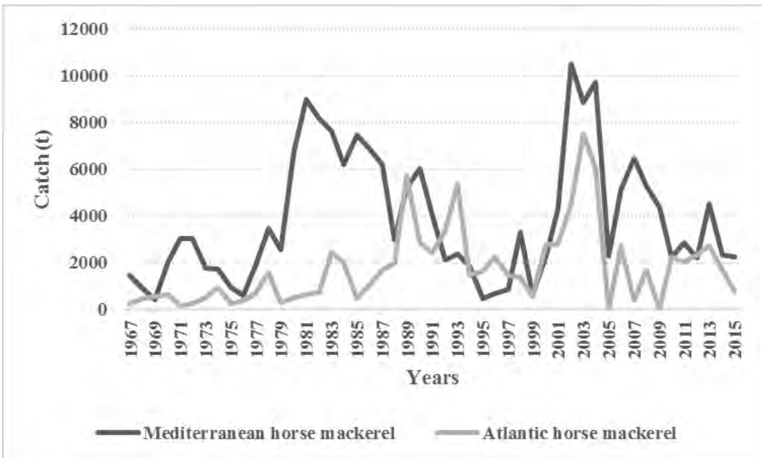


**Figure 4.** The annual Mediterranean horse mackerel and Atlantic horse mackerel catch statistics in the Sea of Marmara between the years 1967 and 2015.

Sardine is one of the other commercially important small pelagic fish in the Sea of Marmara. Especially in recent years, an increase in the catch of sardines has been observed (Figure 5). The lowest catch was recorded 163 tonnes in 2001 since then sardine fishery shows high fluctuation with the second highest catch in 2011. In order to consider last 5 years catch statistics of sardine, the average annual catch is 7209 tonnes.

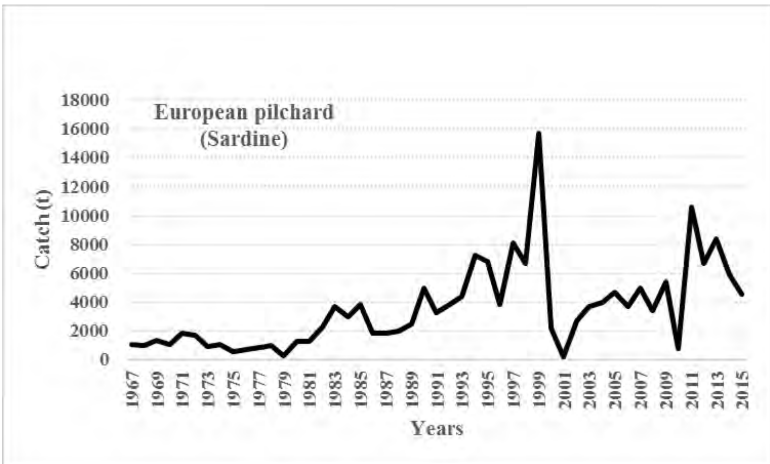


**Figure 5.** The annual sardine catch statistics in the Sea of Marmara between the years 1967 and 2015.

The sprat fishery has been included fish statistics of the Sea of Marmara since 1993 and this small pelagic fish has the less contribution in the area with the obtained 265.3 tonnes catch during the 22 years. Sprat catch statistics present high fluctuations in the Sea of Marmara (Figure 6). Its lowest production was recorded 5 tonnes in 2013, while the amount of the highest production was 662 tonnes in 1996.

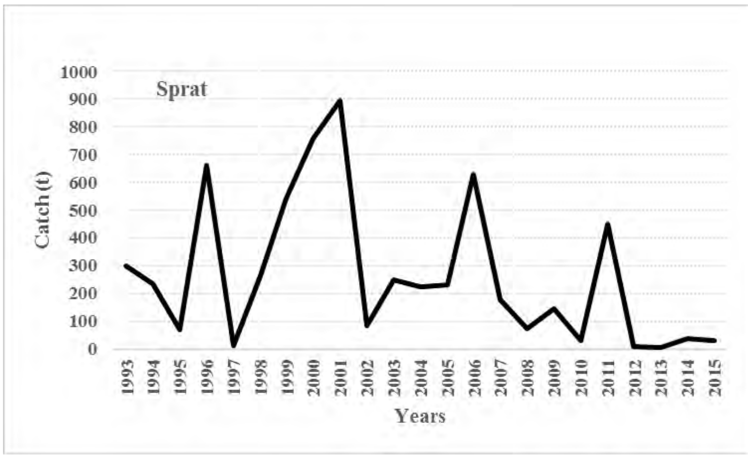


**Figure 6.** The annual sprat catch statistics in the Sea of Marmara between the years 1993 and 2015.

## 3. Fishing fleet and fisheries regulation in the Sea of Marmara

Small pelagics are schooling species and spent their lifes near the surface marine waters. Fishing activity on small pelagics are mainly performed by surrounding the schools of fish which is known seine fishing with the common type of seine called as purse seine.

The schooling pelagic fishes are very important in fisheries, and because of their economic importance, pelagic fisheries became an industrialized activity in the world. Industralization has been launched with the increasing the engine power of the fishing boats and their catch capacity, development of high-tech fish finder devices such as echo-sounder and sonars and their extending usage by state-funds (Hoşsucu 2010). Since 1970, easy findable of schooling fishes, even determination of species level by acoustic methods has been very common in fishing activity (Reid and Simmonds 1993). It is obvious to say that those innovations on fishing methods are the main contribution on increased fishing pressure on the small pelagic fish stocks.

Nowadays, most of the purse seine boats are equipped echo-sounder and sonar devices in the world. A total of 454 purse seiner boats are recorded in Turkish waters, 90% percent of them are equipped with echo-sounder and while 80% percent were with sonar devices. Considering the Sea of Marmara, %12 and 49.3% percent of registered fishing boats have been equipped sonar and echo-sounder respectively (TUIK 2015) (Figure 7).

The Ministry of Food, Agriculture and Livestock is the main state organization responsible for fisheries (including aquaculture) administration, regulation, protection, promotion and technical assistance. All activities in fisheries and aquaculture are based on the Fisheries Law No. 1380, enacted in 1971 (Düzgüneş and Erdoğan 2008). Small pelagic fishing are usually performed by purse seines and mid-water trawls in our country. According to abovementioned fiheries law, it is prohibited fishing by purse seine and trawling in all of our sea between April 15 to August 31.

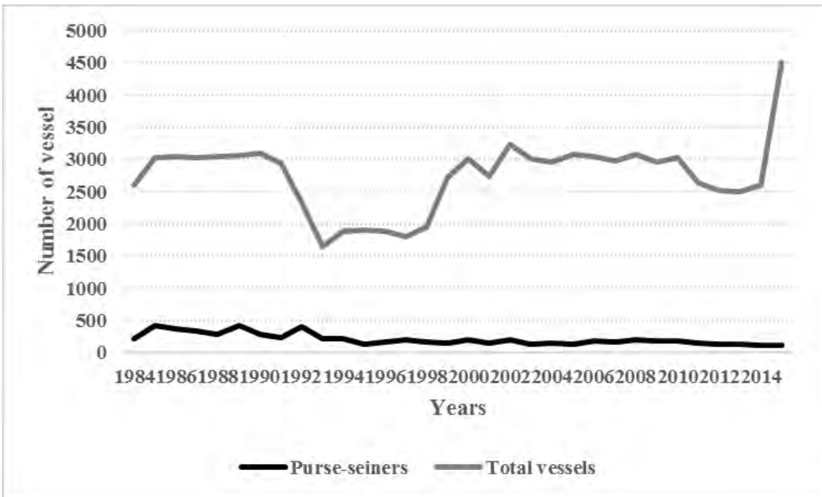


**Figure 7.** Changes in the registered total number of fishing vessels and purse seiners in the Sea of Marmara between the years 1984 and 2015.

### 4. The European Anchovy (*Engraulis encrasicolus* L.,1758) in the Sea of Marmara

Anchovies, the genus *Engraulidae*, are the most important marine fish species with high economic value both in our country and in the world. Anchovies are widely distributed around the world, and their production capacity is very high. Anchovy species with the highest biomass around the world are Peru anchovetta (*Engraulis ringens*, Mysak, 1986), South African anchovy (*Engraulis capensis*, Hampton, 1996), European anchovy (*Engraulis encrasicolus*) and the Black Sea anchovy (*Engraulis encrasicolus ponticus*) (FAO 2016).

Anchovy is a planktivorous species mainly feed on copepods and cirripeds and in a big competition with the other small pelagic species such as sprat, shad, sardine as well as ctenophors and jellyfishes for the food resources (Bingel and Gücü 2010). Anchovy is the fast-growing species with short life-span and it is highly sensitive to the environmental changes (Prodanov *et al.* 1997).

Anchovy reaches sexual maturity at the age 1+, usually between 9 and 12 total lengths. Spawning period is reported from May to August (Demir 1959). As a batch spawner, according to Owen (1979) anchovy spawns 9-12 times while Lisovenko (1985) reported 50 times for the Black Sea.

There are very limited study on the biology and stock of anchovy in the Sea of Marmara. Azgider (2016) performed a detailed study on biology of anchovy from the northerneast part. The results of mortality rates were stated Z=1.37 $y^{-1}$, M=0.38 $y^{-1}$, F=0.99 $y^{-1}$ and estimated exploitation rate was E= 0.72 with the indication of high fishing pressure (Azgider 2016). Zengin *et al.* (2015) investigated a comparative study on morphometric characteristic and otolith shapes anchovy in Black Sea and in the Sea of Marmara. Their results indicated there are statistical differences in the measurements of individiual belongs to diffferent seas. Although, it is still an ongoing discussion, those results are supported the idea that anchovy caught in the Sea of Marmara forms a separate stock from the Black Sea (Gücü 2013).

## 5. Mediterranean Horse Mackarel (*Trachurus mediterraneus*, Steindachner, 1868) in the Sea of Marmara

The Mediterranean horse mackerel, *Trachurus mediterraneus* (Steindachner, 1868), is distributed in the temperate waters of the Atlantic Ocean (from Mauritania to the Bay of Biscay), the Mediterranean Sea, and the Black Sea. The habitat of this species includes a wide range of water types such as marine, brackish waters and the pelagic ocean (Froese and Pauly 2016). Mediterranean horse mackerel constitutes one-fourth of the total marine fish catch of Turkey (TÜİK 2015) and also provides income for the fishermen, who use simple fishing methods such as setlines, long lines, and gillnets. Additionally, it is the most common recreational fish for anglers and small-scale fishermen around the Istanbul region throughout the year. Especially in the summer season, Istanbul residents cluster around both sides of the Istanbul Strait and the entrance of the Golden Horn Estuary in order to angle. It is prohibited by Turkish fishery law to use any fishing gear or methods except angling in the Golden Horn Estuary.

Many marine fishes are classified as visitors when they randomly appear in estuaries (McLusky and Elliott 2004). Mediterranean horse mackerel was also evaluated as an irregular visitor to the Golden Horn Estuary of Istanbul metropolitan area; thus, no spawning or nursery dependency should be ascribed to this species (Demirel and Yüksek 2014).

First studies on biology of *Trachurus* species in the Sea of Marmara was performed by Neumann (1956) and Demir (1958). Additionally, Demir (1961) pointed out eggs and larvae distirbution of *Trachurus mediterraneus* in the Sea of Marmara. Kukul (1987) was studied first maturity size and distributional pattern on 737 individual of *Trachurus mediterraneus* in the Strait of Istanbul. It was determined that first maturity size of this species was 13.5 cm at the age of 2+.

Demirel and Yüksek (2013a) reported that spawning of this species starts in May, peaks in July–August and ends in September but the spawning season extended to October for males according to results of gonad histology and gonadosomatic index values (Figure 8). Females reach maturity at smaller sizes than males. Sizes at 50% maturity in females were reported 12.2 cm and in males were 12.5 cm.

Oocyte development in *T. mediterraneus* was determined to be asynchronous with indeterminate fecundity (Demirel and Yüksek 2013b). Observations of all stages of oocytes, with a continuous size distribution and no distinct hiatus in the pre-spawned ovaries were defined as asynchronous ovarian organization and indeterminate fecundity type (Hunter *et al.,*1985; Murua *et al.* 2003).

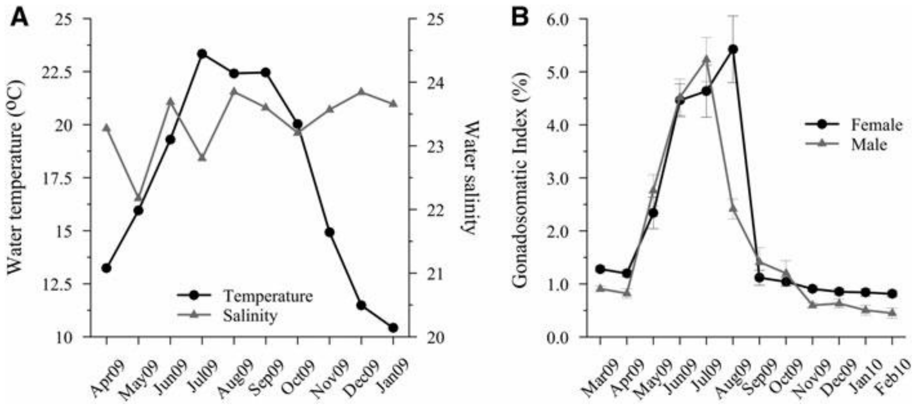


**Figure 8.** Hydrographical conditions and mean gonadosomatic index values in the northern part of the Sea of Marmara. (A) Monthly distribution of water temperature and salinity; (B) monthly changes of mean gonadosomatic index (GSI%) for female and male (Demirel and Yüksek 2013a).

## 6. Conclusion

Significant decline in small pelagics statistics of the Sea of Marmara display an urgent action for the fishery regulation and management. In this context, the question should be: “How successful is management based on such simple harvest control rule, if compared with management informed by full stock assessments?” Gücü (2013) stated that increasing eutrophication in the Sea of Marmara once helped small pelagics to built up their carrying capacity, however this turn to a challenge quickly and environmental changes such as mucilage event abruptly decrease the small pelagic stocks.

Good fishery management should consider well-designed national stock assessment programme with sub-indicators and reference points by international agreement (MSFD 2008) such as:

1. Spawning stock size (SSB) relative to the stock size (SSBmsy) that can produce the maximum sustainable yield.
2. Fishing mortality (F) relative to the natural mortality (M).

3. Mean length (Lmean) in commercial catches relative to the mean length where 90% of the females have reached sexual maturity (Lm90).
4. Abundance measured as catch-per-unit-effort (CPUE) relative to the mean CPUE in the time series.

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## APPENDIX

**Table 1.** Checklist of fish species in the Sea of Marmara (Bilecenoğlu *et al.* 2014).

| **Species** | **Species** |
|---|---|
| *Hexanchus griseus* (Bonnaterre, 1788) | *Myliobatis aquila* (Linnaeus, 1758) |
| *Carcharodon carcharias* (Linnaeus, 1758) | *Chimaera monstrosa* Linnaeus, 1758 |
| *Lamna nasus* (Bonnaterre, 1788) | *Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833 |
| *Alopias superciliosus* Lowe, 1841 | *Acipenser nudiventris* Lovetsky, 1828 |
| *Alopias vulpinus* (Bonnaterre, 1788) | *Acipenser stellatus* Pallas, 1770 |
| *Galeus melastomus* Rafinesque, 1810 | *Acipenser sturio* Linnaeus, 1758 |
| *Scyliorhinus canicula* (Linnaeus, 1758) | *Huso huso* (Linnaeus, 1758) |
| *Scyliorhinus stellaris* (Linnaeus, 1758) | *Anguilla anguilla* (Linnaeus, 1758) |
| *Galeorhinus galeus* (Linnaeus, 1758) | *Muraena helena* Linnaeus, 1758 |
| *Mustelus asterias* Cloquet, 1821 | *Conger conger* (Linnaeus, 1758) |
| *Mustelus mustelus* (Linnaeus, 1758) | *Alosa fallax* (Lacepede, 1803) |
| *Prionace glauca* (Linnaeus, 1758) | *Alosa caspia* (Eichwald, 1838) |
| *Dalatias licha* (Bonnaterre, 1788) | *Alosa maeotica* (Grimm, 1901) |
| *Oxynotus centrina* (Linnaeus, 1758) | *Alosa tanaica* (Grimm, 1901) |
| *Centrophorus granulosus* (Bloch & Schneider, 1801) | *Clupeonella cultriventris* (Nordmann, 1840) |
| *Centrophorus uyato* (Rafinesque, 1810) | *Sardina pilchardus* (Walbaum, 1792) |
| *Squalus acanthias* Linnaeus, 1758 | *Sardinella aurita* Valenciennes, 1847 |
| *Squalus blainville* (Risso, 1827) | *Sprattus sprattus* (Linnaeus, 1758) |
| *Echinorhinus brucus* (Bonnaterre, 1788) | *Engraulis encrasicolus* (Linnaeus, 1758) |
| *Squatina oculata* Bonaparte, 1840 | *Argentina sphyraena* Linnaeus, 1758 |
| *Squatina squatina* (Linnaeus, 1758) | *Maurolicus muelleri* (Gmelin, 1789) |
| *Torpedo nobiliana* Bonaparte, 1835 | *Argyropelecus hemigymnus* Cocco, 1829 |
| *Torpedo marmorata* Risso, 1810 | *Stomias boa* (Risso, 1810) |
| *Torpedo torpedo* (Linnaeus, 1758) | *Benthosema glaciale* (Reinhardt, 1837) |
| *Dipturus batis* (Linnaeus, 1758) | *Hygophum benoiti* (Cocco, 1838) |
| *Dipturus oxyrinchus* (Linnaeus, 1758) | *Lampanyctus crocodilus* (Risso, 1810) |
| *Leucoraja naevus* (Müller & Henle, 1841) | *Myctophum punctatum* Rafinesque, 1810 |
| *Raja asterias* Delaroche, 1809 | *Notoscopelus elongatus* (Costa, 1844) |
| *Raja clavata* Linnaeus, 1758 | *Trachipterus trachypterus* (Gmelin, 1789) |
| *Raja miraletus* Linnaeus, 1758 | *Nezumia aequalis* (Günther, 1878) |
| *Raja montagui* Fowler, 1910 | *Nezumia sclerorhynchus* Valenciennes, 1838 |
| *Raja radula* Delaroche, 1809 | *Gadiculus argenteus* Guichenot, 1850 |
| *Dasyatis pastinaca* (Linnaeus, 1758) | *Merlangius merlangus* (Linnaeus, 1758) |
| *Gymnura altavela* (Linnaeus, 1758) | *Micromesistius poutassou* (Risso, 1827) |

**Table 1.** Continued

| Species | Species |
|---|---|
| *Trisopterus minutus* (Linnaeus, 1758) | *Scorpaena scrofa* Linnaeus, 1758 |
| *Gaidropsarus biscayensis* (Collett, 1890) | *Dactylopterus volitans* (Linnaeus, 1758) |
| *Gaidropsarus mediterraneus* (Linnaeus, 1758) | *Chelidonichthys cuculus* (Linnaeus, 1758) |
| *Gaidropsarus vulgaris* (Cloquet,1824) | *Chelidonichthys gurnardus* (Linnaeus, 1758) |
| *Merluccius merluccius* (Linnaeus, 1758) | *Chelidonichthys lastoviza* (Bonnaterre, 1788) |
| *Ophidion barbatum* Linnaeus, 1758 | *Chelidonichthys lucernus* (Linnaeus, 1758) |
| *Ophidion rochei* Müller, 1845 | *Lepidotrigla cavillone* (Lacepède, 1801) |
| *Parophidion vassali* (Risso, 1810) | *Lepidotrigla dieuzeidei* Blanc & Hureau, 1973 |
| *Carapus acus* (Brünnich, 1768) | *Trigla lyra* Linnaeus, 1758 |
| *Lophius budegassa* Spinola, 1807 | *Peristedion cataphractum* (Linnaeus, 1758) |
| *Lophius piscatorius* Linnaeus, 1758 | *Dicentrarchus labrax* (Linnaeus, 1758) |
| *Apletodon dentatus* (Facciolà, 1887) | *Anthias anthias* (Linnaeus, 1758) |
| *Diplecogaster bimaculata* (Bonnaterre, 1788) | *Epinephelus marginatus* (Lowe, 1834) |
| *Lepadogaster candolii* Risso, 1810 | *Serranus cabrilla* (Linnaeus, 1758) |
| *Lepadogaster lepadogaster* (Bonnaterre, 1788) | *Serranus hepatus* (Linnaeus, 1758) |
| *Atherina boyeri* Risso, 1810 | *Serranus scriba* (Linnaeus, 1758) |
| *Atherina hepsetus* Linnaeus, 1758 | *Apogon imberbis* (Linnaeus, 1758) |
| *Scomberesox saurus* (Walbaum, 1792) | *Pomatomus saltatrix* (Linnaeus, 1766) |
| *Belone belone* (Linnaeus, 1761) | *Echeneis naucrates* Linnaeus, 1758 |
| *Hirundichthys rondeletii* (Valenciennes, 1847) | *Remora remora* (Linnaeus, 1758) |
| *Zeus faber* Linnaeus, 1758 | *Lichia amia* (Linnaeus, 1758) |
| *Gasterosteus aculeatus* Linnaeus, 1758 | *Naucrates ductor* (Linnaeus, 1758) |
| *Hippocampus guttulatus* Cuvier, 1829 | *Trachurus mediterraneus* (Steindachner, 1868) |
| *Hippocampus hippocampus* (Linnaeus, 1758) | *Trachurus trachurus* (Linnaeus, 1758) |
| *Nerophis maculatus* Rafinesque, 1810 | *Boops boops* (Linnaeus, 1758) |
| *Nerophis ophidion* (Linnaeus, 1758) | *Dentex dentex* (Linnaeus, 1758) |
| *Syngnathus abaster* Risso, 1827 | *Dentex gibbosus* (Rafinesque, 1810) |
| *Syngnathus acus* Linnaeus, 1758 | *Diplodus annularis* (Linnaeus, 1758) |
| *Syngnathus phlegon* Risso, 1827 | *Diplodus puntazzo* (Cetti, 1777) |
| *Syngnathus schmidti* Popov, 1927 | *Diplodus sargus* (Linnaeus, 1758) |
| *Syngnathus tenuirostris* Rathke, 1837 | *Diplodus vulgaris* (Geoffroy St. Hilaire, 1817) |
| *Syngnathus typhle* Linnaeus, 1758 | *Lithognathus mormyrus* (Linnaeus, 1758) |
| *Helicolenus dactylopterus* (Delaroche, 1809) | *Oblada melanura* (Linnaeus, 1758) |
| *Scorpaena notata* Rafinesque, 1810 | *Pagellus acarne* (Risso, 1827) |
| *Scorpaena porcus* Linnaeus, 1758 | *Pagellus bogaraveo* (Brünnich, 1768) |

**Table 1.** Continued

| Species | Species |
|---|---|
| *Pagellus erythrinus* (Linnaeus, 1758) | *Symphodus tinca* (Linnaeus, 1758) |
| *Pagrus pagrus* (Linnaeus, 1758) | *Thalassoma pavo* (Linnaeuus, 1758) |
| *Sarpa salpa* (Linnaeus, 1758) | *Xyrichtys novacula* (Linnaeus, 1758) |
| *Sparus aurata* Linnaeus, 1758 | *Gymnammodytes cicerelus* (Rafinesque, 1810) |
| *Spondyliosoma cantharus* (Linnaeus, 1758) | *Echiichthys vipera* (Cuvier, 1829) |
| *Spicara flexuosa* Rafinesque, 1810 | *Trachinus araneus* Cuvier, 1829 |
| *Spicara maena* (Linnaeus, 1758) | *Trachinus draco* Linnaeus, 1758 |
| *Spicara smaris* (Linnaeus, 1758) | *Trachinus radiatus* Cuvier, 1829 |
| *Argyrosomus regius* (Asso, 1801) | *Uranoscopus scaber* Linnaeus, 1758 |
| *Sciaena umbra* Linnaeus, 1758 | *Tripterygion tripteronotus* (Risso, 1810) |
| *Umbrina cirrosa* (Linnaeus, 1758) | *Clinitrachus argentatus* (Risso, 1810) |
| *Mullus barbatus* Linnaeus, 1758 | *Aidablennius sphynx* (Valenciennes, 1836) |
| *Mullus surmuletus* Linnaeus, 1758 | *Blennius ocellaris* Linnaeus, 1758 |
| *Chromis chromis* (Linnaeus, 1758) | *Coryphoblennius galerita* (Linnaeus, 1758) |
| *Cepola macrophthalma* (Linnaeus, 1758) | *Microlipophrys adriaticus* (Steindachner & Kolombatović, 1883) |
| *Chelon labrosus* (Risso, 1827) | *Parablennius gattorugine* (Linnaeus, 1758) |
| *Liza aurata* (Risso, 1810) | *Parablennius incognitus* (Bath, 1968) |
| *Liza haematocheila* (Temminck & Schlegel, 1845) | *Parablennius sanguinolentus* (Pallas, 1814) |
| *Liza ramada* (Risso, 1810) | *Parablennius tentacularis* (Brünnich, 1768) |
| *Liza saliens* (Risso, 1810) | *Parablennius zvonimiri* (Kolombatović, 1892) |
| *Mugil cephalus* Linnaeus, 1758 | *Paralipophrys trigloides* (Valenciennes, 1836) |
| *Oedalechilus labeo* (Cuvier, 1829) | *Salaria pavo* (Risso, 1810) |
| *Coris julis* (Linnaeus, 1758) | *Callionymus fasciatus* Valenciennes, 1837 |
| *Ctenolabrus rupestris* (Linnaeus, 1758) | *Callionymus lyra* Linnaeus, 1758 |
| *Labrus bergylta* Ascanius, 1767 | *Callionymus maculatus* Rafinesque, 1810 |
| *Labrus merula* Linnaeus, 1758 | *Callionymus pusillus* Delaroche, 1809 |
| *Labrus mixtus* Linnaeus, 1758 | *Callionymus risso* LeSueur, 1814 |
| *Labrus viridis* Linnaeus, 1758 | *Aphia minuta* (Risso, 1810) |
| *Symphodus cinereus* (Bonnaterre, 1788) | *Chromogobius quadrivittatus* (Steindachner, 1863) |
| *Symphodus doderleini* Jordan, 1890 | *Deltentosteus quadrimaculatus* (Valenciennes, 1837) |
| *Symphodus mediterraneus* (Linnaeus, 1758) | *Gobius auratus* Risso, 1810 |
| *Symphodus melanocercus* (Risso, 1810) | *Gobius bucchichi* Steindachner, 1870 |
| *Symphodus ocellatus* (Forsskål, 1775) | *Gobius cobitis* Pallas, 1814 |
| *Symphodus roissali* (Risso, 1810) | *Gobius cruentatus* Gmelin, 1789 |
| *Symphodus rostratus* (Bloch, 1791) | *Gobius geniporus* Valenciennes, 1837 |

**Table 1.** Continued

| Species | Species |
|---|---|
| *Gobius niger* Linnaeus, 1758 | *Lepidorhombus boscii* (Risso, 1810) |
| *Gobius paganellus* Linnaeus, 1758 | *Lepidorhombus whiffiagonis* (Walbaum, 1792) |
| *Knipowitschia caucasica* (Berg, 1916) | *Scophthalmus maximus* (Linnaeus 1758) |
| *Lesueurigobius friesii* (Malm, 1874) | *Scophthalmus rhombus* (Linnaeus, 1758) |
| *Mesogobius batrachocephalus* (Pallas, 1814) | *Zeugopterus regius* (Bonnaterre, 1788) |
| *Neogobius melanostomus* (Pallas, 1814) | *Arnoglossus imperialis* (Rafinesque, 1810) |
| *Ponticola syrman* (Nordmann, 1840) | *Arnoglossus kessleri* Schmidt, 1915 |
| *Pomatoschistus adriaticus* Miller, 1973 | *Arnoglossus laterna* (Walbaum, 1792) |
| *Pomatoschistus bathi* Miller, 1982 | *Arnoglossus thori* Kyle, 1913 |
| *Pomatoschistus marmoratus* (Risso, 1810) | *Platichthys luscus* (Pallas, 1814) |
| *Pomatoschistus minutus* (Pallas, 1770) | *Buglossidium luteum* (Risso, 1810) |
| *Zosterisessor ophiocephalus* (Pallas, 1814) | *Dicologlossa cuneata* (Moreau, 1881) |
| *Sphyraena sphyraena* (Linnaeus, 1758) | *Microchirus ocellatus* (Linnaeus, 1758) |
| *Auxis rochei* (Risso, 1810) | *Microchirus variegatus* (Donovan, 1808) |
| *Euthynnus alletteratus* (Rafinesque, 1810) | *Monochirus hispidus* Rafinesque, 1814 |
| *Katsuwonus pelamis* (Linnaeus, 1758) | *Pegusa impar* (Bennett, 1831) |
| *Sarda sarda* (Bloch, 1793) | *Pegusa nasuta* (Pallas, 1814) |
| *Scomber colias* Gmelin, 1789 | *Pegusa lascaris* (Risso, 1810) |
| *Scomber scombrus* Linnaeus, 1758 | *Solea solea* (Linnaeus, 1758) |
| *Thunnus alalunga* (Bonnaterre, 1788) | *Synapturichthys kleinii* (Risso, 1827) |
| *Th nnus thynnus* (Linnaeus, 1758) | *Balistes capriscus* Gmelin, 1789 |
| *Xiphias gladius* Linnaeus, 1758 | *Stephanolepis diaspros* Fraser-Brunner, 1940 |
| *Capros aper* (Linnaeus, 1758) | *Lagocephalus spadiceus* (Richardson 1845) |
| *Citharus linguatula* (Linnaeus, 1758) | *Mola mola* (Linnaeus, 1758) |

## DEMERSAL FISHES AND FISHERIES IN THE SEA OF MARMARA

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### 1. Introduction

The term "demersal fish" defines fish species live near the sea-floor. In general, they are long-lived and slow growing. Demersal fish of commercial interest are mainly confined to the upper 200 m. Main fishing method is called bottom trawling that is towing a net just above the sea bottom.

Marine ecosystems, and the way species interact within them, are complex. Many species occupy different trophic levels throughout their life cycle, while species and/or sizes at the same trophic level often occupy different habitats and ecological niches and are, therefore, not necessarily co-occurring in space and/or time (FAO 2014). However, given the extensive coverage of the world's shelf ecosystems by bottom trawling, generally longer-lived, demersal (bottom) fishes have tended to decline faster than shorter-lived, pelagic (open water) fishes, a trend also indicated by changes in the ratio of piscivorous (mainly demersal) to zooplanktivorous (mainly pelagic) fishes (Pauly *et al.* 1998, Pauly *et al.* 2002). Major fisheries separately target both small pelagics as well as large demersal stocks. The demersal fish resources are to a large extent fully fished to overfished in most of the area in the world (FAO 2014).

The Marmara Sea is a small inter-continental basin. It is connected with Aegean Sea and Mediterranean Sea via Dardanelles Strait and with Black Sea via İstanbul Strait (Bosporus). Turkish Straits System. The hydrography of the Marmara Sea is dominated by the Mediterranean and Black Seas water. Within the strait system two major currents are prevailing. The under current is generated by the Mediterranean waters flows in through the Dardanelles and out through the İstanbul Strait. The surface current is generated by Black Sea waters flows in through the Istanbul and out through the Dardanelles (Beşiktepe *et al.* 1994). Those hydrographical characteristics support to inhabit some demersal Black Sea species, for example gobies, in the Sea of Marmara (Keskin 2010), succeeding in establishing themselves in the Istanbul Strait is an evidence of the optimal environmental conditions in the strait which serves as a biological corridor between the Mediterranean and Black Seas (Öztürk and Öztürk 1996; Keskin 2012). Hence, it represents different types of habitats and mixed species diversity of the Black Sea and Mediterranean Sea.

This chapter aims to evaluate current situation of demersal fishery with total demersal catch statistics, reviewing previous studies and knowledge on some notable demersal fish in the Sea of Marmara.

## 2. Previous studies of fish fauna and fisheries in the Sea of Marmara

The historical records on fish biodiversity and fisheries method in the Sea of Marmara date back to ancient times. Istanbul Strait and Golden Horn Estuary of Istanbul have had significant socioeconomic importance for centuries with their flourishing natural living resources (Tekin 1996). The entire Istanbul area are known for their important fishing grounds with rich fish biodiversity, with the notable presence of top predators such as dolphins and blue fish from the ancient times (Tekin 1996) until the 1950s (Güvengiriş 1977). Bilecenoğlu *et al.* (2014) reviewed the very early notable studies on ichthyofauna of the Sea of Marmara. According to this important review study, two authors provided significant information on Turkish marine fish during the 17th century. One of them was Evliya Çelebi (1611–ca. 1682), who mentioned the occurrence of some 20 species by their common Turkish names along the Marmara coastline in his 10 volume travelogue (Seyâhatnâme), followed by the Italian naturalist Count Luigi Ferdinando Marsigli (1658– 1730), who carried out extensive oceanographical surveys at the Bosphorus, emphasizing also local fish species and their migratory behavior to the Black Sea (Bilecenoğlu *et al.* 2014).

Since 1950's, several researches have been conducted and contributed the literature on the taxonomy, distribution, biology catch composition of the demersal fishes of the Sea of Marmara. Artüz (1957) conducted eco-survey studies to determine the spawning area of important fish species in the Sea of Marmara. Demir (1958) published systematics of 3 deep sea fish and identification of their eggs and larvae in the north-eastern part of the sea. Since the 1960s, several researches were performed on biology of various fish species.

Eryılmaz and Meriç (2005) examined earlier fish biodiversity studies by Ninni (1923) and Devedjian (1926) who was the first director of Fish Market in Istanbul. They listed 230 fish species in the Sea of Marmara. Later, Keskin and Eryılmaz (2010) added 5 new records to listed fish species. According to latest study, 415 fish species inhabited in the Sea of Marmara with new records including Indo-Pasific originated fishes also known as Lessepsian migrants (Bilecenoğlu *et al.* 2014). Over half of 415 fish species are recognized demersal (Tıraşın and Ünlüoğlu 2013).

Notable researches on demersal fish of the Sea of Marmara are chronologically listed as biology of common sole (*Solea solea*) (Oral 1996), catch composition and biology of tub gurnard (*Chelidonichthys lucerna*)in the southern part (Eryılmaz 1999), biology of surmullet (*Mullus surmuletus*) in the northern part (Moldur 1999), composition and population of juvenile fish in Erdek Bay (Keskin 2002), comparative study on stomach contents of some teleost fishes (Gönülal 2006), biology of picarel (*Spicara smaris*) in the northern part (Çorbacı 2008), feeding habits of Eurepean hake (*Merluccius, merluccius*) in the northern part (Murat-Dalkara 2009), length-weight relationship of some fish species (Keskin and Gaygusuz 2010; Bök *et al.* 2011; Demirel and Murat-Dalkara 2012a), distributional patterns of demersal fishes (Keskin 2010; Keskin *et al*. 2011), juvenile fish population in the Istanbul Strait (Keskin 2012), age and growth of blotched picarel and picarel (*Spicara maena* and *Spicara smaris*) (Saygılı *et al.* 2014), distribution and bioecology of brown comber (*Serranus hepatus*) (Yazıcı 2015) and population structure of European hake (Gül *et al.* 2016). Some ichthyoplankton studies performed to determine distribution and abundance of pelagic fish eggs and larvae of some teleost fish in order to consider important spawning grounds (Yüksek 1993; Okuş *et al.* 1998; Demirel 2004). Compatible results of those studies pointed out that northern part of the Sea of Marmara, Around Princes Islands and the entrance of Gemlik Bay were important spawning grounds with high diversity and abundance of fish eggs and larvae. In addition, several researches contributed to update the fish fauna with identifying new species and/or observing alien fish species. Besides that, some researches focused fish parasites, fatty acid contents of commercial fish. There are also many researches for pollution level such as heavy metal accumulation and organochlorine level in the consumed demersal fishes of the Sea of Marmara.

The first research on demersal catch composition was obtained by the support of Japan International Cooperation Agency (JICA) in 1993. Afterwards, Kocataş *et al.* (1993) performed a research to review the fishery resources. Gözenç *et al.* (1997) estimated total demersal stock size 6000 tonnes in 1992 and 1200 in 1994. Their results pointed out that, European hake (*Merluccius merliccius*) constituted the main portion of the catch composition with the following other demersal fish such as whiting, tub gurnard, piper gurnard, red mullet, turbot, sole. Gözenç *et al.* (1997) discussed the decline of catch due to overfishing and demographic growth and urbanization with the load of solid waste on the sea-bed.

Akyol *et al.* (2009) directly focused on the demersal fishery and main resources and performed an investigation on coastal fisheries and fishery resources around Marmara Island. Yığın and İşmen (2012) classified fisheries type and gears into 4 categories such as pelagic, artisanal, shrimp and sea snail fisheries.

There is also very important problem of the demersal fishery namely bycatch and discards. Previous studies and important results were evaluated under the “Discards” section.

Although, its contribution is important for Turkish fishery, unfortunately, stock assessment researches and related management strategies for fisheries in the Sea of Marmara are very limited.

### 3. Demersal fish fauna and catch landings of demersal fish species in the Sea of Marmara

Demersal fishery in Turkey mainly constitutes 41 fish species (Tıraşın and Ünlüoğlu 2013), and the Sea of Marmara contributed with 29 demersal fish (Table 1). Of the 29 demersal fish, 80% percent of catch provided by 6 notable species such as whiting (*Merlangius merlangus*) with 33%, surmullet (*Mullus surmuletus*) with 13%, goatfish (*Mullet spp*.) with 12%, European hake (*Merluccius merluccius*) with %7, anglerfish (*Lophius piscatorius*) with 6% and salema (*Sarpa salpa*) with %6 (TÜİK 2015).

Demersal fish production was 3% of the total fish production in 2015 (Figure 1). Comparison of the catch statistics between 1990 and 2015 show significant difference and low amounts in demersal fish production in the Sea of Marmara (Table 1). In addition, annual catch statistics show decreasing pattern since 2000s (Figure 2).

Turbot is a highly valuable fish with high market prices. Its production is significantly decreasing since mid-2000s and catch size mostly constitutes juvenile fish. Similar decreasing pattern also can be seen in production of another valuable fish, common sole since 2007 (Figure 3).

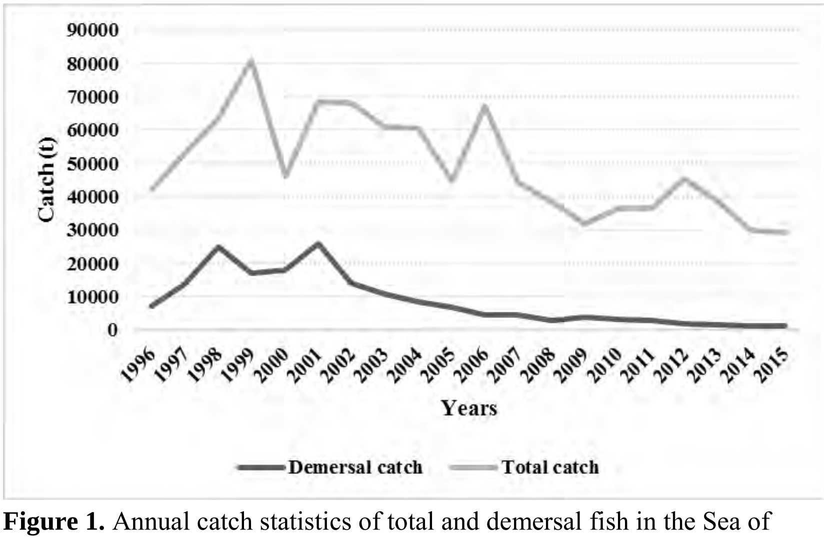


**Figure 1.** Annual catch statistics of total and demersal fish in the Sea of Marmara.

**Table 1.** Comparison of the demersal fish catch in the years 1990 and 2015 in the Sea of Marmara.

| Scientific name | Turkish name | Common name | Catch (t) 1990 | Catch (t) 2015 |
|---|---|---|---|---|
| *Merlangius merlangus* | Mezgit | Whiting | 2047 | 351 |
| *Mullus surmuletus* | Tekir | Striped red | 676 | 135 |
| *Mugil spp.* | Kefal | - | 1631 | 132 |
| *Merluccius merluccius* | Berlam | European hake | 937 | 81 |
| *Lophius piscatorius* | Fener balığı | Angler fish | - | 66.9 |
| *Salpa Salpa* | Sarpa | Saupe | 69 | 62.6 |
| *Solea solea* | Dil | Common sole | 358 | 37 |
| *Lithognathus mormyrus* | Mırmır | Striped seabream | 126 | 20.1 |
| *Scorpaena porcus* | İskorpit | Black scorpion fish | 68 | 18.8 |
| *Spicara smaris* | İzmarit | Picarel | 1074 | 17.1 |
| *Diplodus annularis* | İsparoz | Annular seabream | 110 | 15.1 |
| *Scophthalmus maximus* | Kalkan | Turbot | 43 | 14.5 |
| *Dicentrarchus labrax* | Levrek | Seabrass | 297 | 13.9 |
| *Chelidonichthus lucerna* | Kırlangıç | Tub gurnard | 245 | 13.2 |
| *Boops boops* | Kupez | Bogue | 279 | 12.8 |
| *Sparus aurata* | Çipura | Seabream | 18 | 11.9 |
| *Diplodus vulgaris* | Karagöz | Two banded bream | 221 | 6.5 |
| *Pagellus spp.* | Mercan | Seabream | 33 | 6.5 |
| *Trigla lyra* | Öksüz | Piper | - | 5.4 |
| *Mullus barbatus* | Barbunya | Red mullet | 91 | 5 |
| *Zeus faber* | Dülger | Jonh dory | - | 2.9 |
| *Umbrina cirrosa* | Minekop | Croaker | 162 | 2.4 |
| *Pleuronectes spp.* | Pisi | - | - | 1.8 |
| *Dentex dentex* | Sinagrit | Dentex | 24 | 1.5 |
| *Trigloporus Lastoviza* | Kırlangıç (Mazak) | - | - | 0.7 |
| *Scorpaena scrofa* | Lipsöz | Red scorpion-fish | 29 | 0.6 |
| *Oblada Melanura* | Melanurya | Saddled seabream | - | 0.6 |
| *Spondyliosoma cantharus* | Sarıgöz | Black Sea-bream | - | 0.2 |
| *Gaidropsarus sp.* | Gelincik | Rockling | 13 | 0.1 |

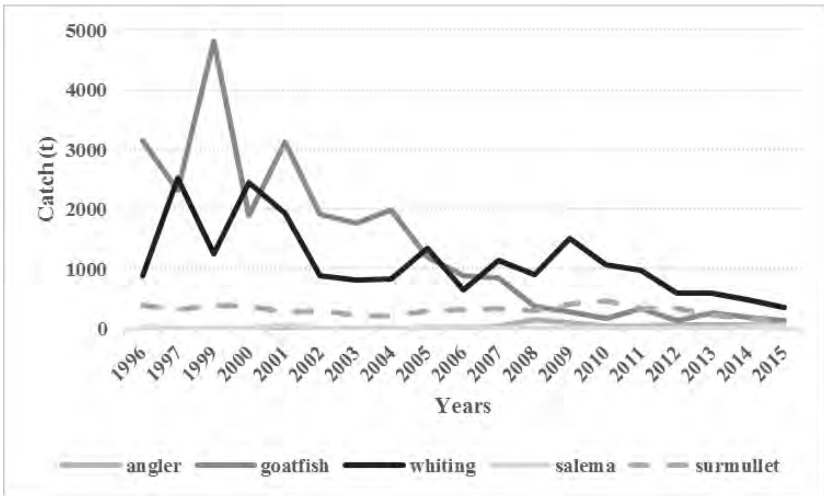


**Figure 2.** Annual catch statistics of 5 important demersal fish species in the Sea of Marmara. European hake was not included.

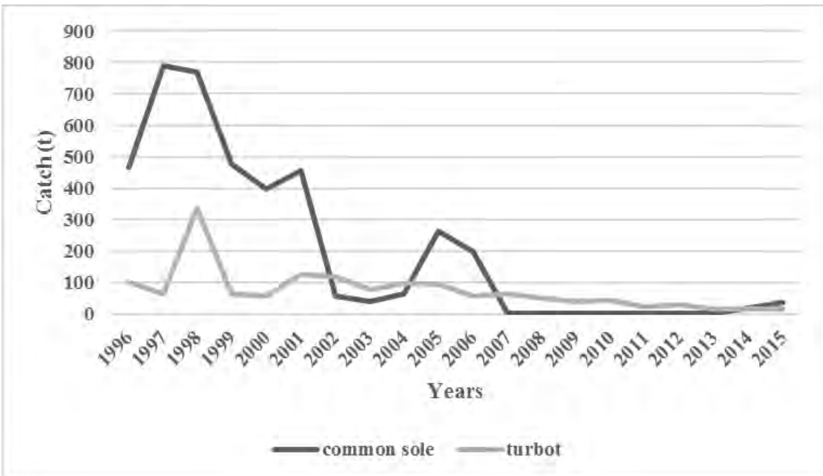


**Figure 3.** Annual catch statistics of common sole and turbot in the Sea of Marmara.

## 4. European hake (M*erluccius merluccius*) and its fishery in the Sea of Marmara

European hake has an important role on the food web with 4.4 trophic level is of namely a top predator in demersal zone (Froese and Pauly 2016). This species is mainly distributed eastern coast of Atlantic Ocean including Mediterranean Sea. The maximum length and weight of this medium-large gadoid species are about 140 cm and 15 kg, respectively with the maximum age of 12 + (Murua 2010). The biggest size was recorded 75 cm TL in early 1990s and 65 cm TL in 2009 in the Sea of Marmara (JICA 1993, Murat-Dalkara 2009). Juvenile and small European hake usually live on muddy beds on the continental shelf, whereas large adult individuals are found on the shelf slope, where the bottom is rough and associated with canyons and cliffs. Juveniles (around 10 cm TL) mainly feed on echinoids and adults (>25 cm TL) feed on other teleosts (Murat-Dalkara 2009).

Certainly, the most important demersal fish species is the European hake in the Sea of Marmara. Its production occupied around %50 percent of demersal fishery in the Sea of Marmara in mid-90s. Decreasing started in mid-2000s and drastically deteriorated below 10% percent in 2015 (Figure 4). According to TUIK (2015) catch statistics, only 81 tonnes European hake caught in the Sea of Marmara last year.

There are several researches conducted to determine catch composition and fishery resources in the Sea of Marmara. European hake were always reported dominated species in the catch composition according to results of several research until 2011 (JICA 1993; Kocataş *et al.* 1993; Gözenç *et al.* 1997; Okuş *et al.* 1997; Torcu-Koç *et al.* 2012; Demirel *et al.* 2016).

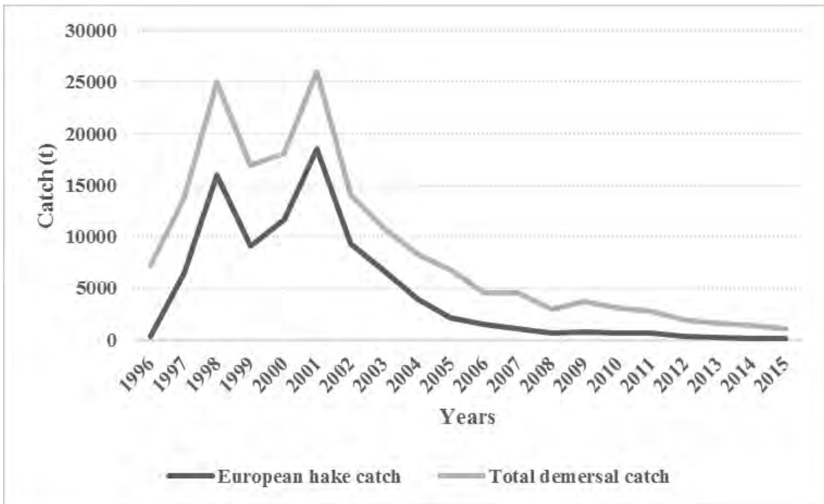


**Figure 4.** Annual catch statistics of European hake and total demersal fish in the Sea of Marmara.

**5. Fishing fleet and fisheries regulation in the Sea of Marmara**

Main fishing vessels can be classified 4 types as trawler, purseiner, beam trawlers and carrier vessels. Today, there are 14340 registered fishing vessels in various size in Turkey and 17% percent of them are operating in the Sea of Marmara (Table 2).

According to Turkish fisheries law, any kind of trawling (mid and bottom) is strictly forbidden in The Turkish Strait System (Sea of Marmara Sea and both Dardanelles and Istanbul Straits). However, coast-guard records show illegal trawling activity while data obtained from TUIK (2015) indicates the three times increase of fleet size in the past 20 years (Figure 5).

**Table 2.** Comparison of the number of fishing vessels in various types between Turkish waters and the Sea of Marmara in 2015.

| Vessel type | Turkey | The Sea of Marmara |
|---|---|---|
| **Trawler** | 650 | 131 |
| **Purseiner** | 411 | 117 |
| **Carrier vessels** | 93 | 22 |
| **Beam trawlers** | 418 | 177 |
| **Other** | 12768 | 1268 |
| **Total vessels** | 14340 | 2493 |

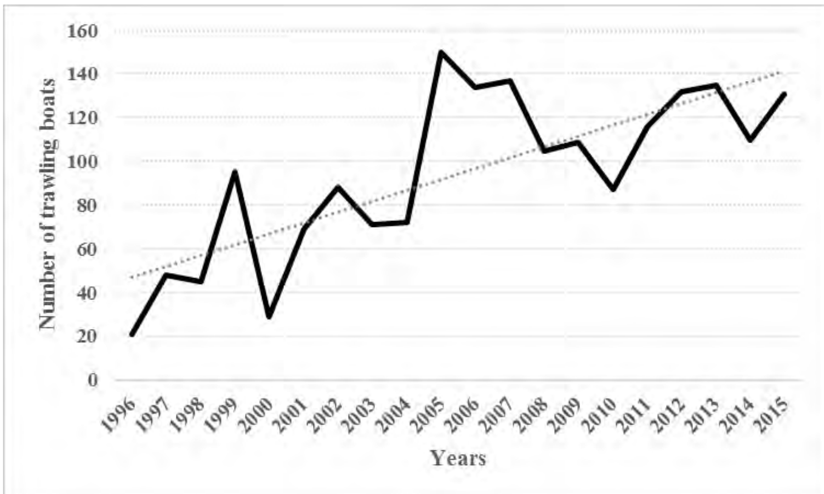


**Figure 5.** Annual changes in number of registered trawling boats in the Sea of Marmara.

## 6. Discards

The term "discards" is defined as the portion of marine animals and plants caught in fishing activity and dumped back at sea (Sarda *et al.* 2013). Discards in fisheries have been considered a serious problem for 20 years. Kelleher (2005) estimated worldwide discards at an average of 7.3 million tonnes per year, or around 8% of the total catch, although the discard rate was much higher in certain fisheries. Fishery by-catch and discarding have attracted serious attention in the world fisheries research recently due to the increasing recognition of their negative impact on marine ecosystems. Today good fisheries management is referred as considering ecosystem health and providing necessary regulation to reduce discards. Discard problem carries several relational subproblems for social, economic and enironmental objectives. Kelleher (2005) listed policy implications for discard problem as follows:

- ✓ "the moral problem of responsible stewardship of marine resources;
- ✓ designing a management regime that limits or prevents discarding,
- ✓ the practical problem of enforcing regulations designed to prevent or minimize discards,
- ✓ the technical problems of gear selectivity and utilization of species with a low market demand through transformation or adding value; and
- ✓ the economic problems posed by efforts to reduce bycatch, increase landing of bycatch or increase utilization of bycatch."

Very common fishing methods, trawling and dredging are responsible approximately half of the total discarded fish worldwide. Bottom trawling causes seriously chronic and widespread problems on the demersal zone with the removal of growing epifauna, damaging and shifting the habitat and benthic community and demersal fish fauna.

Although trawling is prohibited with law in Turkish Strait System, shrimp fisheries with beam trawl method is allowed certain part of the Sea of Marmara. Whereas, it has been reported that the longline fishing has the lowest while shrimp fisheries has the highest discard ratio due to low net selectivity with smaller mesh size. Bottom-trawled catches produced greater species diversity and higher discard rates while longline catches produced larger specimens of teleost fish (Connoly and Kelly 1996). Yazıcı *et al.* (2006), contributed a research to determine catch composition and discards in shrimp fisheries. According to their results, besides the target species, deep water rose shrimp (*Parapenaeus longirostris*), half of the catch composition constituted demersal fish (%30.9) with hake, whiting, common sole, thornback ray (*Raja clavata*) and echinoids (15.3%). Zengin *et al.* (2004) reported catch composition of beam trawling with the discard ratio of %12 in abundance and 24% in biomass. Bayhan *et al.* (2006) conducted an experimental study with different mesh sizes in shrimp beam trawl and determined 35% of the catch composition was discarded fish species. Zengin and Akyol (2009) reported that the highest discard ratio (0.6:1) was in the Sea of Marmara while the ratio was 2-3 times lower in other Turkish waters, i.e. eastern Mediterranean Sea (Kınacıgil *et al.* 1999). Bök *et al.* (2011), reported that every 1 kg of targeted catch responded 1.5 kg of discarded species in the catch composition. Demirel and Murat-Dalkara (2012b) performed three demersal trawl surveys in 40 different locations in the

Sea of Marmara. They determined that 55% of total catches was discards which consisted of mostly rays, sharks, tiny crabs, ascidians, annelids, and sea stars.

There are also several studies established differences in selectivity of mesh size and type to provide better practice reducing discard ratio (Deval *et al.* 2006; Ateş *et al.* 2010; Bök *et al.* 2011).

## 7. Discussion

The aim of ecosystem based fisheries management is to provide the maximum sustainable take of target organisms with the minimum impact on other ecosystem components. The main challenge of the approach is that in the developing countries, including Turkey, stock assessments have been made only for a tiny minority of stocks with the rest of these being categorized as “data poor species”. This is mainly because of the insufficient fish market data as well as the discontinuity of already-few stock assessment projects. As a result, many commercial species including the most important demersal one, hake, are categorized as "data poor species" in Turkey. These shortcomings, in turn, pose an obstacle to the healthy management of fisheries (Demirel 2016). Based on this motivation, we should focus on the question: Can we successfully develop an ecosystem based management scheme for the data-poor fish of Turkey?

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## ELASMOBRANCHS OF THE SEA OF MARMARA: CATCH, BIODIVERSITY AND CONSERVATION

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### 1. Introduction

The Sea of Marmara is an inter-continental basin with a surface area of 11 500 km$^2$ and a volume of 3378 km$^3$. It is connected to the Black Sea and the Aegean Sea through the straits of Bosphorus and the Dardanelles, respectively (Ünlüata *et al.* 1990). As a result, the chemical and physical oceanography of the Sea of Marmara is significantly influenced by these adjacent seas. While the surface waters (0.5-20 m) are under the influence of less saline waters coming from the Black Sea, the subhalocline waters are under the influence of oligotrophic Mediterranean waters (Yüce and Türker 1991; Balkıs *et al.* 2004). Differences in characteristics of these water masses results in a dynamic structure that is characterized by changes in composition and concentrations of nutrients, which in turn effect spatial and temporal changes in the phytoplankton, zooplankton and fish assembladges throughout the entire region. The Sea of Marmara, therefore, has relatively higher faunal and floral biodiversity than that of the Black Sea and is the feeding and breeding ground for a variety of pelagic fishes that migrate to or out of adjacent seas (Oğuz and Öztürk 2011). However, the negative effects of increased anthropogenic inputs and fishing pressure over the last 20-30 years have taken a toll on the fisheries production in the Sea of Marmara. Historical data indicate major decline in total fishery production as well as abundance of many fish species not targeted by commercial fisherman (Kabasakal 2002; Kabasakal 2003). Among these threatened species, sharks and rays are particularly vulnarable to overexplotation, environmental degradation and habitat destruction due to their lower fecundity and late maturation periods. Today, the Sea of Marmara can still be considered as a refuge to many species of Elasmobranches most of which are threatened and listed on the IUCN red list.

In the Sea of Marmara, elasmobranches are not targeted by any specific fishing operation and catches of sharks and rays are considered as by-catch or incidental. Sharks and rays are incidentally captured by commercial fishing boats mainly by purse-seiners, gill-netters and trammel-netters (Kabasakal 2009a). Increased fishing pressure as a result of extensive deployment of these non-selective fishing gears during the last 50 years, has resulted in reduced landings of sharks and rays in the Marmara Sea (Kabasakal 2003). For example, in the last 15 years, Elasmobranch landings reduced from 363 tonnes in 2000 to 153 tonnes in 2015 that corresponds to a 62% decrease (TUIK 2016; Figure 1). Figure 1 indicates that catches of angelsharks, sharks and rays fluctuated significantly in the Marmara Sea. The shares of angelshark, shark and ray catches in total landings were 0.3, 25.2 and 74.5%, respectively, in the Sea of Marmara in 2015. On the other hand, historical data indicate that shark catches showed significant fluctuations; total shark catch was 1198 tonnes in 1970 reaching a historical maximum of 11 125 tonnes in 1979 (Doğan 2006). In the following years, the production dramatically decreased and was only 77.6 tonnes in 2015 (Figure 2).

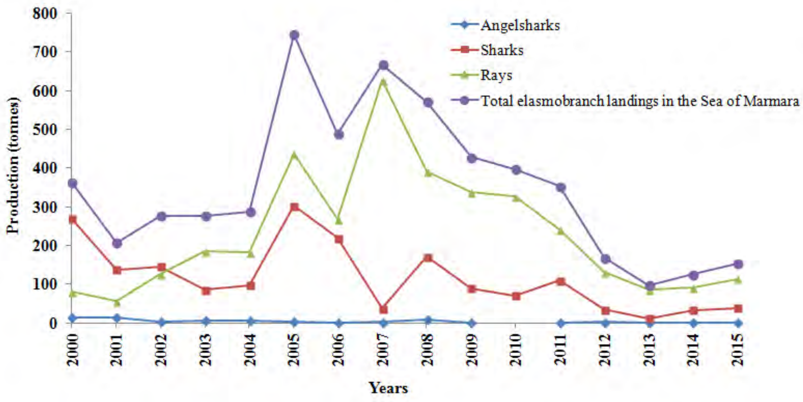


**Figure 1.** Elasmobranch landings during 2000-2015 in the Sea of Marmara (TUIK 2016).

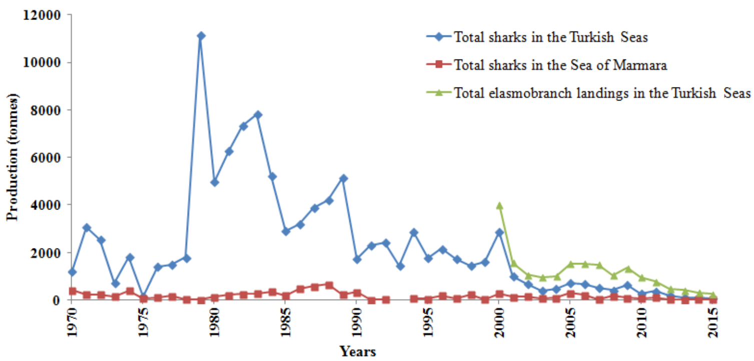


**Figure 2.** Total Elasmobranch and shark landings in the Turkish Seas and total shark landings in the Sea of Marmara during 1970-2015 (Doğan 2006; TUIK 2016).

## 2. Biodiversity and Conservation

There are currently 76 species of sharks and rays that are considered native to the Mediterranean Sea (Abdul Malak *et al.* 2011). According to the IUCN's assessment of the cartilaginous fishes in the Mediterranean Sea conducted in 2003 (Cavanagh and Gibson 2007), 42% of the Mediterranean chondrichthyan fishes were considered to be threatened within this region (i.e. Critically Endangered, Endangered or Vulnerable).

Since 1980s, increased urbanization and industrilisation of the Marmara region have resulted in dramatic reductions in the populations of Elasmobranches and degradation of their habitats. In attempts to reduce fishing pressure on mainly demersal stocks, trawling has been prohibited since the early 1970s (Karakulak *et al.* 2004). However, recent figures do not indicate recovery of elasmobranch stocks in the Sea of Marmara.

The fish fauna of the Sea of Marmara includes a total of 257 species (Bilecenoğlu *et al.* 2014). Of these, 35 are sharks and batoids are found in the Sea of Marmara, corresponding to 53% of total shark species in Turkey (Bilecenoğlu *et al.* 2014). A complete checklist of nominal chondrichthyan species in the Marmara Sea and their conservation status is presented in Table 1. Among these species, *Centrophorus uyato*, is found only in the Sea of Marmara (Meriç 1995).

The earliest records of sharks and rays from the Sea of Marmara have been reported by Devedjian (1926). Species such as Carcharodon carcharias, Lamna nasus and Alopias vulpinus were reported to be caught as bycatches at the Istanbul Fish Market (Kabasakal 2002). Among these species, occurrence of Alopias vulpinus is occasionally found in the Sea of Marmara and often associated with schools of small pelagic fishes (Erazi 1942; Kocataş *et al.* 1993; Kabasakal 2002; Kabasakal 2007). Today, the majority of sharks and rays in the Sea of Marmara are threatened and their conservation status based on IUCN criteria are discussed below.

### 2.1. Critically Endangered and Endangered sharks and rays

Two species of angel sharks, the smoothback angelshark, Squatina oculata and the angelshark, Squatina squatina are listed as "critically endangered" (IUCN 2016). The demersal chondrichthyan species blue skate, Dipturus batis is also listed as "critically endangered". One species of rays, the rough ray, Raja radula is the listed as "Endangered" (IUCN 2016) In Turkish seas, the angelshark was first reported by Ninni (1923), and was once considered as a common species in the Sea of Marmara. The presence of S. squatina have also been reported by Deveciyan (1926) and Rhasis Erazi (1942) and recently by Kabasakal and Kabasakal (2014). Despite its current conservation status, there are no regulatory measures in the Sea of Marmara on any species of sharks implemented by the Ministry of Food, Agriculture and Livestock.

**Table 1.** Diversity of Sharks and Batoids in the Marmara Sea by Order and Families (adapted from Bilecenoğlu *et al.* 2014; IUCN 2016). Abbreviations: CR: Critically Endangered; NT: Near Threatened; VU: Vulnerable; LC: Least Concern; DD: Data Deficient; BS: Black Sea; SM: Sea of Marmara; AS: Aegean Sea; M: Mediterranean.

| | **Family** | **Species** | **Common name** | **Conservation Status** | **Region** |
|---|---|---|---|---|---|
| *Sharks* | | | | | |
| Hexanchiformes | Hexanchidae | *Hexanchus griseus* | Bluntnose sixgill shark | NT | BS, SM, AS, M |
| Lamniformes | Alopiidae | *Alopias superciliosus* | Bigeye thresher | VU | SM, AS, M |
| | Lamnidae | *Carcharodon carcharias* | Great white shark | VU | SM, AS, M |
| | | *Lamna nasus* | Porbeagle | VU | SM, AS, M |
| Carcharhiniformes | Scyliorhinidae | *Galeus melastomus* | Blackmouth catshark | LC | SM, AS, M |
| | | *Scyliorhinus canicula* | Lesser spotted dogfish | LC | BS, SM, AS, M |
| | | *Scyliorhinus stellaris* | Nursehound | NT | SM, AS, M |
| | Triakidae | *Galeorhinus galeus* | Tope shark | VU | SM, AS, M |
| | | *Mustelus asterias* | Starry smooth-hound | LC | BS, SM, AS, M |
| | | *Mustelus mustelus* | Smooth-hound | VU | SM, AS, M |
| | Carcharhinidae | *Prionace glauca* | Blue shark | NT | SM, AS, M |
| Squaliformes | Dalatiidae | *Dalatias licha* | Kitefin shark | NT | SM, AS, M |
| | Echinorhinidae | *Echinorhinus brucus* | Bramble shark | DD | SM, AS, M |
| | Squalidae | *Squalus acanthias* | Picked dogfish | VU | BS, SM, AS, M |
| | | *Squalus blainvillei* | Longnose spurdog | DD | BS, SM, AS, M |
| | Oxynotidae | *Oxynotus centrina* | Angular roughshark | VU | SM, AS, M |
| | Centrophorida e | *Centrophorus granulosus* | Gulper shark | VU | SM, AS, M |
| | | *Centrophorus uyato* | Little gulper shark | DD | SM |
| Squatiniformes | Squatinidae | *Squatina oculata* | Smoothback angelshark | CR | SM, AS, M |

| | | | | | |
|---|---|---|---|---|---|
| | | *Squatina squatina* | Angelshark | CR | BS, SM, AS, M |
| *Batoids* | | | | | |
| Torpediniformes | Torpedinidae | *Torpedo nobiliana* | Electric ray | DD | SM, AS, M |
| | | *Torpedo marmorata* | Marbled electric ray | DD | SM, AS, M |
| | | *Torpedo torpedo* | Common torpedo | DD | SM, AS, M |
| Rajiformes | Rajidae | *Dipturus batis* | Blue skate | CR | SM, AS, M |
| | | *Dipturus oxyrinchus* | Longnosed skate | NT | SM, AS, M |
| | | *Leucoraja naevus* | Cuckoo ray | LC | SM, AS, M |
| | | *Raja asterias* | Mediterranean starry ray | NT | SM, AS, M |
| | | *Raja clavata* | Thornback ray | NT | BS, SM, AS, M |
| | | *Raja miraletus* | Brown ray | LC | SM, AS, M |
| | | *Raja montagui* | Spotted ray | LC | SM, AS, M |
| | | *Raja radula* | Rough ray | EN | SM, AS, M |
| Myliobatiformes | Dasyatidae | *Dasyatis pastinaca* | Common stingray | DD | BS, SM, AS, M |
| | Gymnuridae | *Gymnura altavela* | Spiny butterfly ray | VU | BS, SM, AS, M |
| Chimaeriformes | Chimaeridae | *Chimaera monstrosa* | Rabbit fish | NT | SM, AS, M |

## 2.2. Vulnerable sharks and rays

Ten chondrichthyan species listed as "vulnerable" in the Sea of Marmara, including the bigeye thresher, *Alopias superciliosus*, the great white shark, *Carcharodon carcharias,* the porbeagle, *Lamna nasus,* the tope shark, *Galeorhinus galeus,* the smooth-hound, *Mustelus mustelus,* the picked dogfish, *Squalus acanthias,* the angular roughshark, *Oxynotus centrina,* the gulper shark, *Centrophorus granulosus,* the spiny butterfly ray, *Gymnura altavela* and the little gulper shark, *Centrophorus uyato* (IUCN 2016). Among these species, *Alopias superciliosus* was recently discovered in the Sea of Marmara, (Serena 2005), which was considered as a rare or occasional shark in the Mediterranean Sea (Kabasakal and Karhan 2007). The occurrence of rare lamniforms such as *Carcharodon carcharias* and *L. nasus*, as well as *Prionace glauca* around the southern entrance of Dardanelles Strait (Kabasakal and Gedikoğlu 2008; Kabasakal 2014), may also be an indication of their potential temporary presence in the Sea of Marmara in pursuit of pelagic prey fish.

### 2.3. Near Threatened sharks and rays

Eight species of chondrichthyans are listed as “near threatened” including the bluntnose sixgill shark, *Hexanchus griseus*, the nursehound, *Scyliorhinus stellaris*, the blueshark, *Prionace glauca*, the kitefin shark, *Dalatias licha*, the longnosed skate, *Dipturus oxyrinchus*, the thornback ray, *Raja clavata*, the rabbit fish, *Chimaera monstrosa* and the Mediterranean starry ray, *Raja asterias* (IUCN 2016).These species are caught as by-catch using a variety of fishing gears including gill nets, bottom-set long lines, handlines and fixed bottom nets. However, there is limited information on their exploitation and abundance.

### 2.4. Least Concern and Data Deficient sharks and rays

Six species of chondrichthyans found in the Marmara Sea are listed as “least concern” (IUCN 2016). These species are the blackmouth catshark, *Galeus melastomus*, the lesser spotted dogfish, *Scyliorhinus canicula*, the starry smooth-hound, *Mustelus asterias*, the cuckoo ray, *Leucoraja naevus*, the brown ray, *Raja miraletus*, and the spotted ray, *Raja montagui*. In addition, eight species of sharks and rays are listed as “data deficient” in the Sea of Marmara. These are the bramble shark, *Echinorhinus brucus,* the longnose spurdog, *Squalus blainvillei*, the electric ray, *Torpedo nobiliana*, the marbled electric ray, *Torpedo marmorata,* the common torpedo, *Torpedo torpedo*, the rough ray, *Raja radula*, the common stingray, *Dasyatis pastinaca,* the common eagle ray, *Myliobatis aquila* and the little gulper shark, *Centrophorus uyato*. Among these species, the existence of the bramle shark, *E. brucus,* in the Sea of Marmara has been re-reported in recent years based on deep-sea imaging surveys (Kabasakal *et al.* 2005), following its first reports in 1920s (Ninni 1923; Deveciyan 1926).

The severe fishing pressure coupled with overall deterioration of the marine environment due mainly to rapid urbanization of the region has resulted in a major decline of many shark and ray species in the Sea of Marmara. However, it is very important to recognize the importance of this unique ecosystem which provides a permanent habitat for hundreds of local species and a temporary sanctuary to acclimate and feed for many species before their migration to the adjacent seas with very different chemical and physical properties. An updated list of studies on distributions, occurrences and morphometrics of elasmobranchs in the Sea of Marmara are summarized in Table 2.

In order to develop sound conservation and management measures, it is of great importance to determine the population status of all elasmobranches and provide critical research data on mating areas, spawning and nursery grounds in the Sea of Marmara. Obtaining accurate data on landings of all by-catch species would be a major step towards understanding trends in the population status of these species. All this information will then help to bring about new regulations for shark and ray conservation. Development of new policies and their implementation is critical to prevent any further decreasing trends in Elasmobranch landings and to ensure recovery of all threatened species in the Sea of Marmara.

**Table 2.** List of studies on elasmobranchs in the Turkish waters of the Marmara Sea.

| References | Type of study | Species |
|---|---|---|
| Kabasakal 1998 | First record | Hexanchus griseus |
| Kabasakal 2002 | Occurrence | *Hexanchus griseus, Alopias vulpinus, Galeus melastomus, Scyliorhinus canicula, Scyliorhinus stellaris, Mustelus asterias, Mustelus mustelus, Oxynotus centrina, Dalatias licha, Centrophorus granulosus, Centrophorus uyato, Squalus acanthias, Torpedo nobiliana, Torpedo marmorata, Torpedo torpedo, Dipturus oxyrinchus, Raja clavata, Raja radula, Dasyatis pastinaca, Myliobatis aquila* |
| Kabasakal 2003 | Occurrence | *Carcharodon carcharias*, *Lamna nasus*, *Alopias vulpinus*, *Galeus melastomus*, *Scyliorhinus canicula*, *Scyliorhinus stellaris*, *Galeorhinus galeus*, *Mustelus asterias*, *Mustelus mustelus*, *Prionace glauca*, *Oxynotus centrina*, *Dalatias licha*, *Centrophorus granulosus*, *Centrophorus uyato*, *Squalus acanthias*, *Squalus blainvillei*, *Echinorhinus brucus*, *Squatina oculata*, *Squatina squatina* |
| Karakulak *et al.* 2004 | Biomass | *Mustelus mustelus*, *Raja clavata*, *Rostroraja alba* |
| Kabasakal 2004 | Occurrence | *Hexanchus griseus* |
| Kabasakal *et al.* 2005 | Monitoring | *Echinorhinus brucus* |
| Bayhan *et al*. 2006 | By-catch species | *Mustelus mustelus*, *Scyliorhinus stellaris*, *Oxynotus centrina*, *Raja spp.* |
| Kabasakal, 2006 | Distribution and Biology | *Hexanchus griseus* |
| Yaka and Yüce 2006 | First records | *Raja radula* |
| Yazıcı *et al*. 2006 | Catch composition | *Scyliorhinus canicula*, *Raja clavata* |
| Kabasakal 2007 | Occurrence | *Alopias superciliosus*, *Alopias vulpinus* |
| Kabasakal 2008 | Recent records | *Carcharodon carcharias* |
| Kabasakal and Karhan 2007 | Occurrence | *Alopias superciliosus* |
| Kabasakal 2009a | Occurrence | *Hexanchus griseus* |
| Kabasakal 2009b | Occurrence | *Oxynotus centrina* |
| Zengin and Akyol 2009 | By-catch species | *Raja batis*, *Raja clavata*, *Scyliorhinus canicula* |
| Kabasakal 2010 | Occurrence | *Oxynotus centrina* |
| Keskin and Eryılmaz 2010 | Fish Assemblages | *Oxynotus centrina*, *Dasyatis pastinaca, Myliobatis aquila*, *Raja clavata*, *Raja miraletus,Scyliorhinus stellaris, Scyliorhinus canicula, Squalus acanthias, Torpedo marmorata* |
| Oral 2010 | Feeding | *Galeus melastomus* |

| | | |
|---|---|---|
| Altuğ *et al.* 2011 | Biodiversity | *Oxynotus centrina*, *Dasyatis pastinaca*, *Myliobatis aquila*, *Raja clavata*, *Raja miraletus*, *Scyliorhinus canicula*, *Squalus acanthias*, *Torpedo marmorata* |
| Bök *et al.* 2011 | Length-weight relationships | *Raja asterias*, *Raja clavata* |
| Kabasakal and Dalyan 2011 | Occurrence | *Echinorhinus brucus* |
| Demirel and Murat Dalkara 2012 | Length-weight relationships and Occurrence | *Scyliorhinus canicula*, *Raja clavata*, *Mustelus asterias*, *Mustelus mustelus*, *Raja ocellata*, *Oxynotus centrina*, *Squalus acanthias*, *Torpedo marmorata* |
| Ismen *et al.* 2013 | By-catch species | *Raja clavata*, *Scyliorhinus stellaris*, *Raja miraletus*, *Dasyatis pastinaca*, *Scyliorhinus canicula*, *Torpedo marmorata*, *Squalus acanthias*, *Oxynotus centrina* |
| Kabasakal and Bilecenoğlu 2014 | Occurrence | *Echinorhinus brucus* |
| Kabasakal and Kabasakal 2014 | Occurrence | *Squatina squatina* |
| Kabasakal and Karhan 2015 | Shark biodiversity | *Hexanchus griseus, Alopias superciliosus*, *Alopias vulpinus*, *Galeus melastomus*, *Scyliorhinus canicula*, *Scyliorhinus stellaris*, *Mustelus asterias*, *Mustelus mustelus*, *Oxynotus centrina*, *Squalus acanthias*, *Squalus blainville*, *Echinorhinus brucus*, *Squatina squatina* |
| Kabasakal 2015 | Occurrence | *Carcharhinus* spp. |

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# BLUEFIN TUNA FISHERY IN THE SEA OF MARMARA

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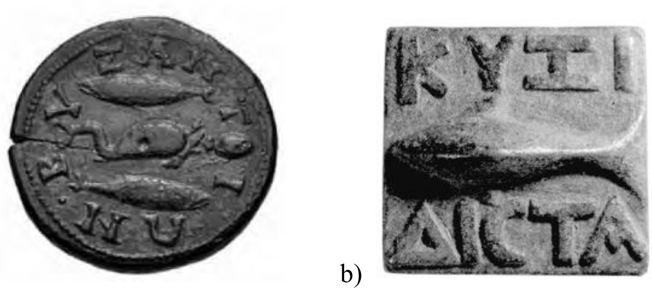
## 1. Introduction

Atlantic bluefin tuna (*Thunnus thynnus* - ABFT) is an epi and mesopelagic species which can migrate interoceanic waters. Immature individuals tend to be distributed in warm waters while matures can be found in cold waters for feeding (UNESCO 1986; FAO 1987). They have adaptation characteristic to different environments from polar to tropical regions by way of thermoregulation system which ensures temperature increase by running metabolism (Carey and Teal 1969; Linthicum and Carey 1972; Carey and Lawson 1973; Dizon and Brill 1979).

ABFT, which is one of the species with high economic value in the world and widely caught, takes an important place in Turkish fishery sector in terms of being an export commodity. History of ABFT fishing is very old in Turkey. ABFT were caught with dalians set (fish traps) in the Sea of Marmara notably in the Istanbul Strait and the Dardanelles. Since İstanbul (Byzantium) is located on the passing way of migratory fishes from the Black Sea to the Aegean Sea, fishing was an important source of income in prehistoric period. Various ancient authors such as Homeros (8th century B.C.), Plinius (1st century A.D.), and Athenaios (2nd - 3rd centuries A.D.) have mentioned bonitos and ABFTs both in the Istanbul Strait and the Dardanelles. In Byzantium, these fishes could be found very abundant as many as Haliç was called "golden horn or horn of plenty" (Devedjian 1926; Sara 1964; Cuvier 1969). Bonito and ABFT were so important that they have become symbol of Byzantium city. Thus, bonitos and ABFTs have been painted on back face of bronze coins monetized under sway of Roman Empire during the one to third centuries A.C. (Figure 1a) (Tekin 1996; Tekin 2010a). Moreover, most bronze and leads with figured of ABFT have been found in Kyzikos excavation which was an extinct city within the boundaries of Balıkesir (Figure 1b) (Weiss 1990; Tekin 2013).

In the excavation of Yenikapı Subway and Marmaray which started in 2004 (Istanbul, European side), besides other archeological materials a large number of animal bones were obtained as dispersed whole area. It was determined that this area was Theodosius harbor which was the most important in the Sea of Marmara in the Byzantium period. Also, animal bones were dated different period of time such from Early Byzantium (4-7th century) to Late Byzantium (15th century) by radiocarbon technique

(Onar *et al.* 2008). Among fish species, residuals of ABFT were revealed at the very most (Figure 2). Vertebra of 150 big size ABFTs were found. Common chopper and knife traces that determined on the bones of these fishes (Onar *et al.* 2012) are findings which support for naming of Byzantium as “tuna metropolis” or “homeland of tunas” (Tekin 2010b).




a) b)

**Figure 1.** a) Bronze coins (17.06 g, 28 mm), Byzantion, Geta (MS 209-212) (Tekin 2010a) b)Square bronze weight measuring 32 x 31 x 5 mm and weighing 42.0 g; patinated. On the obverse is a tuna fish to left; above, KYZI; below, ΔICTA; all in relief (Tekin 2013).

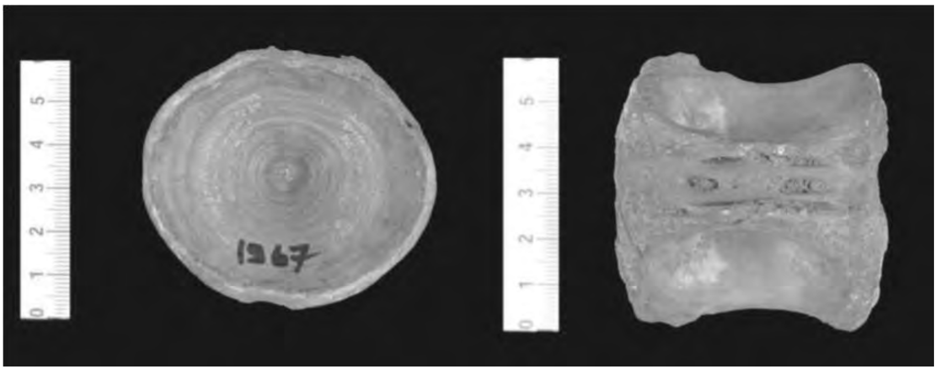


**Figure 2.** Vertebras of ABFT (*Thunnus thynnus*) uncovered from Yenikapı Subway and Marmaray excavation (Onar *et al.* 2012).

**2. Fishing methods**

The migration of tuna available in Turkish waters; started right from the Aegean Sea to the Black Sea in April (Figure 3), this migration became more intense in July and it ends at the end of August. The return started in October and continues until December (Devedjian 1926; Akyüz 1956; Akyüz and Artüz 1957; Sara 1964). It has been reported that ABFT did not migrate from the Sea of Marmara until February and March for some years and feed on bonito, mackerel and horse mackerel etc. (Akyüz 1956; Üner 1960a). ABFT fishing was intensely performed during this migration.

Until 1950, fishing of ABFT was performed by dalians and hand lines in Turkey (Iyigüngör 1957; Üner 1960a). Fishing tests with purse seine nets were started in 1950s (Akyüz 1956; İyigüngör 1957) and purse seine fishery developed in the later years.

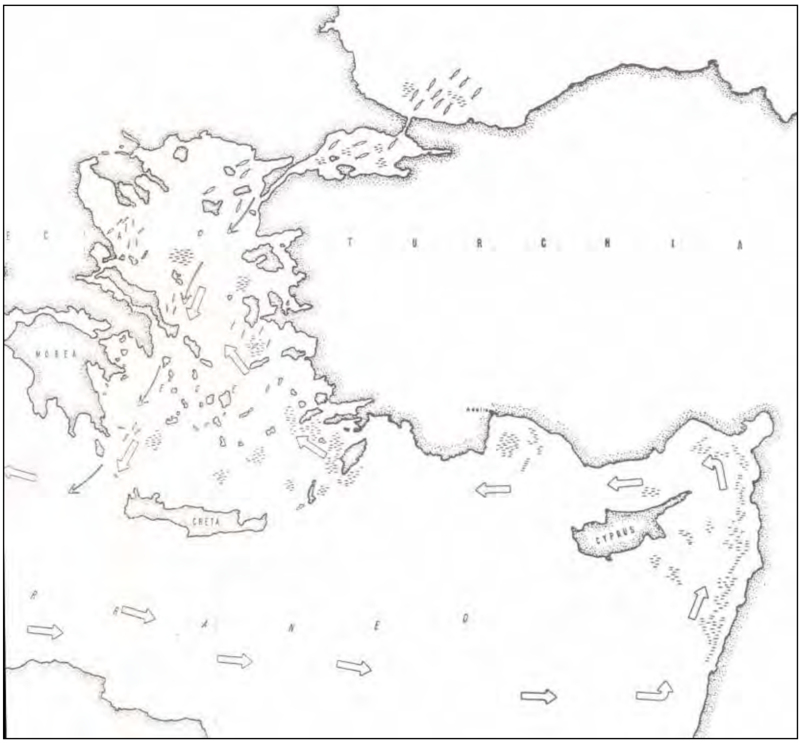



**Figure 3.** Migration routes of ABFT in Turkish waters (Sara 1964)

### 2.1. BFT fishing with dalians

Dalians were set in April-May in the Istanbul Strait and the Dardanelles (Figures 4 and 5), they remained open until the end of August and fishing was done in these periods. The oldest known tuna dalians were Filburnu, Çankaya, Beykoz, Bülbülsokak, Anaşya, Küçükçekmece, Tuzburnu, Kartal, Salistra, Fenerbahçe, Büyükada and Karamanoğlu (Devedjian 1926; İyigüngör 1957; Sarıkaya 1980).

Devedjian (1926) indicated that ABFT was caught in Asian side dalians set in the Istanbul Strait especially in Tuzburnu (Tuzla), Salistra (Suadiye) and Fenerbahçe, since coasts of European side of the Sea of Marmara is not deeper, ABFT used not to close these coasts and thus ABFT did not enter dalians here. And he also mentioned that most of caught fishes were around 150 cm in length and 300 kg in weight, sometimes 275 cm and 450 kg.

Off these dalians, Salistra dalian had 113 fathom length, 33 fathom width and 9 fathom depth. Kartal dalian was 112 fathom in length, 33 fathom in width and 22 fathom in depth. Beykoz dalian was as well 241 m in length, 43 m in width and 25 fathom in depth. 20-25 people are needed in a dalian system. In a fishing season, 100-150 ABFT were caught in every dalian and each caught tuna were weighed as100 to 450 kg (Iyigüngör 1957; Karakulak 2000).

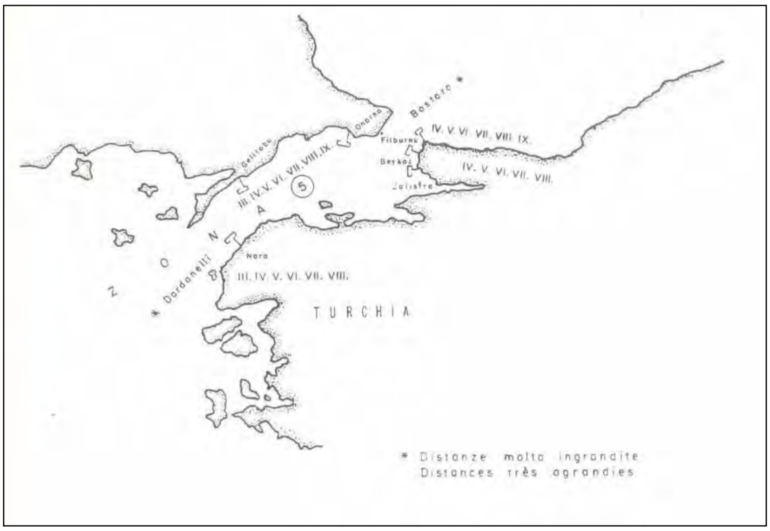



**Figure 4.** Dalian locations in the Sea of Marmara and the Bosporus (Sara 1964)

**Figure 5.** Map of the Marmara Sea, the Gulf of Bandırma, Erdek, and Imralı Island, which was attached to an application for granting a bluefin tuna fishery permit, showing the various locations for installing tuna traps (Document DH. ID No. 17-65, December 8.1913) (Örenç *et al.* 2014).

These dalians have lost their importance by reason of some factors such as heavy marine traffic, urbanization, marine pollution, development of fishing technology and decreasing of fish stocks. After 1987, as a result of ABFT did not migrate to Black Sea, ABFT fishing with dalians finished. Nowadays, dalians are continue activity only in Filburnu, Beykoz (Figure 6) and Anaşya and small pelagic such as horse mackerel and silver atherina are caught in these dalians (Karakulak 2000; Karakulak 2003; Karakulak and Oray 2009).

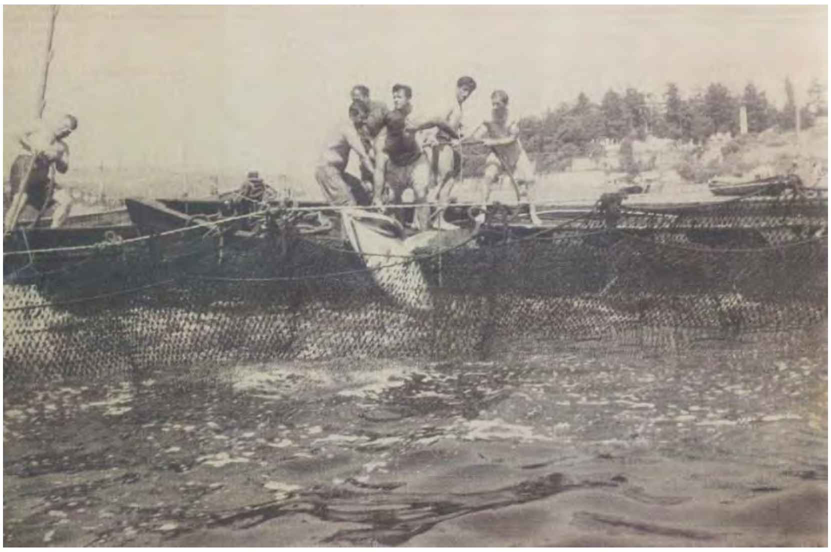


**Figure 6.** Bluefin tuna fishing in the Beykoz Dalian (Istanbul) in 1980

**2. 2. ABFT fishing with hand line**

Üner (1960b) indicated that ABFTs were caught with hand lines from fronts of Ortaköy to Dike (fishing area between Sarayburnu and Tophane), in fronts of Kumkapı, Prens Island coasts frontage to the Sea of Marmara and in Izmit Bay during migration from the Black Sea to the Sea of Marmara. Fishing with hand line continued from end of December to end of February, and sometimes continued until mid-March. This fishing activity indicates that ABFT stayed in the Sea of Marmara for feeding in winter.

Very big fishes that each of weighted 100-450 kg were caught with hand lines in ABFT fishery. Fishery were done in depths between 14 and 25 fathoms with moving vessel. Bonito, mackerel and bluefish were used as bait (İyigüngör 1957; Mengi 1977). Since ABFT do not migrate to Black Sea and decreasing stock which enter to the Sea of Marmara, ABFT fishing with hand lines cannot perform nowadays.

### 2. 3. ABFT fishing with purse seine

Using and developing of new fishing methods except of dalian and hand line were considered in order to increase ABFT catch amount. For this purpose, Kumkapı fishermen has prepared two purse seine nets for catch ABFT in the Sea of Marmara in 1950. A total of 20-40 tons including 25-50 kg of small ABFTs were caught in Gemlik Bay, between Zeytinburnu and Ahırkapı. These trials have shown that ABFT fishery with purse seine had the edge over (İyigüngör 1957). In 1956, another fishing trial was done by Fisheries Research Center of Meat and Fish Authority in İzmit Bay (Akyüz 1956). Using this type of fishing has been recommended to increase the tuna fishery.

Developments were seen in purse seine fishery (Figure 7) by decreasing in dalians. Number of purse seine vessels increased as a result of government support by opening credits for construction of new vessels in 1980. Increasing of tuna price in Japan markets has been remarked by Turkish fishery sector especially in mid 1980s. Fishing was limited to the Sea of Marmara in these years. Per caught ABFT was 300-400 kg and fishing season was in winter months (Mert *et al.* 2000).

In 1989-1990, decreasing in anchovy fishery which is very important for Turkey caused to fishing for ABFT in the Aegean and Mediterranean Sea by purse seiners. Hereby, ABFT fishing area enlarged and catch volumes increased. However, decreasing in fishing has been drawn attention in the Sea of Marmara. Oray and Karakulak (1997) noted that ABFT fishing was not done in the Sea of Marmara between years of 1993 and 1995. In 1998 and 1999, only 3 and 30 metric tons of ABFT, respectively, were caught in the Sea of Marmara (around Marmara Island) (Mert *et al.* 2000). Oray and Karakulak (2001), reported that 25 big size ABFTs (13.5 tons) caught that ranged 206-248 cm in length and 201-344 kg in weight in the Sea of Marmara in 1999.

ABFT fishing area has shifted to eastern Mediterranean by the reason of ABFT fishing is done for farming nowadays and done in May-June according to the recommendation of ICCAT. Since ABFT is more abundant in the summer months in the eastern Mediterranean, purse seine fishing was done in this region (Karakulak 2012; Karakulak and Yıldız 2015; Karakulak *et al.* 2016). Although ABFT has been caught as a by-catch in anchovy and sardine fishery in the Sea of Marmara and Aegean Sea, they are not target species no longer.

**Figure 7.** Bluefin tuna purse seine fishing

### 3. BFT catches

When Turkey's ABFT catches are examined, statistical data can be available since 1957 (ICCAT 2015). In 1957, 800 metric tons (t) of ABFTs were captured in Turkish waters. The catches increased by 5093 t in 1997 (ICCAT 2015; TUIK 1970-2014). In 1999, ICCAT introduced catch quotas for ABFT in the Mediterranean Sea Turkey becoming a member to ICCAT in 2003, could not receive a certain catch quota and used the quotas in others category with six other non-member Mediterranean countries (1184 t). In 2007, Turkey received in scope of the ICCAT management plan, an ABFT quota of 918.32 t (Figure 8). Depending on the quota implementation of ICCAT Turkey’s catch volume vary year by year.

Although it is unclear which fishing method was used for the tuna in 1957-1981 years, it is stated that fishing is done by dalians in 1982-1984 and all fishing is dominated by purse seine gear after 1985 (ICCAT 2015). Due to purse seine fishery developed since 1980, we can noted that fishing made before 1982 were done by dalian and hand line. ABFTs caught by dalian and hand line in the Sea of Marmara were sold in Istanbul Fish Market. Quantity of ABFT sold in Istanbul Fish Market between the years of 1909-1955 were demonstrated in Figure 9 and in Table 1, 2, and 3.

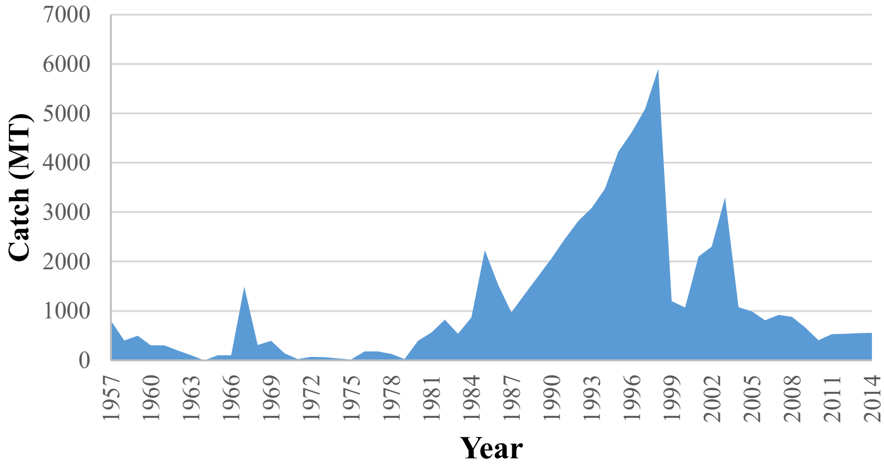



**Figure 8.** ABFT catch amounts of Turkey (ICCAT 2015)

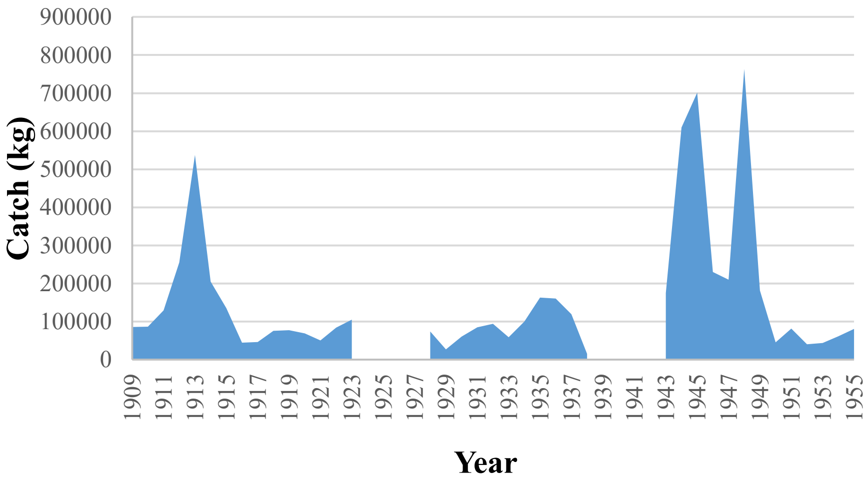



**Figure 9.** ABFT amounts sold in Istanbul Fish Market between years of 1909-1955 (Devedjian 1926; Akyüz 1956)

**Table 1.** ABFT catch amounts and average prices which sold in Istanbul Fish Market (Devedjian 1926)

| Fiscal Year | Quantity (kg) | Mean Price (Kuruş) | Value (Kuruş) |
|---|---|---|---|
| 1909-10 | 85.279 | 0.92 | 79.168 |
| 1910-11 | 86.023 | 0.68 | 59.327 |
| 1911-12 | 129.052 | 0.65 | 83.660 |
| 1912-13 | 255.452 | 0.66 | 169.877 |
| 1913-14 | 537.455 | 0.60 | 321.062 |
| 1914-15 | 204.375 | 0.82 | 168.867 |
| 1915-16 | 135.027 | 1.28 | 173.326 |
| 1916-17 | 44.242 | 2.50 | 110.761 |
| 1917-18 | 46.098 | 15.83 | 729.571 |
| 1918-19 | 74.995 | 22.32 | 1.673.732 |
| 1919-20 | 77.300 | 14.57 | 1.126.478 |
| 1920-21 | 63.648 | 19.17 | 1.220.251 |
| 1921-22 | 50.338 | 15.93 | 802.170 |
| 1922-23 | 83.782 | 12.52 | 1.048.906 |
| 1923-24 | 104.503 | 14.41 | 1.506.553 |

**Table 2.** ABFT catch amounts sold in Istanbul Fish Market between 1915-1923 (Devedjian 1926)

| Year | 1915 | 1921 | 1922 | 1923 |
|---|---|---|---|---|
| March | 27.191 | 285 | 1.169 | 49.687 |
| April | 22.894 | 3.198 | 28.629 | 16.378 |
| May | 1.442 | 5.129 | 3.639 | 6.176 |
| June | 5.819 | 540 | 978 | 1.195 |
| July | 22.396 | 29.985 | 24.106 | 20.895 |
| August | 21.782 | 3.829 | 8.182 | 1.042 |
| September | 204 | 4.288 | 1.195 | 534 |
| October | 801 | 2.119 | 185 | 2.816 |
| November | 3.164 | 828 | 2 | 3.270 |
| December | 16.270 | - | 5.687 | 2.023 |
| January | 10.128 | 137 | 671 | 394 |
| February | 2.486 | - | 9.339 | 93 |
| **Total** | **135.027** | **50.338** | **83.782** | **104.503** |

When ABFT catch amounts of Turkey examine with regard to regions (TUIK 1975-2014), it is seen that ABFT fishery especially in the Black Sea is continue in 1990s and 2000s. (Table 4). However, scientific researches and observations demonstrate the exact opposite of that. This situation is originated from TUIK's sampling method which regarding port of vessel. Data from 2010 seems to be more accurate. According to ICCAT rules, information about ABFT fishery and fishing field data are recorded and declaration is made to ICCAT in recent years.

**Table 3.** ABFT catch amounts sold in Istanbul Fish Market between 1928-1955 (Akyüz 1956; Akyüz and Artüz 1957)

| Year | Quantity (kg) | Year | Quantity (kg) | Year | Quantity (kg) |
|---|---|---|---|---|---|
| 1928 | 73932 | 1938 | 14694 | 1948 | 763601 |
| 1929 | 26788 | 1939 | - | 1949 | 180804 |
| 1930 | 60455 | 1940 | - | 1950 | 45272 |
| 1931 | 84815 | 1941 | - | 1951 | 81408 |
| 1932 | 93330 | 1942 | - | 1952 | 39828 |
| 1933 | 58215 | 1943 | 174267 | 1953 | 42987 |
| 1934 | 99202 | 1944 | 610065 | 1954 | 61265 |
| 1935 | 162272 | 1945 | 700950 | 1955 | 79993 |
| 1936 | 159927 | 1946 | 229915 | | |
| 1937 | 119307 | 1947 | 209920 | | |

ICCAT has recommended the revision in the fishing amount of all countries before starting the quota implementation for ABFT fishery. This revision is made in Turkey (Mert *et al.* 2000), catch quantities in Istanbul Fish Market for between the years of 1987-1998, export amounts and quantities at the ABFT processing factory were controlled again (Figure 10).

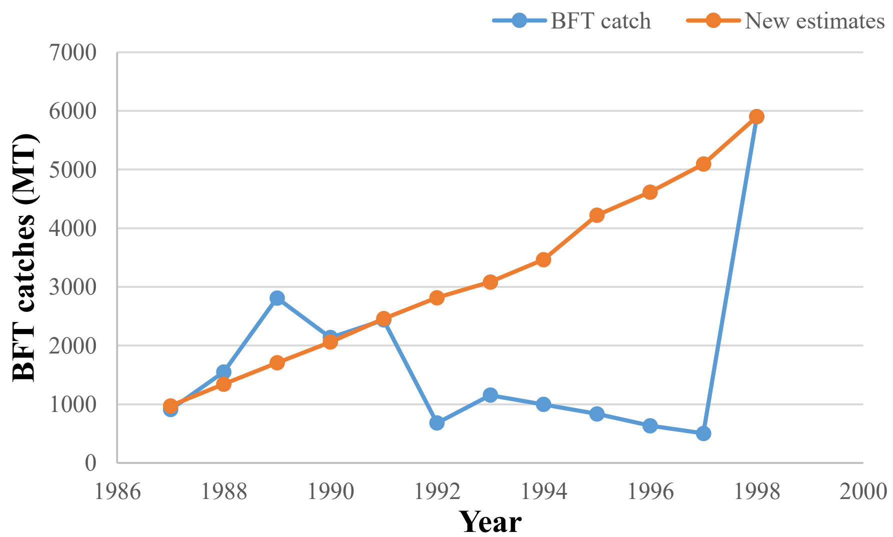



**Figure 10.** ICCAT Task 1 reported catches compared with new estimated bluefin catches.

**Table 4.** ABFT catch amounts regarding years and regions, MT (TUIK 1975-2014).

| Year | Black Sea | Sea of Marmara | Aegean Sea | Mediterranean | Total |
|---|---|---|---|---|---|
| 1975 | 5 | 1 | 11 | - | 17 |
| 1976 | - | 120 | 61 | - | 181 |
| 1977 | 1 | 80 | 79 | 17 | 177 |
| 1978 | 37 | 17 | 71 | 2 | 127 |
| 1979 | 13 | 5 | 7 | 1 | 27 |
| 1980 | 205 | 103 | 77 | 6 | 391 |
| 1981 | 302 | 53 | 54 | 156 | 565 |
| 1982 | 442 | 77 | 78 | 228 | 825 |
| 1983 | 21 | 123 | 31 | 382 | 557 |
| 1984 | 453 | 99 | 40 | 272 | 869 |
| 1985 | 1937 | 152 | 95 | 46 | 2230 |
| 1986 | 162 | 474 | 778 | 110 | 1524 |
| 1987 | 97 | 283 | 464 | 66 | 910 |
| 1988 | 353 | 411 | 592 | 194 | 1550 |
| 1989 | 2678 | 54 | 55 | 22 | 2809 |
| 1990 | 1194 | 885 | 13 | 45 | 2137 |
| 1991 | 2292 | 95 | 39 | 10 | 2436 |
| 1992 | 625 | 21 | 21 | 12 | 679 |
| 1993 | - | 45 | 428 | 682 | 1155 |
| 1994 | 727 | 37 | 115 | 119 | 998 |
| 1995 | - | 21 | 483 | 332 | 836 |
| 1996 | - | 63 | 317 | 253 | 633 |
| 1997 | 162 | 86 | 269 | 233 | 750 |
| 1998 | 523 | 677 | 2458 | 1891 | 5549 |
| 1999 | 190 | 383 | 327 | 300 | 1200 |
| 2000 | 59 | 130 | 333 | 548 | 1070 |
| 2001 | 14 | 928 | 1026 | 132 | 2100 |
| 2002 | - | 101 | 139 | 2060 | 2300 |
| 2003 | - | 132 | 198 | 2970 | 3300 |
| 2004 | - | 43 | 65 | 967 | 1075 |
| 2005 | - | 48 | 208 | 734 | 990 |
| 2006 | - | 120 | 86 | 600 | 806 |
| 2007 | - | 33 | 45 | 840 | 918 |
| 2008 | - | - | 246 | 641 | 887 |
| 2009 | 65 | - | 296 | 849 | 1210 |
| 2010 | - | - | 6 | 417 | 423 |
| 2011 | - | - | - | 527.5 | 527.5 |
| 2012 | - | - | 0.5 | 535 | 535,5 |
| 2013 | - | - | - | 551.4 | 551.4 |
| 2014 | - | - | - | 555 | 555 |

## 4. Conclusion

Although the Sea of Marmara was an important ABFT fishing area since ancient times, it lost this importance in last years due to marine pollution, declining ABFT stocks, doing the ABFT fishing only in May and June according to the recommendations of ICCAT and for farming in the eastern Mediterranean. In 2002, ABFT farming activities were started in Turkey. From this date on, purse seine fishing for ABFT has been intensively done in the Levantine Sea. Targeted ABFT fishing were not done in the Sea of Marmara. Besides, ABFT catch has been encountered as by-catch during anchovy fishing in the Sea of Marmara. Beside, as in past it is seen that ABFTs have not migrate from in the Sea of Marmara and fed here in winter period.

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## SHRIMP FISHERIES IN THE SEA OF MARMARA

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### 1. Introduction

Shrimps are decapod crustaceans belonging to suborder Natantia with about 3000 known species. They are abundant in all marine waters and one of the most important fishery products worldwide. In many tropical countries, shrimp is the most valuable fishery export. The annual wild shrimp catch is about 3.4 million tons corresponding to about 18 percent of the total value of all world trade (Gillett 2008).

Despite a large number of species, slightly fewer than 300 shrimp species are of economic interest worldwide and the majority of world catch comprises only about 100 species (Gillett 2008). FAO statistics on marine shrimp catches cover 66 “species items”. Only three groups have major economic importance including Penaeoidea (penaid shrimps) Caridea (caridean shrimps) and Sergestoidea (paste shrimps). Commercially important genera within these major groups include *Penaeus, Metapenaeus, Parapenaeopsis* and *Trachypenaeus* in penaeid shrimps, *Pandalus* and *Heterocarpus* in caridean shrimps and *Acetes* in paste shrimps. Within these genera, six shrimp species including *Acetes japonicus, Trachypenaeus curvirostris, Pandalus borealis, Penaeus monodon* and two aggregated groups-Natantia and Penaeus spp., account for 82 percent of the global shrimp catch (FAO 2007). The akiami paste shrimp *(Acetes japonicus)* is the most important single species in the world by weight and accounts for 19% of global total shrimp catch in 2005. The “all other species items” category (37 species items in 2005) accounts for less than 1 percent of the global shrimp catch (Gillett 2008). Fisheries data indicate that aquaculture supply of shrimps exceeds that of capture fisheries; in 2012, the total world shrimp production was 7.8 million tones and about 60% of this production was from aquaculture (FAO 2012). Currently, about ten species of shrimps are commercially raised in captivity and all belong to penaeid shrimps.

Since the above mentioned taxonomic classifications differ greatly with respect to their biology and habitat, shrimp resources are highly diversified. Most commmercially important species of shrimps are bottom-dwellers and live near the sea floor with sandy, silty and muddy bottoms at depths of up to 500-1000 m. Shrimp fishing takes place in equatorial and subpolar waters as well as in most intermediate ocean regions, mainly in coastal areas and estuaries. A majority of the global shrimp catch is taken by large industrial fishing operations mainly by trawling, but small-scale fishing, including gillnets, push nets, lift nets, beach seines, stow nets and trap fishing are also important.

Shrimp catch in Turkey is relatively insignificant and accounts for only 1.5% of all marine capture fisheries. During 2000-2014, annual shrimp catch ranged between 2000-6339 tons (BSYM, 2016). The share of total shrimp catch by major fishing regions in Turkey is as follows: 19.1% in the Aegean Sea, 29.8% in the Mediterranean, 51.1% in the Marmara Sea and 0.03% in the Black Sea (Table 1; TUIK 2013). Data indicates that half of the shrimp catch comes from the the Sea of Marmara.

In Turkish waters, more than 60 species of shrimp have been reported (Kocatas *et al.* 1991). Of these species, only 5 species have major commercial importance (TUIK 2014). These are *Parapenaeus longirostris* (Deep-water rose shrimp), *Aristaeomorpha foliacea* (giant gamba prawn), *Penaeus semisulcatus* (green tiger prawn), *Melicertus kerathurus* (Caramote shrimp), *Metapenaeus monoceros* (speckled shrimp) (Table 2; TUIK 2014).

In Turkey, *Parapenaeus longirostris* is the most important species in terms of biomass landed followed by *Aristaeomorpha foliacea.* For both species, the majority of the catch comes from the Sea of Marmara. *P. longirostris* is a commercially important species throughout the world. *P. longirostris* accounted for about 1 percent (19938 tons) of the global shrimp catch (Gillett 2008). Other commercially important shrimp species in Turkish seas are *Marsupenaeus japonicus* (kuruma shrimp), *Trachysalambria curvirostris* (southern rough shrimp), *M. stebbingi* (peregrine shrimp), *Plesionika heterocarpus* (arrow shrimp), *P. martia* (golden shrimp), *Melicertus hathor, Metapenaeus affinis* (Jinga shrimp) and *Aristeus antennatus* (blue and red shrimp) (Kocatas *et al.* 1991; Bayhan *et al.* 2006; Zengin and Akyol 2009; Dinçer and Aydın 2014).

## 2. Structure of shrimp fisheries

The Sea of Marmara, located in northwest Turkey, is an inland sea which is connected to the Black Sea and the Aegean Sea through two narrow straits, Bosphorus in the northeast and the Dardanelles in the southwest, respectively. In contrast to its relatively smaller surface area that occupies only 4.5% of total fishing area, the Sea of Marmara has high biological diversity and is one of the productive fishing grounds in Turkey contributing to about 11% of total fishery production (TUIK 2013). The Sea of Marmara is a very dynamic ecosystem driven by constant inflow of more saline Mediterranean waters through the Dardanelles and inflow of less saline Black Sea waters from Bosphorus. These two currents with different physical, chemical and biological characteristics are largely responsible for higher biodiversity and production in the Sea of Marmara.

**Table 1.** Catch regions, total catch (tons), capture production rate (%) and types of shrimp products, 2013.

| | Total | Black Sea | (%) | Marmara | (%) | Aegean | (%) | Mediterranean | (%) |
|---|---|---|---|---|---|---|---|---|---|
| Green tiger prawn | **451.8** | 1.4 | 0.31 | 11.7 | 2.6 | 51.5 | 11.4 | 387.2 | 85.7 |
| Caramote prawn | **354.4** | 0 | 0.00 | 7.1 | 2.0 | 3.2 | 0.9 | 344.1 | 97.1 |
| Giant gamba prawn | **1363.6** | 0 | 0.00 | 828.7 | 60.8 | 370.3 | 27.2 | 164.6 | 12.1 |
| Deepwater rose prawn | **1619.9** | 0 | 0.00 | 1209.1 | 74.6 | 344.7 | 21.3 | 66.1 | 4.1 |
| Speckled shrimp | **237.9** | 0 | 0.00 | 0 | 0.0 | 0 | 0.0 | 237.9 | 100.0 |
| **Total shrimp** | **4027.6** | **1.4** | **0.03** | **2056.6** | **51.1** | **769.7** | **19.1** | **1199.9** | **29.8** |
| Capture other sea products | **43879** | 37191 | 84.8 | 2419.9 | 5.5 | 1793.3 | 4.1 | 2474.6 | 5.6 |
| Capture of sea fish | **295168** | 209310 | 70.9 | 38284 | 13.0 | 30143 | 10.2 | 17431 | 5.9 |
| Capture marine products | **339047** | 246501 | 72.7 | 40704 | 12.0 | 31936 | 9.4 | 19906 | 5.9 |
| **Total shrimp/capt. marine product. (%)** | | **0.001** | | **5.05** | | **2.41** | | **6.03** | |

**Table 2.** Capture production of other sea products (crustaceans, molluscs) and prawn (tons)

| **Type of fish** | **2005** | **2006** | **2007** | **2008** | **2009** | **2010** | **2011** | **2012** | **2013** | **2014** |
|---|---|---|---|---|---|---|---|---|---|---|
| Total other products | 46133 | 79021 | 70928 | 57453 | 44410 | 46024 | 45412 | 80685 | 43879 | 35019 |
| Total prawn | 6339 | 3856 | 3917 | 4668 | 4614 | 4705 | 4770 | 5038 | 4028 | 4416 |
| Speckled shrimp | - | - | 359.0 | 437.0 | 329.0 | 417.0 | 301.2 | 255.1 | 237.9 | 53.5 |
| Green tiger prawn | - | - | 275.0 | 405.0 | 531.0 | 562.0 | 543.4 | 640.9 | 451.8 | 469.5 |
| Caramote prawn | - | - | 372.0 | 449.0 | 442.0 | 951.0 | 642.9 | 383.9 | 354.4 | 271.9 |
| Giant gamba prawn | - | - | 150.0 | 754.0 | 1 239 | 1 362 | 1 801 | 2 158 | 1 364 | 1 120 |
| Deep water rose prawn | - | - | 2 761 | 2 623 | 2 073 | 1 413 | 1 481 | 1 600 | 1 620 | 2502 |

The potential of this unique ecosystem resulted in a dramatic increase of fishing pressure since the beginning of industrial fisheries in Turkey. In the Sea of Marmara, while pelagic and migratory fish species have been the main target of commercial fishery operations, fishing exploitation has reduced yields of all commercial fish species including demersal stocks (Ulman *et al.* 2013). As a result, the Sea of Marmara's share of Turkey's total marine catches has declined; in the late 1960s, while 18.7% of total catches came from the Sea of Marmara, it was 13.7% and 10.9% by 1980 and by 2013, respectively. During the last 50 years, major fluctuations in total catch were also experienced in the Sea of Marmara; lowest reported landings (over the 1967- 2013 period) were in 1968 with 7143 tons, and highest in 1999 with 81005 tons. Shrimp fisheries was no exception and data indicate reduced yields in recent years compared to figures in late 1980s (Figure 1).

In the Sea of Marmara, shrimp is extensively caught in the coastal zone (40–150 m). In shrimp fishing, a variety of fishing gear is used including beam trawls, otter trawls, traps and gillnets. The shrimp fishing fleet mainly target deepwater rose-shrimp, *Parapenaeus longirostris*. Most important fishing grounds of this species in the Sea of Marmara are coastal areas off of Tekirdağ, Silivri, Hoşköy, Şarköy, Mürefte and Marmara Islands. Shrimp fishing fleet consists of over 200 medium-sized boats, including 125 bottom trawlers, 54 seiners and 40 beam trawlers as well as illegal trawlers (Zengin and Akyol 2009). Recent data indicate that out of a total of 297 beam trawls and dredges in Turkey, 131 vessels are registered in the Sea of Marmara (TUIK 2013). Lengths and engine powers of the beam trawl boats vary from 7 to 13 m and from 9 to 160 hp, respectively (Zengin *et al.* 2004). These boats are also used in gillnet, trammel net, and longline fisheries in the Sea of Marmara (Deval *et al.* 2006). While gillnets are used in the southern Marmara Sea for caramote shrimp fisheries, trammel nets are used in the eastern, southeastern and northeastern Marmara Sea (Bayhan *et al.* 2006). Although beam trawls are commonly used to catch shrimp, sea cucumber and sea snail in the Sea of Marmara and in the Black Sea, they are forbidden in the Aegean and Mediterranean Seas.

The beam trawl for shrimp fishery began in 1969 and today beam trawls are stil in use. Initially, only a few cutters with single beam trawl had been fishing for years along the shore of Tekirdağ - Şarköy. Annual production was 168 ton in 1970. In 1983, the catch was at the peak level with 561 tons (Öztürk 2009). Between 1970 and 1987, a total of 3242 tons of shrimp was caught in the Marmara Sea (Figure 1).

Technical properties of beam trawls have slightly changed since its first introduction. Until 2012, single beam trawls with one cod-end and twin beam trawls with two cod-ends were used in the Sea of Marmara. The beam trawl with one cod-end had a maximum beam length of 5 m with opening heights of 50 cm. The twin beam trawl had two identical nets rigged side by side on the same beam with a total length of 7-7.5 m with opening heights of 50 cm. Each boat was allowed to carry a maximum of either 3 single beam trawls or two twin beam trawls so that maximum beam length did not exceed 15 m. After 2012, the use of twin beam trawls were banned and only single beam trawls with a beam length of 5m and a vertical net opening of 50 cm were allowed (Figure 2). Each boat was allowed to use only two single beam trawls so that the maximum beam length did not exceed 10 m. The cod-end of the beam trawl was made of polyamide (PA) material (32 mm mesh size) with chafer (80 mm mesh size, PP, O 2.5 mm rope thickness) to protect the cod-end against chafing. Total length of the net was 11 m. Towing speed varies from 1.5 to 2.0 knots and trawling time is usually 3-4 hours.

In 1971, bottom trawl fishing was banned. Interestingly, the illegal bottom trawling remained as an effective operation to harvest shrimp due to increased demands for seafood during the 1980's and 90's. As a result, the majority of shrimp catches were from bottom trawls. During 1988-90, bottom trawl catches were maximum with annual landings of 4.000-6.000 tons. (Ulman *et al.* 2013).

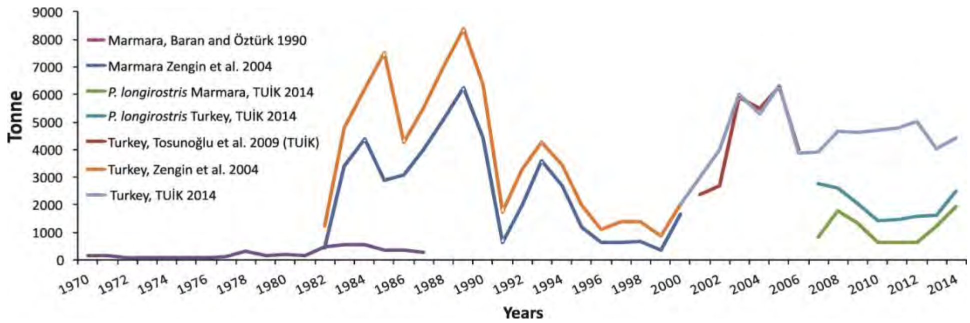


**Figure 1.** Total shrimp and *P. longirostris* production in the Sea of Marmara and Turkey

**Figure 2.** Single beam trawl and twin beam trawl used in the Sea of Marmara (Zengin *et al.* 2004, İşmen *et al.* 2015) A. Single beam trawl, B. Twin beam trawl.

## 3. Shrimp Species, Catch and Effort

In the Sea of Marmara, the deep-water rose prawn *P. longirostris* is the most abundant and important species and accounts for 59% of the total shrimp catches with 1209.1 tons in 2013 followed by giant gamba prawn, *Aristaeomorpha foliacea* (40.2%; 828.8 tons); green tiger prawn *Penaeus semisulcatus* (0.5%; 11.7 tons) and caramote prawn, *Melicertus kerathurus* (0.3%;7.1 tons) (Table 1).

The deep-water rose prawn *P. longirostris* (Lucas 1846) is distributed in the eastern Atlantic from the north of Spain to the south of Angola and throughout the Mediterranean including its adjacent seas of the Tyrrhenian, Adriatic, Aegean and the Sea of Marmara (Sbrana *et al.* 2006). In the Mediterranean, the deep-water rose shrimp ranked as the fifth abundant species in terms of biomass landed during the period 1972-1991 (Sbrana *et al.* 2006). In the south central Mediterranean sea, *P. longirostris* is caught mainly in Italy, Malta and Tunusia by trawling. In 2009, a total of 8806 tons of deep water rose shrimp were landed in this region. Data indicate 82.6% of the catch was landed by the Scilian trawlers followed by Tunusian (17.2%) and Maltese (0.2%) trawlers (Knittweis *et al.* 2013). Deep water rose shrimp is also targeted in the eastern Atlantic, Balearic islands, Greece and Libya.

Although this species shows a wide bathymetric distribution at depths 20-750 m, trawl and beam trawl survey results suggest that in the Sea of Marmara the greatest biomass is found at depths between 50 and 150 m on muddy or sandy muddy bottoms (Zengin *et al.* 2004; İşmen *et al.* 2015). Preference of water temperature is between 14-15 °C. The maximum total length was 160 mm for males and 186 mm for females, but they are usually shorter than 140 mm for males and 160 mm for females. Reproduction takes place between May and July (Öztürk 2009; Zengin *et al.* 2004; İşmen *et al.* 2015).

Deep-water rose prawn catches in the Sea of Marmara fluctuated between 624 and 1940 tonnes from 2007 to 2014 (TUIK 2014). The highest catches occurred in the 2014 season (Figure 1). Deep water rose prawn production formed about 3% of the capture marine production in the Sea of Marmara (TUIK 2013) (Table 1).

There is no information on annual CPUE of licenced shrimp vessels because data on annual shrimp catch is subject to controversy. Nevertheless, some information from research data is available. In a study by Erden and Erim (1971), CPUE for beam trawl was estimated as 4.5 kg/h. Yazıcı *et al.* (2006) reported that catch productivity (CPUE) for beam trawl fishery was estimated as 10.1 kg/h (20.5 kg/h in January; 3,0 kg/h in March, 4.9 kg/h in April and 2.7 kg/h in July) in the southwestern Marmara Sea. In another study Zengin and Akyol (2009) reported the CPUE as 5.91 kg/h. İşmen *et al.* (2015) provided detailed information on CPUE of beam trawl fishery in the Sea of Marmara. CPUE was found to be 8.5 kg/h. The highest seasonal CPUE was 14.6 kg/h in

Spring 2013 and the lowest seasonal CPUE was 5.1 kg/h in winter 2012. The highest regional CPUE was 15.1 kg/h off of Tekirdağ Coast and the lowest seasonal CPUE was in 3.4 kg/h off of Yalova Coast. According to depth contours, CPUE values of *P. longirostris* were determined as 8.8 kg/h in 50-100 m, 7 kg/h in ≥100 m.

### 4. Management

Current regulations in shrimp fisheries are brief and does not cover detailed species-specific restrictions. Shrimp fisheries using beam trawl and ⁄or small beach seine are allowed in Turkish waters only in the Sea of Marmara, with closure periods from 15 April to 31 August, and 1–31 January, respectively. However, set net fisheries (gill or trammel nets) are allowed in the Sea of Marmara for caramote shrimp between 15 April and 31 August. Shrimp fishing by beam trawl in the Sea of Marmara is banned in the areas given in Figure 4 and the straits of Dardanelles and Bosphorus. Shrimp fishing by seine net in the Sea of Marmara is banned in the areas given in Figure 3 and the straits of Dardanelles and Bosphorus. Minumum allowable mesh size of seine net is 32 mm at the cod-end.

According to Turkish Fishery Regulations (Fisheries Law-No.1380), beam trawl fishing of rose shrimp is allowed in waters deeper than 50 m using a maximum cod-end length of 11 m and minimum mesh size of 32 mm. Each boat is allowed to use maximum two single beam trawls with maximum total beam lengths of 10 m (5 m x 2).

The minumum catch size has not been defined for any type of shrimp in the commercial fisheries circular published by the General Directorate of Fisheries and Aquaculture in the Ministry of Food, Agriculture and Livestock (MFAL 2012).

Fishing vessels using beam trawl and seine nets are legally required to have a fishing license. Shrimp fishing is allowed only between sunrise and sunset.

### 5. Bycatch Issues

Bycatch and discards are very important fishery concerns throughout the world. FAO reports that the annual discard estimate by marine fisheries is 7.3 million tonnes that corresponds to a weight discard rate of 8%. Tropical shrimp trawl fisheries generate more discards than any other fishery and account for over one-third of the global total of discarded catch (Zengin and Akyol 2009). Conventional shrimp trawls are poorly selective fishing gear and thus retain large amounts of non-target species. Estimates indicate a bycatch to shrimp mass ratio of 5:1 in temperate waters and 10:1 in tropical waters that correponds to 3-5 million tonnes of bycatch per year (Zengin and Akyol 2009).


**Figure 3.** Closed fishing areas for seine net fisheries (Circular No: 2012/65)


**Figure 4.** Closed fishing areas for beam trawl fisheries (Circular No: 2012/65)

There is very limited data on Turkish shrimp fishery bycatch rates. The estimated bycatch to shrimp mass ratio of shrimp trawlers in Taşucu Bay, Mersin (eastern Mediterranean) was 3:1 in winter and 6:1 in summer (Kınacıgil *et al.* 1999).

Öztürk (2009) provided some information on shrimp bycatch composition of beam trawls in the Sea of Marmara. A total of 44 bycatch species (24 fish and 20 invertebrates) were identified in the northern Marmara Sea during 1987-1988. The most abundant fish and invertebrate species were the European hake, *Merluccius merluccius* and European flat oyster, *Ostrea edulis,* respectively. In the southeastern Marmara Sea, a bycatch to shrimp ratio of 1:3 was reported for beam trawl fishery (Bayhan *et al.* 2006). The target species *Parapenaeus longirostris* formed 64.5% of the total catch and the bycatch the ratio was 35.5%. Bycatch included a diverse assemblage of fish and invertebrates including 50 species. The bycatch composition included species of Osteichthyes (17.16%), Crustacea and Decapoda (8.58%), Echinodermata (4.94%), Mollusca (2.53%), Cnidaria (2.14%) and Chondrichthyes (0.13%).

The catch composition of shrimp beam trawl in the southwestern of Marmara Sea included a total of 37 species (Yazıcı *et al.* 2006). The target species, *Parapenaus longirostris* formed 50.8 % of the total catch and about 40% of the catch was discarded. Bycatch to shrimp ratio was 1:1 (1:3.4 in winter and 1.8:1 in summer).

Zengin and Akyol (2009) reported composition of catches and bycatches of shrimp beam trawlers in the Sea of Marmara. The bycatch consisted of 57 species belonging to six groups of marine fauna, including Osteichthyes (25 species), Chondrichthyes (three species), Crustacea (6 species), Mollusca (11 species), Cephalopoda (5 species) and Echinodermata (7 species). Osteichthyes formed the most abundant (52.6%) bycatch group, followed by Crustacea, Chondrichthyes, Echinodermata, Cephalopoda, and Mollusca. Whiting, *Merlangius merlangus* and hake, *Merluccius merluccius* dominated the commercially utilized part of the bycatch. Discarded part of the catches dominated by swimming crab, *Leocarcinus depurator* and goby species, mainly *Gobius bucchichi*, *G. niger*. The bycatch to shrimp ratio was 1:2.4 (1:8.5 in winter and 1:1.7 in autumn). About 55% of the total bycatch was discarded.

İşmen *et al.* (2015) reported catch and bycatch composition of shrimp beam trawls in the Sea of Marmara. A total of 90 species including 40 teleost fish, 7 cartilaginous fish and 36 invertebrate species were reprted during operations carried out between 2011-2014. The bycatch to shrimp ratio by weight was 3:1. The target species, *P. longirostris* was 25% of the total catch. Bycatch rate was 75% and bycatch composition included 13% teleost fish, 2% cartilaginous fish and 60% other invertebrates. The lowest bycatch rate was found in the Marmara island (65%) and the highest in Yalova (89%). Bycatch rate increased as a factor of depth and increased from 76% in 50-100m zone to 89% in > 100 m.

The above mentioned findings indicate the importance of selectivitiy studies for reducing bycatch in shrimp fisheries management. Throughout the world, one of the important mechanisms to reduce bycatch is bycatch reduction devices (BRDs). In Turkey, the use of BRDs in any type of shrimp trawl is not legislated. However, there are preliminary data on the effects of BRD's in shrimp trawl fisheries. Zengin *et al.* (2004) determined the bycatches and selectivities of different fishing gears including beam trawls that have diamond-mesh codends with two different mesh sizes; a seine net that has a square-mesh codend with one mesh size and a standart beam trawl equipped with bycatch reduction devices (BRDs). The results showed that nets equipped with bycatch reduction devices (BRDs) caught less (57% by weight) bycatch than the standart nets. Selectivity was higher for square-mesh codends and larger mesh sizes.

Deval *et al.* (2006) investigated the selective properties of standart net-32mm nominal polyethylene (PE) and 32, 36, 40 and 56 mm nominal polyamide (PA) cod-ends in beam trawl fisheries targeting rose shrimp, *P. longirostris*, in the Sea of Marmara. The results showed that the selectivity lengths decreased in PE nets compared to PA nets. In addition, standart nets (32 mm) were not appropriate for beam trawl fishing of rose shrimp with a first maturity size of 10 cm.

## 6. Economic contribution

Shrimp composes the most economically important class of decapods. In 2013, the amount of wild caught shrimp in the Turkey was 4027 tons with a value of 45.521.883 TL (23.958.885 $). The majority (51%) of this production comes from the Sea of Marmara. In addition, 75% (1209 ton) of deepwater rose prawn catch is from the Sea of Marmara. The contribution of deepwater rose prawn fishing is 7.119.461 TL (3.747.084 $) (the average sales price; 5,86 TL/kg (3.08 $/kg) (Table 3)(TUIK 2013).

**Table 3.** Quantity, price and value of prawn products (1$ =1.90 TL) (2013).

| Prawn | Quantity (Tons) | Price (TL/kg) | Value (TL) |
|---|---|---|---|
| Total other sea products | 43879 | - | 113 414 160 |
| Total prawn | 4027,6 | - | 45 521 843 |
| Green tiger prawn | 451,8 | 31,12 | 14 060 016 |
| Caramote prawn | 354,4 | 19,28 | 6 832 832 |
| Giant gamba prawn | 1363,6 | 9,49 | 12 940 564 |
| Deep water rose prawn | 1619,9 | 5,86 | 9 492 614 |
| Speckled shrimp | 237,9 | 9,23 | 2 195 817 |

In Turkey, the source of shrimp as a commodity is through capture fisheries only and currently there is no established shrimp farming industry. Marmara's shrimp fisheries trade includes mainly capture, sales to the wholesalers/restaurants/retailers, and processing for local and export markets. Jobs associated with transportation, logistics, gear sales/repair and cold-storage facilities should also be taken into consideration as other aspects for employment. The employment aspect is also significant. Data indicate that the beam trawl fisheries provide employment for a total of 771 people in Turkey (TUIK 2013). Since beam trawl fishery is only allowed in the Sea of Marmara, it can be suggested that a great majority of fishermen are employed in this region.

Shrimp consumption in Turkey is relatively less than that in European countries. A high proportion of shrimp catch is exported and therefore, the nutritional contribution from shrimp fisheries is not large. Shrimp is exported as canned, fresh and individually frozen, mostly to Italy, Greece, France and Spain (Öztürk 2009).

## 7. Trade aspects

In the Sea of Marmara, since relatively smaller vessels are used, shrimp fishing period is subject to fluctuations due to weather conditions. Shrimp fishing is allowed during fall, winter and early fall but not in summer with no regional differences throughout the Sea of Marmara in terms of fishing season. Güngör *et al.* 2007 provides information on the shrimp trade, incomes and sales in the Sea of Marmara. The quantity of shrimp catches, selling prices, average incomes and marketing channels according to the vessel classification are shown in the Table 4. Small vessels (<10 m) had a mean daily catch of 24.6 kg shrimps while medium (10-14.9 m) and larger size vessels (>15 m) had a mean daily catch of 27.3 kg and 32.2 kg, respectively. Larger vessels (>15 m) are able to fish for longer periods during the fishing season. This has positive impact on income because larger vessels continue fishing during unsuitable weather conditions when availability of shrimp is limited and price is higher (2.2 €/kg). This factor explains the relatively large difference in the mean income of different size vessels. Güngör *et al.* 2007 reports that 78.6% of income of small vessel owners come from shrimp fishing. The share of income contributed from shrimp fishing decreases for larger size vessels.

**Table 4.** The quantity of shrimp catches, selling prices, average income and marketing channels according to the vessel length.

| Vessel lengths groups | Amount of shrimp landing | Fishing period (Day) | Total kg/year | Price €/kg | Average İncome (€) | Marketing channels (%) | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | Vessels | Wholesalers | Cooperatives |
| **<-9.90** | 24.6 | 114 | 2804 | 1.9 | 5239.5 | 12.5 | 82.7 | 4.8 |
| **10.0-14.90** | 27.3 | 126 | 3440 | 2.0 | 6742.4 | 14.6 | 73.0 | 12.4 |
| **15.0-<** | 32.2 | 167 | 5478 | 2.2 | 12020.3 | 16.3 | 69.2 | 14.5 |
| **Average** | 26.8 | 125 | 3.394 | 1.9 | 6607.6 | 13.9 | 76.7 | 9.4 |

Fishermen usually sell their catches to wholesalers. A small portion of sales are through fisheries cooperatives. Although illegal, a small percentage of sale occurs on the vessels directly to customers or restaurants (Güngör *et al.* 2007).

## 8. Research

Systematics, biology, ecology and reproduction of *P. longirostris* was investigated by a number of authors (Demir 1954, 1958; Erden and Erim 1971; Bilecik

1985; Zengin *et al.* 2004; Artüz 2005; Bayhan *et al.* 2005; Tosunoğlu *et al.* 2008; Öztürk 2009; İşmen *et al.* 2015).

Although the commercial importance of shrimps has drawn attention in the field of fisheries sciences, there are a few published studies and they are limited to *P. longirostris.* These studies focus on trawl net selectivity, population structure and catch composition in the Sea of Marmara. Yazıcı *et al.* (2006); Bayhan *et al.* (2006); Zengin and Akyol (2009) and İşmen *et al.* (2015) studied the catch composition and bycatch of shrimp beam trawl fisheries in the Sea of Marmara. Zengin *et al.* (2004); Artüz (2006); Erten (2009) investigated the catch composition and bycatch of the seine-nets and trawls in the Sea of Marmara. Akyol *et al.* (2009) reported technical characteristics of set net, handline and longlines in the Marmara Island. Deval *et al.* (2006) and Zengin and Tosunoğlu (2006) studied the selectivitiy of beam trawls.

Stock assessment and CPUE of *P. longirostris* have also been studied DEÜ/DBE (1993), Yüksek *et al.* (2000), Bök *et al.* (2000) and Karakulak *et al.* (2000) reported seasonal and depth related biomass distribution of *P. longirostris*. The stock assessments of this species in the Sea of Marmara were reported by different researchers (Baran and Öztürk 1990; Zengin *et al.* 2004; İşmen *et al.* 2015).

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## DEEP SEA IN THE SEA OF MARMARA

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### 1. Introduction

The Sea of Marmara is a unique inland sea of Turkey with small size basin ~70km x 250 km (surface area: ~11,500 km$^2$, maximum depth 1390 m). This basin is located between the continents of Europe and Asia. Black Sea water with less saline which is present surface layer of The Sea of Marmara between 0 and 25 m depth, whereas the high salinity Mediterranean water that presents downward 25 m deeper layers (Beşiktepe *et al.* 1994). It seems the difference in benthic assemblages between shallow water and deep water of the Sea of Marmara (Rullier 1963; Çınar *et al.* 2009).

### 2. What is deep sea?

The deep sea is often described as beginning at the edge of the continental shelf that around the world, but on average it is around 200 m (Peres 1985). Gage and Tyler (1991) also defined "The deep sea" accurately is the portion of the ocean that stands below 200 m depth, both in the water column and in the benthos. What is considered the deep sea is an expanse almost totally devoid in light. This also means that, descending into the depths, we arrive at a level below which photosynthesis may not be performed with enough efficiency to sustain life. This level, called compensation depth, is found at about 150-200 m in the most clear ocean waters and, logically, is shallower in more turbid waters.

### 3. Marmara Deep sea morphology and hydrography

The basin consist of three topographic depressions located in the northern part of the Marmara Sea. The eastern basin (maximum depth-1240 m) has been characterized as a pull apart basin, while the central and western basins (1390 m and 1097 m depths respectively) have been characterized as compressional depressions (Şengör *et al.* 1985) (Figure 1). The sills connecting each pair of basins have depths of 750 m; the eastern sill has a length of 40 km, and the western sill has a length of 20 km.

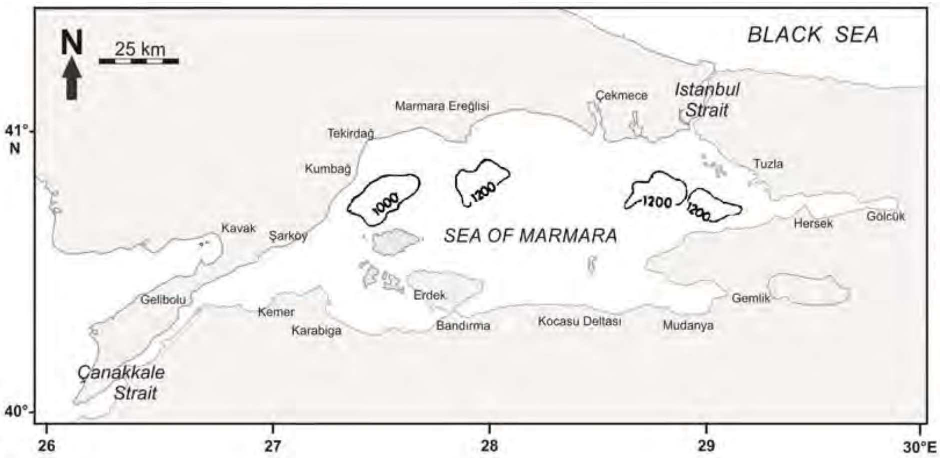


**Figure 1.** The Marmara Sea with its basins (it is modified after Şengör *et al.* 1985)

The basin receives a total of 1.9 x $10^6$ tons of total organic carbon and 2.7 x $10^5$ tons of total nitrogen per year from the Black Sea inflow (Polat and Tugrul 1995). The Marmara Sea is now the recipient of a large number of wastewater discharges from land based sources (Albayrak *et al.* 2006). The oceanographic features (chemical, biological) of the basin are influenced by the Black Sea and the Aegean Sea via the İstanbul Strait and the Çanakkale Strait, respectively.

The renewal time of deep waters in the Sea of Marmara by surface water is much faster than in the Black Sea (6-7 years) such that deep water in the Sea of Marmara is oxygenated (Besiktepe *et al.* 1993). The negatively buoyant plume of well-oxygenated Mediterranean waters is the only means of renewal of the deep waters, partially compensating for the oxygen consumed by the degradation of organic matter sinking from the upper layer into the lower layer.

## 4. Biological studies

Luigi Ferdinando Marsili (1679-1680) conducted made the first time measurement in the Istanbul Strait. He provided the dynamics of the exchange currents and observed the current reversal at depth of Turkish Staits System. It is accepted that the measurement are the beginning of modern oceanography (Pinardi *et al.* 2010). In additions, he recorded some corals, mollusca, fishes (turbot, red mullet, gobi etc.) and seal.

Another study was conducted in 1894 from The Marmara Sea named "Thessaloniki expetidion". Dr A. Ostroumoff who wrote a report of the Marmara Sea in regards to its biology. He informed that deep of The Marmara Sea is dense muddy also sandy and small stony. He also found Mediterranean origin benthic populations from deep of The Marmara Sea (See Table 1).

JICA (Japan International Cooperation Agency) conducted a development study on demersal fisheries resources survey between 20-500 m depths in territorial waters of Turkey (JICA 1993). Doğan *et al.* (2016) investigated in detailed mollusca fauna at bathyal zone of the Sea of Marmara. Two species (*Akritogyra conspicua* and *Liostomia hansgei*) are new records for the marine molluscan fauna of Turkey and they informed that richer fauna at depth of 500 m (25 species) compared to 1000 m (17 species).

Although, the studies began long before there is little information about the ecology and biodiversity of the deep-sea fauna of The Sea of Marmara. Demir (1958a) described three deep sea fishes from The Marmara Sea that was the first works among the Turkish Scientifics.

Kabasakal and Dalyan (2011) published a report on the recent captures of the bramble shark, *Echinorhinus brucus* between 100 and 700 m. Also same species was imaged by means of a ROV camera at depth of 1214 m in Tekirdağ trench (Kabasakal *et al.* 2005).

Öztürk *et al.* (1994) wrote a preliminary report for the bathial decapoda fauna and recorded five species (Table 1). Although the species have been recorded before, for the first time they have been found from deeper than 500 m.

In 2008, a total of 1127 specimens belonging to three crustacean species (*Calocaris macandreae*, *Polycheles typhlops* and *Sergestes robustus*) was collected in all three depressions of the Sea of Marmara (Topaloğlu 2014). The most abundant species was *C. macandreae* at all stations. The species is considered as a typical soft sediment species in the Aegean Sea, but not typical for the Marmara Sea (Ateş and Katağan 2008). It thus seems that the deep sea fauna of the Marmara Sea is thus directly related to the Aegean Sea fauna as the lower layer originated from the Aegean Sea (Beşiktepe *et al.* 1994).

Alavi (1988) studied on benthic foraminiferal assemblages deep-sea sediments of the eastern depression of the Sea of Marmara. In conculation, the study pointed out faunal similarities with fossil assemblages in association with some late-Quaternary sapropels and related facies from the eastern Mediterranean basins. He suggest that they were deposited under palaeo-oceanographic conditions closely similar to those of the actual situation of The Sea of Marmara.

Quaiser *et al.* (2011) produced metagenomic data from bathypelagic plankton (1000 m depth) and bottom sediment of the Sea of Marmara then compared Aloha deep-sea and surface plankton, whale carcasses, Peru subsurface sediment. They found metagenomes clustered deep-sea Marmara plankton with deep Aloha plankton and whale carcasses, likely because of the suboxic conditions in the deep Marmara water column. They showed that the Marmara sediment plays ecological importance of both types of microbial communities in the degradation of organic matter and the completion of biogeochemical cycles.

Taviani *et al.* (2011) discovered deep-water coral sites in the Marmara Sea. *Desmophyllum dianthus* and *Caryophyllia* sp. have been recorded between 900 and 1,200 m in the Cinarcik Basin of the Marmara Sea. Giant Desmophyllum (up to 15 cm high) clusters have been observed and sampled by the Nautile.

Small unnamed species *Idas*-like mussels have been discovered living on carbonate crusts associated with cold-seeps in the Marmara Sea (Ritt *et al.* 2012). The species tentatively ascribed to the genus Idas, and *Idas modiolaeformis*, a species identified in the eastern Mediterranean cold 20 seeps with very close relatives recently sampled and investigated in the north east Atlantic (Duperron *et al.* 2013). Idas-like nov. sp. is morphologically different from Idas aff. modiolaeformis of the eastern Mediterranean Sea and represents a new lineage in the Mytilidae tree. These mussels, here referred to as *Idas*-like nov. sp., differ morphologically and genetically from another species identified as *Idas* aff. *modiolaeformis*, living in the same type of ecosystem eastern Mediterranean Sea (Ritt *et al.* 2012).

Oral (2010) was studied stomach content of *Galeus melastomus* obtained from 1200 m depth in the Sea of Marmara. He determined invertebrate species *Calocaris macandreae* and *Sergestes robustus*.

The deep water poorly oxygenated bottom-water conditions and show low diversity and are dominated by a group of species adapted to an infaunal life style with wide bathymetric distribution in the Mediterranean Sea. Their distributionis primarily controlled by substrate conditions. These environmental conditions and the mostly muddy substrate of the depressions of the Marmara Sea seem to be suitable for this burrowing species, which was reported from similar habitats in the Aegean Sea (Kocataş and Katağan 2003; Ateş *et al.* 2005; Ateş and Katağan 2008).

The deep sea is considered impenetrable, difficult and expensive to reach and observe. All the above to realize that to date, the definitions applied on the deep sea are varied and not always overlapping. This is also because the realization that the deep sea was a separate biome with its peculiar environmental conditions happened only in recent years (Gage and Tyler 1991).

The species that observed greater than 200 m depht are listed in Table 1 with references.

**Table 1.** Marmara Deep sea fauna that recorded greater than 200 m depth Depth range (I: 200-500 m; II: 500-1000 m; III >1000 m)

| **Species** | **References** | **Deep range** |
|---|---|---|
| **Phylum: Porifera** | | |
| *Haliclona (Reniera) aquaeductus* (Schmidt, 1862) | Ostroumoff 1896 | II |
| *Thenea muricata* (Bowerbank, 1858) | Ostroumoff 1896 | II |
| **Phylum: Cnidaria** | | |
| *Caryophyllia sp.* | Taviani *et al.* 2011 | III |
| *Cerianthus membranaceus* (Spallanzani, 1784) | Ostroumoff 1896 | II |
| *Muggiaea kochii* (Will, 1844) | Ostroumoff 1896 | II |
| *Parantipathes larix* (Esper, 1788) as *Anthipathes larix* | Ostroumoff 1896 | II |
| *Desmophyllum dianthus* (Esper, 1794) | Taviani *et al.* 2011 | III |
| **Phylum: Annelida** | | |
| *Amage gallas*i Marion, 1875 | Ostroumoff 1896 | I |
| *Amphitritides gracilis* (Grube, 1860) | Ostroumoff 1896 | II |
| *Aponuphis bilineata* (Baird, 1870) | Rullier 1963 | I |
| *Drieschia pelagica* Michaelsen, 1892 as *Nectochaeta caroli* | Wesenberg-Lund E 1939 | II |
| *Fauvelicirratulus dollfusi* (Fauvel, 1928) | Çinar and Petersen 2011 | II |
| *Janita fimbriata* (Delle Chiaje, 1822) | Ostroumoff 1896 | II |
| *Melinna palmata* Grube, 1870 as *M. adriatica* | Ostroumoff 1894 | II |
| *Metavermilia multicristata* (Philippi, 1844) | Ostroumoff 1896 | II |
| *Nephtys cirrosa* Ehlers, 1868 | Ostroumoff 1894 | I |
| *Nephtys hombergii* Savigny, 1818 | Ostroumoff 1896 | II |
| *Notophyllum foliosum* (M. Sars, 1835) | Ostroumoff 1896 | II |
| *Panthalis oerstedi* Kinberg, 1856 | Ostroumoff 1896 | II |
| *Pherusa plumosa* (O. F. Müller, 1776) | Ostroumoff 1896 | I |
| *Pista cristata* (O. F. Müller, 1776) | Ostroumoff 1896 | II |
| *Praxillella praetermissa* (Malmgren, 1866) | Ostroumoff 1896 | I |
| *Serpula vermicularis* Linnaeus, 1767 | Ostroumoff 1894 | I |
| *Spiophanes reyssi* Laubier, 1964 | Gillet and Ünsal 2000 | I |
| *Sternaspis scutata* (Renier in Ranzani, 1817) | Ostroumoff 1896 | I |
| *Terebellides stroemi* M. Sars, 1835 as *T. carnea* | Ostroumoff 1894 | I |
| *Tomopteris vitrina* Vejdowsky, 1878 | Ostroumoff 1896 | II |
| **Phylum: Mollusca** | | |

| | | |
|---|---|---|
| *Akritogyra conspicua* (Monterosato, 1880) | Doğan *et al.* 2016 | III |
| *Benthonella tenella* (Jeffreys, 1869) | Doğan *et al.* 2016 | III |
| *Crenilabium exile* (Jeffreys, 1870) | Doğan *et al.* 2016 | III |
| *Cuspidaria cuspidata* (Olivi, 1792) | Sturany 1895 | II |
| *Cylichna cylindracea* (Pennant, 1777) | Doğan *et al.* 2016 | II |
| *Entalina tetragona* (Brocchi, 1814) | Doğan *et al.* 2016 | III |
| *Falcidens gutturosus* (Kowalewsky, 1901) | Ritt *et al.* 2010 | II |
| *Hyala vitrea* (Montagu, 1803) | Doğan *et al.* 2016 | III |
| *Isorropodon perplexum* Sturany, 1896 | Ritt *et al.* 2010 | II |
| *Kurtiella bidentata* (Montagu, 1803) | Ostroumoff 1896 | II |
| *Ceratia proxima* (Forbes & Hanley, 1850) | Doğan *et al.* 2016 | II |
| *Liostomia hansgei* Warén, 1991 | Doğan *et al.* 2016 | III |
| *Megastomia conoidea* (Brocchi, 1814) | Doğan *et al.* 2016 | III |
| *Myrtea amorpha* (Sturany, 1896) | Ritt *et al.* 2010 | III |
| *Myrtea spinifera* (Montagu, 1803) | Ostroumoff 1896 | II |
| *Odostomia silesui* Nofroni, 1988 | Doğan *et al.* 2016 | II |
| *Odostomia unidentata* (Montagu, 1803) | Doğan *et al.* 2016 | II |
| *Parthenina interstincta* (Adams, J., 1797) | Doğan *et al.* 2016 | II |
| *Pterotrachea coronata* Forsskål in Niebuhr, 1775 | Ostroumoff 1896 | II |
| *Pusillina inconspicua* (Alder, 1844) | Doğan *et al.* 2016 | II |
| *Roxania utriculus* (Brocchi, 1814) | Doğan *et al.* 2016 | III |
| *Syrnola minuta* H. Adams, 1869 | Doğan *et al.* 2016 | III |
| *Yoldiella philippiana* (Nyst, 1845) | Ostroumoff 1896 | III |
| *Abra alba* (Wood W., 1802) | Sturany 1895 | II |
| *Abra longicallus* (Scacchi, 1835) | Sturany 1895 | II |
| *Abra nitida* (Müller O.F., 1776) | Ostroumoff 1896 | I |
| *Acanthocardia paucicostata* (Sowerby G. B.II, 1834) | Ostroumoff 1896 | II |
| *Aequipecten opercularis* (Linnaeus, 1758) | Sturany 1895 | II |
| *Alvania cancellata* (da Costa, 1778) | Ostroumoff 1896 | I |
| *Alvania cimicoides* (Forbes, 1844) | Doğan *et al.* 2016 | III |
| *Alvania testae* (Aradas & Maggiore, 1884) | Ostroumoff 1896 | I |
| *Aporrhais serresianus* (Michaud, 1828) | Ostroumoff 1896 | II |
| *Azorinus chamasolen* (da Costa, 1778) | Sturany 1895 | II |
| *Bittium submamillatum* (de Rayneval & Ponzi, 1854) | Ostroumoff 1896 | I |
| *Caecum trachea* (Montagu, 1803) | Ostroumoff 1896 | I |
| *Cardiomya costellata* (Deshayes, 1835) | Ostroumoff 1896 | I |
| *Centrocardita aculeata* (Poli, 1795) | Sturany 1895 | I |

| | | |
|---|---|---|
| *Chama gryphoides* Linnaeus, 1758 | Ostroumoff 1896 | II |
| *Chiroteuthis veranii* (Férussac, 1835) | Degner 1925 | II |
| *Corbula gibba* (Olivi, 1792) | Sturany 1895 | II |
| *Delectopecten vitreus* (Gmelin, 1791) | Ostroumoff 1896 | II |
| *Diodora graeca* (Linnaeus, 1758) | Ostroumoff 1896 | I |
| *Ennucula aegeensis* (Forbes, 1844) | Ostroumoff 1896 | II |
| *Ennucula tenuis* (Montagu 1808) | Ostroumoff 1896 | I |
| *Eulimella scillae* (Scacchi, 1835) | Ostroumoff 1896 | I |
| *Euspira fusca* (de Blainville, 1825) | Ostroumoff 1896 | II |
| *Flexopecten glaber* (Linnaeus, 1758) | Ostroumoff 1896 | II |
| *Fusinus rostratus* (Olivi, 1792) | Tortonese 1959 | II |
| *Galeodea echinophora* (Linnaeus, 1758) | Ostroumoff 1896 | II |
| *Globivenus effossa* (Philippi, 1836) | Ostroumoff 1896 | I |
| *Idas-like nov. sp* | Ritt *et al.* 2012 | III |
| *Kelliella miliaris* (Philippi, 1844) | Ostroumoff 1896 | II |
| *Laeviphitus verduini* van Aartsen, Bogi & Giusti, 1989 | Doğan *et al.* 2016 | III |
| *Loripes lucinalis* (Lamarck, 1818) | Ostroumoff 1896 | II |
| *Lucinella divaricata* (Linnaeus, 1758) | Ostroumoff 1896 | II |
| *Lucinoma borealis* (Linnaeus, 1767) | Ostroumoff 1896 | II |
| *Lucinoma kazani* Salas & Woodside, 2002 | Ritt *et al.* 2010 | II |
| *Mangelia nuperrima* (Tiberi, 1855) | Ostroumoff 1896 | II |
| *Modiolula phaseolina* (Philippi, 1844) | Sturany 1895 | I |
| *Nuculana pella* (Linnaeus, 1767) | Sturany 1895 | II |
| *Parthenina flexuosa* (Monterosato, 1874) | Öztürk 2014 | II |
| *Parvicardium exiguum* (Gmelin, 1791) | Ostroumoff 1896 | II |
| *Philine scabra* (Müller, O.F., 1784) | Ostroumoff 1896 | II |
| *Pitar rudis* (Poli, 1795) | Sturany 1895 | II |
| *Putzeysia wiseri* (Calcara, 1842) | Doğan *et al.* 2016 | III |
| *Ringicula conformis* Monterosato, 1877 | Ostroumoff 1896 | I |
| *Saccella commutata* (Philippi, 1844) | Sturany 1895 | II |
| *Scaphander lignarius* (Linnaeus, 1758) | Ostroumoff 1896 | II |
| *Spondylus gussonii* Costa O.G., 1829 | Ostroumoff 1896 | II |
| *Teretia teres* (Reeve, 1844) | Ostroumoff 1896 | I |
| *Thyasira granulosa* (Monterosato, 1874) | Ostroumoff 1896 | II |
| *Timoclea ovata* (Pennant, 1777) | Sturany 1895 | II |
| *Trophonopsis muricata* (Montagu, 1803) | Houart 2001 | I |
| *Turbonilla micans* (Monterosato, 1875) R238 R230 | Öztürk 2014 | II |

| | | |
|---|---|---|
| *Vexillum granum* (Forbes, 1844) | Ostroumoff 1896 | I |
| *Xylophaga dorsalis* (Turton, 1819) | Ostroumoff 1896 | II |
| *Yoldiella striolata* (Brugnone, 1876) | Ritt *et al.* 2010 | II |
| **Phylum: Arthropoda** | | |
| *Acanthocythereis hystrix* (Reuss, 1850) | Tunoğlu 1999 | II |
| *Buntonia sublatissima* (Neviani, 1906) | Tunoğlu 1999 | II |
| *Calocaris macandreae* Bell, 1853 | Topaloğlu 2014 | III |
| *Chlorotocus crassicornis* (A. Costa, 1871) | Kocataş and Katağan 1993 | II |
| *Costa punctatissima* Ruggieri, 1962 | Tunoğlu 1999 | II |
| *Eusergestes arcticus* (Krøyer, 1855) | Müller 1986 | II |
| *Falunia plicatula* (Reuss, 1850) | Tunoğlu 1999 | II |
| *Galathea dispersa* Bate, 1859 | Marion 1898 | II |
| *Gennadas elegans* (Smith, 1882) | Stephensen 1923 | II |
| *Geryon longipes* A. Milne-Edwards, 1882 | Ostroumoff 1896 | II |
| *Loxoconcha obliquata* (Seguenza, 1879) | Tunoğlu 1999 | II |
| *Monodaeus couchii* (Couch, 1851) | Ostroumoff 1896 | II |
| *Munida rugosa* (Fabricius, 1775) | Ostroumoff 1896 | II |
| *Munida tenuimana* G.O. Sars, 1872 | Ostroumoff 1896 | II |
| *Nephrops norvegicus* (Linnaeus, 1758) | Kocataş and Katağan 1993 | II |
| *Pagurus alatus* Fabricius, 1775 | Colombo 1885 | II |
| *Pandalina profunda* Holthuis, 1949 | Kocataş and Katağan 2003 | II |
| *Paradoxostoma simile* G.W. Müller, 1894 | Tunoğlu 1999 | II |
| *Parapenaeus longirostris* (Lucas, 1846) | Ostroumoff 1896 | II |
| *Pasiphaea sivado* (Risso, 1816) | Müller 1986 | II |
| *Plesionika heterocarpus* (A. Costa, 1871) | Ostroumoff 1896 | II |
| *Pleuromamma abdominalis* (Lubbock, 1856) | Demir 1959 | II |
| *Polycheles typhlops* Heller, 1862 | Topaloğlu 2014 | III |
| *Polycope reticulata* G.W. Müller, 1894 | Tunoğlu 1999 | II |
| *Pontocypris acuminata* (G.W. Müller, 1894) | Tunoğlu 1999 | II |
| *Quadracythere prava* (Baird, 1850) | Tunoğlu 1999 | II |
| *Sergia robusta* (Smith, 1882) | Topaloğlu 2014 | III |
| *Solenocera membranacea* (Risso, 1816) | Ostroumoff 1896 | II |
| *Urocythereis favosa* (Roemer, 1838) | Tunoğlu 1999 | II |
| *Xestoleberis dispar* G.W. Müller, 1894 | Tunoğlu 1999 | II |
| *Metridia lucens* Boeck, 1864 | Demir 1959a | I |

| | | |
|---|---|---|
| *Neocalanus gracilis* (Dana, 1849) | Ünal *et al.* 2000 | I |
| *Medicorophium rotundirostre* (Stephensen, 1915) | Ateş *et al.* 2012 | I |
| *Melphidippella macra* (Norman, 1869) | Aslan-Cihangir *et al.* 2009 | I |
| *Microjassa cumbriensis* (Stebbing and Robertson, 1891) | Sowinsky 1897 | I |
| *Microprotopus maculatus* Norman, 1867 | Sowinsky 1897 | I |
| *Meganyctiphanes norvegica* (M. Sars, 1857) | Demir 1959b | I |
| *Aegaeon lacazei* (Gourret, 1887) | Ateş *et al.* 2010 | I |
| *Calocaris macandreae Bell, 1853* | Kocataş and Katağan 1993 | I |
| *Plesionika heterocarpus* (A. Costa, 1871) | Ostroumoff 1896 | I |
| *Bairdia conformis* (Terquem, 1878) | Nazik 2001 | II |
| *Buntonia sublatissima* (Neviani, 1906) | Tunoğlu 1999 | II |
| *Xestoleberis dispar* G.W. Müller, 1894 | Tunoğlu 1999 | II |
| **Phylum: Echinodermata** | | |
| *Anseropoda placenta* (Pennant, 1777) | Colombo 1885 | I |
| *Astropecten bispinosus* (Otto, 1823) | Colombo 1885 | I |
| *Astropecten irregularis pentacanthus* (Delle Chiaje, 1827) | Colombo 1885 | I |
| *Brissopsis lyrifera* (Forbes, 1841) | Ostroumoff 1896 | II |
| *Cidaris cidaris* (Linnaeus, 1758) | Ostroumoff 1896 | II |
| *Echinaster sepositu*s (Retzius, 1783) | Colombo 1885 | I |
| *Ocnus koellikeri* (Semper, 1868) | Özaydın *et al.* 1995 | II |
| *Oestergrenia digitata* (Montagu, 1815) | Ostroumoff 1894 | II |
| *Ophiocten abyssicolum* (Forbes, 1843) | Ostroumoff 1896 | I |
| *Psammechinus microtuberculatus* (Blainville, 1825) | Colombo 1885 | II |
| **Phylum: Chordata (Subphylum: Hemichordata)** | | |
| *Glandiceps talaboti* Marion, 1876 | Ostroumoff 1896 | I |
| **Phylum: Chordata (Subphylum: Vertebrata)** | | |
| *Argyropelecus hemigymnus* Cocco, 1829 | Colombo 1885 | II |
| *Benthosema glaciale* (Reinhardt, 1837) | Taning 1918 | II |
| *Centrophorus granulosus* (Bloch & Schneider, 1801) | JICA 1993 | I |
| *Centrophorus uyato* (Rafinesque, 1810) | Meriç 1995 | I |
| *Conger conger* (Linnaeus, 1758) | JICA 1993 | I |
| *Dalatias licha* (Bonnaterre, 1788) | Meriç 1995 | I |
| *Dipturus oxyrinchus* (Linnaeus, 1758) as *Raja oxyrinchus* | JICA 1993 | I |
| *Echinorhinus brucus* (Bonnaterre, 1788) | Kabasakal *et al.* 2005 | II |
| *Galeus melastomus,* Rafinesque, 1810 | Oral 2010 | III |
| *Helicolenus dactylopterus* (Delaroche, 1809) | Meriç 1995 | I |

| | | |
|---|---|---|
| *Hygophum benoiti* (Cocco, 1838) | Taning 1918 | II |
| *Lampanyctus crocodilus* (Risso, 1810) | Taning 1918 | II |
| *Merluccius merluccius (Linnaeus, 1758)* | JICA 1993 | I |
| *Micromesistius poutassou* (Risso, 1827) | JICA 1993 | I |
| *Mustelus asterias* Cloquet, 1819 | JICA 1993 | I |
| *Nezumia aequalis* (Günther, 1878) | Meriç 1995 | I |
| *Notoscopelus elongatus* (Costa, 1844) | Demir 1958a | II |
| *Oxynotus centrina* (Linnaeus, 1758) | JICA 1993 | I |
| *Scyliorhinus canicula* (Linnaeus, 1758) | JICA 1993 | I |
| *Squalus acanthias* Linnaeus, 1758 | JICA 1993 | I |
| *Squalus blainville* (Risso, 1827) | JICA 1993 | I |
| *Stomias boa* (Risso, 1810) | Colombo 1885 | II |
| *Trigla lyra* Linnaeus, 1758 | JICA 1993 | I |

Based on literature review, a total of 180 species belonging to 7 phyla are presented in the checklist. Various species reported from the deeper than 200 m depth. Mollusca and Arthropoda are dominant groups that they have 77 and 43 species, respectively. However, a total of 64 alien species was determined in the Marmara sea (Çınar *et al.* 2011), there aren't any alien species in this review. There are still gaps in detailed systematic data on deep of Marmara Sea. It is only after systematic work in deep parts of the Marmara Sea that a clear picture can emerge about the regional biodiversity.

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# TRADITIONAL FISHING IN THE SEA OF MARMARA: FROM THE PAST TO THE PRESENT

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## 1. Introduction

Fishing gear and methods used depend on the species fished. Techniques vary from very simple, such as the hand collection or gleaning of shoreline invertebrates, to complex and expensive operations such as purse seining for tuna. A large range of fishing gear is used by commercial and artisanal fishers (King 1995). Artisanal fishing, defined as a small scale fishing where the fisherman's wealth is his fishing gear (boats, motors, nets, and lines), which is subject to rapid depreciation and loss, is a major form of fishing. Many of these fishermen use traditional techniques and equipment. They depend their success on local and indigenous knowledge, much of which has been passed down from generation to generation though a strong oral tradition (Quinn 2011).

The Sea of Marmara is a unique inland sea of Turkey and a link between the Black Sea and Mediterranean Sea. This sea is one of the productive fishing grounds in Turkey (Öztürk 2009) in that it has a rich fauna than the Black Sea in terms of both demersal and pelagic migratory fishes (Zengin 1995). This richness of fish species in Turkey especially in the Istanbul Strait is based from its location between the Black Sea and Mediterranean Sea which geological origins are very different (Akşıray 1954). It is like a big aquarium which watercourses for local and migratory fish species (Bilge 1971). Although the Sea of Marmara has small area by comparison with other seas, it is in advance in terms of fishing. The Sea of Marmara and Straits are the migration corridor for migratory fishes from the Black Sea to Aegean Sea. Nowadays, fishing is dominated by notably anchovy and sardine, horse mackerel, whiting, pink shrimp (WWF 2013). Turkish fisheries in the Sea of Marmara are today among the largest fisheries in the Middle East (Knudsen 2004). The Sea of Marmara has kept the fishing advantage from pride of position in every period. This sea is the smallest of Turkey's four seas, occupying only 4.5% of Turkey's total fishing area (Ulman *et al.* 2013).

In ancient times and nowadays, some cities within borders of the Sea of Marmara has come into prominence with incomes from fishing. Istanbul, the most important of those, constitute the major center of fishing in contemporary Turkey (Maniatis 2000; Knudsen 2004). People of Istanbul has made use of this opportunity and consisted a rich fish culture. Istanbul has an important cultural position in becoming a tradition of fishing.

Traditional fishing techniques in which Byzantium, following in the Greek and Roman tradition (Dagron 2002) were transferred until today. In Ottoman Empire and notably Istanbul the capital city, fishing was depend on traditions from centuries-old. Almost all of the fishers in Istanbul and the Bosporus were Ottoman Greek citizens. This situation hardly had changed to the early years of the Turkish Republic (Doğan 2011). Many claim, even contemporary Turkish fishermen themselves, that the Turks learned the art of fishing from the Greeks (Knudsen 2004). In addition, the contemporary wordbook of Turkish fishing culture are originated from Greek.

Among other cities, conditions of Istanbul is original in that there is special fish consumption of city. In certain seasons, fishes migrate to Istanbul Strait in big schools (Faroqhi 1998). Also, existing of human communities lived on fishing in the Bosporus is known since sixth century B.C. (Bursa 2007). Since ancient times a variety of different fishing technologies has been known and used there and elsewhere in the empire. Certainly fishing in Constantinople had a special position in the empire and was considered throughout Europe to be very advanced (Knudsen 2004). Besides harpoons, simple traps, nets and hand lines which used ancient times, fishermen of Constantinople have used quasi-permanent installations along the migration routes in seventh-twelfth centuries (Dagron 2002). In this chapter, traditional fishing techniques were summarized in the context of historical tradition in the Sea of Marmara.

## 2. Types of traditional fishing in the Sea of Marmara

### 2.1. Trap nets (Dalians)

Dalians were mostly mentioned by ancient authors and sources (Figure 1a). Historical records showed that dalians have been used in the Sea of Marmara since pre-Byzantine (von Branth 1984). Dalian fishing was a major source of the capital's high-value fish supply in X century Constantinople (Maniatis 2000). After Byzantium, fishing in Ottoman Empire is usually done by using dalians or nets (Doğan 2011). Although fishing by dalians was more profitable both in Byzantium (Dagron 2000) and in Ottoman (Ertuğ 2015) but requiring an expensive fishermen team. According to Devedjian (1926), the old director of the Istanbul fish market, dalians from far in the past are the most important nets among other stationary nets used in Turkey. Their usage has been existing even decreasingly until today. Devedjian (1926) noted that 155 dalians were set in the Sea of Marmara and 52 dalians in the Bosporus, especially western shore, where the current is less violent than upon the Asiatic bank (32 in European Side, 20 in Asian Side) (White 1845). Evliya Çelebi, noted traveler and writer in XVII century, mentioned in his famous itinerary that there were 300 dalians and 700 fishermen worked in dalians of İstanbul (Dağlı and Kahraman 2014). As is understood from these numbers, dalians had played an important role in fishing of the Sea of Marmara and the Bosporus and they were used commonly. Besides, both Çelebi and Devedjian started with dalians when they described fishing gears. These dalians used in İstanbul coasts had a special place in fishing of city. Such that, it is understood that empire established some regulations in ninth century. When number of dalians set in the Sea of Marmara and Bosporus consider, conflict and problems were inevitable between owners of dalians. With Novel 57 codified as law that established the minimum distance between two adjacent dalians as 700 m for ensuring that dalians did not encroach on one another (Dagron 1994). This implementation has been continued in Ottoman time and this distance was established as 2500 steps (Doğan 2011).

There are six type of dalian systems as *Şıra*, *Kurtağzı*, *Kırma-Kepasti*, *Çekme*, *Çökme*, and *Çit* (Devedjian 1926). The dalians are usually constructed by driving pieces of wood into the seabed to form a trap into which fish, in particular migratory fish. Sometimes the entire trap is constructed of wood; more often nets are stretched between poles. One or more men keep watch from a tower located beside the dalian and as soon as a shoal has entered the weir signal to other crew to close the opening of the dalian (Knudsen 2004). In the past, dalians had watch-boxes or wooden huts. In Ottoman and Early Republic of Turkey, occasionally aid the watchmen vision by dropping oil to calm the ruffled waters (White 1845). Nowadays, strong poles elevated from 4-5 m above the water are fixed to seabed in order to watch fish schools but no oil no longer.

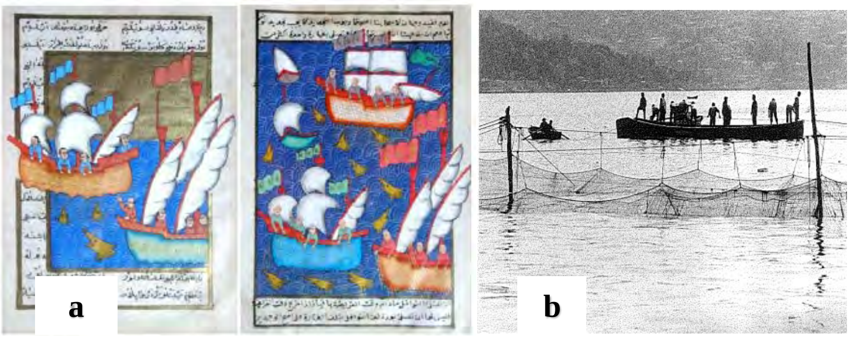


**Figure 1.** a) Images of Turkish painting showing bluefin tuna and swordfish fishery in Turkish area, made by unknown artist. The paintings are made in tempera colours, possibly done between the last part of the XIX century and the first part of XX century, on older pages, both possibly coming from a Holy books. The image on the left shows a fisherman harpooning the tunas (Örenç *et al.* 2014). b) Beykoz Dalian.

Nowadays, only limited number of dalians are left. It seems as if their use gradually decreased from around the turn of the century until the mid-1970s (Knudsen 2004). Dalians can only be set over fish migration routes and should be protected from wave movements and currents. Also, location of dalians has been selected according to fishermen's long experience by a few generations. Seascapes primarily shallow waters close to shore, are called *voli* places are proper for setting of a dalian. The disappearance of migratory fish such as swordfish and mackerel, urbanization and increasing marine traffic caused losing of traditional *voli* and dalian places. Using of dalian system is also limited by high costs. Dalians are called with different names according to size and shapes. Size of dalian vary in accordance with fishing area. The dalian nets are set parallel to the shoreline, about 100 m in length and 20-40 m in maximum width (Karakulak 2000). Today, dalian systems can only be set in the locations of Beykoz, Filburnu, Prens Islands and Bağlaraltı, however, most of them were small scale. The most known of those is Beykoz Dalian that rumored about first established in 1553 (Aydınyazıcı 1960). It became famous for big amount of tuna and swordfish catch in Ottoman (Figure 1b) and Early Republic of Turkey. In the past, dalians were set as only winter dalian, only summer dalian or both winter and summer dalian while they are set as only summer (April-July) dalians today. Summer dalians were set from beginning of April to mid-August while winter dalians were set from mid-August to end of February (Devedjian 1926). According to Devedjian (1926), average 15-20 fishermen worked for a dalian. This fishermen necessity is continue today because manpower is very important for fishing by dalians. They use non-motorized traditional boats called *mavna* which has not a rudder. Fishermen have special cable system to move and direct the *mavna* by hand within the dalian nets. They control the dalian nets by hands in the day and night times. A wide variety of fish species including silverside, horse mackerel, bluefish, bonito, anchovy, mullet, garfish, pilchard, sprat, chub mackerel, two-banded bream, annular bream, picarel, corb fish, red mullet, striped red mullet, scorpion fish, grey mullet, and goby are caught by dalians. Among these species silverside, horse mackerel, bluefish, bonito, mullet, picarel, red mullet, and striped red mullet are economically important species for dalian fishery.

### 2.2. Coastal seine nets

Coastal seine nets are came under three types as *manyat*, *tarlakoz* and *ığrıp*. History of *ığrıp* which is the oldest type of net come from the Roman (Figure 2a). They have been used in Istanbul since Byzantium period (Figure 2b). *Iğrıp* was the biggest net used in İstanbul except for dalian system which is fix net mechanism (Somçağ 1994). Evliya Çelebi noted that there were 2000 fishermen worked for beach seining (Dağlı and Kahraman 2014). Their size and shape were kept since Byzantium (Devedjian 1926). General structural diagram of three types is identical and their size are indicated by length of arm. In general order, *ığrıp* type is the biggest and *tarlakoz* type is the smallest. Essential character which distinguish each other is the structure of arm. Since they are used in special areas called *voli* places like in dalians, urbanization and increasing marine traffic restricted using of *manyat* nets. *Manyat* nets can only be used on the sandy and smooth bottoms. Pink shrimp (*Parapenaeus longirostris*) in the Sea of Marmara and striped red mullet (*Mullus surmuletus*) in the Bosporus are targeted with these nets (Uzer 2011). Old fishing areas for manyat nets in the Bosporus are located in Beykoz, Büyükdere, İstinye, Bebek, Çengelköy, Tarabya, Umuryeri, Keçili, Ortaköy, Beşiktaş, Kabataş, Anadoluhisarı, Vaniköy, Küçüksu and Büyükliman (Öztürk *et al.* 2002; Ertan 2010). All type of coastal seine nets were forbidden except for red shrimp in the Sea of Marmara since 2012. Seven fishing vessels existed in the Istanbul Strait specialized for seining and their length are vary between 7-12.6 m. They used *manyat* nets from 65 m to available shallow waters in the Bosporus. Nets were gathered to vessel deck by hand, not to beach or coast as in the past. Small rollers were as well used for gathering the ropes. Number fishing vessels which targeting pink shrimp in the Sea of Marmara is 25 and they gather in Tuzla province. Fishing areas of them are southern shore of Burgazada and Heybeliada, area between Tuzburnu–Koç Adası–Darıca Yelkenkaya, area between Yalova and Çınarcık, area between southern shore of İmralı Island and Yeniköy. In the Sea of Marmara around Prens Islands fishing depth is 50-55 m, but towards Yalova they can dig down deep of 150-200 m. Productivity of fishing area for seining between Balıkçı Island-Pendik Güzelyalı Stream-Tuzburnu decreased by bottom construction for natural gas pipeline. Area between Yassıada and Balıkçı Island became useless by the reason of illegal building wastes.

Length of a *manyat* net used in the Bosporus is 143 m except for ropes. Polypropylene (PP) ropes are 180 m in length and 18 mm in width. Mesh sizes are 50 mm, 32 mm and 26 mm toward the cod end, respectively. Cod end part where fishes gather is 210d/9 no in thickness and 26 mm in mesh size (Uzer 2011). In one day, 3-4 operations can be done according to yield and weather conditions. Operations are only performed in the daytime. Red and stripped red mullet, scorpion fish, horse mackerel, gar fish, sole, and gurnards can be caught by *manyat* nets in the Bosporus.

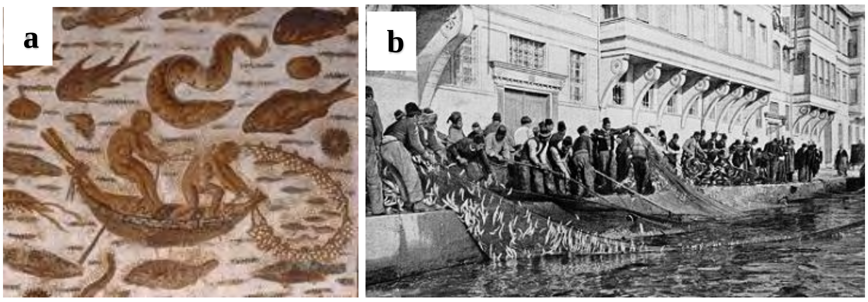


**Figure 2.** a- Mosaic of the third century AD from Hadrumetum (Bekker-Nielsen and Casasola, 2007) b- *Iğrıp* operation in Arnavutköy-Bebek coasts in Ottoman times (Ertan 2010)

### 2. 3. Simple funnel-shaped wattle traps (pots)

Fish pots is one of the fishing gear have been used since Byzantium period (Dagron 2002; Figure 3a). Figures of fishermen pots was seen on the Byzantium medallions in the period of Alexander the great (Devedjian 1926). White (1845) noted that wicker pots were in general use and they were employed along the shore, and at the mouths of sheltered bays and inlets. Twenty or more of these pots, connected by a strong cord and spot were marked by a buoy, consisted of two or more empty gourds (Figure 3c). Ottoman fishermen used four types of wattle pots. They were specialized for lobster, rockling fish, picarel, and shrimp (Devedjian 1926). Evliya Çelebi indicated that 200 fishermen used these wattle pots (Dağlı and Kahraman 2014). A pot is consisted of a channel, a body and a cover in the posterior. These pots are used fishing for rocking fish by a few fishermen, nowadays. Pots for rocking fish are made with dried wattles by weaving and their length is longer than width. Sort of wattle is very important for weaving process (Ertan 2010). It is necessary that wattles should be protect from rain and dried by laying on sand (Devedjian 1926). Wattle stems are weaved at intervals of 1.1 cm. Length of traps is around 30 cm and diameter is 24 cm. Crushed crab and mussels are used as bait. Entrance of pots is funnel shaped and in the strait ahead of entrance there is a cover. When trap is removed from the sea, yield is harvested by opening this cover. Current shape of pots shows that traditional form is already continued (Figure 3b). Nowadays, fish pots for rocking fish are used as a set with gathering 25-30 of pots at depths of 3-5 m by one or two fishermen in only bays such as Kandilli, Aşiyan, Kanlıca and Arnavutköy (Yıldız 2010). Jewish people buy rocking fish mostly. They have a special meal cooked with red and sour plums in the spring.

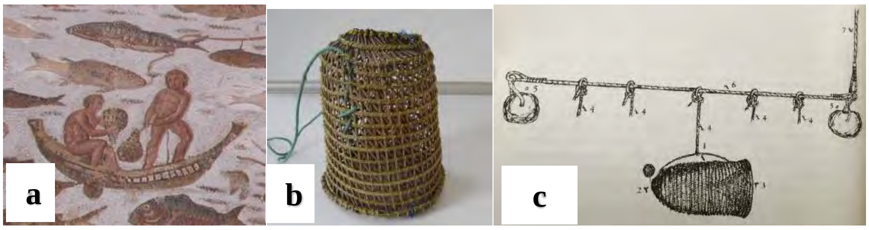


**Figure 3.** a- Fish pots in Byzantium (Bekker-Nielsen and Casasola, 2007), b- current form, c- in Ottoman (Devedjian 1926)

### 2.4. Lift nets

There is no any written source indicates usage of lift net in the Sea of Marmara and the Bosporus in the past. They are generally set right after the capes, namely where eddy current that comprise of after very strong currents intersects with main current (Ertan 2010). Ertan (2010) noted that Kandilli Cape, Kanlıca Cape, Yeniköy Cape, Tarabya, Paşabahçe, and Çubuklu Çakal Cape are the traditional locations for lift net fishing. Öztürk *et al.* (2006) reported six lift net systems in the Istanbul Strait. However, according to Yıldız *et al.* (2013) this number gone down to three and they are located to Arnavutköy, Yeniköy and Tarabya from south to north, respectively (Figures 4a, b). Pelagic fishes which migrate diurnal or seasonal such as sand smelt (*Atherine boyeri*), mullet (Mugil sp.) and gar fish (*Belone belone*) are caught and fishing generally is done in the months of March, April and May and sometimes extend to mid-June. These lift nets work according to the lever principle or bearing posts. Fishing operations are maintained during day times and generally 2-3 fishermen work for lift nets. During fishing operations any bait are not used to attract fishes, but one or two marbles are put to the bottom for easy noticing fishes schools. Bearing posts and legs are produce from iron (Yıldız *et al.* 2013). Lift net system set in Arnavutköy is somewhat different from Arnavutköy and Yeniköy. Its net is little big than others and 4x9 m in length. The other nets are 4x5 and 5x5 m in length and width.

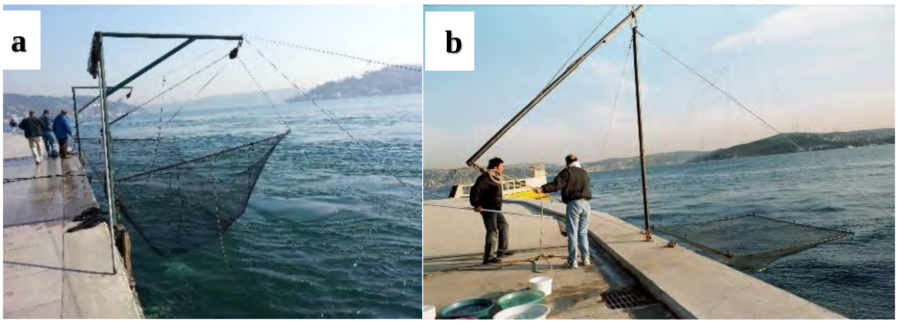


**Figure 4.** Lift net system set in the Istanbul Strait (a-Arnavutköy, b-Tarabya)

### 2.5. *Voli* nets (*Alamana*)

These nets have been used for bluefish and bonito in the Sea of Marmara, the Bosporus and the Black Sea since Ottoman period (Devedjian 1926). *Alamana* net resembles a small purse seine net that operated by two boats (Ertan 2010; Figure 5a). Although Akyüz (1954) stated *alamana* nets were replaced with developed purse seine nets, this determination is not valid. However in *alamana* nets that used in close to shore where depth relatively is known, the ground line of nets do not gathered as in the purse seine nets. These nets are consisted of 2-5 interlaced panel of nets. Nets consisted of 3-5 set are called *alamana* nets (Mengi 1977). Devedjian (1926) has given directions related to this nets: *alamana* nets were used in 10-15 fathoms waters and could be used by two boats. Size of net varied 200-250 fathoms in length and 7.5-25 fathoms in width. A total of 1000 floaters each of 80 okka (1 okka=1283 g) were used in head line while a total of 1000 lead each of 80 okka were used in ground line. In each *alamana* boat, fishermen team sometimes exceeded 20 people (Devedjian 1926). Half of *alamana* nets were folded on the one boat while other half to other boat (Figure 5b). Fish school was determined by ripples on the sea surface a daytime and by sea sparkle at night. Fishing by *alamana* nets started in September and continued to November and December according to the yield (Somçağ 1994). In the past, mesh size was 120-180 mm in trammels and there were 6-12.5 mesh in height. Mesh size was 24-32 mm in main net and there were 50-120 mesh in height (Mengi 1977). Nowadays, these nets can be used by one vessel by virtue of developing fishery technology and two or three fishermen can carry out the fishing operations. Fish school surrounded by net is scared towards to net by some sound and then fishes tangle the nets. Fishing period as well is similar with given by Devedjian (1926). At present time, *alamana* nets equipped by synthetic filaments are intensively used for bluefish and bonito in the Sea of Marmara and the Bosporus during the migration period. Yıldız and Karakulak (2010) noted that around 150 motorized vessel that have 4.1 panels per vessel use these nets at depths of 5-40 m in the coasts of İstanbul.

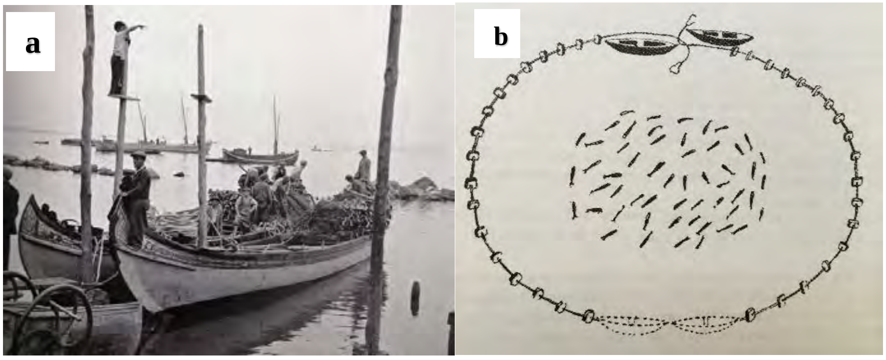


**Figure 5.** a) *Alamana* vessels and nets in Istanbul in 1952 (Güler, 2010) b) operation in Ottoman times (Devedjian 1926)

Modern *alamana* nets are manufactured by polyamide multifilament. These nets are consisted of one main net (210d/4 no in thickness, 48-64 mm in mesh size) and two trammels (210d/6-9 no in thickness, 240-320 mm in mesh size). Hanging ratio is 0.54. Length of a panel net is 109.2 m. A set of net is consisted by overlapping of 2-8 panels of net. Number of panel vary according to length of vessel and fishing depth. Depth of main net is 80-100 meshes while trammels are 7.5-10 meshes (Yıldız and Karakulak 2010).

### 2.6. Swordfish nets

Swordfish was one of the fish species particular to Byzantium city. Aelianus noted that fishermen prayed to Poseidon for not happen on a swordfish which destroy their nets and release all fish after a reliable tuna catch in the Black Sea (Bursa 2007). Fishing for swordfish was done by longlines and bluefin tuna nets in the Sea of Marmara, by dalians in the Bosporus and the Sea of Marmara, and by swordfish nets notably in dark nights in the Bosporus (Devedjian 1926; Karapınar 1964; Artüz 1958). They were also caught mostly by bluefin tuna hand lines (Devedjian 1926). Yield of dalian fishery was in low levels due to swordfish catch depended on incidence (Karapınar 1964). Swordfish nets were used in *voli* places around Beykoz, Paşabahçe, Çubuklu, Kanlıca, Yeniköy ve Baltalimanı (Devedjian 1926; Karapınar 1964). It is understood that surface nets was easily used due to low level of marine traffic in the Bosporus in those years. Swordfish could be caught in still waters and at dark nights. Catch was impossible in the daytime and moonlit nights except for dalians (Devedjian 1926). Onat (1970) reported that swordfishes were caught by special swordfish nets in September and November by utilizing darkness in the Bosporus.

Swordfish nets were simple and form of gillnet. One of the line was equipped with floaters while other line was free and consisted of meshes, there is no any weight. Each of net was about 50 fathoms, a set of net consisted of three panels was called *tonoz*. All vessels used a *tonoz* about 150 fathoms in length (Tezel 1958). As understood from these descriptions, these nets are drift net in the class of pelagic and floating nets. There were 10-13 meshes in depth (Mengi 1977) and vertical length of net were and 2.5-3 or 3.5 fathoms (Tezel 1958). Hanging ratio was 0.38 and mesh size was 20-26 cm (Mengi 1977). Among pelagic and surface nets, swordfish nets went the first thing of the past. When swordfish nets was out of action, nylon nets constructed from synthetic material was not come into the market (Ertan 2010). Nowadays, swordfish are not encountered in the Sea of Marmara. Alıçlı (2010) emphasized marine pollution and overfishing responsible for extinction of swordfish from the Sea of Marmara.

### 2.7. Other types of traditional gears

In XVII century, some fisher's guilds specialized in other fishing techniques with stake nets; common nets (1000 fishermen); cast nets (300 fishermen); line for goby, picarel and horse mackerel (1000 fishermen); harpoons for bonito, sea bass, chub mackerel; baskets (300 fishermen); divers for sponges (300 fishermen) and dredge for oyster, mussel, sea urchin, and other bivalves fishery (800 fishermen) in the around Istanbul (Dağlı and Kahraman 2014). Although these fishing techniques were used until mid-XX century, their usage have not been seen due to decreasing and losing of fish stocks in the Sea of Marmara after 1950s. Furthermore, carpet shell fishing with dredge, started in 1986 in the Sea of Marmara (Deval and Oray 1992) was prohibited in 2000 due to decreasing stocks (Anonymus 2000).

## 3. Conclusion

Small-scale fisheries can have significant comparative advantages over industrial fisheries in terms of: greater economic efficiency, fewer negative impacts on the environment, the fact they are decentralized and geographically spread out and therefore have the ability to share economic and social benefits more widely, and their contribution to cultural heritage, including environmental knowledge (FAO 2005).

Cultural heritage of fishing, by Byzantium even older centuries, was come to these days by Turkish fishermen with changing fishing strategies, varying boat designs, new perspectives, and so forth. Since basic targeted species such as swordfish, bluefin tuna, and chub mackerel did not seen in the Sea of Marmara traditional fishing gears were adversely affected. While there were 70 edible fish species in 1840s (Grosvenor 1845) this number decreased many more today. The Sea of Marmara where divers gathered sponges became like poor sea by means of biodiversity.

Devedjian (1926) mentioned about 385 *voli* places in the Sea of Marmara and 80 in the Bosporus. Clearly, as a result of development in fishery technology as well as the destruction of *voli* and dalian places along the Sea of Marmara and the Bosporus, traditional fishing techniques disappeared gradually. When we take care that there were only 17 dalians in the Bosporus in 1960 (Aydınyazıcı 1960) it is first signal of losing favour of traditional fishery. A total of 3 $km^2$ coastal areas were filled up between years of 1963 and 2005 in the Marmara coasts of Istanbul (Döker 2006) caused to losing of traditional fishing areas. In establishing of coastal management plans, remarks of fishing sector should be took in consideration.

In the current fisheries regime, swordfish net, pots and *manyat* nets were not used no longer. Alamana nets, dalians and lift nets are still used for fishing in the Sea of Marmara. Although they were occasionally and culturally supported in modern times, traditional fishery was overshadowed of industrial fishing. Traditional fishing can make significant contributions to national economy as a central element in livelihood strategies. Involvement of small-scale fishers and fisher workers in policy, legislation and management processes is needed (FAO 2005). Moreover, a distinct fisheries management strategy should be implemented for traditional fishing.

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# CHECK LIST OF THE METAZOAN PARASITES OF FISHES FISHING IN THE SEA OF MARMARA

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## 1. Introduction

All living organisms, including fish, can have parasites. Parasites are a natural occurrence, not contamination. They are found in various parts of the fish body, including internal organs, gills and fins. As these parasites can cause damages and inflammations on gill, eye and internal organ etc., they provide portals of entry for other pathogens in fish.

There are about 10 000 parasite species known species to live in fishes. Fish parasites are divided into two major groups which are protozoan and metazoan containing helminthes, arthropods. While 18 percent of these parasite belong to protozoa, 82 percent of them to metazoa.

There are a lot of factor effecting the distrubion of parasites such as host selection, their life cycle, their infection rates, seasonal variations and their geographical location.

It has been investigated the morphology and antomy of parasites species, their life cycle, their infection rates, seasonal variations and their georgraphical location. Although there is a lot of studies about metazoan parasites in fish in the world, it is found very few working in the region of Marmara.

The aim of this paper is to give a list of metazoan parasites found in marine fish species in the sea of Marmara.

## 2. Material And Methods

This review was compiled using the articles shown in referenses.

## 3. Results

As the result of this compilation study, it has been indicated the occurrence a total of 59 fish parasite species belonging to the different order and families. The species of these parasites included 7 species of monogenea, 19 species of digenea, 6 species of cestoda, 3 species of nematoda, 5 species of acanthocephla, 2 species of hirudinea, 8 species of copepoda, 9 species of isopoda. Table 1 shows the isolated helmints and respective hosts, table 2 shows the isolated arthropods and respective hosts.

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**Table 1.** List of parasitic helminthes and their host species, location, and reference citations

| | Host | Location | Reference |
|---|---|---|---|
| **MONOGENEA** | | | |
| Family**: Anthocotylidae** | | | |
| *Anthocotyle merluccii* (van Beneden & Hesse,1863) | *Merluccius merluccius* | Sea of Marmara | Oğuz and Bray 2008 |
| Family**: Axinidae** | *Belone belone* | Sea of Marmara | Öktener 2005 |
| *Axine belones* Abilgaard,1794 | | | |
| Family **: Capsalidae** | | | |
| *Trochopus pini* (van Beneden & Hesse, 1863) | *Eutigla gurnardus* | Sea of Marmara | Oğuz and Bray 2008 |
| Family**: Dactylogyridae** | | | |
| *Ligophorus confusus* Euzet & Suriano 1977 | *Lisa ramada* | Sea of Marmara | Oğuz and Bray 2008 |
| Family**: Microcotylidae** | | | |
| *Solotamenides mugilis* (Vogt, 1878) | *Lisa ramada* | Sea of Marmara | Oğuz and Bray 2008 |
| | *Mugil cephalus* | Sea of Marmara | Sezen and Price 1967 |
| *Microcotyle pomatomi* Goto,1891 | *Pomatomus saltatrix* | Sea of Marmara | Sezen and Price 1967 |
| Family**: Tetraoncoididae** | | | |
| *Tetraonchoides paradoxus* Bychowsky, 1951 | *Uranoscopus scaber* | Sea of Marmara | Oğuz and Bray 2008 |
| **DİGENEA** | | | |
| Family **Acanthocolpidae** | | | |
| *Stephanostomum caducum* (Looss, 1901) Manter, 1934 | *Merluccius merluccius* | Sea of Marmara | Oğuz and Bray 2006 |
| *Stephanostomum gaidropsari* Bartoli & Bray, 2001 | *Gaidopsarus mediterraneus* | Sea of Marmara | Oğuz and Bray 2006 |
| Family **Bucephalidae** | *Gaidopsarus mediterraneus* | Sea of Marmara | Oğuz and Bray 2006 |
| *Bucephalus marinus* Vlasenko, 1931 | *Zesterisessor ophiocephalus* | Sea of Marmara | Oğuz 1995 |
| Family: **Crytogonimidae** | *Uranoscopus scaber* | Sea of Marmara | Oğuz and Bray 2006 |
| *Anisocladium capitellatum*(Rudolphi,1819) Lühe,1900 | | | |
| *Anisocladium fallax* (Rudolphi, 1819) Looss, 1902 | *Uranoscopus scaber* | Sea of Marmara | Oğuz 1995 |
| Family **Fellodistomidae** | | | |
| *Monascus filiformis* (Rudolphi, 1819) | *Trachurus trachurus* | Sea of Marmara | Oğuz and Bray 2006 |
| | *Trachurus trachurua* | Dardanelles | Keser *et al*. 2007 |

| | | | |
|---|---|---|---|
| | *Trachurus trachurus* | Sea of Marmara | Akmırza 2001 |
| Family: **Haploporidae** | | | |
| *Dicrogaster perpusilla Looss,1902* | *Lisa saliens* | Sea of Marmara | Oğuz and Bray 2006 |
| *Saccocoelium obesum* Looss, 1902 | *Lisa saliens* | Sea of Marmara | Oğuz and Bray 2006 |
| Family: **Haplosplanchnidae** | | | |
| *Schikhobalotrema sparisomae* (Manter, 1937) | *Lisa saliens*<br>*Lisa saliens* | Sea of Marmara<br>Dardanelles | Oğuz and Bray 2006<br>Keser *et al*. 2007 |
| **Family: Hemiuridae** | | | |
| *Ectenurus lepidus* Looss, 1907 | *Trachurus trachurus* | Dardanelles | Keser *et al.* 2007 |
| *Lecithocladium excisum* (Rudolphi, 1819) | *Scomber scombrus* | Dardanelles | Keser *et al*. 2007 |
| *Hemiuridae metacercaria* | *Solea solea* | Dardanelles | Keser *et al*. 2007 |
| **Family: Lepocreadiidae** | | | |
| Opechona bacillaris (Molin,1859) | *Pomatomus saltrix*<br>*Scomber scombrus* | Dardanelles<br>Dardanelles | Keser *et al*. 2007<br>Keser *et al*. 2007 |
| *Prodistomum polonii (Molin, 1859) Bray*&Gibson,1990 | *Trachurus trachurus*<br>*Trachurus trachurus* | Dardanelles<br>Sea of Marmara | Keser *et al*. 2007<br>Akandere 1972 |
| *Lepocreadium pyriforme* (Linton.1900) | *Trachurus trachurus* | Sea of Marmara | Akmırza 2001 |
| Family : **Opecoelidae** | | | |
| *Gaevskajatrema perezi* (Mathias,1926) | *Symphodus tinca* | Sea of Marmara | Oğuz and Bray 2006 |
| *Helicometra fasciata* (Rudolphi,1819*)* | *Gobius cobitis*<br>*Gaidopsarus mediterraneus*<br>*Scorpaena* scrofa<br>*Symphodus tinca*<br>*Zosterisessor ophiocephalus* | Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara | Oğuz and Bray 2006<br>Oğuz and Bray 2006<br>Oğuz and Bray 2006<br>Oğuz and Bray 2006<br>Oğuz and Bray 2006 |
| *Macvicaria alacris (Looss,1901)* | *Symphodus tinca* | Sea of Marmara | Oğuz and Bray 2006 |
| Family:**Zoogonidae** | | | |
| *Diphterostomum brusinae* (Stossich, 1888) Stossich, 1903 | *Zosterisessor ophiocephalus* | Sea of Marmara | Oğuz and Bray 2006 |
| *Lecithostaphylus retroflexus* (Molin,1859) | *Belone belone* | Dardanelles | Keser *et al*. 2007 |
| **CESTODA** | | | |
| Family: **Acrobothriidae** | | | |
| *Didymobothrium rudolphii* Nybelini1922 | *Solea solea* | Sea of Marmara | Oğuz and Bray 2008 |
| Family: **Bothriocephalidae** | | | |
| *Bothriocephalus scorpii* (Müller, 1776) | *Solea solea* | Dardanelles | Keser *et al*. 2007 |

| | | | |
|---|---|---|---|
| *Clestobothrium crassiceps* (Rudolphi, 1819) | *Merluccius merluccius* | Sea of Marmara | Oğuz and Bray 2008 |
| Family**: Grillotiidae**<br>*Grillotia sp* | .<br>*Solea solea* | Dardanelles | Keser *et al*. 2007 |
| Family: **Progrillotiidae**<br>*Progrillotia dasyatidis* Beveridge, Neifar & Euzet, 2004 | *Gobius niger* | Sea of Marmara | Oğuz and Bray 2008 |
| *Scolex pleuronectis Müller, 1778* | *Solea solea* | Dardanelles | Keser *et al*. 2007 |
| Tetraphylidean larvae | *Gobiues niger*<br>*Gobius cobitus*<br>*Merluccius merluccius*<br>*Eutrigla gurnardus*<br>*Solea solea*<br>*Scorpaena scrofa* | Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara Sea<br>of Marmara<br>Sea of Marmara | Oğuz and Bray 2008<br>Oğuz and Bray 2008<br>Oğuz and Bray 2008<br>Oğuz and Bray 2008<br>Oğuz and Bray 2008<br>Oğuz and Bray 2008 |
| **NEMATODA** | | | |
| Family: **Anisakidae** | | | |
| *Anisakis simplex* (Rudolphi1809) | *Scomber scombrus*<br>*Trachurus trachurus*<br>*Trachurus mediterranues*<br>*Engraulis encrasicolus* | Dardanelles<br>Dardanelles<br>Dardanelles<br>Sea of Marmara | Keser *et al*. 2007<br>Oğuz *et al*. 2000<br>Oğuz *et al*. 2000<br>Tuncel and Akmırza 2006 |
| *Hysterothylacium aduncum* (Rudolphi1819) | *Trachurus trachurus*<br>*Trachurus trachurus*<br>*Trachurus mediterraneus*<br>*Solea solea*<br>*Sparus auratus*<br>*Pomatomus saltatrix*<br>*Engraulis encrasicolus*<br>*Lisa saliens*<br>*Engraulis encrasicolus*<br>*Merluccius merluccius*<br>*Gobius niger* | Dardanelles<br>Sea of Marmara<br>Sea of Marmara<br>Dardanelles<br>Dardanelles<br>Dardanelles<br>Dardanelles<br>Dardanelles<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara | Keser *et al*. 2007<br>Oğuz 1995; Akmırza 2001<br>Öktener 2003<br>Keser *et al*. 2007<br>Keser *et al*. 2007<br>Keser *et al*. 2007<br>Keser *et al*. 2007<br>Keser *et al*. 2007<br>Tuncel and Akmırza 2006<br>Oğuz 1995<br>Oğuz 1995 |
| Family: **Cystidicolidae**<br>*Spinitectus oviflagellis*(Forment,1883) | *Gaidropsarus mediterraneus* | Sea of Marmara | Oğuz 1995 |
| **ACANTHOCEPHALA** | | | |
| Family: **Arhythmacanthidae** | | Sea of Marmara | Oğuz and Kvach 2006 |

| | | | |
|---|---|---|---|
| *Acanthocephaloides propinquus* (Dujardin, 1845) | *Uranoscopus scaber*<br>*Gobius niger*<br>*Gobius cobitis*<br>*Merluccius merluccius*<br>*Scorpaena scrofa*<br>*Eutrigla gurnardus*<br>*Solea vulgaris* | Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara<br>Sea of Marmara | Oğuz and Kvach 2006<br>Oğuz and Kvach 2006<br>Oğuz and Kvach 2006<br>Oğuz and Kvach 2006<br>Oğuz and Kvach 2006<br>Oğuz and Kvach 2006 |
| *Paracanthocephaloides kosttylewi* (Meyer,1932 | *Solea vulgaris* | Sea of Marmara | Oğuz and Kvach 2006<br>Kvach and Oğuz 2010 |
| Family **Echinorhynchidae**<br>*Solearhynchus soleae* (Porta, 1905) | *Solea vulgaris* | Sea of Marmara | Oğuz and Kvach 2006 |
| Family **Neoechinorhynchidae**<br>*Neoechinorynchus agilis* (Rudolphi, 1918 | *Liza saliens* | Dardanelles | Keser *et al*. 2007 |
| Family P**omphorhynchidae**<br>*Longicollum pagrosomi* (Yamaguti, 1935) | *Trachurus trachurus* | Sea of Marmara | Oğuz and Kvach 2006 |
| **HIRUDINEA** | | | |
| Family: Piscicolidae | | | |
| *Pontobdella muricata* Linnaeuas,1758 | *Torpedo marmorata*<br>*Raja clavata*<br>*Raja sp.* | Dardanelles<br>Dardenelles<br>Sea of Marmara | Sağlam *et al*. 2003<br>Sağlam *et al*. 2003<br>Ergüven and Candan 1992 |
| *Trachelobdella lubrica (Grube,1840)* | *Labrus bergylta*<br>*Scorpaena porcus*<br>*Scorpaena scrofa* | Bosphorus, Sea of Marmara<br>Dardanelles<br>Dardenelles | Öktener and Utevsky (2010*)*<br>Sağlam *et al*.2003<br>Sağlam *et al*.2003 |

**Table 2.** List of parasitic arthropods and their host species, location and referance citations

| | Host | Location | Reference |
|---|---|---|---|
| **COPEPODA** | | | |
| Family: **Caligidae** | | | |
| *Caligus sp.* | *Sardina pilchardus* | Sea of Marmara | Demirhindi 1961 |
| Family**: Lernaeidae** | | | |
| *Lernaea sp.* Linnaeus,1758 | *Trachurus trachurus* | Sea of Marmara | Akmırza 2001 |
| Family: **Lernaeopodidae** | | | |
| *Clavellisa scombri* Kurz,1877 | *Scomber scombri* | Sea of Marmara | Öktener and Trilles 2009 |
| *Clavellotis strumosa* ( Brain,1906) | *Pagellus erythrinus* | Sea of Marmara | Öktener *et al*. 2008 |
| *Neobrachiella impudica* Nordmann, 1832 | *Trigla lucerna* | Sea of Marmara | Öktene and Trilles 2004 |
| Family: **Lernanthropidae** | *Trachurus mediterraneus* | Bosphorus | Öktener and Trilles 2004 |
| *Lernanthropus trachuri* Brian, 1903 | | | |
| Family: **Poecilostomatoidae** | | | |
| *Chondracanthus lophii* Johnston, 1836 | *Lophius piscatorius* | Sea of Marmara | Öktener and Trilles 2004 |
| Family **Taeniacanthidae** | | | |
| *Anchistrotos laqueus* Leigh-Sharpe, 1935 | *Serranus hepatus* | Sea of Marmara | Öktener and Trilles 2009 |
| **ISOPODA** | | | |
| **Family: Cymothoidae** | *Spicara smaris* | Sea of Marmara | Demir 1952 |
| *Anilocra physodes* (L.1758) | *Belone belone*<br>*Trachurus trachurus*<br>*Sparus aurata* | Sea of Marmara<br>Dardanelles<br>Dardanelles | Öktener *et al*. 2009<br>Oğuz and Öktener 2007<br>Oğuz and Öktener 2007 |
| *Ceratothoa italica* Scheidte et Meinert,1883 | *Spicara maena* | Bosphorus | Öktener and Trilles 2004 |
| *Ceratothoa oestroides* (Risso,1826) | *Sardina pilchardus*<br>*Sardina pilchardus*<br>*Spicara maena* | Dardanelles<br>Sea of Marmara<br>Bosphorus | Oğuz and Öktener 2007<br>Öktener and Trilles 2004b<br>Öktener and Trilles 2004b |
| *Cerathothoa paralella* (Otto,1828 | *Boops boops* | Sea of Marmara | Öktener and Trilles 2004b |
| *Emetha audoini* (Milne Edwards,1840 | *Spicara maena* | Sea of Marmara | Öktener and Trilles 2004b |
| *Gnathia sp.* | *Scorpaena scrofa*<br>*Serranus cabrilla*<br>*Pagellus erythrinus* | | Alaş *et al*. 2009<br>Alaş *et al*. 2009<br>Alaş *et al*. 2009 |
| *Livoneca punctata* (Uljanin,1872 | *Alosa fallax* | Bosphorus | Öktener and Trilles 2004 |
| *Mothocya taurica* (Czerniavsky, 1868**)** | *Trisopterus minutus* | Sea of Marmara | Öktener *et al*. 2009 |
| *Nerocila bivittata* (Risso,1816) | *Pagellus sp.* | Sea of Marmara | Demir 1952 |

# SOME REMARKS ON ILLEGAL FISHING IN THE SEA OF MARMARA

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Illegal, unreported and unregulated fishing (IUU fishing) involves fishing without a license or quota for certain species, unreported catches or making false reports, keeping under minimum landing sized fish or fish which are protected by legislation, fishing in closed areas or during closed seasons and using prohibited fishing gears (Agnew *et al.* 2009).

IUU fishing depletes fish stocks, destroys marine habitats and weakens the economic and social status of the coastal communities (Öztürk 2013; Ulman *et al.* 2013; Baulch *et al.* 2014; Forrest *et al.* 2014). Illegal fishing can lead to overfishing and theatens marine ecosystems and sustainable fisheries. Therefore IUU fishing is an unfair competition for other fishermen who practice fishing legally and cause also unreported fishery data (Agnew *et al.* 2009; Öztürk 2013; Öztürk 2015).

It is accepted that there are problems with future global food security, driven by substantial world population growth. Demand of fish protein continues to increase, which has resulted in depletion of many fish stocks currently (FAO 2007). It is reported that there is loss of billions of dollars of annual economic benefits in the world due to IUU fishing (Pauly *et al.* 2002 and MRAG 2005). In the Mediterranean Basin, the General Fisheries Commision for the Mediterranean (GFCM) under the umbrella of Food and Agriculture Organization (FAO) has addressed issues of IUU fishing over the past decade, always in agreement with the FAO International Plan of Action to Prevent Deter and Eliminate IUU fishing (IPOA-IUU). In addition, the first workshop on IUU fishing for the Mediterranean was conducted by the GFCM with FAO (Swan 2004).

The Sea of Marmara which is an internal sea of Turkey has a coast of 240 km in length, the surface area of 11,500 km². It is 70 km in width and has 1390 m in maximum depth, with a wide continental shelf at about 100 m depth (Özsoy *et al.* 2000). The Sea of Marmara, a part of the Turkish Straits System, plays a crucial role for both the Black Sea and Mediterranean Sea due to its unique biological and oceanographic characteristics. Moreover, this sea is a spawning and breeding ground for some economical fishes and together with the Istanbul and Canakkale Straits constitute a biological corridor for the Mediterranean and Black Sea species (Öztürk and Öztürk 1996). The Sea of Marmara is an important fisheries area in Turkey. The fisheries product in Turkey is about 672,000 tons in 2015 and Sea of Marmara composes 31,765 kg (9%) of the fisheries. According to Tuik (2015) there are 131 trawl vessels, 117 purse seines and 2,225 small size fishing vessels registered in the Sea of Marmara.

General Directorate of Protection and Control of Fisheries, the Coast Guard and the Marine Police Departments are responsible institutions against IUU fishing in the Sea of Marmara. Despite these institutions and several control and surveillance measures, IUU fishing activities are prevailing and several fishing violations have been detected during 2012-2016. Table 1 summarizes the number of fishermen fined for IUU fishing, the amount of confiscated products, the number of confiscated vessels and gears according to three authorities Ministry of Food, Agriculture and livestock (Istanbul), The Sea of Marmara Coast Guard Command and Istanbul Marine Police Department.

**Table 1.** The Summary of the Illegal Fishing in the Sea of Marmara in 2012-2015. (www.tarim.gov.tr) ₺: Turkish Lira (TL)

| | **2012** | **2013** | **2014** | **2015** | **Total** |
|---|---|---|---|---|---|
| **Source** | **The Sea of Marmara Coast Guard Command** | | | | |
| Number of illegal fishermen | 3.837 | 3.765 | 3.441 | 2.633 | 13.676 |
| Amount of administrative penalty applied (₺) | 8.808.698 | 6.400.533 | 5.554.173 | 4.603.630 | 25.367.034 |
| Amount of C confiscated sea product (kg) | 26.448 | 55.951 | 42.285 | 14.135 | 138.819 |
| Number of confiscated fishing vessels and gears | 224 | 141 | 195 | 86 | 646 |
| **Source** | **Ministry of Food, Agriculture and Livestock (Istanbul)** | | | | |
| Number of illegal fishermen | 973 | 1.004 | 185 | 129 | 2.291 |
| Amount of administrative penalty applied (₺) | 175.931 | 243.204 | 255.700 | 307.016 | 981.851 |
| Amount of C confiscated sea product (kg) | 32.171 | 23.643 | 55.162 | 23.878 | 134.854 |
| Number of confiscated fishing vessels and gears | 239 | 156 | 185 | 130 | 710 |
| **Source** | **Istanbul Marine Police Department** | | | | |
| Number of illegal fishermen | 42 | 62 | 19 | 107 | 230 |
| Amount of administrative penalty applied (₺) | 58.494 | 132.184 | 21.131 | 138.807 | 350.616 |
| Amount of C confiscated sea product (kg) | 3.129 | 4.695 | 2.896 | 2.996 | 13.716 |
| Number of confiscated fishing vessels and gears | 32 | 103 | 5 | 5 | 145 |

## Conclusion

The Ministry of Food, Agriculture and Livestock (MoFAL) is the national competent authority to develop and implement policies on fisheries and aquaculture, to ensure the conservation and the sustainable exploitation of fisheries resources and limitation of fishing effort and fisheries research. Besides, Automatic Identification System (AIS) is compulsory for vessels longer than 15 m. There is also a monitoring centre for AIS.

Turkey also has started to establish satellite based Fishing Vessels Monitoring System integrated with electronic logbook, covering all vessels of 12 m and over in length. Nevertheless, it is clearly shown that there is lack of efficient controlling system for illegal fishing in the Sea of Marmara.

In the Sea of Marmara several benthic fish species are effected by IUU fishing mainly red mullet (*Mullus barbatus*), European hake (*Merluccius merluccius*), whiting (*Merlangius merlangus*) and turbot (*Scophthalmus maximus*) which are the species have high commercial value and high demand in market. In addition, anchovy (E*ngraulis encrasicolus*), horse mackerel (*Trachurus trachurus*), bonito (*Sarda sarda*) and bluefish (*Pomatomus saltatrix*) species are main pelagic species which are caught as illegally. Concerning benthic species deep sea rose shrimp (*Parapenaeus longirostris*) is the main illegally caught invertebrate species. This species is already overfished in the Sea of Marmara (Öztürk 2009).

All types of trawl fishery have been banned in the Sea of Marmara and Straits according to the Fisheries Law No. 1380 issued in 1971. However, illegal trawl fishery has been carried out because of the big fishery potential and high market demand for demersal species in the Sea of Marmara. Besides, Karakulak *et al.* (2000) reported that illegal trawling is one of the threats for the undersized fish in the Sea of Marmara. Alkan (2000) reported that, the illegal trawl fishery has begun in the Sea of Marmara in recent years by lack of fishery control systems. Illegal fishery in the Sea of Marmara is comprised of trawl fishery, purse seine fishery using light and landing of fish smaller than minimum size for the species.

Solving the illegal fishing problem by successful management of fishery depends on the multipoint protecting and controlling system. National fleet management plans and Monitoring, Control and Surveillance (MCS) System should be applied in the Sea of Marmara. In addition, a detailed monitoring scheme is needed from the fishing net to the fish at the market mainly around Istanbul. All fisheries associations and cooperatives should take an effective role in fishery and zero tolerance must be given against IUU fishing in the Sea of Marmara. An effective program should be devolped to halt IUU fishing that involves relevant academic institutions and research centers. The conservation and control systems must be supported in terms of personnel, equipment and financial resources and also the punishment must be effective for the illegal fishery. The law that numbered 1380 has to be reformed to be persuading, punishments must be enhanced, illegal fishing vessels must be withdrawn and the markets which sell fish under minimum landing size or prohibited species must have banned.

Altough unreported and unregulated fishing is not examined in this review, several cases have been detected in the Sea of Marmara mostly for shrimp fisheries and high number of purse seining. Finally, zero tolerance should be targeted to mitigate and stop IUU fishing practices in the Sea of Marmara. Besides, more detailed studies and dedicated database are needed to monitor trends, options and new policies should be presented to both decision makers and other stakeholders.

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# EUTROPHICATION IN THE SEA OF MARMARA

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## 1. Introduction

The entry of wastes into marine environment not only changes water quality parameters but also increases the risk of eutrophication, leading to dramatic changes in+ food chain, including planktonic, pelajik and demersal habitats, benthic organisms and, thereby, causes the area to become susceptible. The Urban Wastewater Treatment Directive (UWTD; EC 1991), therefore, defines the term of "eutrophication" as the "enrichment of water by nutrients, especially compounds of nitrogen and/or phosphorus, causing an accelerated growth of algae and higher forms of plant life to produce an undesirable disturbance to the balance of organisms present in the water and to the quality of the water concerned".

Eutrophication is the most extensively studied marine pollution problem observed especially in enclosed seas, bays fed by organic matter and nutrient-polluted rivers and direct wastewater discharges (Karydis 2009). Nutrient enrichment is followed by alterations in the phytoplankton community structure, growth of excessive algal biomass and possible toxic algal blooms; if the accumulated organic matter exceeds system's carrying capacity, the hypoxia can lead to a decline in fisheries and shellfisheries yields, poor water quality and ecosystems deterioration (Karydis 2009).

The Sea of Marmara an enclosed sea connecting the Black Sea the Mediterranean via the two shallow and narrow straits, has a severely deteriorated marine habitat, due to large nutrient inputs from the Black Sea and direct waste water discharges mainly from the city of Istanbul in recent decades (Tuğrul and Polat 1995). Massive localized eutrophication in the NW Black Sea expectedly collapsed Black Sea ecosystem and fisheries, and has led to appear similar changes in the Sea of Marmara since 1980's (Mee 1992; Polat and Tuğrul 1995).

Accoring to the first estimates of annual nutrient loads entering the Marmara Sea in 1990's (Polat and Tuğrul 1995), the Black Sea inputs dominate the Marmara Ecosystem; however, large increases in population of major cities of Marmara region drastically chemical inputs to the Marmara, reaching the levels of Black influxes (MEMPIS 2007).

Since the Marmara basin is occupied by the two-layer water masses, the permanent halocline formed between 15-30m markedly limits vertical mixing and thus, ventilation of salty deep waters of Mediterranean origins. Development of eutrophic conditions over the Marmara basin has increased POM export to the lower layer, resulting in the formation of suboxic conditions, subsurface oxygen minimum just below the halocline, and other processes of eutrophication have appeared in the Marmara ecosystem (Tuğrul and Polat 1995).

There have been a number of studies focused on the levels of nutrients and physicochemical variables of the water column in the Sea of Marmara (Tuğrul *et al.* 1995; Polat and Tuğrul 1995; Polat *et al.* 1998; Balkıs 2007; Tuğrul *et al.* 2015; Balcı *et al.* 2014). Very few published data are available on eutrophication in the Marmara Sea (Tuğrul and Morkoç 1990; Morkoç *et al.* 1997; Balkıs *et al.* 2012; Tuğrul *et al.* 2015).

A national monitoring programme has only been performed since 2009 in the Marmara Sea with the support of Ministry of Environment. Institute of Marine Sciences and Management of İstanbul University, Institute of Marine Sciences of METU and Marmara Research Center of TÜBİTAK have been carried out oceanographic and monitoring cruises in the Marmara Sea since 1986 to collect data for different projects supported by TUBITAK, EU, ministries and the municipalities. The data collected during these cruises have been the basis to understand the oceanography and as well as the eutophication status of the Marmara Sea.

## 2. General Aspects of the Sea of Marmara

The Sea of Marmara an intercontinental basin with shallow and narrow straits connects the Black and Mediterranean Seas and together with its two straits İstanbul (Bosphorus) and Çanakkale (Dardanelles) constitutes an oceanographic system called the "Turkish Strait System" (TSS) which provides the exchanges of salty and less saline waters between the Aegean and the Black Seas. The Marmara basin itself is a transitory site between these two adjacent basins and the straits determine the two-layer flow regime in the TSS due to great density differences between the Black Sea and the Mediterranean.

There is a permanent two-layer flow in the straits and the Marmara Sea with the halocline formed between the depths of 15-30 m, displaying seasonal and regional variations (Ünlüata *et al.* 1990; Besiktepe *et al.* 1994). The chemical oceanography of the Marmara upper layer is dominated by the Bosphorus inflow carrying the brakish surface waters of Black Sea with the associated biochemical properties (Polat and Tuğrul 1995).

Concentrations of nutrient species in the surface layer of the Marmara Sea are determined primarily by the chemical properties of the inflowing Black Sea waters and by the chemically modified salty waters of Mediterranean origin entrained into the upper layer during the winter mixing and from the counter flow regime in the Bosphorus region (Polat and Tuğrul 1995).

The Sea of Marmara region is densely populated and industrialized with more than Turkey's 20% population and 50% industry located in its drainage basin. The municipal and industrial inputs from its drainage basin, together with nutrients, organic inputs from the Black Sea, have polluted the Marmara Sea since the 1970's (Orhon *et al.* 1994; Polat and Tuğrul, 1995).

Before the 1980's, anthropogenic inputs had secondary importance for the open waters (Tuğrul and Polat 1995) but have a critical influence on primary production in coastal regions and semi-enclosed bays where water exchange with the open sea is relatively weak (Tuğrul and Morkoç 1990). The influences of anthropogenic input have increased markedly in the last two decades (Orhon *et al.* 1994), reaching the levels comparable with the Black Sea influxes (MEMPIS 2007).

The metropolitan area of İstanbul with a population of about 13.5 million is the most important pollution source for the Marmara Sea, with other important sources located in the İzmit, Gemlik and Bandırma Bays and Tekirdağ area, and from small rivers such as the Susurluk carrying important agricultural loads. Large fractions of partly treated wastewaters are discharged into the lower layer of Marmara (Tuğrul *et al.* 2015).

Changes in environmental and hydrographic conditions determines the intensity of phytoplankton production in the Marmara Sea. Nutrient inflow from land based sources and entrainment contribute to the increase of nutrient concentrations in surface layer and thus winter blooms occur in the Marmara Sea. During summer, the phytoplankton production fluctuates more or less randomly, depending on supply of nutrients from internal and external sources and grazing pressure.

Algal production is confined to the first 20m (the euphotic zone thickness) in the upper layer of the Marmara Sea throughout the year. Maximum chlorophyll-a values were generally observed in surface layer. However, a sub-surface chlorophyll-a maximum is formed at the upper halocline boundary, varying locally between 10-20m and coinciding perfectly with the nutricline over the basin. The annual algal production in the Sea of Marmara estimated from chlorophyll-a data is nearly 100 $gC/m^2/y$ (Ergin *et al.* 1993). In October 1991 and March 1992, the primary production was estimated by the $^{14}C$ technique as 45 and 95 gC/m$^2$/y at the central Marmara Sea. The annual primary production measured at a location close to the İzmit Bay by $^{14}C$ technique was about 170 gC/m$^2$/y (Tuğrul *et al.* 1989).

Dissolved oxygen (DO) concentrations are at saturated levels in the thin upper layer waters of Black Sea origin and then decrease steeply in the permanent pycnocline which coincides with the nutricline because algal production is confined to the upper layer for most of the year (Figures 1 and 2). DO concentrations, as high as 10-12 mg/L during cold season in surface layer, diminish drastically to suboxic levels of 1-2 mg/L in the lower layer waters over deep basins (Figure 1). The steep halocline separating the upper and lower layer highly limits ventilation of the deep waters. The major source of DO for the deep basin is the inflow of oxygen rich Mediterranean waters via the Dardanelles undercurrents. Therefore, DO deficiency in the Marmara lower layer waters increases from the Dardanelles-Marmara exit to the eastern basin. In the last decades, DO has decreased further in the deep Çınarcık basin due to insufficient ventilation of deep waters and increased organic matter inputs from the surface layer (Figure 1). The lowest DO values have been recorded in the enclosed bay of İzmit polluted by land-based inputs (Ediger *et al.* 2016). The renewal time of the brakish upper layer is about 4-5 months surface waters whilst the average residence time of the deep basin waters is estimated to be 6-7 years (Ünlüata *et al.* 1990; Beşiktepe *et al.* 1994).

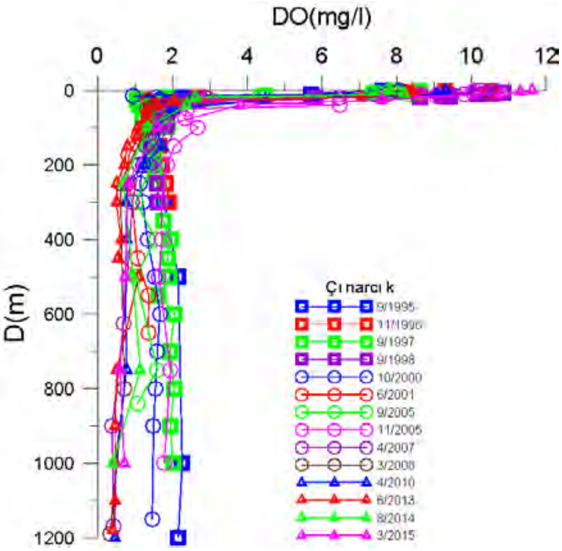


**Figure 1.** Vertical distribution of DO in Çınarcık Basin.

The Marmara upper layer is constantly supplied with nutrient inputs from the Black Sea, the bottom layer waters by mixing especially at the Bosphorus-Marmara Junction, direct wastewater discharges and fresh waters inflows from the its drainage basin. However, most of these nutrients are used in photosynthesis. Therefore, the upper layer concentrations of nitrate and phosphate are generally low during the year (Figure 2). Seasonally, the upper layer concentrations increase in winter due to enhanced inputs and lower uptake rate in photosynthesis. The lowest values of inorganic nutrient are reached during the summer-autumn period. Therefore, nutrients export from the Marmara to Aegean Sea occurs in the form of organic compounds.

The nutricline is located at depths of 15-25m, coinciding with the permanent halocline (Figure 2). Thus the concentrations of nitrate and phosphate increase steeply with depth in the interface, displaying a broad subsurface maximum below the halocline. In this zone, expectedly, the DO profiles exhibit a subsurface minimum.

The Mediterranean salty waters entering the Marmara deep basin originally have very low nutrients but almost saturated levels of DO concentrations (Polat and Tuğrul 1995). These salty waters are highly enriched (about 10-fold) in nutrients while losing the dissolved oxygen during their residency for almost seven years in the Marmara deep basin (Ünlüata *et al.* 1990; Beşiktepe *et al.* 1994; Tuğrul *et al.* 2002).

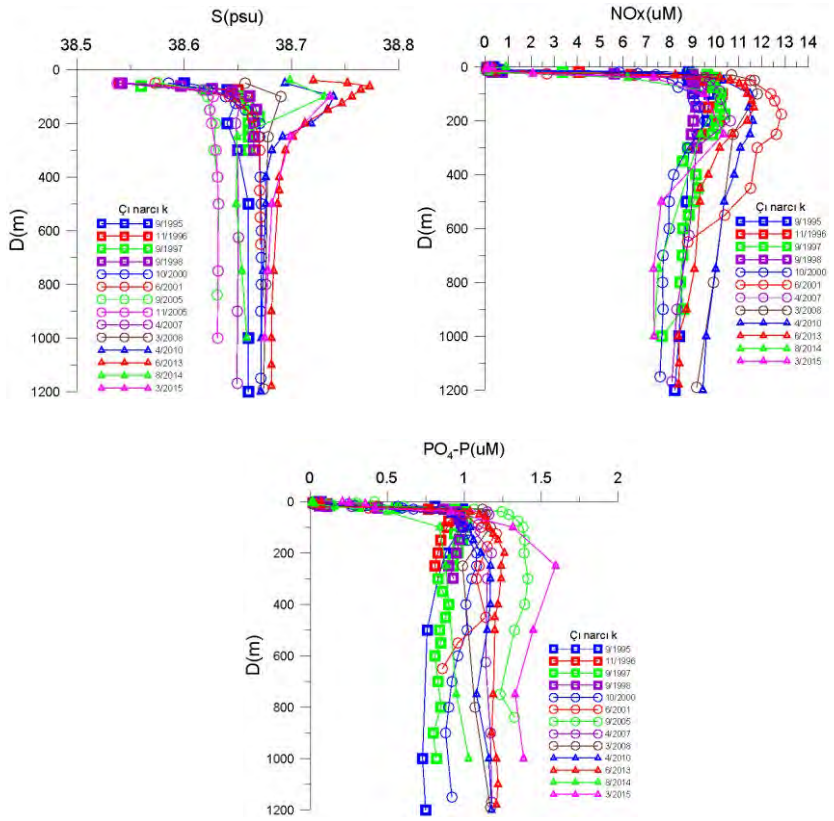


**Figure 2.** Vertical distribution of salinity and nutrients in Çınarcık Basin.

The Black Sea inflow via the Bosphorus surface flow increases during spring-early summer period when the river inflows to the Black Sea reaches the maximum levels and decreases markedly in late summer-autumn period (Özsoy *et al.* 1998). Therefore, chemical transport via the Bopshorus surface flow display similar a seasonal trend (Polat and Tuğrul 1995; Altıok *et al.* 2014).

The concentrations of inorganic nitrate and phosphate and their seasonal/annual fluxes through the Bosphorus and Dardanelles Straits were calculated by Polat and Tuğrul 1995 (Table 1). The winter and spring fluxes by the Bosphorus surface flow are much greater than summer and autumn fluxes, accounting for about 80% of the annual nutrient fluxes. Nutrients export from the Marmara to the Black Sea via the Bosphorus undercurrent are less variable, but have maximum values in spring and summer when the volume flux increases. It can also be noted that the lower layer nutrient fluxes are 3-6 times greater than the mass fluxes via the upper layer flow (Table 1). The nutrients influx to Black Sea from the Marmara lower layer occur mainly in dissolved inorganic form whilst the majority of nutrient from Black Sea are transported in dissolved organic form (Polat 1995, Polat and Tuğrul 1995).

In the Bosphorus Strait, the upper layer nitrate and phosphate concentrations (N/P ratio: 14-26) and fluxes are much higher in winter. The lowest mass flux occur in autumn. Though the lower layer fluxes display seasonality, the N/P ratio of the Bosphorus deep waters is almost constant (9-10.5) throughout the year (Tuğrul *et al.* 2015).

The salty Mediterranean water enters the Marmara deep basin via the Dardanelles undercurrent, with very low nitrate and phosphate but nearly saturated levels of oxygen concentrations (Table 1). These salty waters are enriched by about 10-fold (nitrate: 8-12 μM; phosphate: 0.7-1.2 μM) during about 6-7 year stay in the basin. The nutrient out fluxes from the Marmara via the Dardanelles surface layer flow also display seasonal variations, increasing in winter is observed in the Bosphorus surface fluxes (Table 1).

The Secchi Disk Depth (SDD) measured between 1986-1994 in the Marmara Sea regionally and seasonally ranged from 8 to 14m (Ediger and Yılmaz, 1996) and then the period 2009 to 2014 ranged from 4-10m. The lowest SDD values were expectedly measured in the highly polluted and eutrophic coastal waters and semi-enclosed bays, especially in the İzmit Bay. It appears that the photosynthesis has been limited to thin upper layer over the basin, reaching the upper halocline and thus nutricline depths when the surface waters being depleted nutrients during summer-autumn period (Sur *et al.* 2009, 2010; Tutak *et al.* 2012; Ediger *et al.* 2013; Polat-Beken *et al.* 2015).

The Chl-a parameter is used as indicator of eutrophy or water quality in many studies (Harding 1994 in Harding and Perry 1997; Boyer *et al.* 2009) and its concentration represents a simple, integrative measure of phytoplankton community responding to nutrient enrichment in aquatic environments (Devlin *et al.* 2007). Throughout the oceanographic studies in the Sea of Marmara (1986-2014) concentration of Chlorophyll-a values were recorded to vary between 0,2-18 µg/L (Göçmen 1988; Baştürk *et al.* 1990; Polat *et al.* 1998; Sur *et al.* 2009, 2010; Balkıs *et al.* 2012; Polat-Beken *et al.* 2015), displaying apparent spatial increasing trend from the Dardanelles to the enclosed bay of İzmit polluted by land-based inputs.

**Table 1.** Seasonal and annual fluxes of nitrate and phosphate exchanged between the adjacent seas through the Bosphorus and Dardanelles Straits for the period of

| | | BOSPHORUS | | | | | DARDANELLES | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Flow type | Season | Vol. flux ($*10^9$ $m^3$) | NO3 conc. (mmol/$m^3$) | NO3 flux ($*10^8$mol) | PO4 conc. (mmol/$m^3$) | PO4 flux ($*10^7$ mol) | Vol. flux ($*10^9$ $m^3$) | NO3 conc. (mmol/$m^3$) | NO3 flux ($*10^8$ mol) | PO4 conc. (mmol/$m^3$) | PO4 flux ($*10^7$ mol) |
| Upp | Spring | 200 | 1,32 | 2,64 | 0,05 | 1 | 307 | 0,2 | 0,61 | 0,06 | 1,84 |
| Upp | Summer | 158 | 0,42 | 0,66 | 0,03 | 0,47 | 194 | 0,12 | 0,23 | 0,03 | 0,58 |
| Upp | Autumn | 105 | 0,22 | 0,23 | 0,05 | 0,52 | 142 | 0,3 | 0,42 | 0,05 | 0,71 |
| Upp | Winter | 145 | 3,2 | 4,64 | 0,14 | 2,03 | 234 | 0,36 | 0,84 | 0,09 | 2,1 |
| **Upp** | **Annual** | **608** | **1,29** | **8,17** | **0,07** | **4,02** | **877** | **0,24** | **2,1** | **0,06** | **5,23** |
| Low | Spring | 94 | 9,17 | 8,62 | 0,92 | 8,65 | 202 | 1,14 | 2,3 | 0,05 | 1,01 |
| Low | Summer | 76 | 10,46 | 7,95 | 0,99 | 7,52 | 112 | 0,47 | 0,53 | 0,03 | 0,34 |
| Low | Autumn | 49 | 9,34 | 4,58 | 0,91 | 4,46 | 87 | 0,88 | 0,76 | 0,05 | 0,44 |
| Low | Winter | 68 | 9,81 | 6,67 | 1,07 | 7,28 | 158 | 1,62 | 2,56 | 0,05 | 0,79 |
| **Low** | **Annual** | **287** | **9,7** | **27,8** | **0,97** | **27,91** | **559** | **1,09** | **6,15** | **0,05** | **2,58** |

1990-2000 (after Tuğrul *et al.* 2015). Upp: upper Low: lower

## 3. Eutrophication Status of the Sea of Marmara

Different tools/measures have been developed to classify eutrophication status of water masses impacted by human pressures, based on principal direct and indirect indicators of eutrophication classification (Vollenweider *et al.* 1998, HELCOM, 2009, MEDGIG, 2011, Andersen *et al.* 2010). TRIX index, developed by Vollenweider et al. (1998) for the western Mediterranean waters, have been widely used the other seas (EEA, 2001, UNEP, 2003, Moncheva *et al.* 2002, Alves *et al.* 2013). TRIX method is based on chlorophyll-a, oxygen saturation, total dissolved inorganic nitrogen and total phosphorus to characterize the trophic state of coastal marine waters. The index values vary from 0 to 10, ranging from oligotrophic to eutrophic conditions. TRIX values exceeding 6 indicate strong eutrophication due to human impact and <4 indicate low anthropogenic impact (Cloern, 2001). Giovanardi and Vollenweider (2004) indicates that only values higher than 6 units indicate strong eutrophication. The TRIX eutrophication index is an important tool that has been used in the management of coastal regions, in the analysis of the trophic state in the environment and water quality.

TRIX index estimates for the Marmara Sea ranged between from 2.09 in the open sea to 7 in the eutrophic coastal waters and bays (Tutak *et al.* 2012; Ediger *et al.* 2013; Polat-Beken *et al.* 2014, 2015) (Table 2 and Figure 3). Spatial distribution of TRIX values increases from Dardanelles to the enclosed bays and close to river and land based inputs (Figure 3). Detailed examination of the TRIX index values for the Marmara Sea indicate that generally a moderate to bad trophic conditions due to anthropogenic+ natural inputs appear in during wet winter period, and then these impact decreased in late summer, resulting in good trophic status in the open sea whereas bad trophic status lasts in the enclosed bays due to human impact (Table 2 and Figure 3).

**Table 2.** TRIX index values in the Sea of Marmara

| Site | Time | TRIX | Ref |
|---|---|---|---|
| Marmara Sea | Summer 2011 | 2.8-6.54 | Tutak *et al.* 2012 |
| Marmara Sea | Autumn 2011 | 4.0-6.0 | Tutak *et al.* 2012 |
| Marmara Sea | Summer 2013 | 2.09-5.43 | Ekozone 2013 |
| Marmara Sea | Autumn 2013 | 2.82-5.3 | Ekozone 2013 |
| Marmara Sea | Summer 2014 | 3.85-6.21 | Polat-Beken *et al,* 2014 |
| Marmara Sea | Winter 2015 | 5.19-7.45 | Polat-Beken *et al.* 2015 |
| İzmit Bay | 2008-2013 | 3.0-6.8 | Ediger *et al.* 2013 |

Within the scope of the DEKOS (Marine and Coastal Waters Quality Status Determination and Classification) project, boundary values of the eutrophication indicator parameters were estimated in the surface layer of the Marmara Sea and given in Table 3 (Polat-Beken *et al.* 2014, 2015).

According to the Method of MEDGIG 2011, boundary values determined for the Marmara Sea indicate the transition of good/moderate quality status for each eutrophication indicator.

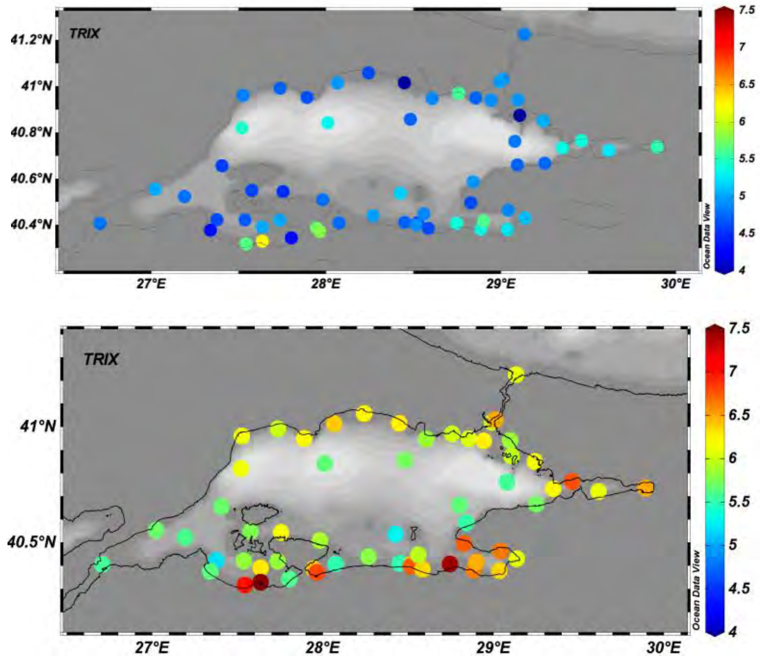


**Figure 3.** Spatial distribution of TRIX index in the Sea of Marmara a) Summer 2014 b) Winter 2015 (Polat-Beken *et al.* 2015, 2016)

**Table 3.** Recommendations of Boundary Values for the Surface Waters of the Central and Eastern Marmara Sea Regions (Polat-Beken *et al.* 2014)

| PARAMETER | PROPOSED BOUNDARY VALUES |
|---|---|
| Phosphate ($PO_4$) | *<0.15 µM* |
| Total Phosphorus (TP) | |
| Nitrate ($NO_3$) | *< 0.5 µM* |
| Nitrite ($NO_2$) | *< 0,2 µM* |
| Ammonium ($NH_4$) | *< 0.4 µM* |
| Silicate (Si) | *> 1.0 µM* |
| Si/($NO_3$) | *>3* |
| ($NO_3$)/$PO_4$ | *> 2* |
| Chlorophyll-a | *< 1.5 µg/* |
| Secchi Disc Depth | *> 4.0 meters* |
| Oxygen Saturation % | *% > 20 (waters close to the seafloor; depth >30 m)* |

## 4. Conclusion

The two-layer ecosystem of Marmara Sea has been drastically modified by the increasing chemical input from Black Sea, domestic and industrial discharges from the Marmara region. Until the 1990's the Black Sea input was the major source of organic+inorganic nutrients reaching the Marmara upper layer (Polat and Tuğrul 1995, 1998). Secondary input was partly treated waste waters of the Istanbul Metropolitan city (Polat and Tuğrul 1995; Okuş *et al.* 2008). The Black Sea inputs supply the majority of the nutrients and organic matter loads reaching the Marmara. However, the contribution of land-based has increased during the last two decades with highly increased coastal or basin population, new infrastructures and constructions (new bridges, airports, industrial areas etc.) and besides yet not completed advanced treatment systems for municipal and industrial wastes.

Istanbul is one of the most populated metropolises in the region with a population of over 13.5 million people (TUIK 2014). Today, more than 75% of domestic and industrial primary or secondary treated effluents are disposed directly into the Bosphorus lower layer and the strait-Marmara Sea junction via sewage outfalls with a daily capacity of 1,671,060 $m^3$ $day^{-1}$ (Okuş *et al.* 2008).

In conclusion, development of eutrophication conditions in the Marmara Sea has not only altered the upper layer ecosystem but also the chemical properties of the sub halocline waters of Mediterranean origin. The Dardanelles under-current introduces the Aegean salty waters with almost saturated levels of dissolved oxygen but low values of nitrate and phosphate concentrations into the Marmara basin (Polat and Tuğrul 1995; 1998; Tuğrul *et al.* 2015). The enhanced eutrophication reduced the lighted zone in the upper layer and algal production has been limited to the upper layer and more POM exported into the halocline and sub halocline waters. Thus, the depths of nutricline and oxycline have shifted upward in the last 3 decades. These changes also highly influenced pelagic and demersal ecosystem over the basin. Enhanced nutrient inputs with the appropriate meteorological conditions has led to occur red-tides, mucilage formation and increased jelly organism blooms in the recent years. Anoxic conditions were also seen in the lower layer of polluted bay of İzmit (Balkıs 2012).

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**OIL AND DETERGENT POLLUTION IN THE SEA OF MARMARA**

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## 1. Introduction

Various reports and a few books were published on the pollution parameters of the Sea of Marmara (Baykut *et al.* 1984; Doğan and Eryılmaz 1991; Johnston *et al.* 2000; Öztürk *et al.* 2000; Annonymus). In this article the pollutants especially oil and detergents which are inconvenient for marine life and therefore a risk for human health since the presence of these pollutants were detected in fish tissues were discussed.

The oil can enter into the marine environment in different ways. The biggest input of oil into the sea is from oil tanker traffic and land sources. Detergents are used as cleaning agents in domestic and industrial areas.

In this article important pollutants divided into two headings: Oil and detergent pollution.

## 2. Oil Pollution

The term "oil" was used instead of petroleum for pollution literature even though it is confused with natural oils. Petroleum was used 4000 years ago by Babylonians and Persians. The composition of oil depends on its origin. When the aliphatic content forms approximately 15-60 %, aromatics vary between 3-30 % and asphaltics 6 %. Gasoline oil (petrol) mainly contains alkanes (pentane, octane, nonane, hexadecane), hexadecane upwards fuel, lubricating oil, asphalt (carbon numbers >35). Fractional distillation products are gasoline, diesel fuel and kerosene (Baars 2002).

Some aliphatic hydrocarbons in oil are also biogenic (autogenous) but important proportion of oil is aromatic coming from petroleum (exogenic, anthropogenous). Especially polycyclic aromatic compounds (PAH) are very toxic compounds, accumulates in marine organisms (in sea food) which are consumed by humans. The limit of oil concentration of 2.5 µg $L^{-1}$ in seawater can be classified as unpolluted (Marchand *et al.* 1982).

**The first marine research in Turkey was initiated by ISKI (Istanbul water and sewage Administration). The work was developed by first ODTU and then Istanbul University, Institute Marine Science and Management.*

Oil contains many types of compounds such as aliphatic (saturated, unsaturated), aromatic groups with one benzene ring (BTEX: benzene, toluene, ethylbenzene and xylene) have toxic effect on organisms. Polyaromatic hydrocarbons (PAH) consist of at least two benzene rings. The acute toxicity of petroleum to marine organisms is depended on the concentration and continuity of pollution. These products changed by various metabolic processes in marine organisms (Tomruk and Güven 2012). Marine birds and animals may be especially vulnerable to oil pollution. PAHs are responsible for many different biological activities for example most of them are carcinogenic (Pohjola *et al.* 2004).

Incomplete combustion of oil produces also very toxic oxygenated nitro aromatic compounds such as nitrostyrene, nitropyrene and nitrophthalic acids (Cumalı and Güven 2007; Güven *et al.* 2016a). The most polluted area in this respect is İzmit Bay. Aliphatic and cyclic hydrocarbons, aromatic benzene, biphenyl, naphthalene, phenanthrene, indene and cholestan derivatives were found according to the paper on İzmit Bay published by Green Peace (Johnston *et al.* 2000).

The origin of oil pollution in the Sea of Marmara is from a various sources such as the Russian tanker traffic through the straits, as well as the discharge of wide range of industry and refinery, İzmit, Golden Horn, Istanbul as urban waste (Güven *et al.* 1998b). The Black Sea water in the Istanbul Strait (as the surface water) was surveyed monthly by ISKI (Istanbul Water and Sewage Management) since 1991, and after 1996 by the Marine Science Institute to monitor the effect of Russian tanker traffic and only the findings of the southern exit of Istanbul Straits near Uskudar (B2) and near Galata Bridge Golden Horn (GK) were summarized here in the Table 1 between the years 1997-2007. The oil pollution measurements made in several depths of the stations are shown in figures 1-2. Tables 1-2 are listed only the most polluted stations (Güven *et al.* 1996, 1997a, 1998b, 2000, 2002, 2003abc, 2004,2005; 2008a; Okuş *et al.* 1996, 2007; Ünlü *et al.* 2000 Cumalı and Güven 2008).

**Table 1.** The oil pollution of the southern exit of Istanbul Strait near Uskudar (B2) and near Galata Bridge (GK) Golden Horn.

| Years | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B2 (s) | 66.8 | 45.3 | 20.7 | 11.0 | 16.0 | 20.8 | 205.4 | 1293.0 | | 75.099 | 68.0 |
| GK (s) | 200.0 | | | 28.0 | 80.8 | 52.0 | 122.8 | - | 4214.3 | 161.0 | 59.7 |
| GK (d) | - | | | 16.3 | 4.8 | 166.4 | 136.6 | - | - | 81.8 | 71.8 |

s: surface water; d: deep water

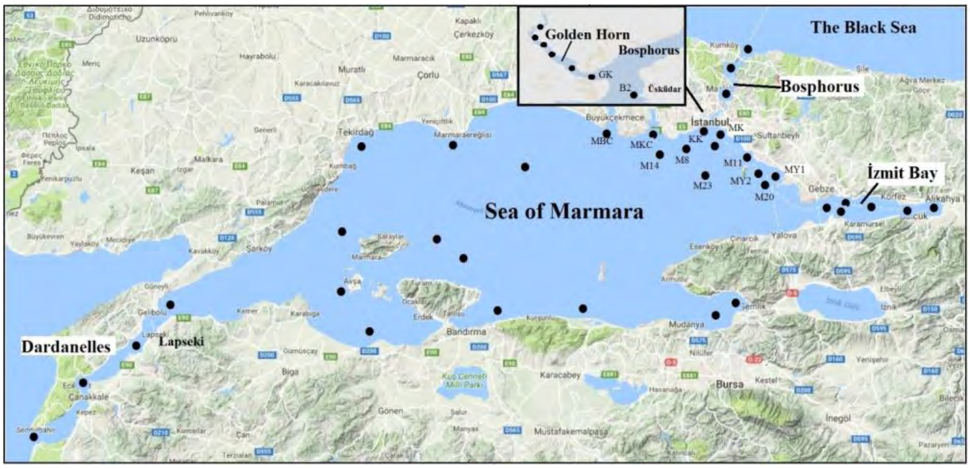


**Figure 1.** The sampling stations of the Sea of Marmara and Çanakkale Strait.

The black points indicate the locations of the stations measurements made on the samples taken from several depths. Only the stations which are mentioned in the text are labeled on the map.

**Table 2.** The maximum amounts of oil pollution in the Sea of Marmara.

| **Years** | **µg $L^{-1}$ stations** | |
|---|---|---|
| 1997 | 66.3(S) M8 | 51.0(S) M14 |
| | | 60.0(T) M14 |
| 1998 | 35(S) M20 | - |
| 1999 | 16.0(S) MY1 | 30.2(T) M8 |
| 2000 | 49.7(S) MY1 | 66.3(T) MY1 |
| | | 319.6(D) MBC |
| 2001 | 49.7(S) MY1 | 319.6(D) MBC |
| 2002 | 74.2(S) MY1 | 319.0(D) MBC |
| | 136.5(S) M11 | |
| 2003 | 490.3(S) MY1 | 132.7(D) MY2 |
| | 451.0(S) MY2 | 124.0(D) MY1 |
| | 343.0(S) MKC | 132.7(D) MKC |
| | 120.0(S) MBC | 146.1(D) M3 |
| | 142.3(S) MK | |
| 2004 | 321.3(s) M8 | 375.(D) MK |
| 2005 | 27042(S) MKC | 239.7(D) MY1 |
| 2006 | 896.0(S) MY2 | 231.5(D) MK |
| 2007 | 96.0(S) MY2 | 43.66(D) MY2 |
| | 710.8(S) MKC | 585.1(T) MY2 |

*S= surface, D= deep or T= thermocline

Oil pollution near İzmit refinery varied between 12.74 and 383.44 µg $L^{-1}$ (Güven *et al.* 1997a). Oil pollution data after the 1999 earth quake in İzmit Bay was also investigated and found as 4-40 µg $L^{-1}$ (Güven and Ünlü 2000). Telli-Karakoç *et al.* (2002) investigated the same area and found as 1.16-13.68 µg $L^{-1}$ in sea water and 2.3-21.6 µg $g^{-1}$ (wet weight) in sediment. The predominant PAHs are phenanthrene, chrysene and benz[*a*]anthracene. 16 PAH components were identified in mussel samples in İzmit bay (Turkey) after Marmara earthquake and subsequent refinery fire (Okay *et al.* 2003).

*Oil pollution in sediments*

Oil pollution in sediments is especially important for deep sea fish, bivalves and shrimps. It is deleterious as other contaminants for humans and limit value in sediment is 100 µg $g^{-1}$ (Marchand *et al.* 1982). As regards oil pollution of sediments it was found 3.4 benzpyrene (BP) 0.22-3.02 ng/g, 1.12 benzperylene (BPE) 0.92-5.6 ng/g and butiminous matter (BM) 0.01-0.15 g/kg in the Sea of Marmara sediments. The maximum amount of 3.4 BP in Büyükçekmece, 1.12 BPE in Marmara Island and BM in Büyükada regions were found. The oil in the Sea of Marmara sediments was found in MK station as 535-1094 µg/g in 2004 and 728-2763 µg/g in 2005. Apparent differences can be attributed to the varying in locations, collection dates and the analyzed compounds (Shimkus *et al.* 1993). Table 3 shows oil level found in sediment of the Sea of Marmara.

**Table 3.** The Oil level found µg $g^{-1}$ (wet weight) in sediment of the Sea of Marmara.

| | | | |
|---|---|---|---|
| 2002 | MKC | 1690.2/1051.7/ | MK 4541.5/1102.5/1229.0 |
| 2003 | MY1 | 1499.5/1299.8/ | MY2 1498/ 1209.8 |
| 2004 | MK | 715.06 | |
| 2005 | MK | 1392.30/2763.76/1689.25/ | MKC 1315.51 |
| 2006 | MKC | 745.7/ | MK 1859.1/1527.25 |
| 2007 | MK | 9050.28/1217.55/ | MY1 1714.22 |

The highest levels of oil pollution were in stations MK and MKC. Oil pollution of sediments in Çanakkale Strait was in the entrance 338.76 µg $g^{-1}$ in 1996 and 339.56 µg $g^{-1}$ (wet weight) in 1997 (Güven and Ilgar 2002; Güven *et al.* 2002). On the other hand in İzmit Bay near Tüpraş refinery 423.0 µg $g^{-1}$ in 1999, 1500.6 µg $g^{-1}$ in 2006 and 788.4 µg $g^{-1}$ (wet weight) in 2007 (Güven *et al.* 2007). In Zeytinburnu Port sediment the oil level was 3.8 mg $g^{-1}$ (wet weight) (Güven *et al.* 2003b).

*Oil pollution of marine organisms*

Marine organisms are capable of accumulating of oil in their body. Oil pollution levels of marine organisms collected after Nassia accident, were found as 13.6 µg $g^{-1}$ in *Merlangus merlangus*, 78.7 µg $g^{-1}$ in *Trachurus trachurus* collected from Büyükada in March 1994, 253.38 µg $g^{-1}$ in shrimp collected from M2, 140.36 µg $g^{-1}$ in shrimp collected from M6, 175.0 μg $g^{-1}$ in alga *Ulva lactuca* collected from B3. The oil pollution levels of fish collected from the Sea of Marmara reported as in digestive tract of *Sarda sarda* 472 μg $g^{-1}$; in flesh and digestive tract of *Engralius encrasicolus* 3.82 μg $g^{-1}$, 1.14 μg $g^{-1}$ respectively; ; in flesh and digestive tract of *Mullus surmulatus* 0.439 μg $g^{-1}$ and 0.310 μg $g^{-1}$ respectively (Güven *et al.* 2005). Many aliphatic and aromatic components of oil were detected by GC/MS analyses (Güven *et al.* Unpublished data).

As a result of analyses completed on *Mytilus galloprovencialis* collected from the Çanakkale Strait in 2001-2002 was 28.26 μg $g^{-1}$ and 17.2 μg $g^{-1}$ respectively (Güven *et al.* 2003a).

Various components of oil such as alkanes, branched alkanes cyclic aliphatic alkanes, ketones, naphthalene derivatives, anthracenes, phenanthrolines, benzthionenes, benzthiazaole, phenol, cresols were detected in red and brown algae (Erakın and Güven 2008).

*Oil Tanker Accidents*

Oil pollution is a very important for the countries in the tanker routes because tanker accidents happen very often. Many examples of tanker accidents have been observed on the Turkish coasts most importantly Independenta occurred in November 1979 and Nassia occurred in 13 March 1994. Unfortunately in both accidents Turkey received no compensation. There were no reports published on the oil pollution by Independenta. This is a major shortcoming. After Nassia accident the oil pollution was surveyed for two years by Istanbul University, Institute Marine Science and Management.*

Oil pollution Nassia accident was monitored in a number of studies in sea water after (Okuş *et al.* 1996; Güven *et al.* 1996; Güven *et al.* 1998a) in mussels *Mytilus galloprovencialis* (Güven *et al.* 1995). TPAO tanker accident occurred on 13 Feb 1997 in Tuzla Bay, 214.3 tons of oil spilled and 250 tons oil burnt. The pollution level of 32.2 mg $L^{-1}$ in sea water and 423.0 μg $g^{-1}$ in sediment were measured (Unlu *et al.* 2000).

Volgoneft-248 tanker accident occurred on 29.12.1999 in Istanbul, Florya-Küçükçekmece area, 4365 tons of fuel oil spread to the sea surface and the oil pollution level was monitored after the accident and found 567.6 μg $L^{-1}$ in sea water and 441.0 μg $g^{-1}$ (Okuş *et al.* 2007). M/V GOTIA ship accident occurred in 2002 (Güven *et al.* 2004).

Various methods were used for the measurement of oil pollution in sea water such as Ultra violet fluorescence (UVF), GC/MS, HPLC and MS. Among these, fluorescence spectroscopy is the most widely used technique but an important point is a crude oil or chrysene used as reference material for the calibration material which influences the result of the measurement for UVF application because of the dissimilarity of fluorescence intensity of references and the pollutant oil which varies depending on the origin of the crude oil. An alternative reference material technique was proposed for the solution of this problem (Güven *et al.* 2016b).

## 3. Detergent Pollution

LAS are linear alkylbenzene sulfanates containing C10-14 alkyl group the condensation of benzene ring with alkyl side chain alkylbenzene compounds are formed, after sulfonization of the benzene ring LAS occur. These are not uniform and when analyzed, result depends on the reference material.

Detergents are used as cleaning agents in domestic and industrial areas. Their main substances are surface active agents known as surfactants. They are divided mainly three subgroups: anionic, cationic and nonionic.

Anionic surfactants are composed of sulfuric acid esters, carboxylic acid esters, alkane sulfonates, alkylaryl sulfonates, petroleum sulfonates etc. LAS are linear alkylbenzene sulfonate containing a C16-C18 carbon chain. Cationic surfactants are composed of aliphatic hydrocarbons with quaternary amine groups. Non-ionic surfactants are composed of alkylphenolpolyethoxylate (APE). These alkylphenols are based on nonylphenol which is toxic to marine organisms. Amphoteric detergents contain anionic and cationic groups in the same molecules and they are degraded well under aerobic conditions. Detergents apart from surfactants contain meta, ortho, piro, hexa, poly phosphates, Calgon, $Na_3P_8O_{10}$ etc. These phosphate components increase toxicity of detergents.

Between these surfactants mainly LAS and APE are used. The most of the global production (about 65%) of surfactants are anionic agents mainly LAS and thus pollution research was concentrated on LAS. It is used as 5.5 g per head per day in developed countries (Rubio *et al.* 1996).

Determination of LAS is important because it is toxic to marine organisms as well as it decreases oxygen content of water. 1 to 20 ppm LAS is fatal to fish (Weith and Konasewich 1975; Spehar *et al.* 1979) and 5 ppm destroys epithelial gill cells of fish (Abel 1974). Toxicity of LAS on rainbow trout was investigated in aquarium. The lethal dose was found as 12.5 mg $L^{-1}$ in single dose and 13.5 mg $L^{-1}$ in progressive dose (Koç and Güven 2001; 2002; Koç *et al.* 2001; 2001). LC50 values (mg $L^{-1}$) in 48 h were found for crustacean (*Cragon cragon*) 9.25, for mussel (*Mytilus galloprovencialis*) 3.75 and for fish (*Proterorhinus marmoratus*) 8.75 (Güven *et al.* 2007).

Various methods were used for the determination of LAS in the environment such as spectrophotometric method using methylene blue as an active marker (MBAS)

(Standard Methods 1995), metachromatic method (Güven *et al.* 1994; Akıncı and Güven 1997; 1998; Bektaş and Güven 2004), potentiometric (He *et al.* 1993), atomic absorption (Crips *et al.* 1976; Barrais *et al.* 1984), IR spectrophotometry (Helman 1978) GC/MS (Hon-Nami *et al.* 1978, 1980; Eganhouse *et al.* 1983) and HPLC (Marcomini *et al.* 1987; Terzic and Ahel 1993).

*The problems of these methods are:*

Uniformity of LAS: LAB (linear alkylbenzene), precursor of LAS is not uniform for carbon numbers and phenyl ring attached to the linear carbon chain. In addition to its sulfonation many isomers occur. Thus, standard curve changes depending of the product and its manufacturer.

Salinity of sea water affects LAS determination in sea water (Güven and Cumalı 2007). The detergent pollution of station M23 in the Sea of Marmara changes depending on the different salinity levels: 121.90 µg $L^{-1}$ for 18‰, 125.90 µg $L^{-1}$ for 22‰ and 144.00 µg $L^{-1}$ for 34‰ salinity (Çetintürk and Güven 2009; Koç *et al.* 2002; Güven *et al.* 2008).

Degradation products of LAS are *p*-sulfonic phenylbutanoic acid and *p*-sulfonic phenylpentanoic acid (Gonzalez-Mazo and Gomez-Parra 1996; McAvoy *et al.* 1993; Mungray and Kumar 2009). Desulfonation process occurs by mono oxygenase and reductive effect of bacteria. Degradation of LAS also depends on the type of bacterial population (*Vibrio*, *flavobacterium*, *Klebsiella*, *Pseudomonas*, *Enterobacter*, *Basillus*, *Escherichia*, *Shigella*, *Citrobacter*, *Proteus*, *Anaebena*) (Yediler *t al.* 1989) and pH of water. The bacterial contact oxidation occurs in waste water treatment plants (Han and Yang 1992). LAS are degraded 97% in 34 days (Hon-Nami and Hanya 1980). The degradation of LAS in water, tap water, sea water (the Sea of Marmara) was investigated and found that LAS was degraded in Sea of Marmara in 4 days 66.74%, in 9 days 83.07%, in 14 days 93.20% (Koç *et al.* 2002). The loss of LAS in Sea water of Golden Horn in 22 days 91.20%, in Black Sea 8-90.1% (Güven *et al.* 2008a; 2008b).

*The storage time after sample collection influence the LAS determination*

The method used in the determination of LAS also influences the level of LAS pollution. It is not distributed uniformly in sea water. The distribution of LAS on sea water depends on the current and wind conditions. Thus sampling is also a problem for the determination of LAS.

*Pollution data*

The first record on detergent pollution of the Sea of Marmara in 1996, published in 1999 (Güven *et al.* 1999). There is no limit value for detergent amount in sea water. The maximum LAS levels (µg $L^{-1}$) were found in M23 as 28.98 for surface water and in M14 as 52.28 in deep water. The LAS pollution level (µg $L^{-1}$) for the surface water at the exit of Çanakkale Straits was 76.3 in 1996 and 539.1 in 1997 and in the sediments at the entrance of the Strait 51.13 and at the exit 338.7 in 1996 (Güven and Ilgar 2002). Balcıoğlu (2014a; 2014b; 2015) investigated LAS pollution and found that the levels in 2012 Jan was 24.24 µg $L^{-1}$ in Çanakkale Strait and 42.15 µg $L^{-1}$ in the Sea of Marmara.

In addition to the table, while the pollution level of Çanakkale Strait varies between 14.32 and 34.55 (µg $L^{-1}$) in 2005, 45.97 (µg $L^{-1}$) in 2013. On the other hand in Istanbul Strait the level of pollution varies between 26.0 and 59.0 (µg $L^{-1}$) in 2013 (Güven and Coban 2013). As seen in the table 3 LAS levels in the Sea of Marmara varied as 25.64-314.27 µg $L^{-1}$ and rise during the years. The highest level polluted stations are MK, MY1, MBC for the surface water and MKC station for the deep water (Güven et al 2007; 2008b; 2010). The maximum LAS amounts found in the stations shown in the Table 4.

**Table 4.** The maximum LAS amounts in the stations found of the Sea of Marmara during 1997-2007 (Güven *et al.* 2007; 2008b; 2010).

| Year | Stations | Surface water | Stations | Deep water |
|---|---|---|---|---|
| 1997 | M23 | 25.64 | M20 | 71.43 |
| 1998 | M8 | 51.70 | M20 | 42.46 |
| 1999 | MBC<br>MY1 | 31.71<br>106.07 | M20 | 35.21 |
| 2000 | MK | 85.12 | MBC | 83.78 |
| 2001 | M11 | 42.76 | M11 | 59.60 |
| 2002 | MKK | 85.12 | MKC | 35.30 |
| 2003 | MK | 314.27 | MK | 126.42 |
| 2004 | MK | 243.99 | M23 | 43.57 |
| 2005 | MK | 143.20 | MY2 | 68.53 |
| 2006 | MBC | 192.95 | MKC | 187.61 |
| 2007 | MBC | 77.56 | MBC | 131.89 |

## 4. Conclusion

Investigations made on the oil and detergent pollution for the Sea of Marmara showed that the pollution was on rise during the last 20 years. This research regularly made between surface and deep, the density of oil is higher the in sea water contrary to detergent. The oil depending on substance component sink to the deep and detergent conversely stays on the surface. That's why detergent does not diffuse to the whole water column. Thus, determination of detergent depends on the methods used, storage time of the sample, standard equation substance used, experience of analyst, salt content of sea water tested.

The sewage and the heavy Industry of Black Sea countries and Danube River contribute to the pollution of Sea of Marmara. A pollutant from Danube River was shown to reach to the Çanakkale Strait (Güven *et al.* 2013; 2015)

As declared in The Municipalities Marmara Union Statement the sewage water of surrounding cities should not be discharged into the undercurrent of the Sea of Marmara.

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# PAHS IN THE SEA OF MARMARA USING MEDITERRANEAN MUSSELS AS BIOINDICATOR

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The Mediterranean Mussel (Mytilus galloprovincialis) is native to the Mediterranean, Black, and Adriatic Seas, but has spread (mostly via ballast water and ship hull fouling) to many other regions worldwide. These mussels usually occur in the low intertidal zone of exposed rocky coasts with relatively high wave energy, although in their native range they are also found growing in dense patches on the sandy-muddy bottoms of brackish lagoons (Ceccherelli and Rossi 1984). M. galloprovincialis is a sedentary, filter-feeding mollusk of wide distribution in Turkish waters. Mussels are commonly used as bioindicators of pollution in marine environments because they can accumulate various pollutants as filter-feeders. It occurs throughout the Black Sea, Aegean Sea and Sea of Marmara in Turkey (Aral 1999). Size of mussels for marketing ranges between 50 mm and 80 mm. In terms of Turkey, minimum size of mussels for consumption is approximately 70 mm in lenght. Size of mussels has been affected by temperature, species of mussels, amount of plankton and salinty rate.

Large amounts of petroleum have been transported by pipelines and tankers through waterways. Moreover, the increase of maritime activities such as offshore oil exploration, drilling/exploitation amplifies the potential harms on marine biodiversity, ecosystem and water quality through hydrocarbon toxicity. Additionally to pollution from land-based sources, hazards to the Black Sea maritime environment from shipping, routine operations such as accidents, discharge of ship waste, ballast and bilge water, are of increasing affair (Gilliespie and Yüce 2004). As the only waterway between the Mediterranean and the Black Sea, the Turkish Straits System (TSS) composed of the Istanbul Strait, Marmara Sea, and Çanakkale Strait (Dardanelles) connects these two adjacent basins subject to heavy maritime traffic along the navigational route. Moreover, the heavy maritime traffic (presently three times the traffic of the Suez Canal) constitutes a continuous risk of accident along the Istanbul Strait, which exhibits complex hydrodynamic conditions. Therefore, ship-originated pollution caused by mainly dense navigation and maritime accident has become one of the most important concerns with regard to the environmental degradation of the Istanbul Strait, Marmara Sea, and the surrounding coastal areas.

Polycyclic aromatic hydrocarbons (PAHs) are a extensive environmental pollutants having carcinogenic and mutagenic effects among petroleum hydrocarbons. Therefore, 16 of them are classified as priority pollutants by the United States Environmental Protection Agency (USEPA).

PAHs in Marmara Sea were investigated in various scientific publications by many researchers. The most extensive research as a monitoring study being on Turkish Straits System (Marmara Sea, Çanakkale and Istanbul Straits) was published by Balcıoğlu *et al.* (2014). Total PAHs (T-PAHs) are ranged from 1.2 to 589 µg g-1 in Istanbul Strait, from 0.94 to 36.44 µg g-1 in the Marmara Sea and from 0.4 to 47.9 µg g-1 in Çanakkale Strait. During the sampling the highest PAH concentration was found as 588.9 µg g-1 in Kadıköy. In addition other high values were found in Tekirdağ and Kumkapı samples. These high levels of T-PAHs are related to busy harbours in Kadıköy, Tekirdağ and Kumkapı stations exposing to marine traffic.

Balcıoğlu (2016) investigated PAHs in Prince Islands being exposed to intensive domestic tourism. According to study concentrations of total determined PAHs (sum of 16 compounds) ranged between 664 and 9083 ng g-1. The origin of PAHs has been found pyrolitic according to the PHE/ANT and FLO/PYR ratios in Büyükada. For other islands, PAH origins have been observed as pyrolytic and petrogenic together according to the PHE/ANT, FLU/PYR and BaA/CHR ratios.

PAHs in mussels of Istanbul Strait were examined in another study by Karacık *et al.* (2009). Mussel samples were collected at 19 stations in Istanbul Strait and 2 stations in Marmara Sea (Büyükada). TPAH values varied 43-601 ng g-1 in Istanbul Strait mussels. The most polluted station was found as Istinye station which is situated at the mouth of rivers and TPAH concentrations measured at those stations were found higher compared to the other values measured in the strait.

Nassia accident is one of the most significant environmental disasters occurred in 1994 in Istanbul Strait. Güven *et al.* (1995) investigated oil pollution in mussels after the accident. The highest value was found as 250 µg g-1 which is higher than other values (except Danube) found by previous studies in Black Sea.

Tuzla Bay is one of the most polluted areas in Istanbul, Marmara Sea. A study was performed by Ünlü *et al.* (2000) in seawater, sediment and mussels after TPAO accident. This accident caused 214 tonnes of oil spill. The value of 2067 µg g-1 was found in mussels one month after the accident and the pollution level decreased in one year period. The origin of oil in seawater, sediments and mussels were identified by using fingerprinting analysis technique.

Telli-Karakoç *et al.* (2002) examined 16 PAHs in seawater, sediment and mussels of Izmit Bay. T-PAH concentrations were measured using UVF and found as 1,16- 13,68 µg l-1 in water, 30- 1670 µg g-1 in sediments and 5,67- 14,81 µg g-1 in mussels. The most pollution occurred at Doğu Kanalı and Dil Deresi where were the main rivers containing wastes fall into the the Izmit Bay.

Okay *et al.* (2003) evaluated the changes in T-PAH levels in mussels after the earthquake in Izmit Bay. Although the mussel PAH concentrations show a wide range of spatial variations (approximately 1.5–800 mg kg-1 dw) the values found for Izmit Bay mussels are still much higher than those found in the other marine systems (Villeneuve *et al.* 1999).

Güven *et al.* (2004). This study presents the results of oil pollution in İstanbul after M/V GOTIA accident. The highest pollution level was found in mussels as 0.30 mg g-1 at Galatasaray Island and 0.20 mg g-1 at Bebek.

Oil pollution on mussels were investigated at the enterance and the exit of Dardanelles between June 2001 and May 2002 by Güven *et al.* (2003). The highest value was found in May 2002 in Çanakkale and Gelibolu samples as 28.26 µg g-1 and 17.26 µg g-1, respectively.

Ergül *et al.* (2010) determined PAH concentrations in mussel samples collected from Izmit Bay at the east of Marmara Sea. Total PAH concentrations varied between 2.5-13.9 ng g-1 (ww). Relatively dominant PAH compounds were found as phenanthrene, benzo(e)pyrene and benzo(ghi)perylene. The mussel PAH levels were generally similar (higher than 7 ng g-1 wet wt.) for the sampling points, with the exception of two points located on the north side of the Bay (with PAH levels about 2-3 ng g-1 (ww).

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**MARINE POLLUTION FROM SHIPS IN**
**THE TURKISH STRAITS SYSTEM**

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## 1. Introduction

Marine pollution is one of the most important environmental pollution problems for the last 50 years and shipping is the most important factor causing marine pollution. The main environmental impacts of shipping operations include air pollution, oil discharges or other hazardous substances/wastes and transferring invasive alien organisms in global scale.

More than 90% of the foreign trade of Turkey, in terms of volume, have been realized with maritime transport (İncaz 2007). The Turkish Straits System (TSS), called Strait (Bosphorus; 17 nm) and Çanakkale Strait (Dardanelles; 37 nm) and the Sea of Marmara (110 nm), is the most important ship route in Turkish Seas (Figure 1). It is opened to international maritime vessel traffic under the Turkish governmental control. The narrow straits at Istanbul and Çanakkale with blind turns and dangerous currents (up to 8 knots) have always been potential threats to the passing ships.

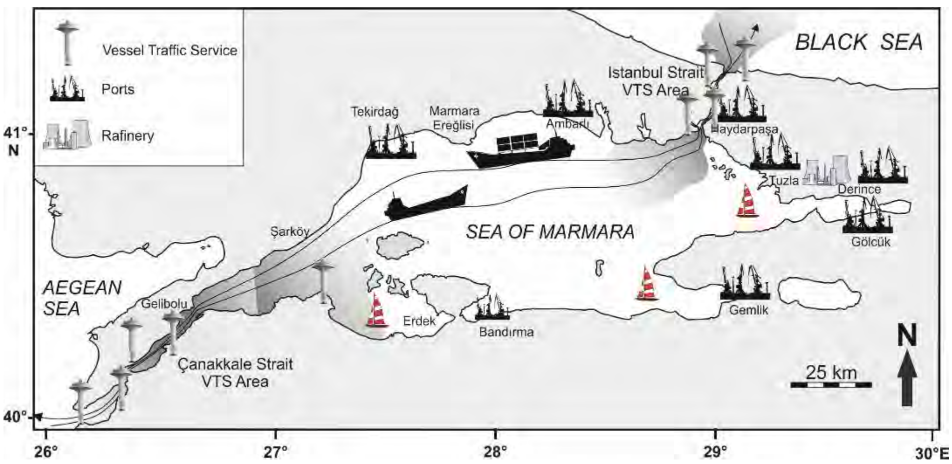


**Figure 1**. The Turkish Straits System (TSS), including the Istanbul Strait, the Sea of Marmara and the Çanakkale Strait, has many obstacles that may result in a negative effect on environmental management (www.turkishstraits.com/).

The economic growth with increasing oil production and maritime transportation make this threat more devastating on the marine environment especially for small and narrow water passages such as the TSS (Alpar *et al*. 2007). Every year more than 40,000 ships cross the Sea of Marmara, and the constricted waterways of the Istanbul and Çanakkale Straits. Oil tankers are most prone vessels to possible accidents during transit passage in narrow straits, along coastlines with heavy maritime traffic, and especially during storms. The marine transportation intensity in the TSS increased significantly until 2012, under the control of economic growth and oil production. There is however a decrement in recent years. According to 2014 data, for example, the transit passages via the Istanbul and Çanakkale Straits are slightly more than 45,000 and 43,000 (Table 1).

**Table 1.** Ships crossing the Turkish Straits (after Maritime Sector Reports, 2014).

| | ÇANAKKALE STRAIT | | | ISTANBUL STRAIT | | |
|---|---|---|---|---|---|---|
| | **Vessel** | **Tonnage (gross million)** | **Cargo (million tons)** | **Vessel** | **Tonnage (gross million)** | **Cargo (million tons)** |
| **2012** | 44.613 | >735 | >454 | 48.329 | >550 | >377 |
| **2013** | 43.889 | >745 | >461 | 46.532 | >551 | >380 |
| **2014** | 43.582 | >761 | >473 | 45.529 | >582 | >394 |

The role of this chapter is to give a short overview of maritime transport activities in the TSS, marine pollution from ships, their types and environmental impacts. In addition, the most important physical impacts of the ships on marine ecosystem will be highlighted.

## 2. Maritime transportation activities and environmental impacts

### 2.1. Ship-generated oil discharges and emissions

**Accidental spillages (tanker and non-tanker accidents):** Oil pollution at sea is of great importance since the major marine environment pollutant is oil, in terms of their volumes. It is a viscous liquid, including crude and refined oils, such as kerosene, gasoline and other heavier petroleum products (diesel and lubricating oils). As it has a density less than that of water, oil spill is rather difficult to clean up. The toxicity and partly smothering effect of oil, especially when it is deposited, cause harm to marine life (Smith 1971). In the intricate and narrow water passages, similar to the Turkish straits, and especially during the times of spawning and migration, the effect of oil pollution on ecosystem and fishing becomes more important (Öztürk 2005). On the basis of the location and sensitivity of the spill area, time, weather and other environmental conditions, the effects of oil spill may last for short or long term. Oil pollution in bottom sediment may continue for years (Ünlü *et al*. 2004; Ünlü and Alpar 2004, 2006).

Regular shipping operations (oil load/discharge operations, oil and cargo transfer etc.) and accidental spillages (e.g. collision, grounding, hull failures, fire and explosion) amounts to around 50 per cent of global marine oil pollution (Table 2). Other half of this share comes from industrial and municipal effluents.

**Table 2.** Type and percentage of disasters of global marine oil pollution.

| | **Oil tanker** | **Regular shipping operations** | **Municipal/ Industrial** | **Others** |
|---|---|---|---|---|
| **Percent** | 7-10 | 35-40 | 45-50 | 5-10 |

The amount of leak entering the sea due to shipping activities has fallen during last 4 decades, which was 2.1, 1.57 and 0.57 million tons in 1973, 1981 and 1990, respectively (IMO 1998). If we look at this decreasing trend from another point of view, large amount of spills (55%) recorded in the 1970s decreased about 7% each decade till the 2000s.

Similarly, numerous accidents and collisions, resulting in oil spills, affected substantially the marine ecosystem and human life in the TSS. Almost all of these accidents occurred in harbours or rather close to the shores. The cargo vessels are most notorious ships involving in these accidents, and they are followed by tankers and passenger ships.

More than 120 transit vessels use the Istanbul Strait per day (Table 1). This is almost 10 times of the ships passing the strait in 1936, when the Montreux Convention was signed for navigation regulations. In addition to transit vessels, the number of passenger ships and small boats crossing between the piers in Istanbul are more than 2000, in other words, two and a half million people per day. These figures increase every year as the city population reached 15 million in 2016. That is, a hundred floating bodies use the water passages of Istanbul in both directions at any time of the day (Oral 2001). More than 450 marine accidents occurred in the Istanbul Strait and at its approaches since 1950, mostly collision due to poor visibility, strong currents and engine failure. The most important sea accidents, which caused severe environmental damage and pollution, are summarized in Table 3 (Marine Ministry Database).

**Table 3.** The most important marine accidents occurred in the Turkish Straits System

| Accident (date) | Vessel name | Accident Area | Spilt /environmental impact |
|---|---|---|---|
| *1960, Dec. 14* | *M/T Petar Zoranić M/TWorld Harmony* | Kanlıca | 18,000 tons of petroleum spilled causing severe marine pollution. |
| *1966, Mar. 1* | *M/TKransky OktiabrM/T Lutsk* | Kız kulesi | The amount of oil spilled was about 1,850 tons, causing fire at a ferry boat terminal at Karaköy. |
| *1979, Nov. 15* | *M/T Independenţa M/V Evriali* | Haydarpaşa | 95,000 tons of crude oil was spilt and then burnt for days (Baykut *et al.* 1987; Etkin 1997). |
| *1988, Oct. 29* | *M/T Blue Star M/T Gaziantep* | Ahırkapı | 1000 tons of ammonia spilled and caused severe water and air pollution. |
| *1990, Mar. 25* | *M/T Jampur M/V Da Tung Shang* | Sarıyer | 2,600 tons oil spilled into the sea. |
| *1991, Nov. 14* | *M/V Madonna Lily M/S Rab Union-18* | Istanbul Strait | The drowned sheep, more than 21,000, in the sunk vessel caused severe pollution (Yurdun *et al.* 1995). |
| *1994, Mar. 13* | *M/T Nassia M/V Shipbroker* | Sarıyer | 20,000 tons of oil burnt for more than 4 days, so ceasing marine traffic. 9,000 tons of oil spilled into the sea, affecting many places severely in the Black Sea, Istanbul Strait and Sea of Marmara (Oguzülgen 1995; Güven *et al.* 1995, 1996). |
| *1997, Dec. 13* | *M/T TPAO* | Tuzla | 1500 tons of oil spilled into the sea. Extreme mortality of fish eggs and larvae was reported due to oil pollution, as well as metal pollution on biota. (Okuş *et al.* 1997; Doğan *et al.* 1998; Ünlü *et al.* 2000). |
| *1999, Nov. 7* | *M/V Semele M/V Şipka* | Yenikapı | Semele damaged severely and sunk, spreading 10 ton fuel oil into the sea. |
| *1999, Dec. 29* | *M/T Volganeft-248* | Florya | 1,578 tons of oil spilled to the sea (ITOPF 2000; Otay and Yenigün 2000; Oğuztimur and Parlak 2002). Oil contamination remained in sediment and caused successive pollutions at the shores due to persistent southerly waves for years (Alpar and Ünlü 2007). Plankton and small organisms were affected Taş *et al.* 2011). |
| *2002, Sept. 5* | *M/V Şahin-3* | Istanbul Strait | More than 26 tons of diesel fuel has leaked into the sea. |
| *2002, Oct. 6* | *M/V Gotia* | Emirgan Dock | 18 tons of fuel oil spilled into the sea. The marina and coastal infrastructures were affected even the majority of oil in the sea was transported into the Sea of Marmara (Otay *et al.* 2003; Güven *et al.* 2004). |
| *2003, Nov. 10* | *M/VSvyatoy Panteleymon* | Anadolu feneri | 500 tons of fuel-oil spilled into the sea. |
| *2004, Feb. 12* | *M/V Strontsy* | Kilyos | In order to reduce the impact on marine life, floating fences were used for 6 days to block oil slick's attempts to expand. |
| *2010, Jan. 19* | *M/V Orcun-C* | Kilyos | 96 tons of fuel oil and 25 tons of diesel oil spread into the area's bays and out to sea. |

**Shipping emissions:** Ships have high powered engines using heavy fuels and the world shipping fleet is powered almost exclusively by diesel engines (Deniz *et al.* 2010). Even though cargo transport by ships is the most efficient transportation method considering its weight and distance crossed, the fuel used by ships is high in sulphur content. The emissions and pollutants from ships (e.g. nitrogen oxide $NO_x$, sulphur dioxide $SO_2$, carbon dioxide $CO_2$, hydrocarbons HC, and particulate matter PM) can be transferred in atmosphere even between the continents. The shipping activities account for almost 3/10 of the $NO_x$ and 1/10 of the sulphur oxides of total global air emissions. Starting from 1990, $NO_x$, $SO_2$, PM, and greenhouse gases were increased from 585 to 1096 million tons in 17 years (Buhaug *et al.* 2009). The $CO_2$ emissions in 2007 were estimated at 943.5 million tons (Psaraftis and Kontovas 2009). This is responsible for 3% of global $CO_2$ emissions (Buhaug *et al.* 2009). In addition, on the basis of fuel consumption, annual $CO_2$, $NO_x$ and $SO_x$ emissions from ship corresponds to 2, 11, and 4% of the global anthropogenic emissions, respectively (Endresen *et al.* 2003). As they cannot be controlled tightly, shipping activities and maritime transportation contributes to air pollution, to ozone creating pollution and therefore to climate change. The impacts of shipping emissions on air quality may increase over domestic and inland seas, gulfs, highly-populated straits, and port areas.

IIASA (2007) estimated the shipping emissions for the Black Sea as 3.85, 0.089 and 0.065 Mt for $CO_2$, $NO_x$ and $SO_2$. The shipping emissions along the TSS were estimated by taking into account ship engines, fuel types, and operations types, navigation parameters for 2003 (Deniz and Durmuşoğlu 2008). The annual total emissions were estimated as slightly more than 5000, 100, 80, 20, 5 and 4 (x1000) tons for $CO_2$, $NO_x$, $SO_2$, CO, VOC and PM, respectively. So, the $NO_x$, $SO_2$ and $CO_2$ emissions correspond to 1% of the global total shipping emissions, and more than those emissions in the Black Sea. The shipping emissions of $NO_x$, PM and CO are 46, 25 and 1.5% of road traffic emissions in Turkey. The greatest effect of ship emissions was reported for territorial waters and ports which are the most important gateways for trade in the World. Later, Kılıç and Deniz (2010) estimated shipping emissions for Izmit Gulf and Ambarlı Port. Even though there is no a comprehensive study about the impact of shipping emission on the Sea of Marmara, research from other regions indicated that $CO_2$, $NO_x$ and $SO_2$ contribute to ocean acidification. New researches are necessary to estimate the potential impacts of emission-induced acidification on the biochemical and physiological processes of the TSS.

### 2.2. Operational discharges and environmental impacts

Vessel-related operational pollution includes releases of bilge water from machinery spaces and ballast water of fuel oil tanks, discharge of raw sewage and litter from ships.

**Bilge water:** It is the water that collects in the lowest compartment of almost every vessel below the waterline. It may contain leaks (solid wastes, urine, detergents, solvents, chemicals) in the hull or stuffing box, or other interior spillage. In case of leakage, untreated bilge water can damage marine life.

**Ballast water discharges and transfer of alien species:** Ballast water carried in ships' ballast tanks are used to improve ships' stability and balance. It contains all kind of biological materials, including viruses and bacteria. Large numbers of organisms (7-to-10,000 species in different life stages such as eggs, larvae, cysts, spores or resting stages) are transferred throughout the world by the world shipping fleet (GloBallast Partnership Project 2016). The harmful microorganism and bacteria moved by ballast water cause not only destruction of marine ecosystem but also serious economic and ecological damages (Streftaris and Zenetos 2006).

Almost half of the ships in the region have ballast water as much as 24,000 and 20,000 tons for the Istanbul and Çanakkale Straits, respectively (Maritime Sector Report 2014). Their total ballast water capacities are 320 and 312 million tons. Considering all of the seas surrounding Turkey, the total share of ballast waters transported in the Sea of Marmara is the highest with 45% (Olgun *et al.* 2012).The highest rate of ballast water transportation in the Sea of Marmara occurs between the ports located in the Gulf of İzmit, with a share of 43%. These figures are 20, 12, 7, 6 and 5% for the ports of Ambarlı, Istanbul Port, Tuzla, Gemlik and Silivri, respectively (Olgun *et al.* 2012). So, in terms of ballast water transport, the riskiest region in the Sea of Marmara is the Gulf of Izmit with its 39 ports visited by national and international ocean-going vessels.

One of the most important environmental hazards to the Black Sea is the introduction of exotic species. An inventory of alien species at the coasts of Turkey indicated 69 alien species transported by ships (Çınar *et al.* 2011). The authors also reported that 47 of the alien species, 6 of them are suspicious, existed in the Sea of Marmara. In general these species are carried by tanker ballast water and fouling of ships' hulls. An example is *Rapana venosa* which appeared in the Black Sea in the late 1960s, presumably introduced by ships coming from the Sea of Japan. Feeding on mussels, oysters, and clams, their population grew rapidly and expanded southward (Öztürk 1998). In the early 1980, the North American comb jellyfish (*Mnemiopsis leidyi*) were transferred to the Black Sea by ballast water taken up at the Atlantic coast of North America (Vinogradov *et al.* 1989). Affecting pelagic and benthic communities in the Black Sea severely, they caused collapse of fisheries.

Since ballast water is usually taken up at often shallow, turbid and highly-productive port areas, the transporting and spreading risk of invasive alien species in various forms is higher. Introduced pathogens carried by ballast water may even cause death in humans. GloBallast Partnerships Programme, a project Maritime Organization) reported many dangerous species including; a) cholera (*Vibrio cholerae,* known to mutate into new strains and travel widely), b) cladoceran water flea (*Cercopagis pengoi*), c) mitten crab (*Eiocheir sinensis*), d) toxic algae (red, brown, and green tides, may form harmful algal blooms depending on the species), e) round goby (*Neogobius melanostomus*), f) North American comb jelly (*Mnemiopsis leidyi*), g) North Pacific seastar (*Asterias amurensis*), h) zebra mussel (*Dreissena polymorpha*, fouls all available hard surfaces in mass numbers), i) Asian kelp (*Undaria pinnatifida*), and j) European green crab (*Carcinus maenas*) (GloBallast Partnership Project 2016).

The ship ballast waters taken from the ships berthed in the Ambarlı Port has shown that pathogenic bacteria and cultivable bacterial existence and their diversity posed a significant risk (Altuğ *et al.* 2012). Unfortunately, at present, there is no strict restriction for discharging of dirty ballast water in our national ports, the major centres of environmental risks and pollution. As of today, the International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM), adopted in 2004, has not been yet approved formally by Turkey.

Comprehensive multiple approaches, specific policies and appropriate strategies, at national and international levels, are needed to cut down the introduction risk of invasive alien species through ballast water. In the national level, for example, the ships can freely discharge their ballast water in Turkish seas and ports without any application of risk reduction activity, as long as their ballast water is not dirty. This poses a serious risk on the highly-populated industrial regions which are more sensitive to environmental pollution. Therefore, necessary action plans must be applied in controlling the ballast waters at all of our ports. The most helpful approaches include careful port and shipping operations, well-training, official instruction and examinations.

**Sewage:** The most important waste water producers (<90%) are the ferries, passenger and cruise ships which dump greywater (from baths, showers, galleys, laundry, sinks and kitchen) and Blackwater (from toilets and medical facilities) into the sea every. Untreated or inadequately treated sewage can contain pollutants at variable strengths and cause bacterial and viral contamination and have adverse effects on the marine environment, producing risks to public health. Faecal coliform bacteria found in untreated wastewater are several times greater than that observed in untreated domestic wastewater.

**Solid waste:** Solid waste (e.g. glass, paper, cans and plastics) discharged at sea, usually from large cruise ships carrying several thousand passengers, can be hazardous and pose threat to marine ecosystem. Unfortunately, there is no available data representing solid wastes discharged in the TSS.

### 2.3. Physical effects of marine vessels on marine habitats

**Anchoring:** Direct physical impact of ships, usually by ship itself, anchors, dragging and swinging of chains and grounding, may be harmful to marine habitat, especially in sensitive areas and benthic species (e.g., sea grasses, shellfish beds and soft corals which take thousands of years to build). Collisions with ship or its propellers may also cause direct physical harm to large marine mammals such as whales. Increasing demand for anchoring/mooring operations cause stresses to the marine environment, such as increased pollution, turbidity and physical damage (Smith 2000). The impacts of such kind of operations are either temporarily by increasing suspended sediments from the disturbance of the bottom or through direct contact with dragging anchors. Damage caused by anchoring may be temporary or permanent depending on type of anchoring/mooring involved, sediment type and sensitivity of benthic species.

**Antifouling paints on ships:** Growth of organisms, such as molluscs and algae, on hull surface cause a reduction in vessel speed as high as 10%. Hence, hulls have long been coated with anti-fouling paint containing Tributyltin- organotin compounds (TBT) since 1960s. Unfortunately TBTs, which constitute broad spectrum of algaecide, fungicide, insecticide and miticide, and act as biocide, have damaging ecological effects due to their strong eco-toxicity (Ashby and Craig 1990). Their solubility in water is low, with a half-life changing between a few days and a few weeks. In addition, if they are accumulated in bottom sediment, their decompositions may even last for several years depending on the environmental conditions (Ref: TBT in antifouling paints: National Institute for Coastal and Marine Management/RIKZ, Netherlands. MEPC 42/Inf.10). The aquatic environments with heavily silted bottoms, as usually observed at harbours, ports and sometimes in estuaries, are more prone to chronic TBT contamination.

World-wide increment of organotin concentrations has been detected in marine organisms and food chain since the beginning of 1970s. The organotin compounds with antifouling effects cause larvae mortality, imposex in many marine species, thickening or structural deformations of shells (Santos *et al.* 2002; Strand and Asmund 2003). The most sensitive organisms are gastropods, bivalves and sea snails. Female marine snails, for example, may develop male sexual characteristics. The organotin compounds affect immune systems of contaminated fish, seabirds, and marine mammals and even to human consumers. Because TBTs reduce the resistance to infection in fishes, e.g. flounder and other flatfish especially living in harbours and estuaries with silty sediment (Ref: TBT in antifouling paints: National Institute for Coastal and Marine Management/RIKZ, Netherlands. MEPC 42/Inf.10). Ship movements through water and waves cause organotin compounds in the sea water to diffuse in air as aerosols.

Considering the unwanted effects of harmful TBTs, their usage in antifouling systems was banned all over the world, firstly by the International Maritime

Organization (IMO) in 2003 and then for TBT coatings on all ships by the Marine Environmental Protection Committee (MEPC) in 2008 (Champ 2003). However, this does not mean that the TBT pollution studies were over, especially at the critical areas such as seaports, marinas and fishing areas where organotin compounds and other biocides having antifouling effects.

The seaports, public and private shipyards and rapidly developing marinas along the shores of TSS are the most notable localities for the investigation of organotin compounds and other biocides (Kırlı 2005). Their impacts to the marine organisms and their reflections to the sea products must be studied as well. Although it is well known that the tributyltin and its derivatives are extremely hazardous to marine ecosystem, there are very rare data on their levels and detrimental impacts on marine environment, particularly at the hot spots involving heavy commercial maritime processes along the TSS. In one of the earlier studies, Yemenicioğlu (1997) discussed methyltin distributions and provided a brief evaluation of butyltin results for the Mediterranean and Black Seas, and the TSS, which all have different physical and biochemical properties.

Yozukmaz *et al.* (2011) stated the importance of organic tin contaminated sediment in marine pollution, emphasizing that sediment is not a final stop for organic tin compounds. Instead it is a renewable resource, so sediment is an important factor for continuation of organic tin compounds (OTC's) concentration. Waste and sludge mix removed from sea bottom in harbours could cause additional contaminations (Hoch 2001). As the present prohibition and regulations in use of TBT will not evidently terminate the level of TBT concentrations rapidly, some comprehensive studies are needed on kinetics and durability of OTC's pollution along the TSS, as well as at its hot spots. Surprisingly no improvements reported from many developing countries, implying that they possibly carry on employing effective biocide and producing OTC's. Employment of new antifouling chemicals in paints, instead of OTC, may also create harmful effects in aquatic environment and should be debated together with prohibition of OTC usage.

## 3. Conclusions and Suggestions

The Sea of Marmara and its connections with neighbouring seas are the most important sea pathways of the World and play a vital role for the fish migration. The environmental rules should be applied strongly due to heavy sea traffic in that region. Action plans and innovative strategies have to be developed for decreasing the sea traffic load as possible. This is important because of for the maritime transportation and safety and also environmental pollution prevention. Although additional information and comprehensive researches are needed to understand the ecological effects on habitats and species, it can be said readily that the impacts of maritime traffic in the Sea of Marmara are high in intensity, repeatability, duration and geographic distribution. Some specific mitigation measures can then be identified. First priority management steps which must be acted upon in the Sea of Marmara in short, medium and long terms were outlined below.

- Short term management steps include a) development of permanent mooring stations at sensitive marine areas, b) preparation of more specific national standards, in addition to international standards, to regulate the ballast waters, which is a must to protect ecosystem and public health.

- Medium term management steps include a) monitoring TBT levels and organic biocides, b) fortify national coastguard surveillance to prevent and reduce oil spills, c) coordinate multilateral efforts in order to enforce MARPOL, d) definition of appropriate methods and technologies in making reduction in ship emissions, and e) implement the recommendations of international conventions developed by IMO.

- Long term management steps include a) enhance public awareness for the effects of maritime transportation on biodiversity, b) encourage the use of cleaner marine fuels, innovative vessels with modern engines, installation of on-board pollution control facilities, c) reduce ship emissions at port operational procedures, d) use very-high frequency radio-based automatic identification systems in order to enable the identification and necessary parameters of ships to prevent accidents and also for estimating ship emissions and monitoring defiant vessels passing through the TSS.

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## HARMFUL ALGAL BLOOMS (HABs) AND MUCILAGE FORMATIONS IN THE SEA OF MARMARA

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### 1. Introduction

Photosynthetic algae support healthy aquatic ecosystems by forming the base of the food web, fixing carbon and producing oxygen. Under certain circumstances, some species can form high-biomass and/or toxic proliferations of cells (or “blooms”), thereby causing harm to aquatic ecosystems, including plants and animals, and to humans via direct exposure to water-borne toxins or by toxic seafood consumption (Kudela *et al.* 2015). Microalgae that may have a deleterious effect on other aquatic species or humans are termed 'harmful algae'. This encompasses a number of different algae taxa such as diatoms, dinoflagellates, haptophytes and cyanobacteria (Kraberg *et al.* 2010).

Algal blooms may appear yellow, brown, green, blue or milky in color, depending upon the causative organisms. Most water discolorations are caused by motile or strongly buoyant species. Dense algal concentrations are most strongly developed under stratified stable conditions, at high temperatures and following nutrient input from land run-off after heavy rains and/or domestic discharges in coastal marine ecosystems. Most of these algal blooms appear to be harmless events, but under exceptional conditions, non-toxic bloom-formers may become so densely concentrated that they constitute anoxic conditions that cause fish and invertebrates kills in sheltered bays. The essential problem for algal blooms is the production of toxins by certain species (especially dinoflagellates). In this case, even low densities of toxic algae in the water column may be sufficient to cause illnesses in humans as Paralytic Shellfish Poisoning (PSP), Amnesic Shellfish Poisoning (ASP), Neurotoxic Shellfish Poisoning (NSP), Diarrhetic Shellfish Poisoning (DSP), Ciguatera Fish Poisoning (CFP) and Azaspiracid Poisoning (AZP). PSP can result from eating either shellfish, and planktivorous, while, DSP, NSP, AZP and ASP are caused by eating shellfish, ciguatera by eating tropical fish. Another group of toxins (Ichthyotoxins) selectively kill fish by inhibiting their respiration (Hallegraeff 2002).

Proliferations of microalgae in marine or brackish waters can cause massive fish kills, contaminate seafood with toxins, and alter ecosystems. A broad classification of harmful algal blooms (HABs) distinguishes two groups of organisms: the toxin producers, which can contaminate seafood or kill fish, and the high-biomass producers, which can cause anoxia. Many coastal region of the world is affected by HABs commonly called red tides. HABs are most common in coastal marine ecosystems as well as brackish and freshwater ecosystems. Most HAB events are caused by blooms of microalgae, including certain cyanobacteria (blue-green algae). HAB events are typically associated with rapid proliferation of toxic or otherwise noxious microalgae at the sea surface or in the water column. Even low cell numbers of highly toxic planktonic species or accumulations of cells on benthic substrates may cause problems. Certain HAB species can directly release compounds that are not toxins and non-toxic HABs cause damage to ecosystems (Anderson *et al.* 2012). Ecosystem damage by high-biomass blooms may include, for instance, disruption of food webs, fish-killing by gill damage, oxygen depletion after bloom degradation. Some species also produce potent natural chemicals (toxins) that can persist in the water or enter the food web, leading to illness or death of aquatic animals and/or human seafood consumers (Kudela *et al.* 2015). The most damaging HABs are those caused by toxin-producing microalgae species. The number of species that normally or perhaps only under specific environmental conditions, contain toxins is quite low (~100). Toxins produced by HAB can be transferred within aquatic food chains. Their toxin content varies depending on the N and P concentrations in the water. Intracellular toxin content in HAB species has been shown to increase when the cells grow under nitrogen and/or phosphorus unbalanced conditions (Granéli 2004).

In recent years, red tide events in coastal waters of the Sea of Marmara have been frequently observed particularly in spring and summer. In the previous studies on phytoplankton have been found a certain number of harmful species (Balkis 2003; Aktan *et al.* 2003, 2005; Tas and Okus 2004; Tas *et al.* 2006, 2009, 2011; Turkoglu 2008; 2010a, b; 2013; Deniz and Tas 2009; Turkoglu and Oner 2010; Turkoglu and Erdogan 2010; Kucuk and Ergul 2011; Balkis and Toklu-Alicli 2014; Tas 2015; Tas and Yilmaz 2015; Tas and Lundholm 2016). Studies on harmful algal blooms including cyanobacteria showed that water discoloration, light attenuation, supersaturated dissolved oxygen (Tas and Okus 2011; Ergul *et al.* 2014, 2015; Tas 2015; Tas and Yilmaz 2015) and mucilage formations (Aktan *et al.* 2008; Tüfekci *et al.* 2010; Balkis *et al.* 2011) were major effects on the ecosystem. A study investigated the influence of *Noctiluca scintillans*, a well-known red tide dinoflagellate species, on the abundance, diversity, and community structure of meso-zooplankton in the Sea of Marmara (Yilmaz *et al.* 2005).

In the recent years, studies on dinoflagellate cysts in sediment conducted in the Sea of Marmara. In one of these studies, cysts belonging to the *Cochlodinium* genus, which are toxic and not observed in Turkish Seas, have been detected (Balkis *et al.* 2016). In a recent study, a bio-toxin caused by microalgae, domoic acid (DA), a neurotoxin produced by the diatom genus *Pseudo-nitzschia,* which caused to Diarrethic Shellfish Poisoning (DSP) was detected in the Sea of Marmara (Dursun *et al.* 2016). There is also some non-toxic but potentially harmful species, i.e., bloom forming species which can reach very high abundances can cause discoloration of water and light attenuation. Non-toxic bloom formers can generate anoxic conditions that cause kills of fish and invertebrates at the bottom during decay of the algal bloom.

The main goal of this review study is to summarize the distribution of harmful algae, algal blooms, mucilage events and harmful effects in the Turkish Strait Systems in the light of the studies made so far.

## 2. Potentially harmful microalgae and HAB events in the Sea of Marmara

The Sea of Marmara is located between the Black Sea and Aegean Sea, where saline lower layer originating from Mediterranean Sea is overlaid with brackish waters from the northwestern Black Sea. The system is permanently stratified together with the Straits (İstanbul and Çanakkale) and the coastal embayment, and changes from meso- to eutrophic conditions depending on the location and the season (Tufekci *et al.* 2010).

İzmit Bay is located at the northeastern edge of the Sea of Marmara and is a 50 km length. The Bay is divided into 3 regions: western, central and eastern. The eastern part is 6 km wide and 11 km long on average and a maximum depth of 40 m. The central part is the widest (up to 12 km) and the longest (up to 25 km) in the Bay and the deepest point is 208 m. The Western Basin is connected to the Sea of Marmara. It is a 12 km long and up to 11 km wide basin deepening towards the West (Kuscu *et al.* 2002).

During last 40 years, industrial development and intense urbanization have occurred around İzmit Bay. Consequently, extensive water, air, and soil pollution has occurred. Many major sources of pollution are located around the coast, carrying domestic waste together with effluents from industrial plants such as petroleum refineries, and shipyard, cement, fertilizer, chlor-alkali, metal, pesticides, detergent, dye etc. factories. In addition, the Bay is also under pressure from heavy shipping activities (Tufekci *et al.* 2010). The situation mentioned above influences the water quality and cause to the eutrophication in İzmit Bay. As a consequence, the appropriate conditions for bloom events in some certain species mainly dinoflagellates may occur in this area. The previous studies on phytoplankton community carried out in İzmit Bay showed that some potentially harmful and/or bloom-forming species have been commonly observed (Artuz and Baykut 1986; Tas and Okus 2004; Aktan *et al.* 2005, 2008; Tufekci *et al.* 2010, Kucuk and Ergul 2011; Ergul *et al.* 2014; Ergul *et al.* 2015). The first HAB event in the İzmit Bay caused by *Noctiluca scintillans* (reported as *N. miliaris*) was reported by Artuz and Baykut (1986).

In a phytoplankton study performed in İzmit Bay between 1999 and 2000 reported that a dense bloom caused by dinoflagellate *Prorocentrum scutellum* occurred in the east part of İzmit Bay. In this bloom event was suggested that the abundance of *P. scutellum* reached $2.4\times10^{6}$ cells $L^{-1}$ and a strong discoloration was observed. As a result of this study, it is highlighted that highly eutrophication particularly in the eastern İzmit Bay stimulates the phytoplankton blooms mainly in dinoflagellates (Tas and Okus 2004). In another study performed between February 1999 and September 2000, it was suggested that the İzmit Bay was characterized by intensive dinoflagellate (mainly *Prorocentrum* spp.) dominated bloom in all sampling period (Aktan *et al.* 2005). In September 1999, it has been reported that *P. scutellum* was the dominant and reached ~$410\times10^{3}$cells $L^{-1}$ at the east part of the Bay. Other common *Prorocentrum* species were *P. micans* and *P. cordatum* (reported as *P. minimum*), which are known potentially harmful species and during the study 14 toxic and harmful species were recorded in İzmit Bay. Authors also reported that red tides caused by *Prorocentrum* species were observed in some periods, but other noxious algal blooms were not recorded during the study period (Aktan *et al.* 2005). In the recent studies, the dense dinoflagellate blooms were reported from the İzmit Bay. *Prorocentrum micans* formed dense blooms in March 2014 and in May 2015 and caused to brownish-red water discoloration. At the same area, the bloom of *Noctiluca scintillans* occurred in mid-April 2014, with the pale red water discoloration (Ergul *et al.* 2014; 2015). It was clearly observed the water discoloration in the red tide events caused by *Noctiluca scintillans* in the Sea of Marmara (Figure 1).

The influence of a heterotrophic dinoflagellate (*N. scintillans*) on zooplankton community structure has been investigated in the Sea of Marmara, a highly stratified basin (Yilmaz *et al.* 2005). They reported that enhanced abundance, year-round occurrence, and high condition of *Noctiluca scintillans* population indicated that optimum conditions had been achieved for explosive development of the species in the Sea of Marmara. Increasing dominance of *Noctiluca scintillans* in the Sea of Marmara shows that the species could have a stronger effect on zooplankton in the following years and interrupt trophic pathways by reducing fodder zooplankton biomass. The highest concentration was encountered in May 2002 as 217 cells $L^{-1}$ (Yilmaz *et al.* 2005).

The bloom of the diatom *Nitzschia longissima* from the north-eastern Sea of Marmara was reported by Deniz and Tas (2009). The abundance of *N. longissima* was found $1.28\times10^{6}$ cells $L^{-1}$ in February 2000, and also raphidophyte *Heterosigma* cf. *akashiwo* was first recorded in the same study. Deniz and Tas (2009) reported 25 potentially harmful species in the north-eastern Sea of Marmara. The first study on coccolithophorids in the Sea of Marmara was done by Aubert *et al.* (1990) and a bloom of coccolithophorid *Emiliana huxleyi* ($1.44\times10^{6}$ cells $L^{-1}$) has been reported from the Sea of Marmara.

**Figure 1**. Red-tide of the dinoflagellate *N. scintillans* observed in the Sea of Marmara.

### 2.1. Golden Horn Estuary

The Golden Horn Estuary (GHE) located southwest of the Istanbul Strait, served as a fishery ground, recreational area, and, after the 1950s, as an industrial ground to the inhabitants of Istanbul. Golden Horn Estuary, extending in northwest–southeast direction, is a 7.5 km length and 200–900 m width and covers about 2.6 $km^2$. The maximum depth is around 40 m in the lower estuary and it rapidly decreases to 14 m in the mid-estuary, and to <5 m in the upper estuary. As a result of unplanned urbanization and heavy industrialization, the GHE has been polluted since the 1950s and has become the most significant environmental problem in Istanbul. In 1990s, the estuarine life was limited to the surrounding of Galata and Atatürk Bridges, and the upper estuary had hypoxia and heavy sedimentation together with wastewater discharges. In 1997, the Golden Horn Rehabilitation Project was initiated. The surface discharges were gradually taken under control, connected to collector systems, and discharged into the lower layer of the İstanbul Strait from two deep discharge systems. As the most important step, $4.25\times10^6$ $m^3$ anoxic sediment was removed from the completely filled upper estuary and at least 5 m depth was gained in this region. The turning point for the Golden Horn ecosystem was the opening of the floating Valide Sultan Bridge and release of freshwater in the following week from a dam on Alibey Stream due to maintenance studies at the end of May 2000. This resulted in rapid renewal and oxygenation of anoxic and highly polluted waters trapped at the upper estuary (Tas *et al.* 2009).

The previous studies on phytoplankton carried out in the GHE before its rehabilitation demonstrated that insufficient water circulation, extreme pollution and light limitation limited the growth of phytoplankton, particularly at the upper part of the estuary (Uysal and Unsal 1996; Tas and Okus 2003; Tas *et al.* 2009). However, the blooms of a cyanobacterium *Microcystis* cf. *aeruginosa* occurred in the GHE before rehabilitation and this bloom conditions was studied from 1998 to 2000. The blooms were recorded at the upper part of estuary in winter in the very low salinity conditions due to high precipitation (<5). The highest abundances of *Microcystis* cf. *aeruginosa* were detected as 1.4×10$^6$ cells mL$^{-1}$ in December 1998 and 2.7×10$^6$ cells mL$^{-1}$ in February 1999. During these blooms, DO concentration increased considerably (~7 mg L$^{-1}$) at the upper part of estuary, where it was normally below 1 mg L$^{-1}$. A remarkable increase in the eukaryotic phytoplankton abundance following the rehabilitation of the GHE occurred, while the *Microcystis* cf. *aeruginosa* abundance remained below bloom level (Tas *et al.* 2006).

Following improving water quality by the rehabilitation project, phytoplankton composition changed rapidly and consecutive blooms observed in the GHE. Increased phytoplankton activity resulted in super saturated dissolved oxygen. The first bloom following the rehabilitation efforts occurred by *Skeletonema marinoi* (reported as *S. costatum*) (5×10$^6$ cells L$^{-1}$) in June 2000. The densest bloom (70×10$^6$ cells L$^{-1}$) was caused by dinoflagellate *Prorocentrum cordatum* (reported as *P. minimum*) in July 2000. Subsequent diatom blooms were caused by *S. marinoi* (~8×10$^6$ cells L$^{-1}$) in March 2001 and *Thalassiosira allenii* (4×10$^6$ cells L$^{-1}$) in June 2001. A dense bloom of *P. cordatum* (~36×10$^6$ cells L$^{-1}$) was observed in July 2001, and dissolved oxygen concentration reached super-saturation levels (19.9 mg L$^{-1}$). Dense blooms continued until the end of 2001. At times, different groups such as euglenophytes dominated the phytoplankton; e.g. *Eutreptiella* sp. had the highest abundance (~3×10$^6$ cells L$^{-1}$) in February 2001 (Tas *et al.* 2009).

The prolonged red tide of dinoflagellate *Heterocapsa triquetra* and phytoplankton succession were investigated in the GHE in 2007 (Tas 2015). Red tide of *H. triquetra* was observed with an orange-brownish water discoloration at the upper part of estuary from January to April and the highest cell density reached 19.2×10$^6$ cells L$^{-1}$ in April 2007, when DO concentration was 20.4 mg L$^{-1}$. Successive blooms continued with dinoflagellate *Prorocentrum cordatum* (reported as *P. minimum*) in May, euglenophyte *Eutreptiella marina* and raphidophyte *Fibrocapsa* sp. in summer (Tas 2015).

In the recent study, the distribution of potentially harmful microalgae and algal blooms were investigated in the GHE during one year between 2009 and 2010 (Tas and Yılmaz 2015). A total number of 23 potentially harmful and/or bloom-forming microalgae (14 dinoflagellates, 4 diatoms and 5 phytoflagellates) were identified throughout this study period, of which nine taxa have been confirmed to be toxic and nine taxa formed dense and successive algal blooms causing water discoloration. Dense algal blooms observed in this study belonged to diatoms *Skeletonema marinoi* (54×10$^6$ cells L$^{-1}$) and *Pseudo-nitzschia* spp. (2.8×10$^6$ cells L$^{-1}$), cryptophyte *Plagioselmis* *prolonga* ($7.8\times10^6$ cells $L^{-1}$) and euglenophyte *Euglena viridis* ($1.3\times10^6$ cells $L^{-1}$) in April and May, *P. prolonga* ($7.5\times10^6$ cells $L^{-1}$), *S. marinoi* ($37\times10^6$ cells $L^{-1}$), prasinophyte *Pyramimonas* cf. *grossii* ($1.2\times10^6$ cells $L^{-1}$) and raphidophyte *Heterosigma akashiwo* ($14\times10^6$ cells $L^{-1}$) in June, *Scrippsiella trochoidea* ($2.3\times10^6$ cells $L^{-1}$) in August, *Thalassiosira* sp. ($16\times10^6$ cells $L^{-1}$) and *H. akashiwo* ($1.6\times10^6$ cells $L^{-1}$) in September (Tas and Yılmaz 2015). Temporal and spatial variability of the potentially toxic *Pseudo-nitzschia* spp. was studied in the GHE between 2009 and 2010. Two blooms caused by *Pseudo-nitzschia* spp. were observed in January and May. Two species, *P. calliantha* and *P. pungens*, were identified based on the SEM examination and *P. calliantha* was the first record for the Sea of Marmara (Tas and Lundholm 2016).

Most harmful microalgae were observed in spring and summer, particularly in the middle and upper part of estuary. Water discolorations from orange-brown (*Scrippsiella trochoidea*), to greenish-brown (cryptophyte *Plagioselmis prolonga*), to green (*Euglena viridis*) were observed during these blooms. At time, DO values increased considerably and oversaturated sometimes, e.g. DO concentration reached 17.6 mg $L^{-1}$ during the *Skeletonema marinoi* bloom in July (Tas and Yilmaz 2015).

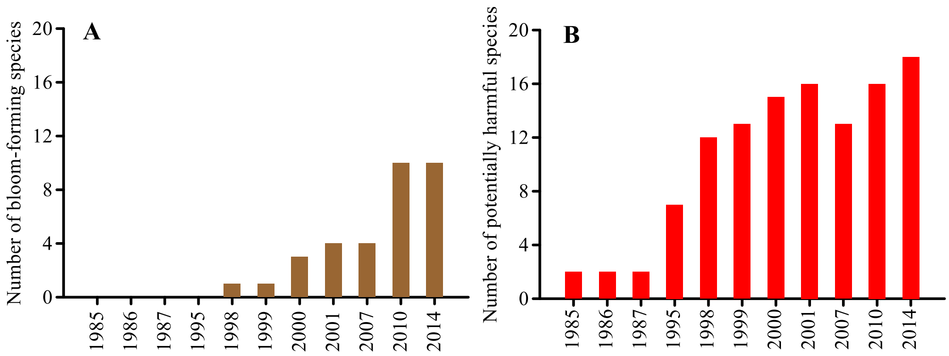


**Figure 2.** Number of bloom-forming species (A) and potentially harmful species (B) in the GHE during the period of 30 years between 1985 and 2014.

The number of the bloom-forming species and potentially harmful species in the GHE increased gradually between 1998 and 2014 and it is obvious that there is a significant increase in HAB events between 2010 and 2014 (Tas and Yilmaz 2015; Tas 2016) (Table 1 and Figure 2). Most of the bloom-forming species is composed of phytoflagellates (5 taxa) and diatoms (4 taxa), while dinoflagellates were represented by one taxon. However, most of the potentially harmful species is composed of dinoflagellates (15 taxa), while diatoms were represented by two taxa. Water discolorations depending on the bloom-forming species were clearly observed in surface of the GHE (Figure 3).

**Table 1.** List of HAB species in eukaryotic phytoplankton observed in the GHE during the period of 30 years between 1985 and 2014.

| 1985-1987 | 1995 | 1998-2001 | 2007 | 2010-2014 |
|---|---|---|---|---|
| **Bacillariophyceae** | **Bacillariophyceae** | **Bacillariophyceae** | **Bacillariophyceae** | **Bacillariophyceae** |
| *Pseudo-nitzschia delicatissima* | *Pseudo-nitzschia delicatissima* | *Pseudo-nitzschia delicatissima* | *Pseudo-nitzschia delicatissima* | *Pseudo-nitzschia calliantha* |
| *P. pungens* | *P. seriata* | *P. pungens* | *P. pungens* | *P. delicatissima* |
| *P. seriata* | | | | *P. pungens* |
| **Dinophyceae** | **Dinophyceae** | **Dinophyceae** | **Dinophyceae** | **Dinophyceae** |
| | *Dinophysis acuminata* | *Akashiwo sanguinea* | *Akashiwo sanguinea* | *Alexandrium* sp. |
| | *D. caudata* | *Dinophysis acuminata* | *Dinophysis caudata* | *Dinophysis acuminata* |
| | *Noctulica scintillans* | *D. acuta* | *Heterocapsa triquetra* | *D. acuta* |
| | *Tripos furca* | *D. caudata* | *Noctiluca scintillans* | *D. caudata* |
| | *Tripos fusus* | *D. sacculus* | *Phalachroma rotundatum* | *D. fortii* |
| | | *Heterocapsa triquetra* | *Prorocentrum micans* | *D. tripos* |
| | | *Gymnodinium. catenatum* | *P. cordatum* | *Heterocapsa triquetra* |
| | | *Noctulica scintillans* | *Scrippsiella trochoidea* | *Lingulodinium polyedrum* |
| | | *Phalachroma rotundatum* | *Tripos furca* | *Noctulica scintillans* |
| | | *Prorocentrum micans* | *Tripos fusus* | *Phalachroma rotundatum* |
| | | *P. cordatum* | | *Prorocentrum micans* |
| | | *Scrippsiella trochoidea* | | *P. cordatum* |
| | | *Tripos furca* | | *Protoperidinium crassipes* |
| | | *Tripos fusus* | | *Scrippsiella trochoidea* |
| | | | | *Tripos furca* |
| | | | | *Tripos fusus* |
| | | **Raphidophyceae** | **Raphidophyceae** | **Raphidophyceae** |
| | | *Fibrocapsa* sp. | *Fibrocapsa* sp. | *Heterosigma akashiwo* |

**Figure 3**. Algal blooms causing water discoloration in the GHE.
(1): diatom *keletonema marinoi,* (2): cryptophycean *Plagioselmis prolonga*,
(3): raphidophycean *Heterosigma akashiwo* (4): euglenophycean *Euglena viridis*
(Photo: S. Tas).

### 2.2. İstanbul and Çanakkale Straits

There are a few studies on HABs performed in the İstanbul and Çanakkale Straits, which have strong current systems. One of them was the study performed by Aktan *et al.* (2003) on the coast of the Istanbul Strait (Bosphorus) between May 1997 and August 1998. A total of five species of coccolithophorids were determined and a bloom was observed during May 1997, and total density of coccolithophorids was detected as $2.34\times10^{6}$ cells $L^{-1}$ dominating by *Calyptrosphaera* species (Aktan *et al.* 2003).

In the study carried out by Turkoglu (2008) in the Çanakkale Strait (Dardanelles) between 7 June and 11 July 2003 has been reported a bloom of *P. micans* reaching $3.3\times10^{6}$ cells $L^{-1}$ and also other dinoflagellates *Tripos* spp. (as reported *Ceratium* spp. containing *C. furca* var. *furca* and *C. fusus* var. *seta*) reached up to $1.05\times10^{6}$ cells $L^{-1}$ in the Sea of Marmara. In the same study performed, it has been investigated the synchronous blooms of the coccolithophoride *Emiliana huxleyi* and three dinoflagellates in the Çanakkale Strait between 7 June and 11 July 2003. In the time-sequence of Sea WiFs images the regions with the highest coccolith accumulations has been observed in the turquoise colour. The algal bloom was first observed in İzmit Bay in early June then quickly spread through the Sea of Marmara and lasted until mid-July. During the bloom period, cell density of *E. huxleyi* reached up to $2.55\times10^{8}$ cells $L^{-1}$ (Turkoglu 2008). Following a summer bloom of coccolithophoride *Emiliana huxleyi* in 2003, a winter bloom has been observed for the first time between December and January in the Çanakkale Strait (Turkoglu 2010a). This winter bloom started middle December 2003 ($7.86\times10^{6}$ cells $L^{-1}$) and then peaked ($5.03\times10^{7}$ cells $L^{-1}$) in early January 2004. Moreover, Turkoglu (2010a) suggested that the bloom started flourishing after diatom and dinoflagellate blooms under nitrogen depletion and moderate light, temperature and salinity conditions.

In the another study, the blooms of coccolithophoride *Emiliana huxleyi* were observed in early December 2004 ($2.36\times10^{6}$ cells $L^{-1}$) and late February 2005 ($1.57\times10^{6}$ cells $L^{-1}$) in Kepez harbor in the Çanakkale Strait (Turkoglu and Oner 2010). Turkoglu (2013) has been investigated red tides of the dinoflagellate *Noctiluca scintillans* associated with eutophication between March 2001 and January 2004 in the Çanakkale Strait and reported that March-June and October-December periods were bloom periods of *N. scintillans*. During bloom periods the density of *N. scintillans* reached $2.2\times10^{3}$ cells $L^{-1}$ and the bloom of *N. scintillans* was associated not only eutrophication, but also with stable temperatures and salinities (Turkoglu 2013).

### 3. Mucilage events in the Sea of Marmara

Mucilage formation in the seas is the aggregation in large amounts of extracellular organic substances producing by various marine organisms under special environmental and trophic conditions (Innamorati *et al.* 2001; Mecozzi *et al.* 2001). It has been stated that diatoms produce extracellular organic substances (Rinaldi *et al.* 1995), and bacteria were reported to participate in this information (Herndl *et al.* 1999; Azam and Long 2001), and dinoflagellates also produce extracellular mucilages (MacKenzie *et al.* 2002). Mucilage formation in the Sea of Marmara began to be observed firstly in İzmit Bay in October 2007 (Aktan *et al.* 2008; Tufekci *et al.* 2010) and in Büyükada Island in the Sea of Marmara (Balkis *et al.* 2011).

Aktan *et al.* (2008) investigated the mucilage event associated with diatoms and dinoflagellates at nine sampling stations in the Sea of Marmara during the bloom period (September 2007- March 2008). During the first days of this bloom, diatom species (*Proboscia alata, Rhizosolenia* sp., *Pseudosolenia calcar-avis*) were most abundant in the phytoplankton community and their total abundance was more than $10^{7}$ cells $L^{-1}$. In February 2008 simultaneously with the diatom bloom, the dinoflagellate *Gonyaulax fragilis* became abundant in the mucilage, but its density did not reach high numbers ($36\times10^{3}$ cells $L^{-1}$). Furthermore, a significant increase of coccolithophores (especially *Emiliana huxleyi*) was observed during the mucilage event (Aktan *et al.* 2008).

In another study, the composition and abundance of phytoplankton together with environmental conditions have been investigated during the mucilage event observed in the Sea of Marmara from October 2007 to February 2008 (Tufekci *et al.* 2010). The most abundant species were *Gonyaulax fragilis, Skeletonema costatum, Ceratoneis closterium* (reported as *Cylindrotheca closterium*) and *Thalassiosira rotula* in the mucilage formation. *G. fragilis* reached $83.6\times10^3$ cells $L^{-1}$ in November 2007 in İzmit Bay, and *T. rotula* was the most abundant diatom species, with $131\times10^3$ cells $L^{-1}$ in the same period. The highest abundance of *G. fragilis* was $96.3\times10^3$ cells $L^{-1}$ in dense mucilage-containing water samples collected from İzmit Bay in January 2008, and *C. closterium* was the dominant diatom species ($161.3\times10^3$ cells $L^{-1}$) in the same sample (Tufekci *et al.* 2010).

Balkis *et al.* (2011) has been investigated the role of single-celled organisms and bacteria in mucilage formation on the shores of Büyükada Island in the Sea of Marmara between January and June 2008. They stated that mucilage formation was very dense in January and February and diatoms *Ceratoneis closterium* (reported as *Cylindrotheca closterium*), *Pseudo-nitzschia* sp., *Skeletonema costatum, Thalassiosira rotula* and dinoflagellate *Gonyaulax fragilis* were the dominant species in mucilage formation. Moreover, it is suggested that bacteria play an important role in the mucilage formations. The highest abundance of *G. fragilis* was $18.2\times10^3$ cells $L^{-1}$ and *C. closterium* was $114\times10^3$ cells $L^{-1}$. As known that a few thousand *G. fragilis* cells release the same amount of carbohydrate as that produced by tens of millions of *C. closterium* cells (Pompei *et al.* 2003). In April, the effect of mucilage began to decline and in June, the mucilage event lost its effect considerably (Balkis *et al.* 2011). Dense mucilage aggregations were observed both in surface and on the sediment of the Sea of Marmara (Figure 4).

**Figure 4.** Mucilage aggregations observed in surface waters of the İzmit Bay (at left) in December 2007 (Photo: S. Tas) and on the sediment in the coast of Erdek Bay (at right) in February 2008 (Photo: N. Balkis).

Although there are many studies on phytoplankton community in the Sea of Marmara as mentioned above, there is only one study on biotoxins caused by microalgae (Dursun *et al.* 2016). In this recent study, domoic acid (DA), a neurotoxin produced by the diatom genus *Pseudo-nitzschia,* which caused to Amnesic Shellfish Poisoning (ASP), from plankton net samples collected in the Sea of Marmara has been firstly investigated in December 2010 and February 2011. In this study, the biotoxin concentrations in samples from coastal waters were detected between 0.96 and 5.25 µg DA/mL in the Sea of Marmara (Dursun *et al.* 2016).

A list of HAB species, which are noxious or toxic and/or bloom-forming species, observed in the Sea of Marmara, has been given in Table 2. A total of 35 taxa were determined as bloom-forming and/or potentially harmful in the phytoplankton community of the Sea of Marmara. Moreover, Aktan and Aykulu (2003) reported three toxic cyanobacteria not included in this Table 2, *Lyngbya* spp., *Planktothrix* sp. and *Pseudoanabaena* sp., from the littoral sediments of İzmit Bay.

**Table 2.** List of potentially harmful and/or bloom-forming microalgae observed in the Turkish Straits System.

| Species | Harmful effect | Most abundant period | Most abundant area | Max. density (cells $L^{-1}$) |
|---|---|---|---|---|
| **Cyanophyceae** | | | | |
| *Anabaena* sp. | Toxic[7] | Aug | NE-SM | $400\times10^3$ |
| *Microcystis* cf. *aeruginosa** | Toxic[7] | Dec, Feb | GHE | $2.7\times10^8$ |
| *Oscillatoria* sp. | Toxic[7] | - | GHE | - |
| **Bacillariophyceae** | | | | |
| *Nitzschia longissima** | Discoloration? | Feb | NE-SM | $1.28\times10^6$ |
| *Pseudo-nitzschia calliantha** | Toxic, ASP[1] | Jan, May | GHE | $1.2\times10^6$ |
| *Pseudo-nitzschia delicatissima* | Toxic, ASP[1] | Jan | GHE | $250\times10^3$ |
| *Pseudo-nitzschia pungens* | Toxic, ASP[1] | Jan, May | GHE | $5.8\times10^5$ |
| *Skeletonema marinoi** (reported as *S. costatum*) | Discoloration | April | GHE | $54\times10^6$ |
| *Thalassiosira* sp.* | Discoloration | Sep | GHE | $15.6\times10^6$ |
| *Thalassiosira allenii** | Discoloration | June | GHE | $4\times10^6$ |
| **Dinophyceae** | | | | |
| *Akashiwo sanguinea** | Ichtyotoxic?[6,10] | May | GHE | $59.5\times10^3$ |
| *Dinophysis acuminata* | Toxic, DSP[1] | May | GHE | $1.3\times10^3$ |
| *Dinophysis acuta* | Toxic, DSP[1] | May, Sep | GHE | $2.6\times10^3$ |
| *Dinophysis caudata* | Toxic, DSP[1] | Sep | GHE | $2.6\times10^3$ |
| *Dinophysis fortii* | Toxic, DSP[1] | May | GHE | - |
| *Dinophysis sacculus* | Toxic, DSP[1] | June | GHE | $5.0\times10^2$ |
| *Phalacroma rotundatum* | Toxic, DSP[1] | May | GHE | $1.3\times10^3$ |
| *Gonyaulax fragilis* | Mucilage formation[2,3,11,12] | Dec, Jan | E-SM | $96.3\times10^3$ |
| *Gymnodinium catenatum* | Toxic, PSP[1] | Jan | GHE | $4.5\times10^3$ |
| *Heterocapsa triquetra** | Discoloration/Fish kills[4,5] | April | GHE | $19.2\times10^6$ |

**Table 2.** (continued)

| Species | Harmful effect | Most abundant period | Most abundant area | Max. density (cells $L^{-1}$) |
|---|---|---|---|---|
| *Lingulodinium polyedrum* | Toxic[6] | May | GHE | - |
| *Noctiluca scintillans** | Discoloration/Ammonia[6] | May | D | $2.2\times10^5$ |
| *Prorocentrum micans** | Discoloration/Fish kills[5] | Sep | D | $3.3\times10^6$ |
| *Prorocentrum cordatum** (reported as *P. minimum*) | Discoloration/Toxic to marine fauna[6] | July | GHE | $70\times10^6$ |
| *Prorocentrum scutellum** | Discoloration | Oct | E-SM | $2.4\times10^6$ |
| *Scrippsiella trochoidea ** | Discoloration/Fish kills[5,6] | Aug | GHE | $2.3\times10^6$ |
| *Tripos furca* (reported as *Ceratium furca*) | Fish kills[5] | June | GHE | $5.2\times10^3$ |
| *Tripos fusus* (reported as *Ceratium fusus*) | Fish kills[5] | March | E-SM | $106\times10^3$ |
| *Tripos* spp. (reported as *Ceratium* spp.: *C. furca* and *C. fusus*) | Fish kills[5] | July | D | $1.05\times10^6$ |
| **Raphidophyceae** | | | | |
| *Heterosigma akashiwo** | Ichthyotoxic/Fish kills[1,8] | June | GHE | $13.9\times10^6$ |
| *Fibrocapsa* sp. | Ichthyotoxic/Fish kills[7] | Nov. | GHE | $288\times10^3$ |
| **Cryptophyceae** | | | | |
| *Plagioselmis prolonga** | Discoloration | May | GHE | $7.8\times10^6$ |
| **Prymnesiophyceae** | | | | |
| *Emiliana huxlei* | Discoloration | July | D | $2.55\times10^8$ |
| **Prasinophyceae** | | | | |
| *Pyramimonas* cf. *grossii ** | Discoloration | June | GHE | $1.6\times10^6$ |
| **Euglenophyceae** | | | | |
| *Euglena viridis** | Discoloration | July | GHE | $11.4\times10^6$ |
| *Eutreptiella marina** | Discoloration | July | GHE | $3.4\times10^6$ |

**Abbrevations**: ASP: Amnesic Shellfish Poisoning; DSP: Diarrethic Shellfish Poisoning; GHE: Golden Horn Estuary; SM: Sea of Marmara; E-SM: Eastern Sea of Marmara; NE-SM: North-eastern Sea of Marmara; D: Dardanelles; The symbol (*) indicates the bloom-forming species: as $mL^{-1}$; ASP: Amnesic Shellfish Poisoning; DSP: Diarrethic Shellfish Poisoning; The numbers ($^x$) indicates the references related to the harmful effects of species: [1]Moestrup *et al.* 2009; [2]Pompei *et al.* 2003; [3]Pistocchi *et al.* 2005; [4]Tas 2015; [5]Lu and Hodgkiss 2004; [6]Hallegraeff 2002; [7]Hallegraeff *et al.* 2003; [8] Heil *et al.* 2005; [9]Koray 2004; [10]Zingone *et al.* 2006; [11]Tufekci *et al.* 2010; [12]Balkis *et al.* 2011.

## 4. Discussion

There was no study on HABs events before 2000s. The studies focusing on HABs have increased in the Sea of Marmara particularly in the GHE, İzmit Bay and Çanakkale Strait. The lack of HABs data before 2000 makes it difficult to compare with the present situations and better understanding the dynamics of HAB events. A few harmful species were reported in the GHE in the period of 1985-1987, because of the one study covering only diatoms. The results obtained from the studies on phytoplankton and HABs performed in the Sea of Marmara showed that there are 35 bloom-forming and potentially harmful species in the Sea of Marmara, as shown in Table 2. Cyanobacteria were represented with 3 species, while diatoms were 7 species, dinoflagellates were 18 species and other marine flagellates were 7 species.

Several species formed successive and dense blooms in the GHE in late spring and summer, particularly between 2010 and 2014. Although neither fish-kill events nor human health problems were witnessed during these blooms, anoxia and light attenuation due to discoloration was observed. But, more harmful effects may occur in the future since the GHE is a potential risk area for future HABs with increase in the number of potentially harmful species and magnitude of blooms in response to rapidly changing environmental conditions (Tas and Yilmaz 2015).

High phytoplankton density in the Çanakkale Strait showed that eutrophication due to high terrestrial discharges coming from Black Sea was the most important factor (Turkoglu and Oner 2010; Turkoglu and Erdogan 2010). High phytoplankton densities in the Çanakkale Strait are generally controlled by smaller forms in size and having generally a short life cycles, such as coccolithophorid *Emiliana huxleyi*, dinoflagellate *Prorocentrum* spp. and diatoms *Dactyliosolen fragilissimus* and *Leptocylindrus* spp. (Turkoglu 2010a). The studies on coccolithophorid *Emiliana huxleyi* indicated that this species came from the Black Sea through the Sea of Marmara and the Çanakkale Strait under favorable conditions. These conditions may be due to climate changes because this species formed not only extensive summer blooms but also winter blooms in the sea of Marmara, in addition to the dramatic eutrophication of the system since 1980s (Turkoglu 2008; 2010a). Bloom of coccolithophorids in the İstanbul Strait may probably be occur because of the hydrodinamics of the Istanbul strait and entry of intensive sources of nutrients from rivers, sewage, industry, heavy marine traffic (Aktan *et al.* 2003).

The bloom of dinoflagellate *Noctiluca scintillans* was associated not only with eutrophication, but also with stable temperatures and salinities. Very excessive blooms of *N. scintillans* caused to gelatinous water and changes in water colour in some recreational swimming areas during late spring and early summer (Turkoglu 2013). Enhanced abundance, year-round occurrence, and high condition of *Noctiluca* population indicated that optimum conditions have occurred for explosive development of the species in the Sea of Marmara (Yılmaz *et al.* 2005). In recent years, brownish-red water discoloration caused by *Prorocentrum micans* and pale red water discoloration caused by *Noctiluca scintillans* were commonly observed in the İzmit Bay (Ergul *et al.* 2014).

During mucilage observations in the Sea of Marmara, neither hypoxia/anoxia nor fish kills have been recorded (Aktan *et al.* 2008), but the large quantity of mucilage aggregates affected fishing activities and fishing associations were highly sensitive to this matter (Aktan *et al.* 2008; Tufekci *et al.* 2010; Balkis *et al.* 2011) and extensive benthic mucilage aggregates were observed on the sediments and mussels (Aktan *et al.* 2008). Moreover, the presence of high dissolved organic carbon (DOC) content in the waters surrounding the aggregate indicate that the vicinity of the material produced was 5-10 times richer in organic material than the usual organic carbon content of the sea (Tufekci *et al.* 2010). In the recent years, the studies on dinoflagellate cysts are very important to monitor the blooms might be in the future caused by these species (Balkis *et al.* 2016). Therefore, the number of these studies should be increased.

In conclusion, as shown in the results, there are significant increases both in algal blooms and the number of potentially harmful species in the Sea of Marmara in recent years. We can assume that nutrient enrichment human induced lead to eutrophication and climate change caused by global warming are the main factors supporting many algal blooms. The resulting stress conditions accelerate the competition among species and promote the reproduction of certain microalgae species particularly in competitive and tolerant species. Considering the increasing algal blooms and harmful species in recent years, it appears clearly that the studies on HABs and their impacts on the ecosystem should be increase and the water quality monitoring studies should be conducted at regular intervals.

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# TOTAL METAL DISTRIBUTIONS IN THE SURFACE SEDIMENTS FROM THE ISTANBUL COAST (MARMARA SEA), TURKEY

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## 1. Introduction

Istanbul is the most heavily populated and industrialized metropolitan area of Turkey. The pollution problems of the Istanbul Strait primarily result from the high population of the city of Istanbul, Black Sea inflow, and ship traffic. Istanbul is the most populated (15 % of the total population) and industrialized (50 % of the total industry) city in Turkey. In addition to industrial and domestic load from Istanbul Metropolitan, dissolved and particulate pollution loads from the Danube River are transported towards the Istanbul Strait by alongshore currents (Tuğrul and Polat 1995). Additionally, this region receives pollution not only from various local land-based sources, but also from the heavily populated and industrialized Istanbul Metropolitan and from maritime transportation (Algan *et al.* 1999; Taşkın *et al.* 2011; Aksu and Taşkın 2012). Algan *et al.* 1999 point out that the Istanbul sediments were found to be less polluted than those of similar marine environments, such as the New York Harbour; the metal concentrations were considerably lower than those of the heavily polluted Golden Horn sediments but comparable to those of Thermaikos Bay, Southern California and the Bristol channel. Okuş *et al.* 2008 also reported that 25% of the wastewater of the total city population was discharged via creeks into the Sea of Marmara and Istanbul Strait coastal waters. Additionally, Balkıs *et al.* 2012 point out that Lead, Cadmium and Mercury levels in the nearshore surface sediments from the European and Anotolian Shores of throughout Istanbul Strait.

## 2. General Aspects of the Istanbul Strait

The Istanbul Strait is characterized by a two-layer flow system, with less saline Black Sea water entering the Sea of Marmara as the surface current, and more saline Mediterranean water flowing to the Black Sea as the under current. The velocity of the surface currents is between 0.20 and 5 m/sec, and that of the under current between 0.05 to 2.50 m/sec (Ozsoy, 1986). As a consequence of such strong current activity, coarse-grained sediments of mainly sand and gravel composition cover the floor of the Strait. Fine-graind (silt and clay) sediments with varying proportions of sand occur near the con- fluence of the Strait and the Sea of Marmara. A mixture of coarse- and fine-grained material is found at the Black Sea entrance of the Strait.

### 3. Metals in sediments

Total Aluminum (Al) , Iron (Fe), Mangenese (Mn) and Copper (Cu) contents of surface sediments from Istanbul Coast vary between 1.8% and 5.4%; 1.1% and 2.8%; 122 and 259 µg $g^{-1}$; 27 and 416 µgg $^{-1}$, respectively (Figure 1 and Table 1). Al, Fe and Mn contents are lower than the shale average 9.4%, 4.7% and 800 µg$g^{-1}$(Krauskopf 1979), respectively in the surface sediments compared to those of the previous studies (Algan *et al.* 1999). On the other hand, EF (EF = Cmetal/CAl)sample/(Cmetal/CAl)-shale and CF (CF = Cs/Cb ; Cs = Measured metal value, Cb = Shale average of the metal as Krauskopf, 1979) values of Fe and Mn are lower than 1.5 and 1, respectively, in all the stations. For these reasons, there is no metal enrichment in this region, and metals found may be entirely from crustal materials or natural weathering processes. In contrast, EF values of Cu are higher than 1.5 at all stations except Station MY2 (Table 1). CF values of Cu are also slightly higher than 1 in the surface sediments of MK and MKC Stations, and these sediments are moderately contaminated by copper. The CF value of Cu is higher than 6 in Station MY1's surface sediment, and there is very high contamination of this metal. This result is connected with the anthropogenic inputs from Tuzla Port, dense ship traffic, and discharges into the lower layer of this location by the General Directory of Istanbul Water and Sewer Administration (ISKI).

**Table 1**. Al, Fe, Mn and Cu concentrations of sediments from the Marmara Sea (µg/g dry wt.) and Enrichment Factors (EF and Contamination Factors (CF) of metals (Taşkın *et al.* 2011).

| | **Al*** | **Fe*** | **Mn** | **Cu** | **EF (Fe)** | **EF (Cu)** | **EF (Mn)** | **CF (Fe)** | **CF (Cu)** | **CF (Mn)** |
|---|---|---|---|---|---|---|---|---|---|---|
| **MKÇ** | 2,1 | 1,06 | 122 | 50 | 0,9 | 5,0 | 0,5 | 0,24 | 1,4 | 0,14 |
| **K0** | 2,9 | 1,4 | 238 | 27 | 0,8 | 1,7 | 0,9 | 0,3 | 0,6 | 0,3 |
| **MY1** | 3,2 | 2,0 | 140 | 416 | 1,1 | 21 | 0,5 | 0,4 | 8,3 | 0,2 |
| **M8** | 3,8 | 1,5 | 151 | 30 | 0,9 | 1,8 | 0,8 | 0,4 | 0,72 | 0,31 |
| **MY2** | 5,38 | 2,76 | 181 | 28 | 1,0 | 0,9 | 0,4 | 0,6 | 0,54 | 0,21 |
| **MK** | 2,4 | 2 | 191 | 48 | 1,5 | 3,5 | 0,8 | 0,44 | 1,1 | 0,23 |
| **MBÇ** | 1,75 | 1,11 | 259 | 38 | 1,2 | 3,5 | 1,5 | 0,23 | 0,7 | 0,3 |

* %

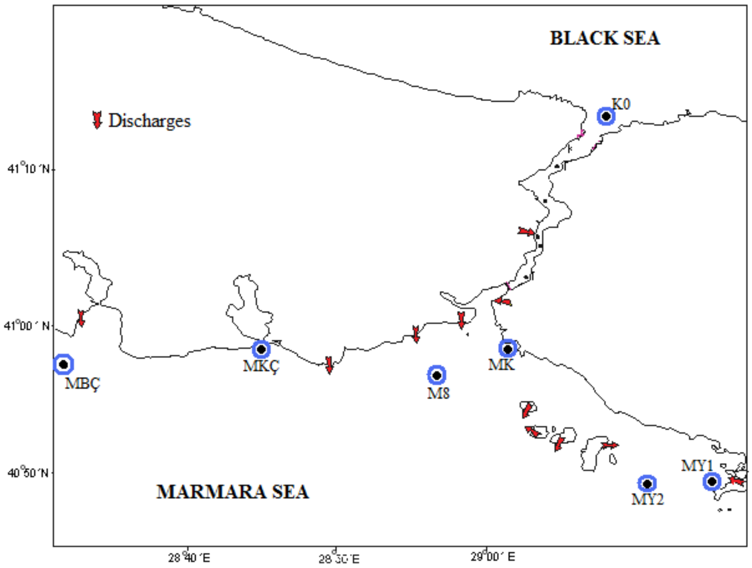


**Figure. 1.**The location of sampling points

**K0:** Bosphorus entry from the Black Sea, Depth 72 m
**M8**: Bosphorus output to the Marmara Sea, Depth 65m
**MBÇ:** Büyükçekmece Bay, the Northern Marmara Sea, Depth 50m
**MKÇ:** Küçükçekmece Bay, the Northern Marmara Sea, Depth 38m
**MY1:** The region's coast under the influence of the Tuzla Port, Depth 42m
**MY2:** The region's open sea under the influence of the Tuzla Port, Depth 89m
**MK:** Moda Bay, The region under the influece of the ship traffic, Depth 8m.

Total Lead (Pb), Cadmium (Cd) and Chromium (Cr) contents in the surface sediments from Istanbul Coast vary between 32 $\mu g.g^{-1}$ and 122 $\mu g.g^{-1}$; 0.19 $\mu g.g^{-1}$ and 1.16 $\mu g.g^{-1}$; 62 $\mu g.g^{-1}$ and 372 $\mu g.g^{-1}$, respectively (Table 2). While Pb contents are higher than the shale average (20 $\mu g.g^{-1}$, Krauskopf, 1979) Cd and Cr contents are lower than the shale average values except MY1 station (Tuzla Port) (0.3 and 100 $\mu g.g^{-1}$, respectively, Krauskopf 1979) in the surface sediments compared to those of the previous studies. On the other hand, EF (EF= $C_{metal}$ / $C_{Al})_{sample}$/ $C_{metal}$ / $C_{Al})_{shale}$ and CF (CF= $C_s$ / $C_b$ $C_s$ = measured metal value, $C_b$ = Shale average of the metal as

Krauskopf, 1979) values of Pb and Cr are quite high in all the stations. Similarly, EF values of Cd are found higher than 1.5 at MKC and MY1 stations. It means that there is metal enrichment in these regions, and these metals found may be entirely from anthropogenic (industrial and domestic) sources. CF values of Cr are lower than 1 in all the surface sediments except MY1 station and these sediments are slightly contaminated by this element. In contrast, CF value of Cr is higher than 3 in Station MY1's surface sediment, and there is very high contamination of this metal. CF values of Pb are determined between 1 and 3 in all the surface sediments except MY1 station and these sediments are moderately contaminated by Pb. In MY1 station, CF value is found higher than 6 and there is very high contamination for this metal. These results are connected with the anthropogenic (domestic and industrial) inputs from Tuzla Port, dense ship traffic, and discharges into the lower layer of this location by the General Directory of Istanbul Water and Sewerage Administration (ISKI).

**Table 2.** Metals concentrations of sediments from the Marmara Sea (μg $g^{-1}$ dry wt.) and Enrichment Factors (EF) and Contamination Factors (CF) of metals (Aksu and Taşkın, 2012).

| | **Pb** | **Cd** | **Cr** | **EF (Pb)** | **EF (Cd)** | **EF (Cr)** | **CF (Pb)** | **CF (Cd)** | **CF (Cr)** |
|---|---|---|---|---|---|---|---|---|---|
| **MKC** | 32 | 0.19 | 77 | 5.87 | 2.26 | 2.82 | 1.61 | 0.02 | 0.77 |
| **K0** | 39 | - | 74 | 5.98 | - | 2.29 | 1.94 | - | 0.74 |
| **MY1** | 122 | 1.16 | 372 | 15.47 | 9.83 | 9.44 | 6.10 | 0.13 | 3.72 |
| **M8** | 43 | - | 89 | 5.27 | - | 2.21 | 2.12 | - | 0.89 |
| **MY2** | 33 | - | 70 | 2.83 | - | 1.21 | 1.64 | - | 0.70 |
| **MK** | 49 | - | 62 | 8.21 | - | 2.11 | 2.43 | - | 0.62 |
| **MBC** | 34 | - | 88 | 9.08 | - | 4.69 | 1.71 | - | 0.88 |
| **Shale average*** | 20 | 0.3 | 100 | | | | | | |

-: not detected

Total Pb, Cd and Hg concentrations in the nearshore surface sediments from the European and Anotolian Shores of Istanbul Strait are given at Table 3 (Balkıs *et al.* 2012). While Pb contents are considerably higher than the shale average (20 μg.$g^{-1}$, Krauskopf, 1979) at stations Harem and Paşabahçe, the lowest Pb values are measured at stations Poyraz and Garipçe. Cd contents are generally found higher than the shale average (0.3 μg.$g^{-1}$, Krauskopf, 1979) in all the stations. In contrast Hg values are lower than the shale average (0.3 μg.$g^{-1}$, Krauskopf, 1979) along the Istanbul Strait. A Contamination Factor (CF), calculated as the ratio between the sediment metal content at a given station and the normal concentration levels, reflects the metal enrichment in the sediment (Pekey *et al.* 2004). CF (CF= Cs / Cb   Cs = measured metal value, Cb = Shale average of the metal as Krauskopf, 1979) values of Pb and Cd range between 1 and 3 whilst CF values of Hg are lower than 1 in all the stations. It means that there are no Hg enrichment by natural or anthropogenic inputs contrary to moderataly contamination for Pb and Cd in this region. There is dense ship traffic especially at station Harem, and discharges into the upper and lower layer by the General Directory of Istanbul Water and Sewerage Administration (ISKI) along the Istanbul Strait. In the earlier studies, the high suspended solid matter and biological oxygen demand contents point out the dense pollution at stations Paşabahçe, Küçüksu and Göksu along the Istanbul Strait (Okuş *et al.* 2008).

**Table 3.** Metal concentrations in the nearshore surface sediments from the European and Anotolian Shores of Istanbul Strait (µg $g^{-1}$ dry wt.) and Contamination Factors (CF) of metals (Balkıs *et al.* 2012).

| | Pb | Cd | Hg | CF (Pb) | CF (Cd) | CF (Hg) |
|---|---|---|---|---|---|---|
| **Harem (St.1)** | 20-202 | <0.01-0.71 | 0.001-0.21 | 3.4 | 1.43 | 0.2 |
| **Paşabahçe (St.2)** | 11-238 | <0.01-0.58 | 0.021 | 2.7 | 1.3 | 0.53 |
| **Poyraz (St.3)** | 5-30 | <0.01-0.82 | 0.001-0.45 | 0.9 | 1.3 | 0.23 |
| **Sarıyer (St.4)** | 5-42 | <0.01-0.92 | 0.012-0.17 | 1.1 | 1.4 | 0.14 |
| **Garipçe (St.5)** | <0.01-34 | <0.01-0.54 | 0.011-0.20 | 0.9 | 1.5 | 0.17 |
| **Shale average*** | 20 | 0.3 | 0.3 | | | |

*From Krauskopf (1979). p.544-545

**Acknowledgements**

We thank the captain, crew, scientists, and technicians on board of the R/V ARAR; the Institute of Marine Sciences; and the Management of Istanbul University for their help during the collection of water samples. This work was supported by the General Directory of Istanbul Water and Sewerage Administration (ISKI).

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# THE ACCUMULATION OF MARINE LITTER ON THE SEABED OF THE SEA OF MARMARA

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## 1. Introduction

It has been accepted that marine litter is a global pollution problem. A number of regional assessments has been made within the UNEP's global initiative including the Mediterranean and the Black Sea. It has also been reserved in the MSFD (2008/56/EC) as one of the descriptors (D10) to define and achieve good environmental status (GES). Considering the importance and current advances in research and monitoring needs of the topic as well as the lack of data and information on the distribution, trends and the impacts on ecosystems, Ministry of Environment of Turkey has started to support a number of studies.

The data and information on the distribution of the sea floor litter is very limited for the Turkish seas since monitoring activities have not been performed up to now. Only few published studies exist as part of fisheries studies (Bingel *et al.* 1987; Topçu *et al.* 2008, 2010). One of the rare data sets, being gathered for DeKoS, of the similar works is presented here for the Sea of Marmara. This study is on the litter accumulation on the sea floor as number, content and weight of the items. A broad comparison of the collected material is presented for two years; 1994 and 2000, and a relationship between the distribution of marine litter and the biodiversity has been cited.

## 2. Material and methods

The soft bottom substratum was sampled between 20-200 meters depth interval at 34 trawl stations (Figure 1).

The litter and the biological material caught in 30 minute samplings were analyzed according to their types, weight and biomass.

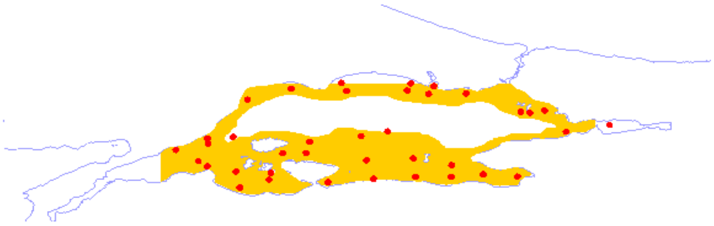

**Figure 1.** Trawl stations in the Sea of Marmara

## 3. Results

The results obtained for different periods have shown that about 90-97% of the trowled items was composed of packing material and a small amount of the litter are related to fishing, sea vehicles and accidents (Figures 2 and 3). About 50% of the pollution caused by packing material was plastics and other petroleum derivatives and 30% of the litter was cans and other aluminum material.

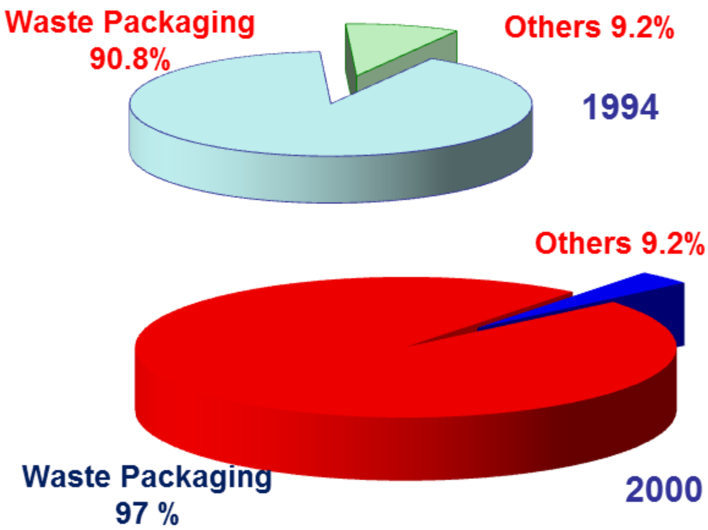


**Figure 1.** Marine litter sources in different years

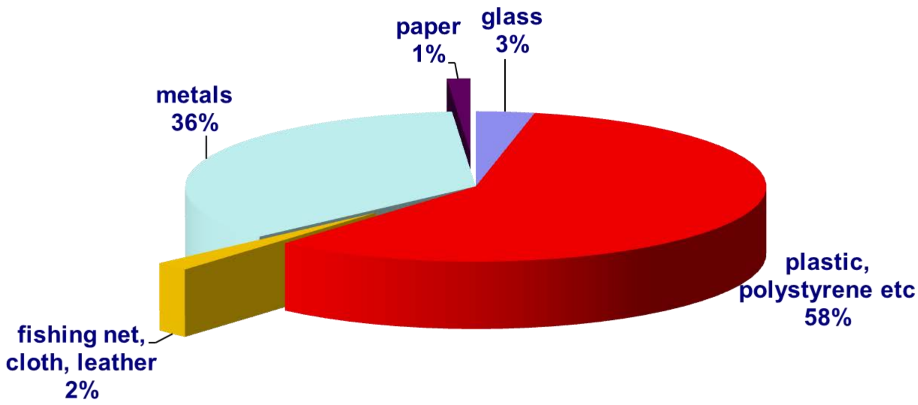


**Figure 2.** Distribution of the different kinds of litter

The litter composition differs due to residential habbits, wind regime and currents; in example while plastic bags in Gemlik Bay and PET bottles in Erdek Bay are in very high amounts, cans are in similar condition in the reagion of İstanbul ve Tekirdağ. And the marine litter as we call “others” is dominant in the environment of İzmit Bay.

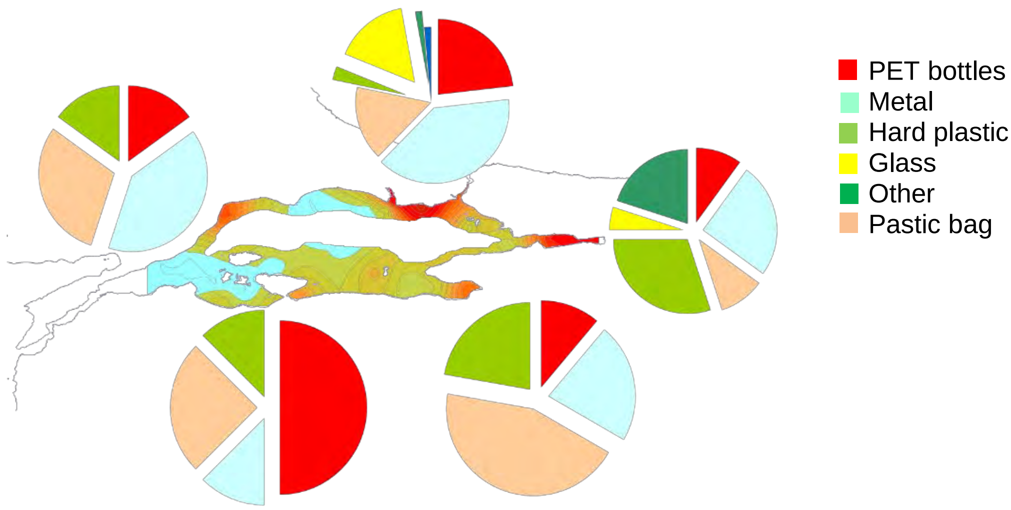


**Figure 3.** The difference of the marine litter composition according to regions

The litter intensively distributed mainly around Istanbul metropolitan area; coastal shelf between Büyükçekmece-Yenikapi (northern coastal strip), Tuzla shipyards area (southern coastal strip) and Izmit Bay. This is illustrated in Figure 5, respectively showing the distribution of number of items and the weight of marine litter in August 2000. In general, 406 kg/m$^2$ litter was calculated for unit area which makes 1925 tonnes of litter for the whole seabed. This value is about 16% of the weight of demersal fish caught during the same survey. In 1994, the amount of litter was about 318 tonnes in the same trowling areas which showed a ~6 times increase until the year 2000. More reliable trends can be obtained with the analysis of similar data sets after 2000.

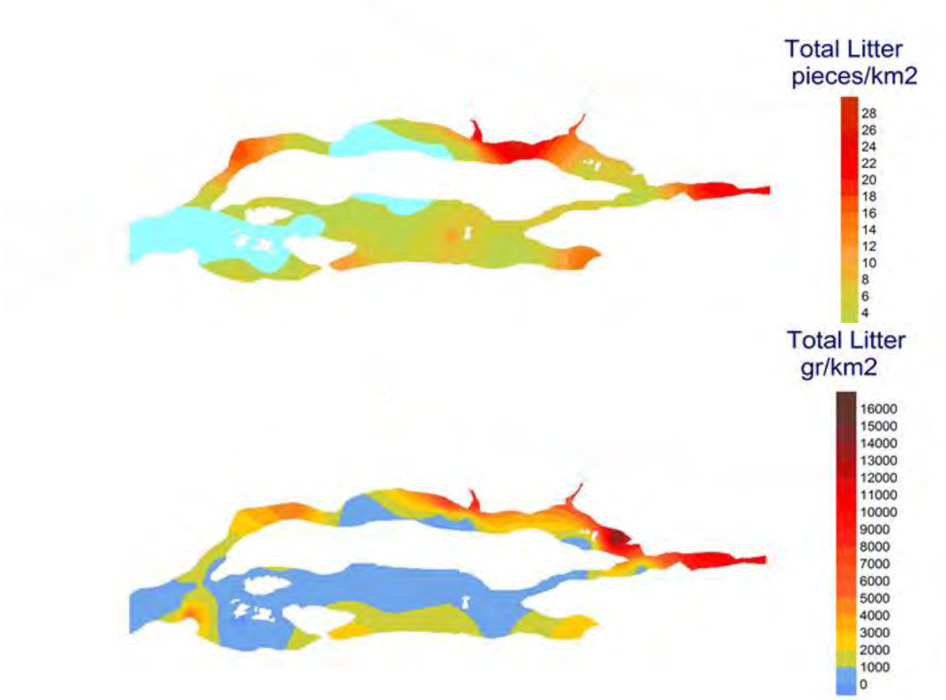


**Figure 5.** Number and weight of the litter per unit area according to regions

**4. Discussion**

The investigations have shown that the species diversity and the biomass of demersal fish was less in areas where quantity of litter was higher. The increasing trend of litter has been causing greater problems for fisheries too. The activities in the river basins as much as in the coastal and marine areas may fairly effect the intense seabed accumulation of marine litter. The problem causing activities in the region are: un-properly managed litter storage sites at the coastal areas and up-stream, intense maritime activities along the Turkish Straits System and lack of enough port reception facilities. The litter collection by fishermen might be encouraged within ongoing fishing activities applying a payment system for the return of wastes. This has to be supported with enough number of waste reception facilities at ports and sea. Nevertheless, the trends and effects of litter at seabed and water column have to be systematically investigated, as being required by the criteria and standards on GES, in order to better understand the present status and the extent of the impact on the sea floor.

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# ORGANOCHLORINE RESIDUE AND SOURCES OF POLYCYCLIC AROMATIC HYDROCARBONS (PAHS) IN SURFACE SEDIMENTS FROM THE ISTANBUL COAST (THE SEA OF MARMARA), TURKEY

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## 1. Introduction

The organochlorines have been associated with significant environmental impact in a wide range of species and at virtually all tropic levels. Many organochlorines have been implicated in a broad range of adverse human health and environmental effects, including impaired reproduction, endocrine disruption, immunosuppression and cancer (UNEP 1996). The primary transport routes into marine and coastal environments include atmospheric deposition and surface run-off, the former being by far the greatest albeit dispersed over large areas (Tolosa *et al.* 1995; Ciscato *et al.* 2002). Because many organochlorines are relatively volatile, their remobilization and long-distance redistribution through atmospheric pathways often complicates the identification of specific sources (Yamashita *et al.* 2000). Nevertheless, those (the majority) used in agriculture are also washed off the land into rivers, thence to the sea or directly into the sea via outfalls or run-off (Majewski and Capel 1995; Pilar and Joan 2003). Istanbul is the most heavily populated and industrialized metropolitan area of Turkey. In addition to industrial and domestic load from Istanbul Metropolitan, dissolved and particulate pollution loads from the Danube River are transported towards Istanbul Strait by alongshore currents (Tuğrul and Polat 1995). Additionally, this region receives pollution not only from various local land-based sources, but also from the heavily populated and industrialized Istanbul Metropolitan and from maritime transportation (Taskin *et al.* 2011).

Polycyclic aromatic hydrocarbons (PAHs) are one of the most important classes of ubiquitous priority pollutants whose carcinogenic and mutagenic properties and endocrine disrupting effects have been reported in several environmental matrices (Peterson *et al.* 2003). Both the natural (such as incomplete high temperature combustions) and anthropogenic sources (such as thermal combustion processes, vehicular emissions, and biomass burning) account for their diffusion into the environment, as a consequence of atmospheric transport, deposition and dispersion in the environment (Simoneit 1984). Furthermore, their semi-volatility and high environmental half-lives result in the global planetary distribution (Lee *et al.* 1999;

Mastral and Callen 2000; Martinez *et al.* 2004; Pilar and Joan 2003). The pollution problem of the Sea of Marmara primarily results from the high population of the large cities, the Black Sea inflow, and dense ship traffics on the Istanbul Strait and Dardanelles Aksu and Taşkın, 2012 also reported PAH contamination of surface sediment from the Istanbul Coast.

## 2. Organochlorine Residues in sediments

Total organochlorine residue concentrations range between 4.33 ng $g^{-1}$ and 22.2 ng $g^{-1}$ in the surface sediments (Figure 1 and Table 1). The highest values are measured at M8 station whilst the lowest contents are found in Station MBC's surface sediments. Concentrations of organochlorine residues in sediments from the Sea of Marmara are associated with the dense agricultural activities in the rest of the Northern and Southern Coastal Shelves. The high DDE and DDD levels of sediments are also caused by the anthropogenic inputs from agricultural areas. The ranking concentrations of the various organochlorine compounds in sediments from the Sea of Marmara are as follows: p, p DDD > o, p DDD > p, p DDE > o, p DDE > alphaendosulphan > endrin > total HCH > beta-endosulphan. While these results show the illegal use of organochlorine insecticides in Turkey in recent years, the other explicable reason for the contamination observed may be inputs from the Black Sea where the levels are quite high.

**Table 1**. Pesticides concentrations of sediments from the Sea of Marmara (ng.g-1 dry wt.) (Aksu and Taşkın, 2012).

| | **T. HCH** | **β END.** | **4'4 DDD** | **2'4 DDD** | **α END.** | **ENR.** | **2'4 DDE** | **4'4 DDE** | **Total Pesticides concentrations** |
|---|---|---|---|---|---|---|---|---|---|
| **MKC** | - | - | 2.75 | 0.50 | - | - | 4.53 | 5.96 | 13.74 |
| **K0** | - | - | 3.48 | 1.14 | - | - | 6.65 | 4.83 | 16.1 |
| **MY1** | - | - | 4.34 | 3.43 | - | - | 2.70 | 4.22 | 14.69 |
| **M8** | - | - | 5.03 | 7.12 | - | - | 3.81 | 6.24 | 22,2 |
| **MY2** | - | - | 5.46 | 1.94 | - | - | 3.23 | 1.92 | 12.55 |
| **MK** | - | - | 4.76 | 2.38 | 1.83 | 0.79 | 3.23 | 4.93 | 17.92 |
| **MBC** | 0.37 | - | 2.72 | 0.33 | - | - | 0.94 | 0.44 | 4.43 |

-: not detected

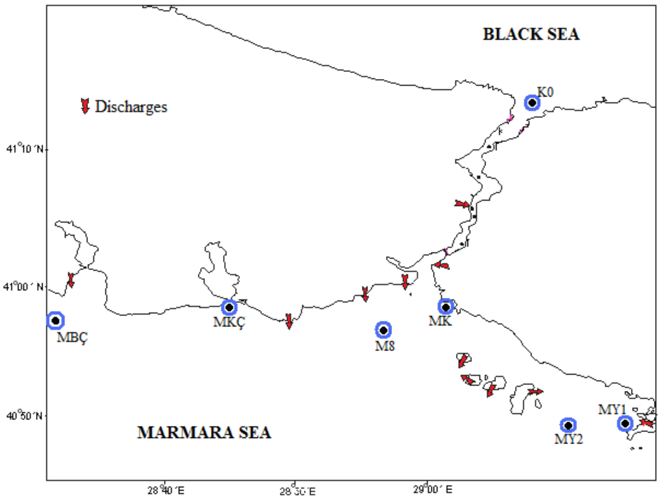


**Figure. 1.**The location of sampling points

**K0:** Istanbul Strait entry from the Black Sea, Depth 72 m
**M8**: Istanbul Strait output to the Sea of Marmara, Depth 65m
**MBÇ:** Büyükçekmece Bay, the Northern Sea of Marmara, Depth 50m
**MKÇ:** Küçükçekmece Bay, the Northern Sea of Marmara, Depth 38m
**MY1:** The region's coast under the influence of the Tuzla Port, Depth 42m
**MY2:** The region's open sea under the influence of the Tuzla Port, Depth 89m
**MK:** Moda Bay, The region under the influece of the ship traffic, Depth 8m.

### 3. PAHs in sediments

Total PAH concentrations range between 125 and 6009 ng $g^{-1}$ in the surface sediments. PAH contents are higher than those found in previous studies, especially at MK and MY2 Stations, because of the dense ship traffic and inputs from Tuzla Port, but are lower than values found in Izmit and Gemlik Bays (Unlu and Alpar 2006). The results show that the most of PAH contamination has originated from pyrolytic inputs per the PHE/ANT ratio (Table 2). On the other hand, the majority of the PAH sources in sediment samples from the Sea of Marmara are pyrolytic. Home heating systems (e.g., cooking and heating oils and coal burning) and vehicular emissions (e.g., automobiles and trucks), and biomass burning (e.g., fireplaces and controlled burning) may be the sources of this contamination. Contrastingly, PAH contamination has also originated from petrogenic sources, according to the FLU/PYR ratio analysis of the surface sediments of K0, MKC and MY1 Stations (Table 2). These results indicate the fresh petroleum inputs from ship traffic into the marine system. In addition,there is a moderate correlation (r = +0.62) between the PAH and Fe concentrations in the surface sediments. This correlation may be result from similar structural features and/or same-source pollutants.

**Table 2**. PAHs concentrations of sediments from the Sea of Marmara (ng/g dry wt.) and PAHs source data for sediment of the Sea of Marmara (Taşkın *et al.* 2012).

| | NAP | ACL | AC | PHE | ANT | FLU | PYR | BaA | PHE/ ANT | FLU/P YR | (PHE/AN T)/(FLU/ PYR) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MKÇ** | 3.37 | 4.21 | 0.42 | 29.5 | 53.9 | 17.4 | 22.5 | 19 | 0.54 | 0.77 | 0.70 |
| **K0** | 4,18 | 6,81 | 0.48 | 42 | 76.9 | 27.9 | ND | 51.1 | 0.54 | - | - |
| **MY1** | 4,57 | 5,84 | 1.58 | 14.5 | 54.7 | 13.5 | 24.1 | 30.5 | 0.26 | 0.56 | 0.47 |
| **M8** | 15 | 8,98 | ND | 9.83 | ND | 94.6 | 24.8 | 94.8 | - | 3.81 | - |
| **MY2** | 17,7 | 12,5 | ND | 458.5 | 1530.5 | 470.5 | 191.6 | 662.6 | 0.29 | 2.45 | 0.12 |
| **MK** | 83,1 | 56,2 | ND | 1548.1 | 833.8 | 1702.6 | 430.2 | 1355.4 | 1.85 | 3.95 | 0.46 |
| **MBÇ** | 6,35 | 5,73 | 1.12 | 15.3 | 21.9 | 14.9 | 14.7 | 44.5 | 0.69 | 1.01 | 0.68 |
| **Pyrolytic origin** | | | | | | | | | <10 | >1 | 0-10/>1 |
| **Petrogenic origin** | | | | | | | | | >15 | <1 | > 10 / <1 |
| **Reference** | | | | | | | | | Soclo, 1986 | Sicre *et al.* 1987 | Baumard *et al.* 1998 |

Naphthalene: *NAP*; Acenaphthylene: *ACL*; Acenaphthene: *AC*; Phenanthrene: *PHE*; Anthracene: *ANT*; Fluoranthene: *FLU*; Pyrene: *PYR*; Benzo(a)anthracene: *BaA*, ND: Not Dedection.

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# LEAD, CADMIUM, ARSENIC, MERCURY AND ORGANOCHLORINE RESIDUE LEVELS IN HAKE (*Merluccius merluccius*) FROM THE SEA OF MARMARA, TURKEY

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## 1. Introduction

Organochlorine pesticides have been extensively used for agriculture and vector control purposes. The pesticides applied on land eventually find their way into the aquatic environment, thus contaminating it. The pesticides are transported to aquatic bodies by rain runoff, rivers and streams and associate with biotic and abiotic macroparticles (Colombo *et al.* 1990). They are removed from the surface to the benthic layers by the settling of particles into the water column (Allan 1986). The lipophilic nature, hydrophobicity and low chemical and biological degradation rates of organochlorine pesticides have led to their accumulation in biological tissues and the subsequent magnification of concentrations in organisms progressing up the food chain (Swackhamer *et al.* 1988; Vassilopoulou & Georgakopoulous-Gregoriades 1993; Ciscato *et al.* 2002). Consumption of biota from contaminated aquatic bodies is considered to be an important route of exposure to persistent organochlorine compounds (Johansen *et al.* 1996). Humans, being a final link in the food chain, are chiefly affected, and consequently, the general public has become increasingly concerned about the potential risks to human health from consumption of such polluted biota (Helle *et al.* 1976; Yücel 2007).

Synthetic organochlorines such as DDTs, PCBs (polychlorinated biphenyls), HCHs (hexachlorocyclohexanes), CHLs (chlordanes), cyclodienes and HCB (hexachlorobenzene) are highly resistant to degradation by biological, photochemical or chemical means. They are also liable to bioaccumulate, are toxic and are probably hazardous to human and/or environmental health. Most are prone to long-range transfer (Tanabe *et al.* 1994; UNEP 1996; Maroni *et al.* 2000; Kaya and Bilgili 2002; Margariti *et al.* 2007). These compounds are also typically characterised as having low water solubility and highlipid solubility. The organochlorines have been associated with significant environmental impact in a wide range of species and at virtually all tropic levels. Many organochlorines have been implicated in a broad range of adverse human health and environmental effects, including impaired reproduction, endocrine disruption, immunosuppression and cancer (UNEP 1996). Their primary transfer routes into marine and coastal environments include atmospheric deposition and surface run-off, the former being far greater, albeit dispersed over larger areas. Because many organochlorines are relatively volatile, their remobilization and long-distance redistribution through atmospheric pathways often complicates the identification of specific sources. Nevertheless, the majority of organochlorines used in agriculture are also washed off the land into rivers, thence to the sea, or directly into the sea via outfalls or run-off. There is substantial information concerning contamination in many industrialised countries, and a number of studies have been conducted regarding organochlorine contamination in Eastern Europe, Asia (Iwata *et al.* 1994a; Iwata *et al.* 1995; Vetter *et al.* 1995; Nakata *et al.* 1997; Tanaba *et al.* 1997a) and the Black Sea (Fillmann *et al.* 2002).

Toxic metal contents of frequent mytilus and occasional fish samples from the Sea of Marmara have been investigated at different times during the previous years (Yıldızdağ 1992; Kocahan 1999; Topçuoğlu 2000; Topçuoğlu *et al.* 2003; Altuğ and Güler 2002; Kurun *et al.* 2006; Kayhan *et al.* 2006; Kayhan *et al.* 2007). They reported high Pb and Hg levels in biota, especially in those collected from the Southern Sea of Marmara. Aksu *et al.* 2011 also point out that the toxic metal (Pb, Cd, As And Hg) and organochlorine residue levels in hake (Merluccius Merluccius) from the Sea of Marmara.

## 2. General Aspects of the Sea of Marmara

The Sea of Marmara constitutes an oceanographical link between two large semi-enclosed basins: the Mediterranean Sea and the Black Sea (Figure 1). It is a land-locked sea between the Thrace and Anatolian peninsulas and is connected to the brackish Black Sea via the Istanbul (Bosporus) Strait and to the normal marine water of the Mediterranean Sea via the Çanakkale (Dardanelles) Strait. Twenty percent of the population of Turkey resides in the Marmara Region (Erel 1992), primarily within its 46 cities. The coastal area of the Sea of Marmara contains 87% of the population of the entire coastal settlement of Turkey (Erel 1997). Increasing industrial and domestic activities in the Marmara Region significantly influence the coastal and shelf areas of the Sea of Marmara. The Izmit Gulf (Tolun *et al.* 2001; Yasar *et al.* 2001; Balkıs 2003) and the Golden Horn (Istanbul) (Ergin *et al.* 1991) are well-defined, polluted coastal inlets of the Sea of Marmara. The Northern Shelf of the Sea of Marmara is more subjected to increasing human interferences in the form of industrial (metal, food, chemistry, and textiles) waste disposal, fisheries, dredging, recreation and dock activities, than the Southern Shelf. It receives pollution not only from various local land-based sources, but also from the heavily populated and industrialized Istanbul metropolis and from maritime transportation. Istanbul is the most heavily populated and industrialized metropolitan area of Turkey. In addition to industrial and domestic load from the Istanbul metropolitan area, dissolved and particulate pollution loads from the

Danube River are transported towards the Istanbul Strait by shore currents (Beşiktepe *et al.* 1994; Tuğrul and Polat 1995). The Kocaçay, Gönen and Susurluk Rivers' drainage areas also have large agriculture fields in the Southern Shelf. Coelhan *et al.* (2006) indicated that organochlorine contamination in edible fish is higher from the Sea of Marmara than in samples collected from the Mediterranean Sea, but significantly lower than in samples from the Black Sea. Also, Barlas *et al.* 2006 suggested the contamination of organochlorine pesticides in Turkey's Ulubat Lake.

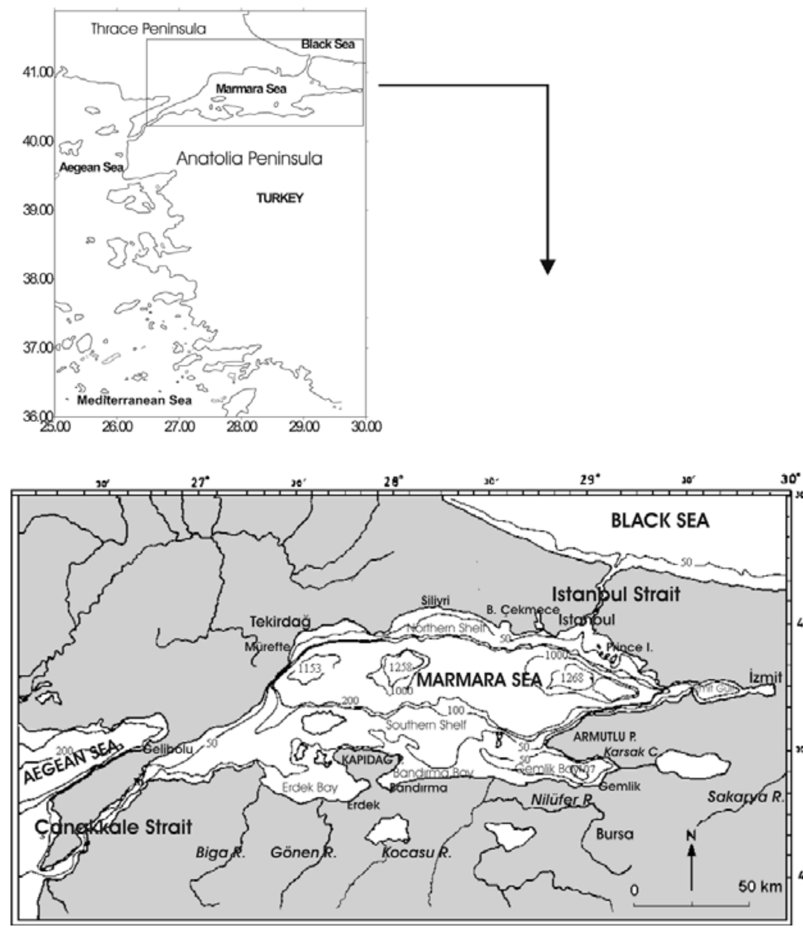


**Figure 1.** General location and physiographic features of study area (Algan *et al.* 2004).

### 3. Lead (Pb), Cadmium (Cd), Arsenic (As) and Mercury (Hg) levels in hake (*Merliccius merlicciua*)

***Lead (Pb).*** Lead concentrations in fish samples ranged from 3.23 to 14.4 µg $g^{-1}$ (dry wt) in both August and December 2009. Pb levels in the Sea of Marmara were found to be higher than the critical limits set by the both Turkish Ministry of Environment for Aquatic Products (1 µg $g^{-1}$ wet wt) and European countries (2.0 µg $g^{-1}$, UNEP 1985). The highest Pb values were observed in the Southern Shelf (Stations 11A, 12A, 13A and 19A). No significant variations were observed between the sample collected in August and the one collected in December. In general, our results indicate that Pb contamination of fish from the Sea of Marmara is higher than the Southern Black Sea Shelf (Table 3, Hiçsönmez 2010). In previous studies, it was reported that metal pollution is caused via the Biga, Gönen and Susurluk Rivers draining from the mineral zones and industries into the rest of the Southern Shelf (Balkıs and Çağatay 2001; Algan *et al.* 2004). The FAO/WHO (1978) maximum tolerable daily intake is 0.43 mg $day^{-1}$ or 7 µg per kg body weight. Consumption of fish containing even the lowest mean levels of lead recorded in the present study would result in 2 or 3 times the maximum tolerable weekly intake of lead. On the other hand, a person can consume 2 or 3 meals per week of this fish in the human diet, which would represent the tolerable weekly intake of lead (3000 µg lead per 60 kg man), according to the UNEP (1985). For this reason, the high Pb levels of fishes from the Sea of Marmara appear to be a considerable threat for human health.

***Cadmium (Cd).*** Cadmium concentrations in fish from the Sea of Marmara varied between <0.01 µg $g^{-1}$ with 2.14 µg $g^{-1}$ (wet wt) in both August 2009 and December 2009 (Table 2a and 2b). Cd levels were found to be considerably higher than the critical limits set by the Turkish Ministry of Environment for Aquatic Products (0.1 µg $g^{-1}$ wet wt) in August 2009, whilst the values were generally lower than the critical limits in December 2009. The highest Cd values found were similar to Pb levels, especially in the Southern Shelf (Stations 18, 13A and 19A). In contrast, Cd contents of fish from the Sea of Marmara are comparable to or slightly lower than those from the Southern Black Sea Shelf (Table 3, Hiçsönmez 2010). The provisionally tolerable weekly intake was estimated by FAO/WHO expert committee at 400-500 µg cadmium per person per week (UNEP 1989). The maximum value of cadmium is 2.14 µg $g^{-1}$ in the sampling area; therefore, a person can consume only one meal of fish from the Sea of Marmara per week.

***Mercury (Hg).*** Mercury concentrations in fish samples from the Sea of Marmara ranged from 0.01 to 0.18 µg $g^{-1}$ (dry wt) in both August and December 2009 (Table 2a and 2b). Hg levels were found to be lower than the critical limits set by the Turkish Ministry of Environment for Aquatic Products (0.5 µg $g^{-1}$ wet wt) in the two periods.

Generally, the highest values were found in the Southern Shelf. Additionally, fish showed lower concentrations in August 2009. This fact is probably related to the fish's biological cycle. Total lipid contents increase in fish during colder periods, and the fish showed slightly higher mercury levels in December 2009. The maximum value of mercury found was mercury 0.18 µg $g^{-1}$ in the edible parts of the fish. Consumption of 1500 g per week of this fish in the human diet would represent the maximum tolerable consumption of mercury (300 µg mercury per week per 60 kg man). Küçüksezgin *et al.* 2001 also found similar results in red mullet from the Eastern Aegean Sea. In contrast, mercury levels in fish from the Southern Black Sea Shelf were found to be higher than mercury levels in those from the Sea of Marmara (Table 3, Hiçsönmez 2010).

***Arsenic (As).*** Arsenic concentrations in fish from the Sea of Marmara varied between 0.01 µg $g^{-1}$ with 0.21µg $g^{-1}$ (dry wt) in both August 2009 and December 2009 (Table 2a and 2b). Arsenic levels of fish in the Sea of Marmara were observed to be lower than the critical limits set by the Turkish Ministry of Environment for Aquatic Products (1.0 µg $g^{-1}$ wet wt) in these two periods, similar to the mercury levels found. The maximum value was measured at Station 26. These high As contents are related to the dense anthropogenic inputs of the İstanbul metropolitan area and İzmit Bay. Arsenic levels are comparable to or slightly lower than the Southern Black Sea Shelf, similar to cadmium distributions (Table 3).

**Table 2a**. Toxic metal contents in Hake (*Merluccius merluccius)* from the Sea of Marmara in August 2009 (µg $g^{-1}$) (Aksu *et al.* 2011).

| Stations[a,b] | Cd | Pb | As | Hg |
|---|---|---|---|---|
| 59 | 0.59 | 9.84 | 0.16 | 0.02 |
| 18 | 1.06 | 5.08 | 0.01 | 0.02 |
| 19A | 2.14 | 11.2 | 0.01 | 0.02 |
| 12A | 0.29 | 14.4 | 0.14 | 0.18 |
| 11A | 0.91 | 10.1 | 0.13 | 0.03 |
| 72 | 0.45 | 7.41 | 0.05 | 0.05 |
| 13A | 1.54 | 13.5 | 0.06 | 0.09 |
| 26 | 0.82 | 9.4 | 0.14 | 0.17 |
| Aquatic Product Directory | 0.1 | 1 | 1 | 0.5 |

[a]No. of invividuals: 10

[b]Range of fork length: 10-15cm

**Table 2b.** Toxic metal contents in Hake (*Merluccius merluccius)* from the Sea of Marmara in December 2009 (µg $g^{-1}$) (Aksu *et al.* 2011).

| Stations | Cd | Pb | As | Hg |
|---|---|---|---|---|
| 72 | 0.08 | 5.21 | 0.12 | 0.16 |
| 13A | 0.21 | 7.70 | 0.12 | 0.11 |
| 19A | <0.01 | 7.64 | 0.08 | 0.08 |
| MBC | <0.01 | 10.5 | 0.19 | 0.15 |
| 54 | <0.01 | 4.60 | 0.14 | 0.15 |
| 10A | 0.14 | 4.27 | 0.16 | 0.16 |
| 12A | 0.06 | 5.33 | 0.02 | 0.01 |
| 18 | <0.01 | 4.89 | 0.14 | 0.13 |
| 16 | <0.01 | 3.52 | 0.20 | 0.18 |
| 11A | 0.28 | 3.23 | 0.11 | 0.11 |
| 59 | 0.07 | 5.11 | 0.15 | 0.12 |
| 67 | 0.54 | 8.86 | 0.06 | 0.04 |
| 26 | 0.42 | 6.07 | 0.21 | 0.16 |
| Aquatic Product Directory | 0.1 | 1 | 1 | 0.5 |

In previous studies, similar variations have been observed in biota samples from the Sea of Marmara. The high metal levels, particularly those of lead and mercury, found in fish and mytilus samples are related to the anthropogenic inputs in the Southern Marmara Shelf rather than Northern Shelf (Yıldızdağ 1992; Kocahan 1999; Topçuoğlu 2000, Başsarı *et al.* 2000; Altuğ and Güler 2002; Kayhan *et al.* 2006; Kayhan *et al.* 2007). Lead and cadmium concentrations in shrimp from the Northern Coastal Shelf were also determined to be substantially higher than those in shrimp from the Mediterranean Sea (Kurun *et al.* 2006).

**Table 3.** Toxic metal contents in various fishes from the both Sea of Marmara and Southern Black Sea Shelf (µg $g^{-1}$) (Aksu *et al.* 2011).

| | Sea of Marmara (2009) min-max | Southern Black Sea Shelf (2009) min-max | Aquatic Product Directory |
|---|---|---|---|
| Cd | <0.01 – 0.54 | 0.01 – 1.05 | 0.1 |
| Pb | 3.23 – 10.5 | 0.05 – 5.75 | 1 |
| As | 0.02 – 0.21 | 0.02 – 0.43 | 1 |
| Hg | 0.01 – 0.18 | 0.07 – 0.40 | 0.5 |

**4. Organochlorine pesticides levels in hake (*Merliccius merlicciua*)**

In the Sea of Marmara, total HCH and endrin contents varied between <0.05 ng $g^{-1}$ with 99 ng $g^{-1}$ and <0.001 ng $g^{-1}$ with 381 ng $g^{-1}$, respectively, in fish samples. The highest total HCH value was measured in the Southern Shelf at Station 19A (Table 4), while the highest endrin value was found in the Northern Shelf at Station 54 (Table 4). Alpha and Beta-endosulphan contents of samples ranged between <0.05 ng $g^{-1}$ with 90 ng $g^{-1}$ and <0.05 ng $g^{-1}$ with 15.3 ng $g^{-1}$, respectively. Whilst the highest alpha-endosulphan value was observed in the middle-south basin at Station 16 (Table 4), the highest beta-endosulphan value was measured in the eastern basin at Station 26 (Table 4). Staions 19A and 16 are under the influence of the Susurluk River. This Susurluk River drainage area contains inputs from agricultural areas in the rest of the Southern Shelf. Additionally, the high organochlorine residue content of Susurluk sediment was caused by anthropogenic inputs (Table 5). o,p-DDE and p,p-DDE contents of fish samples varied between 3.5 ng $g^{-1}$ with 52.4 ng $g^{-1}$ and 7.4 ng $g^{-1}$ with 139 ng $g^{-1}$ , respectively. Both the highest o,p-DDE and p,p-DDE values were found in the Northern Shelf at Station MBC (Table 4). o,p-DDD and p,p-DDD contents of samples ranged between 1.5 ng $g^{-1}$ with 90 ng $g^{-1}$ and 2.7 ng $g^{-1}$ with 86 ng $g^{-1}$ , respectively. While the highest o,p-DDD was found to be similar to beta-endosulphan in the eastern basin at Station 26 (Table 4), the highest p,p-DDD values was measured as similar to p,p-DDE in the Northern Shelf at Station MBC (Table 4). MBC Station is in the Northern Shelf. The highest values are associated with the dense agricultural activities in this region. Although the use of DDT has been restricted or banned in the world since the mid-1970s, effective restrictions were not imposed in Turkey until the 1980s (Tanabe *et al.* 1997a). Between 1976 and 1983, the annual use of organochlorine insecticides in Turkey was 1000-2000 tonnes (Karakaya and Ozlap 1987). Despite the current restrictions, recent studies have shown that DDT is still present in Turkish rivers, streams, and domestic and industrial discharges, which indicates its continued illegal use (Tuncer *et al.* 1998). In this study, we also found high organochlorine residue levels in sediments from the Susurluk, Biga, Gönen and Dil Rivers, which feed into the Sea of Marmara. The ranking of the rivers included to organochlorine levels in the Sea of Marmara is as follow: Dil R>Susurluk R>Biga R>Gönen R. o,p and p,p DDE, and o,p and p,p DDD compounds are metabolites of DDT (Table 5). For this reason, the high values of these metabolites found in this study prove the continued illegal use of DDT. In previous studies, the organochlorines pollution in five fish species and edible fish from the Sea of Marmara was shown (Coelhan and Barlas 1998; Coelhan *et al.* 2006). This study also reported that organochlorine levels in edible fish from the Sea of Marmara was significantly higher than levels from the Mediterranean Sea, but significantly lower than in samples from the Black Sea.

**Table 4.** Organochlorine residue levels in Hake (*Merluccius merluccius)* from the Sea of Marmara (ng $g^{-1}$) (Aksu *et al.* 2011).

| **Stations** | **10A** | **72** | **19A** | **12A** | **13A** | **54** | **MBC** | **16** | **26** | **18** | **67** | **59** | **11A** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tot. HCH | 21 | 19.4 | 99 | 48 | 57 | 16.5 | 58.2 | 13.23 | 23.2 | 66 | <0.05 | 11. 7 | 13.1 |
| Beta-endosulphan | 1.31 | 0.72 | 2.8 | 2.4 | <0.05 | 1.44 | <0.05 | 13.57 | 15.3 | <0.05 | <0.05 | <0.05 | 1.3 |
| o,p DDD | 4.0 | 36 | 83.1 | 29.6 | 17.4 | 1.5 | 32 | 14.27 | 90.2 | 37.4 | 13 | 37.3 | 56 |
| p,p DDD | 24 | 67 | 43.2 | 6.0 | 28.1 | 2.7 | 86.1 | 66.94 | 41.03 | 74.6 | 24 | 19 | 50 |
| Alpha-endosulphan | 10.5 | 20.5 | 11 | 18.5 | <0.05 | 24 | <0.05 | 89.77 | 74.8 | <0.05 | <0.05 | <0.05 | 32 |
| Endrin | <0.05 | 34.5 | 22 | <0.05 | <0.05 | 381 | 111 | 66.47 | 157 | 88.4 | <0.05 | 96 | <0.05 |
| o,p DDE | 13.5 | 19 | 48.5 | 3.5 | 28 | 19 | 52.4 | 9.85 | 14.3 | 11.6 | 24 | 22 | 13.4 |
| p,p DDE | 25 | 40.3 | 22 | 7.4 | 55.4 | 35.2 | 139 | 23.84 | 27.7 | 20 | 43.5 | 31.2 | 21 |

**Table 5.** Organochlorine residue levels in the surface sediments of river mouths in the Sea of Marmara (ng $g^{-1}$) (Aksu *et al.* 2011).

| | **Susurluk** | **Dil River** | **Biga River** | **Gönen River** |
|---|---|---|---|---|
| Tot. HCH | 5.7 | 7.09 | 1.89 | 1.42 |
| Beta-endosulphan | 0.08 | 0.21 | <0.05 | <0.05 |
| o,p DDD | 8.52 | 17.04 | 6.39 | 5.86 |
| p,p DDD | 10.80 | 16.74 | 2.70 | 3.78 |
| Alpha-endosulphan | 1.99 | 7.5 | <0.05 | 2.99 |
| Endrin | 63 | 9.41 | 5.02 | 3.76 |
| o,p DDE | 5.8 | 12.1 | 4.93 | 4.66 |
| p,p DDE | 4. 5 | 6.43 | 5.14 | 4.75 |

## 5. Conclusions

The order of the toxic metal (Pb, Cd, Hg and As) concentrations found in fish from the Sea of Marmara was Pb>Cd>As>Hg. Pb levels were found to be higher than the critical limits set by the both Turkish Ministry of Environment for Aquatic Products (1.0 µg $g^{-1}$ wet wt) and European countries (2.0 µg $g^{-1}$, UNEP 1985). Contrastingly, cadmium values were higher than the critical limits only during the summer period. However, both arsenic and mercury levels were found to be lower than the Turkish Ministry of Environment for Aquatic Products (1µg $g^{-1}$, and 0.5µg $g^{-1}$ wet wt, respectively) in both months studied. Cadmium, mercury and arsenic levels were comparable to or slightly lower than the Southern Black Sea Shelf, whilst lead concentrations were higher. In conclusion, the high metal levels in fish from the Southern Shelf seem to have been caused mainly by land-based natural and anthropogenic inputs via the Biga, Gönen and Susurluk Rivers. The main natural sources for these elements are the mineral zones, which possess naturally high background values, and various industrial zones in the drainage areas of these rivers. Additionally, the Northern Shelf is polluted mostly by the anthropogenic inputs from Istanbul metropolitan area; another possible source of pollution is the Black Sea via the Istanbul Strait (Balkıs and Çağatay 2001; Algan *et al.* 2004).

Concentrations of organochlorine residues in fish from the Sea of Marmara are shown to be generally higher than those reported for the Mediterranean Sea, but significantly lower than in samples from the Black Sea. They are comparable to or slightly higher than those reported for the Aegean Sea. The high organochlorine residue values are associated with the dense agricultural activities in the rest of the Northern and Southern Coastal Shelves. The high DDE and DDD levels of river sediments are also caused by the anthropogenic inputs from agricultural areas. The ranking concentrations of the various organochlorine compounds in fish from the Sea of Marmara are as follows: p,p DDD > o,p DDD > p,p DDE > o,p DDE > endrin> tot. HCH > alpha-endosulphan > beta- endosulphan. While these results show the illegal use of organochlorine insecticides in Turkey in recent years, the other explicable reason for the contamination observed may be inputs from the Black Sea, where the levels are quite high.

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# THE EFFECT OF MARMARA (IZMIT) EARTHQUAKE ON THE CHEMICAL OCEANOGRAPHY OF IZMIT BAY, TURKEY

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## 1. Introduction

Izmit Bay has been subjected to pollution problems (Orhon *et al.* 1984; Tuğrul *et al.* 1989; Morkoç *et al.* 1996), including eutrophication of the water and inputs of toxic industrial and domestic effluents. Total organic matter load of industrial discharges has been reduced to 80% within the last 10 years, whereas domestic organic loads have been increased in two fold (Morkoç *et al.* 1996, 2001). The earthquake with a magnitude of 7.4 was occurred at 17$^{th}$ of August 1999, destroying the eastern Marmara Region. The epicenter of the earthquake was found to be in a small city (Gölcük) located on the southern coast of Izmit Bay. This seismic event caused the destruction of wastewater discharge systems and also dispersal of refined petroleum products onto the sea surface from the subsequent refinery fire. The surface waters of the Bay were partly covered by the thick petroleum layers and partly by a film (Güven *et al.* 2000, Ünlü *et al.* 2000). Petroleum layer covering the surface water reduced the transfer of oxygen from air/sea interface and also caused the subsequent death of living organisms. Increasing effluent discharges into the Bay produced an exceptional plankton bloom. Coupling of such factors leading to oxygen deficiency at the sea floor caused the formation of anoxic conditions. Okay *et al.* (2001) investigated ecological changes in Izmit Bay, however their data is limited with the September 1999. Balkıs, 2003 also reported that the results of one-year monitoring program performed in Izmit Bay after the Earthquake, with the purposes of describing the abrupt changes in chemical oceanography and understanding the mechanism of $H_2S$ generation in the Bay which has not been occurred before.

## 2. General aspects of the Izmit Bay

Izmit Bay is an elongated semi-enclosed water body with a length of 50 km, width varying between 2 to 10 km (Figure 1) and has an area of 310 km$^2$. The bathymetry of the Bay constitutes three sub-basin separated by shallow sills from each other. The eastern basin is relatively shallow (at about 30 m) whereas the central basin has two small depressions with depths of 160 and 200 m. The western basin deepens in westward from 150 m to 300 m and connects the Bay to the Sea of Marmara. Izmit Bay is oceanographically an extension of Sea of Marmara, having a permanent two-layered water system. The upper layer is originated from less saline Black Sea waters (18.0-22.0 psu), whereas the lower layer originated from the Mediterranean Sea waters is more saline (37.5-38.5 psu) (Ünlüata *et al.* 1990). The permanent stratification occurs at about 25 m in the Sea of Marmara (Beşiktepe *et al.* 1994), however it is highly variable in Izmit Bay (Oğuz and Sur, 1986). The thickness of the upper layer changes seasonally from 9 to 18 m spring and autumn, respectively (Oğuz and Sur, 1986; Algan *et al.* 1999). The upper layer enters into the Bay in spring and summer, corresponding to the freshwater inflow changes in the Black Sea, while the lower layer flows to the Sea of Marmara from the Bay. However, the upper layer flows towards the Sea of Marmara in autumn and winter (Oğuz and Sur, 1986). Vertical mixing of the two layers is restricted and occurs at shallow depths. An intermediate layer develops throughout the year in the water column of the Bay with varying thickness (DAMOC, 1971; Baştürk *et al.* 1985; Tuğrul *et al.* 1989; Oğuz & Sur, 1986; Altıok *et al.* 1996).

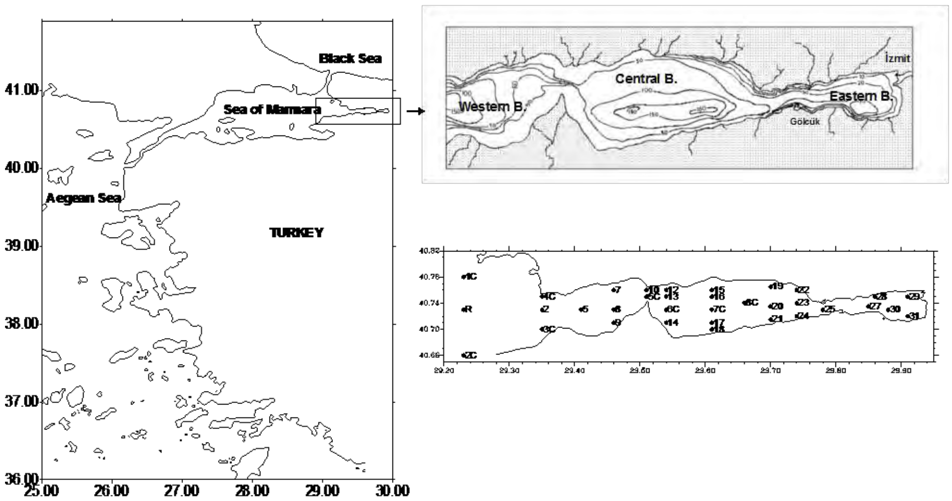


**Figure 1**. The location (left) and bathymetry (above) of the study area. The location of sampling station in Izmit Bay (below) (Balkıs, 2003).

The upper layer of Izmit Bay, in general, is saturated with DO (Tuğrul and Morkoç, 1990). DO concentrations in the lower layer of Izmit Bay has been found to be 2.5-3.0 mgl$^{-1}$ in winter and spring periods and 0.7-1.5 mgl$^{-1}$ in summer, in previous studies (Morkoç, *et al.* 1996). The minimum DO concentrations have been measured locally in the central basin (0.1-0.2 mgl$^{-1}$) and in the eastern basin (0.5 mgl$^{-1}$) during spring-summer period (Tuğrul and Morkoç, 1990). Izmit Bay and its surroundings is one of the most industrialized and populated area of Turkey, receiving more than 300 industrial and domestic effluents (Morkoç *et al.* 1996). Industrial effluents discharges a total of 163,000 m$^3$/day wastewater, 24 tons/day BOD and 19,5 tons/day TSS to Izmit Bay (Morkoç *et al.* 2001). The eastern basin receives the highest inputs compare to other basins of the Bay. Based on the previous studies, no DHS has been measured in Izmit Bay (Morkoç *et al.* 1988; Tuğrul *et al.* 1989; Morkoç *et al.* 1996).Industrial loads have been reduced by treatment and waste minimization within the last 10 years, but domestic wastes has doubled, due to the increasing population in the Bay. Therefore, the total (domestic + industrial) discharge load into the Bay during the last 10 years has not changed significantly (Morkoç, *et al.* 2001). The dissolved oxygen content of Izmit Bay decreased dramatically from 1984 to 1999 and reached to a minimum value at 20 m throughout the Bay (Okay *et al.* 2001).

## 3. Dissolved Oxygen (DO), Dissolved Hydrogen Sulphide (DHS) and pH variations along the water column

DO concentrations of the water column were low in August 1999, after the earthquake, compare to that of other sampling periods. The low DO content was determined in all the stations of Izmit Bay, and particularly in the lower layer waters of the eastern and the central basins, being lower than the detection limit of the method (0.03 $mgl^{-1}$). The negative DO–SDO value along the water column suggested that the oxygen utilization was resulted from the decomposition of organic matter. The limited air-water exchange of free oxygen caused by the spreading petroleum from the refinery fire to the sea surface might be one of the main reasons for lowering of DO content in water column. The highest oil concentration was determined in surface water of south of the central basin as 179.2 $mgl^{-1}$ in August 1999 (Güven *et al.* 2000, Ünlü *et al.* 2000). The oil concentrations of the surface water are more than 500 $\mu gl^{-1}$ in almost half of the western and central basins after the earthquake. In spite of high oil pollution levels of the surface water, the oil concentrations in the lower layer are between 13-55 $\mu gl^{-1}$in the Bay exception of north of the central basin in August 1999. This oil pollution level decreased to 10.5 $mgl^{-1}$ in September 1999 and 3.3 $mgl^{-1}$ in October 1999. The upper layer flows westward to Sea of Marmara, while the lower layer flows into the Bay transporting oxygenated Mediterranean originated Sea of Marmara waters in September and October 1999 (Güven *et al.* 2000). This current system provided the removal of the petroleum layer at the sea surface from Izmit Bay to the Sea of Marmara and consequently DO concentrations increased in the water column accompanied by phytoplankton bloom. Phytoplankton bloom was intense in the eastern basin (2,553,000 cell/l, Güven *et al.* 2000) and possibly the reason for the saturated DO content in this part of the Bay. Since the domestic and industrial wastewater system has been damaged by the earthquake, the nutrient input into the Bay increased, causing the extreme phytoplankton bloom (Okay *et al.* 2001). In spite of high DO concentrations of the upper layer, DHS is found in the lower layer of the eastern and the central basins (Figure 2). This striking condition clearly indicates the excess organic load that rapidly depositing at the bottom of the Bay. Although no DHS data is available for the previous sampling period (August and September 1999), the establishment of this anoxic condition at the bottom might have started to develop earlier than October 1999. Earlier studies related to the ocenographic features of the Bay have never determined anoxic conditions in the water column (Morkoç, *et al.* 1988; Tuğrul *et al.* 1989; Morkoç *et al.* 1996).

The highest pH values found (8.9) at the upper layer compare to other months in the eastern basin confirms the increasing biological activity in October 1999 (Figure 6). During the respiration of phytoplanktons, dissolved $CO_2$ content of water column increases and consequently $CO_3^{-2}$ and $HCO_3^-$ anions increase. Increasing carbonate causes enhancement of alkalinity. The pH values become 7.9 at the lower layer (Figure 7) where the anoxic conditions are developed (Figure 2) and indicate the decomposition of organic matter. The Sea of Marmara water flows as the upper layer into the Bay in December 1999 and the current system is towards the interior of the Bay, whereas the lower layer flows out of the Bay (Güven *et al.* 2000). The available DHS formation in the eastern and the central basins is reduced or completely disappears in this month by the outflow of the lower layer (Figure 2). This current system becomes reversed in February 2000, entering the lower layer and out-flowing the upper layer. The significant increase of DO concentrations of the upper layer in February 2000 might possibly indicate the replenishment of water column in Izmit Bay with oxygenated waters. This is in agreement with the vertical and spatial distribution of DO concentrations in February.

The thickness of the upper layer increases to 25-30 m suggesting the entrance of waters into the Bay. DO content of the both the upper and the lower layer slightly decreases in May 2000, together with increasing alkalinity. The reducing DO content in this month might be related with the water influx enriched with nutrients into Izmit Bay from the Black Sea (via the Sea of Marmara) that receives increasing amount of freshwater inflow during spring (Oğuz and Sur, 1986; Tuğrul and Polat, 1995). In August 2000, DO concentration of the water column is significantly reduced, suggesting the enhanced consumption of DO by decomposition of high organic materials that possibly from the subsequent death of blooming phytoplanktons. In the eastern basin, the lowest pH is found in this month, supporting the increasing decomposition processes and the formation of DHS.

The formation of DHS leading to anoxia at the lower layer of Izmit Bay occurs in the eastern basin where the depths are shallower than 30 m and also locally in the deep site of the central basin where circulation is restricted. After the Earthquake, in the central and the eastern basins, the formation of DHS is resulted from the spreading petroleum from the refinery fire to the surface waters and accumulation of high amounts of organic load from the damaged wastewater systems, and resuspension of bottom sediments releasing the DHS in the anoxic part of the sediment column. This is in agreement with the low DO concentrations of the water column in Izmit Bay during August and September 1999. The removal of anoxia at the bottom of the eastern and the central basins occurred in December 1999 by the replacing of water layers with the oxygenated Sea of Marmara waters. DHS exists in the lower layer consistently throughout the sampling period in station 17, however its thickness varies. The reduced bottom current velocities (Algan *et al.* 1999) and topographic restriction of this small depression might be the reasons for the presence of DHS, by preventing the circulation.

In August 2000, DHS forms again in the eastern basin in low concentrations. This re-occurrence of DHS is related with the extreme phytoplankton bloom. A high amount of organic matter produced from their death consumes oxygen for decomposition in the sediment. High decomposition rates might have led the depletion of DO in the overlying water column and consequent formation of DHS. The seasonal circulation pattern and timing of blooms in Izmit Bay were not different than the present as indicated by the previous studies (Oğuz and Sur, 1986; Tuğrul *et al.* 1989; Morkoç *et al.* 1996). DO content has never been fallen below 0.5 $mgl^{-1}$, and no DHS has been detected in Izmit Bay. Therefore, the re-occurrence of DHS a year after the Earthquake might indicate that Izmit Bay has not been completely return to its regular chemical oceanography. This may be explained by the fact that the amount of organic and possible inorganic wastes into Izmit Bay must have been considerably high and/or must have continued to discharge after the Earthquake. Increasing nutrients, phytoplankton blooms, rapid sedimentation of death organisms and decomposition processes constituted a successive cycle in Izmit Bay and intensified by the Earthquake at 17$^{th}$ August 1999. However, decomposition processes within this cycle might not be completed within a year.

## 4. Conclusions

Izmit Bay has been polluted by increasing industrial activities and domestic discharges since early 1980. However this abrupt event caused short-time drastic changes in the water column. Earthquake at 17 August 1999 initiated a fast variation in the chemical oceanography of polluted Izmit Bay. This variation includes the consumption of DO and formation of DHS in the lower layer. The refinery fire and damaged municipal waste effluents caused the reduction of DO in water column by preventing the oxygen transfer from air/water contact and increasing organic wastes, respectively, and as a result DHS was formed. The increasing wastewater into the Bay stimulated the phytoplankton blooms which cause locally saturated DO concentrations in the eastern basin, however anoxic conditions were prevailing in the lower layer during autumn 1999. The changing circulation pattern during winter provided replenishment of the water column in Izmit Bay and removal of DHS. However, DHS formation established again in August 2000.

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# TOTAL METAL DISTRIBUTIONS IN THE IZMIT BAY (TURKEY) AFTER MARMARA (IZMIT) EARTHQUAKE

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## 1. Introduction

In recent years, aquatic ecosystems have been contaminated by heavy metals; which are of agricultural, industrial, domestic, mining and also natural origins (Ayas and Kolankaya 1996; Han *et al.* 2002). They are potentially toxic to the aquatic environment; if they exceed natural limits, they will be harmful to the aquatic organisms' environments and human health (Forstner and Witmann, 1981). Organisms need some metals such as Fe, Cu, Zn, Co, Se, Ni and Mn in certain amounts; however, exceeding these amounts may cause toxic effects for these organisms. Some metals such as Hg, Cr, Pb and Cd are toxic to organisms and marine habitat. These metals are dissolved in sea water or suspended in solid materials and absorbed through the gills or skin of marine organisms; they also accumulate in the bodies of organisms through the food chain (Forstner and Witmann, 1981). Mussels, in particular, have been used as biological indicator organisms to monitor marine pollution by toxic heavy metals and potentially toxic chemicals due to their properties of inhabitation (Pempcowiac *et al.* 1999; Hu 2000).

Izmit Bay and its surroundings is one of the most industrialized and populated area of Turkey, receiving more than 300 industrial and domestic effluents (Morkoç *et al.* 1996). Industrial effluents discharges a total of 163,000 $m^3$/day wastewater, 24 tons/day BOD and 19,5 tons/day TSS to Izmit Bay (Morkoç *et al.* 2001). The eastern basin receives the highest inputs compare to other basins of the Bay. Based on the previous studies, no DHS has been measured in Izmit Bay (Morkoç *et al.* 1988; Tuğrul *et al.* 1989; Morkoç *et al.* 1996).

Industrial loads have been reduced by treatment and waste minimization within the last 10 years, but domestic wastes has doubled, due to the increasing population in the Bay. Therefore, the total (domestic + industrial) discharge load into the Bay during the last 10 years has not changed significantly (Morkoç, *et al.* 2001). The dissolved oxygen content of Izmit Bay decreased dramatically from 1984 to 1999 and reached to a minimum value at 20 m throughout the Bay (Okay *et al.* 2001).

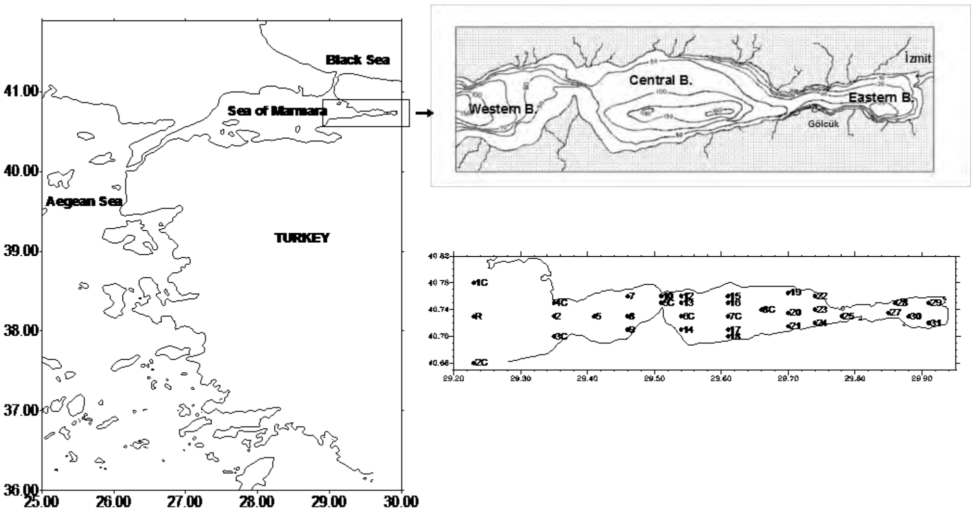


**Figure 1**. The location (left) and bathymetry (above) of the study area. The location of sampling station in İzmit Bay (below).

### 3. Metals in water column

Iron concentrations range between <4 mg/l and 21 mg/l along the water column in İzmit Bay (Figure 1 and Table 1). The highest values are measured after the Earthquake (October-1999). High dissolved Fe concentrations indicate reduction of Fe-oxides by bacteria during mineralization of organic carbon in the sediment and diffusion into bottom waters (Nealson 1982; Lovley and Phillips 1988; Nealson and Myers 1990). Fe values are decrease in May and August 2000 where Fe limitation is thought to control phytoplankton productivity.

Manganese concentrations vary between <1 and 123 mg/l in water column of the Bay (Table 1). The values increased in lower layer water and near the sediment-water interface in eastern and central basins. This was attributable to the degradation of settling organic carbon (Nealson, 1982; Nealson and Saffarini, 1994; Nealson and Myers, 1990). Manganese oxides were reduced to dissolved Mn+2, which diffused from the sediment into the water column occurring the anoxic conditions. The lowest Mn values are obtained in December 1999 and February 2000. In these periods, oxygen-rich waters of Sea of Marmara (Mediterranean originating) flow into the Bay. Thus, Mn-oxides are occurred and flocculated in water column with reoxidation of dissolved Mn in more oxygenated waters.

Lead concentrations range between <0.8 and 1.8 mg/l in the Bay waters (Table 1). The highest values are suggested that atmospheric and anthropogenic inputs.

Copper concentrations vary between <0.4 and 7.4 mg/l along the water column of the Bay (Table 1). The high values shows that Cu was mainly affected by redox reactions involving Mn and Fe in bottom waters of the eastern and central basins. The lowest Cu concentrations are measured in occurring the extreme phytoplankton blooms periods especially in these regions.

**Table 1.** Metal concentrations along the water column of the Izmit Bay (µg/l) (Balkıs *et al.* 2007).

| Element | October 1999 | December 1999 | February 2000 | May 2000 | August 2000 |
|---|---|---|---|---|---|
| Fe | 7-15 | <4-4 | <4-13 | <4 | <4 |
| Mn | <1-4 | 1-7 | 2-4 | 4-12 | <1-13 |
| Pb | <0.8-1 | <0.8-0.9 | 0.9-1 | <0.8-2 | <0.8-1 |
| Cu | 0.5-0.7 | 0.5-0.9 | 0.4-0.8 | <0.4-0.6 | <0.4-0.8 |
| Cd | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 |

Cadmium concentrations are lower than the detection limit of the method (<0.01 mg/l) along the water column of the Bay (Table 1). Since the domestic and industrial waste-water system has been damaged by the earthquake, causing the extreme phytoplankton bloom (Okay *et al.* 1991). This element is incorporated into organic matter by phytoplankton during periods of primary production (Sunda and Huntsman, 1995). Therefore, the relatively low residence time could be the result of biological uptake.

### 3. “Total”metal distributions in surface sediments

The Iron concentrations range between 2.4 % and 11.8 % and are generally above the shale average value of 4.7 % (Krauskopf, 1979) (Table 2). The highest values are measured in southern shelf and eastern basin of the İzmit Bay. The Fe distribution in the Bay sediments is controlled mainly by the riverine and anthropogenic inputs on this land-locked system.

Manganese concentrations are in general, lower than the average abundance of this element in shale (<850 µg/g) (Table 2). The values increase in western basin of the Bay. Here, Mn+2 form of this redox sensitive element derived from the early diagenesis of the sediments, is believed to have been oxidized and flocculated by the oxygen-rich lower layer waters of the Sea of Marmara (Mediterranean originating).

The Copper, Cobalt and Chromium concentrations are in general, below the shale average values of 50, 20 and 100 µg/g (Krauskopf, 1979) (Table 2). The highest values in eastern basins surface sediments shows that the anthropogenic inputs from the industrialized regions in here.

Zinc concentrations range between 84 µg/g and 306 µg/g and are above the shale average value of 4.7 % (Krauskopf, 1979) (Table 2). The high values seem to have been controlled mainly by the anthropogenic inputs from the eastern region similar to the other elements.

**Table 2.** Range of metal concentrations of surface sediments from the **I**zmit Bay (Balkıs *et al.* 2007).

| Element | Average shale (Krauskopf, 1979) | Izmit Bay min - max | Izmit Bay mean - SD |
|---|---|---|---|
| Cu (µg/g) | 50 | 11- 42 | 23 ± 8.87 |
| Zn (µg/g) | 90 | 84 - 306 | 149 ± 57 |
| Fe (%) | 4.7 | 4.6 - 7.1 | 6.1 ± 0.6 |
| Mn (µg/g) | 850 | 139 - 494 | 327 ± 89 |
| Co (µg/g) | 20 | 6 - 20 | 12 ± 3.93 |
| Cr (µg/g) | 100 | 34 - 77 | 58 ± 11 |
| Al (%) | 9.2 | 2.3 - 11.4 | 7.4 ± 2.5 |
| CaCO3 | 6.0[a] | 13 -42 | 13.4 ± 9.9 |
| Corg (%) | 0.8[a] | 0.6 - 6.2 | 3.0 ± 1.6 |

[a] From Mason and Moore (1982, p.153)

## 4. Metal levels in the geochemical phases of surface sediments

The highest values of Al, Fe, Zn, Co, and Cr varied between 2.2 % with 10.9 %, 3.8 % with 5.4 %, 18 % with 98 %, 4 % with 9 %, and 12 % with 51 % in the residual phase, respectively. In contrast, the highest values of Cu and Mn ranged from 6 % to 26 % in organic phase and from 32 % to 276 % in the Fe-Mn oxyhydroxide phase, respectively. While Fe and Cr values were generally lower than the detection limit of the methods (<0.05 and 0.08 $\mu gL^{-1}$) in the exchangeable and carbonate phases, Al contents were also detected in the organic and residual (lithogenous) phases. Zn and Mn showed the highest values in Fe-Mn-oxyhydroxide phase, but Cu those in the organic phase along the bay. In addition, Cu, Zn, Mn and Co levels were relatively high in all geochemical phases (Table 4).

**Table 3.** Metal distributions in different geochemical phases (%) (Balkıs *et al.* 2007).

| Element | Exchangable phase | Carbonate phase | Fe-Mn-oxyhydroxide phase | Organic phase | Residual phase |
|---|---|---|---|---|---|
| Cu (ppm) | 0.3-1.1 | 0.3-1 | 1.3-4.5 | 6-26 | 4-14 |
| Zn (ppm) | 0.1-2.3 | 0.8-37 | 15-121 | 14-46 | 18-98 |
| Fe (%) | <0.05 | <0.05 | 0.1-0.6 | 0.5-1.1 | 3.8-5.4 |
| Mn (ppm) | 1-13 | 6-51 | 32-276 | 32-241 | 32-176 |
| Co (ppm) | 0.1-1.3 | 0.1-2.2 | 0.3-3.7 | 0.2-9 | 4-9 |
| Cr (ppm) | <0.08-4.5 | <0.08 | 1.4-24 | 2-23 | 12-51 |
| Al (%) | <0.03 | <0.03 | <0.03 | 0.1-0.4 | 2.2-10.9 |

## 4. Conclusions

Total metal contents in the Izmit Bay sediments increase towards to eastern basin. The eastern basin receives the highest inputs compare to other basins of the Bay (Morkoç *et al.* 2001). Ergin *et al.* (1991) suggested that the surface sediments in Izmit Bay are uncontaminated by anthropogenic pollution. However Yaşar *et al.* (2001) investigated that the heavy metal concentrations are highest in the eastern and central basins. The western basin was found generally unpolluted with respect to heavy metals in this study, also.

Selective extraction studies indicate that the metals are mainly found in the lithogenous, Fe-Mn-oxvhydroxide and organic fractions. The results show that the main source of high metal concentrations in the Izmit Bay sediments is of anthropogenic origin. The highest metal values in these fractions are found in eastern basin sediments similar to total metal distributions.


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**SEA LEVEL CHANGES ALONG THE TURKISH STRAITS SYSTEM AND CLIMATE CHANGE**

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## 1. Introduction

Description of the processes that influence sea-level changes, particularly those contributing to the recent accelerated rise, is a primary concern for society. The ongoing researches on the fundamentals of the sea-level changes clearly indicate a good, but highly complex, correlation between eustatic (global) sea level and paleoclimate data during the Earth's history (Barron and Thompson, 1990). Such a correlation shows that global climate directly influences eustatic sea-level variations largely by the glacial processes, tectonics and physical mechanisms (e.g., changes in the thermohaline ocean circulation and amount of atmospheric greenhouse gasses such as $CO_2$). Inversely, sea-level changes can affect the natural variability of global climate. Sea-level change, for example, can isolate or connect basins as in the case of the Mediterranean. Similarly, a decrease in ocean salinity contributes to the global cooling. There is always a third possibility that increased concentration levels in carbon dioxide due to volcanism may be the direct reason of global warming observed in paleoclimate data (Berner *et al.* 1983). In that case the statistical relation between climate change and sea level would not be indicative of a straight cause-and-effect relationship (Barron and Thompson, 1990).

The main scope of this chapter is to review sea level changes along the Turkish Straits System (TSS), a highly energetic marine gateway that governs the coupling of the Mediterranean Sea and the Black Sea, over a broad range of time scales from a few seconds to geologic periods. Available sea-level data, seiches, tidal signals, sub-tidal changes, seasonal oscillations, interactions with outside seas, sea-level slopes, long-period trends and eustatic fluctuations along the TSS will be reviewed. The effects of climate change -one-way directed in the normal sense definition but a normal appearance in nature- and accelerated sea level rise to the coastal system will be discussed.

## 2. Turkish Straits System (TSS)

In hydrodynamic sense the TSS consists of the Sea of Marmara and two narrow and shallow straits joining two extremely different water bodies in the world. The İstanbul (Bosphorus) and the Çanakkale (Dardanelles) Straits govern the exchange of flows between the Black Sea and Mediterranean Sea basins as they did before over a wide range of time scales in the geologic past under the control of eustatic and isostatic changes (see Çağatay *et al.* Late Quaternary evolution, this volume). At present, the TSS has a hydraulically controlled and strongly-stratified two-layer current system which is driven by barotropic and baroclinic instabilities. The Black Sea always have a positive water balance, with a net outflow through the İstanbul Strait (0.7–3.4 km wide with a max depth of 110 m). The strait system indicates a maximal hydraulic exchange with supercritical flows at both ends and strongly influenced from the bottom friction throughout the strait (Gregg and Özsoy, 2002). The basic exchange through the Çanakkale Strait (1.2-6.0 km wide with a max. depth of 103 m) is a two-layer flow on long timescales, but with easily variable upper-layer flow under cyclone passages due to its limited thickness (Jarosz *et al.* 2012). Therefore, the brackish Black Sea waters are modified before being discharged into the Aegean Sea throughout this final conduit. Therefore, all of the components of the system constitutes a classical example in ocean sciences and studied extensively in terms of its physical oceanographic characteristics (see previous chapters in this book). Similarly, the straits played important roles in regulating the flow budget between the Black and Mediterranean basins over a wide range of time scales in the geologic past under the control of eustatic and isostatic changes.

The height of sea surface on the dynamic Earth is another important measure used in oceanography, and used to figure out vertical datum, abrupt changes in land level, tidal regimes, tidal currents, water exchange, thermal expansion and ocean surface topography. The sea level measurements along the TSS are mostly carried out for hydrodynamic purposes, to understand response to meteorological forces, seasonal water balance, variations in slope of sea surface, temperature and salinity changes, and most important for flow blockages and reversals (e.g., Möller, 1928; Bogdanova, 1965; DAMOC, 1971; de Filippi *et al.* 1986; Büyükay, 1989; Ünlüata *et al.* 1990; Yüce, 1986, 1993, 1994; Yüce and Alpar, 1994, 1997). The following sections provide background information and additional details related to sea level changes along the TSS.

## 3. Types of Sea Level Change

Global sea level depends on the rising concentrations of greenhouse gases and many dynamic features of the Earth such as gravity, ocean circulation and sea water volume (Williams, 2013). Higher greenhouse gas levels in the atmosphere cause air temperature to increase and precipitation to change. The dynamic features of the Earth affects directly the water masses which play critical roles in a wide range of surface and subsurface Earth. Meteorological events, ocean currents, waves under the action of strong winds, vertical movements of the crust, sediment consolidation, groundwater flow, river dams, drilling, dredging, and construction are the main factors defining local sea level changes. From local to global the sea level changes occur over a wide range of time scales from a few seconds to geological periods.

### 3.1. Eustatic sea level changes

Even though long-term sea-level changes are not spatially uniform, they are generally associated with long-term natural cycles of global climate, which involve various components of Earth system, and considered to be controlled by Earth's orbital and axial frequencies (Milanković cycles). During glacial periods, the water volume in the oceans decreases and therefore sea levels drops, even more than 130 m lower than it is today.

The water level oscillations in the Sea/Lake of Marmara was controlled by two main factors in geological scale; the changes of the basin's volume depending on tectonomorphic evolution and the water volumes contained in the neighboring seas. The opening and first inundation of the Marmara basin was with the Mediterranean waters during the late Serravallian under the control of the first development of the North Anatolian fault (Görür *et al.* 1997). This basin was then flooded by the Paratethys during the late Miocene-early Pliocene and then again in the latest Pliocene. Successive invasions of the Mediterranean and Black Seas occurred through the connecting straits or other water passages depending on glacio-eustatic sea-level changes during the Pleistocene. Cold and dry climatic conditions occurred during the last glacial period. The Marmara basin was completely isolated and turned into a brackish lacustrine environment as global sea-level fell below the sill in the Çanakkale Strait. Following Bolling-Allerod warm period a rapid Mediterranean water incursion occurred at 12 kyr BP, and then the Black Sea waters spilled into the Sea of Marmara at 9.2 kyr BP (see Çağatay *et al.* Late Quaternary evolution, this volume). More stable conditions developed after 6.0 kyr BP as sea-level reached its present shoreline.

The sea-level rise in the 20th century (>14 cm) was extremely faster than during the last 3000 years (Kopp *et al.* 2016). The accelerated rate of sea-level rise was to be expected as the most important and inevitable effect of global warming. In addition, instabilities in large ice sheets pose high risk of triggering rapid rise in sea level. Twentieth century global sea-level change would have been between a decrease of 3 cm and a rise of 7 cm, without considering global warming (Kopp *et al.* 2016). During the last 20 years, satellite measurements of absolute sea-level have provided precise data for global scale rapid variations. The relative tide-gauge measurements obtained using permanent mareographs, however, provide sufficiently long temporal coverage, over several decades, to define climate-driven sea-level changes. In addition, Parker and Ollier (2016) claim that coastal planning should be locally based on proven sea level data.

### 3.2. Tidal gauge records along the TSS

In general, the sea-level data available from the TSS exhibit small-amplitude tidal and non-tidal oscillations, superposed on some long-period and higher amplitude oscillations mainly driven by meteorological forces. The energy distribution percentages show the dominance (92-97%) of the long-period energy inputs on the sea-level variations through the TSS with small amount of diurnal and semi-diurnal percentages. The diurnal tidal energy dominates slightly over the semidiurnal tidal energy.

#### 3.2.1. Short-period oscillations

The natural periods of the short-period oscillations are 1 and 3 hours for the İstanbul Strait and the Sea of Marmara, respectively. The highest amplitudes of seiches in the İstanbul Strait is about 10 cm, with variable periods changing between 30 to 140 minutes along the strait (Alpar and Yüce 1997). Short period oscillations in the Erdek Bay have a period of 3.1 h while they are between 1.1 – 2.2h in the Çanakkale Strait (Yüce, 1994).

#### 3.2.2. Tidal oscillations

The amplitudes of tidal fluctuations are small and vary along the TSS. The Sea of Marmara is not a large sea to generate its own tides and it is isolated from the Black Sea tides almost entirely. Tidal regime in the Black Sea is semi-diurnal; whilst it is mixed/mainly semi-diurnal in the İstanbul Strait, mixed/mainly diurnal at the southern exit of the İstanbul Strait and in the Sea of Marmara; and finally semi-diurnal in the Çanakkale Strait and in the Aegean Sea (Alpar and Yüce, 1997). The semi-diurnal tidal pattern of the Black Sea is only effective in the northern part of the İstanbul Strait where tides are mixed/mainly semi-diurnal. The semi-diurnal tides of the Black Sea mainly dissipate along the İstanbul Strait and tides become mainly diurnal with a spring range of 2.5 cm at the southern part (Yüce, 1986; Yüce and Alpar, 1994). The tidal oscillations are mainly masked by wind-driven forces and by the Black Sea’s surface outflow. Although such kind of small basins co-oscillate usually with adjacent water masses, the Sea of Marmara does not co-oscillate with the neighboring seas in the range of short tidal periods (Yüce, 1993, 1994). Similarly, semi-diurnal tidal oscillations of the Aegean Sea disappear in the Çanakkale Strait (Yüce, 1994).

#### 3.2.3. Subtidal sea-level variations

The most important parameters controlling the large-scale hydrology and therefore subtidal sea-level variations of the Sea of Marmara are static and dynamic atmospheric conditions over the region and variability of the straits inflow. The other factors are caused by wind stress and setups, storm surges particularly in winter, ocean currents, river runoff, steric or thermohaline effects (Yüce and Alpar, 1997; Alpar and Yüce, 1998; Alpar *et al.* 2000). The dominant period of subtidal sea-level fluctuations is greater than 6.5 days, as driven generally by the dominant wind velocity vectors. The subtidal fluctuations occurring between 5 and 15 days are under some disturbances usually moving along the region. Over synoptic time scales, barometric pressure dynamics may be important in driving the mass flux of the TSS and contribute to the destruction caused by for extreme storms (Book *et al.* 2014). Even though intricately configured morphological and hydrodynamic characteristics of long and narrow Turkish straits allow tides to dissipate their energies (Yüce, 1993, 1994), there are some low-frequency interactions between the adjacent basins (Alpar *et al.* 2000).

### 3.2.4. Seasonal and interannual variability

The seasonal variability of average sea level is caused by regular fluctuations in coastal temperatures, salinities, winds, atmospheric pressures, and currents. The average seasonal cycle of mean sea level in the Sea of Marmara exhibits relatively well-defined annual cycles; usually at their highest in June and lowest in autumn (Alpar and Yüce, 1998). Some interannual variations are caused by irregular fluctuations in the oceanographic and meteorological parameters mentioned above. The annual cycles in the Erdek Bay, for example, represent some maxima in the late summer-early spring (5.5 to 6.4 cm) and a minimum in winter (-9.1 to -11.6 cm).

### 3.2.5. Mean sea level and slopes

Möller (1928) is the first researcher who estimated the average decline of the physical sea level between the two ends of the İstanbul and Çanakkale Straits; which were on the order of 6-7 cm. According to Defant (1961) who summarized the systematic surveys of Merz and Möller conducted in 1921 and 1938, the sea-level difference along the İstanbul Strait was about 6 cm in 30 km; greater at the northern end but lesser at the southern end. This figure was only 7 cm along the Çanakkale Strait, even it is two times longer than the İstanbul Strait. Defant (1961) mentioned about higher sea-level values in the middle of the Çanakkale Strait, which must have originated from possible piling-up of waters in the contraction part of this strait. Bogdanova (1965) calculated the average sea-level difference for the two ends of the TSS as 42 cm with a considerable temporal variability depending on the months. The upper-layer current responds simultaneously to these changes. The highest difference was reported for early summer (57 cm) while the minimum one was in October (35 cm). The measured instantaneous sea-level differences between the ends of the İstanbul Strait is typically of the order of 30-40 cm, the slope of surface is found to be non-linear by Gunnerson and Özturgut (1974) and de Filippi *et al.* (1986). These researchers have also shown that the surface slope at the south half was much stepper then the north half. They show the wind effects on the sea level variations, and particularly, notable effects of strong southwesterlies in diminishing, even reversing, sea surface slope. Such kind of slope reversals are transient events which return to normal position after driving forces diminish in a couple of days or more. The calculations by Büyükay (1989) for the annual averages were 28 and 29 cm for the years 1985 and 1986, respectively, but also with some considerable seasonal differences (18-35 cm) and standard deviations (4-13 cm). Recently, the difference of annual average sea levels at Şile and Gökçeada was calculated about 60 cm for the time period of 2008-2011 (Tutsak, 2012).

### 3.2.6. Long-term sea level variations

Long-term sea level variations are either a response to changing ocean volume or to changes in the volume of water contained in the ocean. The oceans, ice, ground and surface waters and atmospheric moisture form 4 major hydrologic reservoirs on the Earth; with volumes of 1370, 30, 8-19, and 0.01 million $km^3$, respectively (Hay and Leslie, 1990). Tidal gauge measurements estimate that sea level has been rising at a rate of 12-22 cm over the $20^{th}$ century, while the satellite altimeters indicated that it was at 31 cm (24-38 cm) per century between 1993 and 2010, almost double the longer period average, with increasing anthropogenic contributions (IPCC, 2007).

The tide gauge in Erdek is actually the only permanent mareograph in the Sea of Marmara, and started to operate at 1985. Long-period oscillations are dominant at 1.7, 2.8 and 12.8 years (Alpar and Yüce, 1998). A relatively high (8.8±0.8 mm/year) sea-level rise rate was calculated (Alpar, 2009), which may be attributed to differential vertical movements, local geotechnical failures, or sediment compaction. A significant contribution to the measured data may come from the sinking of the instrument.

### 3.3. Projecting future sea-level rise

One of the most important projected changes on climate system is the accelerated rise of sea levels around the world. The predictions vary between 10 and 90 cm for the next hundred years, on the basis of relationships between the forces driving emissions (demographic factors, technological changes, social equality, environmental sustainability and economic development) and their evolution (Houghton *et al.* 2001). Even if global emissions were to come to a sudden halt, sea-level would continue to rise due to lagged response of the carbon dioxide in atmosphere (Zecca and Chiari, 2012). On the basis of different $CO_2$ concentrations, model-based projections of IPCC (2014) for global average sea level rise for 2090-2099 show higher values even they only include contributions from increased Greenland and Antarctic ice flow. The present concentration levels can contribute to a temperature rise of 3-5°C above the pre-industrial level. A projected global sea-level rise in that order by the year A.D. 2100 is ascribed to a combination of accelerated melting of glaciers and ice sheets, thermal expansion of ocean water and potential oceanic forcing (Sames *et al.* 2016). Therefore, forecasting sea-level change due to greenhouse-induced climate warming is an important issue for maritime nations worldwide. The magnitude of future sea-level rise, however, remains highly uncertain and open to non-unique interpretations, even assuming it is free from regional and non-climate related components (Church *et al.* 2013). On the basis of topographic elevations, the most vulnerable coastal areas along the TSS to probable sea-level rise in future is shown in Figure 1.

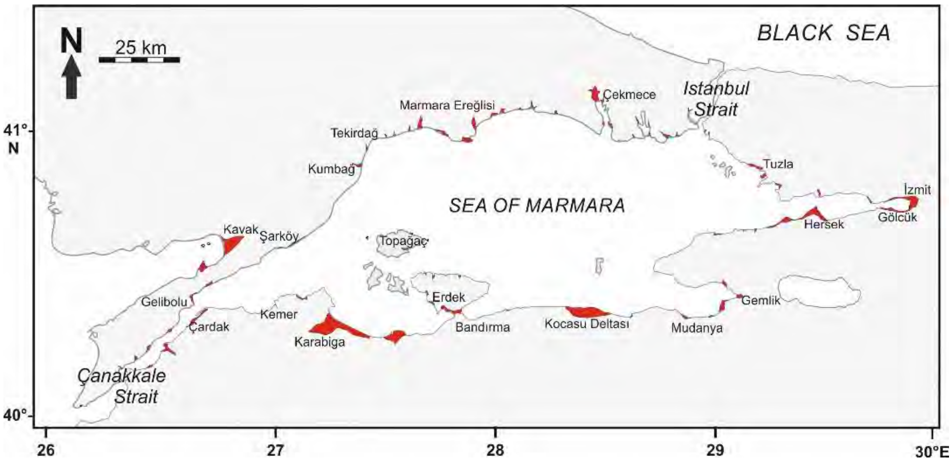


**Figure 1.** Coastal areas which may be most affected from possible sea-level rise.

The deltas of Gönen and Kocasu (Dalyan and Arapçiftliği lagoons) along the southern coasts are made up of sediments transported by the action of rivers, wave and wind. The Gönen delta is less vulnerable to accelerated sea-level rise due to its high sediment input and sheltered position against wave erosion. Meanwhile, the low-lying coastal areas at the mouth of Biga River, as well as Mudanya and Gemlik harbors are the most vulnerable regions to sea-level rise along the southern coast. Higher sea levels may cause tsunamis and even storm waves to become more damaging. In case of accelerated sea-level rise and increase in storminess, the sea may invade the lowlands and salt marshes in the Erdek tombolo region, causing erosion and damaging coastal croplands (Alpar, 2009). Vertical land movements and/or anthropogenic subsidence at the coastal aquifers of Erdek also increase the resulting damage.

To the east, the most vulnerable regions in the Gulf of İzmit are the Lale and Hersek deltas, and the coastal plains at the easternmost part of the gulf. The Hersek delta hosts large wetland areas and an abandoned delta covering a total surface of 145 ha at its northeastern tip. The natural equilibrium of the Kâmil Abduş Lake (80 ha), another lagoon at the Tuzla peninsula, deteriorated severely since its connection to the sea was completely silted up due to nearby shipyard facilities.

Along the northern shores of the Sea of Marmara, the Küçükçekmece lagoon, the largest of the region (1600 ha), is the most vulnerable region to accelerated sea-level. Its beach and channel areas must be protected as natural site. The Büyükçekmece lagoon and low-lying coastal flats at the mouths of small rivers are also vulnerable areas to sea-level rise.

The low-lying flat lands at the Çardak lagoon are the most vulnerable places at the eastern outlet of the Çanakkale Strait, and prone to permanent submergence by accelerated sea-level rise. Even this shallow (<3 m) lagoon is protected from the sea by a picturesque sandspit, it is still under the full marine conditions.

The remaining coasts of the Sea of Marmara are mostly sheltered (medium cliffs and rocky headlands) and appear less vulnerable to accelerated sea-level rise. However, one should not forget that the predictions for sea-level rise and therefore climate projections are highly sensitive to initial conditions and probabilistic in nature. The spatial response of sea-level will not be evidently uniform. Impacts of tectonic deformations, anthropogenic land subsidence, continental margin sedimentation and increased loading by water further add to the complexity of the matter (Conrad, 2013). These are serious issues in consideration of the sea-level hazard from future global warming.

## 4. Impacts of sea-level rise

Coasts are subject to many natural patterns of adjustment controlled by wave and storm energy, sedimentation, erosion and hydrodynamic conditions. Any impacts of rapid sea-level rise and human-induced changes will be an addition to those natural forcing and mechanisms. Projections for many low-lying coastal areas and nations show a dismal future for many coastal communities, as a sea-level rise on the order of 0.3 m can have significant implications for coastal communities and coastal engineering practices. The most important socio-economic impacts for the vulnerable coastal areas along the TSS will be increased flood risk and potential loss of life and properties, damage to coastal infrastructure, loss of agricultural and recreational areas. So, sea level data are vital in estimating the rates of shoreline change or recede, and administration or management of the most vulnerable coastal areas. The engineering responses to reduce damage depend on the rate of sea-level change. An average sea-level rise of 1 m may cause major shifts in shoreline positions and flood significant amounts of upland areas (e.g. Park *et al.* 1989). In some cases, the shifts in shoreline positions have economic and legal significance. Some projections show sea levels could rise as much as 0.6 meters by 2050 and in that case almost 4 million people in Turkey will be exposed to the impacts of sea level rise, particularly considering the sanitary and sewage systems, increased urbanization, harbors and transportation facilities (Englander, 2013). There are worse projections suggesting that sea levels could rise as much as 2 meters by 2100 (Williams, 2013). Another severe adverse impact of sea-level rise, particularly if combined with human induced charges and along low-tide coasts, is saltwater intrusion in coastal aquifers and groundwater; as in the case of Erdek plains.

## 5. Conclusion

The sea-level variations along the TSS depend on many factors: response of the sea to the tidal and atmospheric forcing, tectonic uplift/subsidence, sediment supply, strongly-stratified two-layer exchange flows between the Black and Mediterranean seas controlled with the limiting elements and the sea level difference between the two ends of TSS, and finally to the global climate changes during the recent decades. The range of tidal signals along the TSS is minimal and therefore with no effect on beach morphodynamics and morphology. However, accelerated sea level rise due to the global warming and climate change is one of the most significant concerns. The recurrence periods of extreme water levels could well be shortened with climate change, increasing corresponding risk to coastlines. A probable meltwater pulse, similar to mwp-IA event, may also introduce high risk of triggering rapid rise in sea level. Such changes in sea level have significant impacts on coastal processes such as coastal erosion, meteorologically forced long wave motion of storm surges, tides and waves; driving major shifts in landscape. The consequences of sea level rise along of TSS is not expected to be so high, except low-lying areas. The dynamic coastal ecosystems such as sand bars, dunes and tidal wetlands serve as the first line of defense against the sea, buffering wave action and rising sea level, will be affected. The human activities and development along the TSS, an area with the largest population density in Turkey, should not interfere with the coastal ecosystems and make it more vulnerable against physical impacts of sea-level rise. Therefore, worldwide known parametric models, GIS-based decision support systems and numerically developed or scenario-based computer models of assessing the coastal susceptibility to possible environmental changes, must be applied for the region. The Coastal Vulnerability Index (CVI) highlights the coastal regions where several effects of sea-level rise may be more eminent, by integrating three main sub-indices representing coastal characteristics (geomorphology, coastal slope percentages), coastal forcing (shoreline change rates, mean significant wave height, wave-induced erosion, tidal range) and relevant societal and economic issues. These kind of multi-scale indices can be used as a fast and efficient method in practice.

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**SEA TURTLE RECORDS AND CONSERVATION IN THE SEA OF MARMARA**

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## 1. Introduction

Three species of sea turtle, loggerhead turtle, *Caretta caretta* (Linnaeus, 1758), green turtle, *Chelonia mydas* (Linnaeus, 1758), and leatherback turtle, *Dermochelys coriacea* (Vandelli, 1761) are distributed in the Mediterranean and Aegean Sea coasts of Turkey (Güçlüsoy *et al.* 2014). Some records of sea turtles in neighbouring countries of Turkey including those in the Black Sea were provided by Başoğlu (1973). The *C. caretta* records in the Black Sea are from Romania in 1922, and Bulgaria in 1936, 1947, 1981, 1987 (Nankinov 1998). As for *C. mydas*, the records are from Bulgaria in 1898 (Nankinov 1998) and from the Turkish Black Sea in 2009 and 2014 (Öztürk *et al*. 2011; Ak *et al.* 2016). According to Geldiay *et al*. (1982) and Geldiay (1984), as well as these abovementioned records, sea turtles migrate to the Black Sea via the Turkish Straits System (TSS) and go back to the Aegean and Mediterranean Seas. However, no published data of sea turtle sightings or strandings in the TSS were found except Akdeniz *et al*. (2012). According to this study, based on interviews with fishermen, the occurrence of sea turtles in the Çanakkale Strait and the Marmara Sea entrance of the Strait has been confirmed.

## 2. Current Records

According to media reports of sea turtles and personal communication, there are 16 records in the TSS between 2007 and 2016 (Figure 1, Table 1). A new *C. caretta* sighting was also recorded in Romania, Black Sea, on September 6, 2016 (Hotnews 2016).

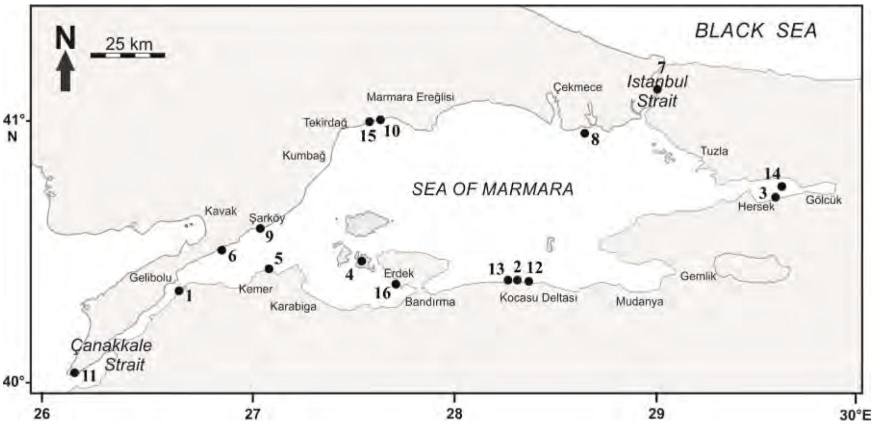
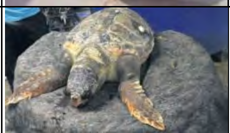



**Figure 1.** Locations of sea turtle records

**Table 1.** Current records of sea turtles in the Turkish Straits System

| No | Photo | Date | Location | Status | Species | Source |
|---|---|---|---|---|---|---|
| 1 |  | 12.10.2007 | Lapseki, Çardak | alive | *C. caretta* | Milliyet Newspaper [1] |
| 2 |  | 21.05.2010 | Bursa Karacabey Yeniköy | alive | *C. caretta* | Hürriyet Bursa [2] |
| 3 |  | 16.08.2011 | İzmit Bay | dead | *C. caretta* | Derin Takip [3] |
| 4 |  | 14.02.2012 | Paşalimanı Island | alive | *C. caretta* | IHA [4] pers. comm. Ahmet Emre Kütükçü |
| 5 |  | 04.03.2013 | Çanakkale Biga | alive | *C. caretta* | Milliyet Newspaper [5] |
| 6 |  | 12.04.2013 | Şarköy Kazanağzı | alive | *C. caretta* | Milliyet Newspaper [6] |

| | | | | | | |
|---|---|---|---|---|---|---|
| 7 | | 29.07.2013 | Istanbul Strait Kandilli | alive | ? | pers. comm. Kürşad Öztek [7] |
| 8 |  | 09.04.2014 | İstanbul Avcılar | alive | *C. caretta* | Çanakkale Memleket [8] |
| 9 |  | 01.05.2014 | Şarköy | dead | *C. caretta* | Devrim Gazetesi [9] |
| 10 |  | 08.05.2014 | Çorlu Yenice | dead | *C. caretta* | Marmara Haber [10] |
| 11 |  | 03.08.2014 | Çanakkale Strait Ertuğrul Bay | alive | *C. caretta* | Milliyet Newspaper [11] |
| 12 |  | 05.01.2015 | Bursa Karacabey | dead | *C. caretta* | Gazete Vatan [12] |
| 13 |  | 15.01.2016 | Bursa Karacabey Yeniköy | alive | *C. caretta* | Akşam Newspaper [13] |
| 14 |  | 25.03.2016 | İzmit Bay | dead | *C. caretta* | Milliyet Newspaper [14] |
| 15 |  | 21.05.2016 | Tekirdağ, Beyazköy | dead | *C. caretta* | pers. comm. Cansın Özden [15] |
| 16 |  | 13.09.2016 | Erdek | alive | *C. mydas* | pers. comm. Deniz Yaşar [16] |

[1] http://gazetearsivi.milliyet.com.tr
[2] http://www.hurriyet.com.tr/bursa/
[3] http://derintakip.blogspot.com.tr/2011/08/mavi-dunyanin-gocebeleri.html
[4] http://www.iha.com.tr/haber-dostum-emin-ellerde-215670/
Vet. Ahmet Emre Kütükçü, Wild Life Rescue
[5]http://www.milliyet.com.tr/marmara-da-yine-caretta-caretta/gundem/detay/1846402/default.htm
[6]http://www.milliyet.com.tr/marmara-da-dev caretta/gundem/gundemdetay/12.04.2013/1692629/default.htm
[7] Kürşad Öztek, Öztek Architecture Company
[8] www.canakkalememleket.com
[9] http://www.devrimgazetesi.com.tr/caretta-caretta-sahile-vurdu/
[10] http://www.marmarahaber.com.tr/haber/28215/olen-caretta-caretta-kiyiya-vurdu.html
[11]http://www.milliyet.com.tr/yarali-kaplumbagayi-elleriyle-beslediler-canakkale-yerelhaber-324640/
[12] http://www.gazetevatan.com/nesli-buyuk-tehlike-altinda-olusu-sahile-vurdu-714083-yasam/
[13] http://www.aksam.com.tr/yasam/balikcilari-sok-eden-surpriz/haber-481170
[14] http://www.milliyet.com.tr/izmit-korfezi-nde-olu-caretta-gundem-2217479/
[15] Cansın Özden, Istanbul Technical University
[16] Deniz Yaşar https://www.youtube.com/watch?v=nCSrcbff1WI

## 3. Discussion

The earliest sea turtle records in the Marmara Sea go back to the Byzantine period in Istanbul. During the excavation of Theodosius harbour for Marmaray project, 37 specimens of sea turtles were identified, which were probably hunted and traded then (Onar *et al.* 2013; Onar 2016). In 1585, during a galley tour between Istanbul and Varna, a large number of sea turtles were seen often (Nankinov 1998). Besides in 1970 and 1971, 2 and 0,8 tonnes of sea turtles were caught in the Sea of Marmara, respectively (Berkes 1977). Nankinov (1998) also mentioned that *C. caretta* occurrence in the Black Sea is neither rare, nor accidental, and thus suggested that a third migration route from northern Aegean Sea passes through the TSS towards the Black Sea. *C. caretta'*s current Mediterranean population trend is increasing and the species is listed in IUCN Red List as Least Concern since 2015, which was Endangered previously (Casale 2015).

Several observations at various localities in the Sea of Marmara during the last decade may be linked with the increasing population trend, as well as multiplication of public awareness campaigns aimed at protection of sea turtles in recent years. Additionally, easy access to digital technologies and the advance of citizen science on a global basis have positively contributed to the process of collecting data for sea turtle specialists around the world. Despite this multi-faceted progress, the status of these two species in the Sea of Marmara is still barely known. It is most likely that the Sea of Marmara and Black Sea may function as a feeding ground for *C. caretta* because of the high jellyfish abundance. Moreover, we consider that this case reflects the mediterraneanization of the Black Sea for which the sea temperature rise is the main cause due to climate change. Besides, we should elaborate some rescue and rehabilitation mechanisms in the region in case of live strandings of sea turtles as well as monitoring programme for strandings.

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# LAND-BASED POLLUTION IN THE SEA OF MARMARA AND ASSESSMENT OF POLLUTION ABATEMENT STRATEGIES

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## 1. Introduction

The Sea of Marmara has been suffering from land-based pollution mainly after the 1960s following high immigration waves from the eastern part of the country to the Istanbul Metropolitan area and also due to natural growth. The uncontrolled expansion of Istanbul coupled with inadequate urban planning has caused a chronic delay in infrastructure facilities which has had significant adverse impact on the receiving waters due to land-based pollution. The main reason for, was the urbanization rate that has been faster than the implementation rate of infrastructure projects that obviously remained behind schedule. Although alleviated to some extent, this heavy urbanization is still a concern for the Istanbul infrastructure and consequently the receiving environment is still subject to land-based pollution. According to official census data based on the "Address Based Population Registration System", which was conducted by the Turkish State Institute of Statistics, the population of the city has reached 18.6% of the total population of Turkey (TUIK, 2015). Currently, more than 9 million people live on the European side, and almost 5 million people live on the Asian side of Istanbul. The population density is of 2,821 people/ km$^2$, far greater than Turkey's density of 102 people/km$^2$ with a population growth rate of 1.93% yearly between 2014 and 2015, of which one third is due to immigration from Eastern rural areas.

As a consequence, Istanbul, the largest city of Turkey, housing a population exceeding 14 million at present, has been the major domestic and industrial wastewater generating hot-spot within the basin of the Sea of Marmara. The population of the Istanbul Metropolis and its surroundings correspond to approximately 20% of the total national population, furthermore 60% of the total industrial facilities are located on the bays and coastal areas where discharges occur either screened / treated or without any satisfactory treatment in some cases.

## 2. Oceanographic Features of the Sea of Marmara

The Sea of Marmara, located on the border of two continents, Europe and Asia and connecting two basins of particular importance, namely the Black Sea and Mediterranean Sea basins, is undoubtedly one of the most attractive marine environments. As an inland semi-enclosed water body of 11 111km$^3$ with an average depth of 260m it connects the Black Sea and the Aegean Sea via the Istanbul Strait (Bosphorus) and Çanakkale Strait (Dardanelles) respectively (Gazioğlu *et al.* 2001). The oceanographic system composed of the Sea of Marmara, the Istanbul Strait (Bosphorus) and the Çanakkale Strait (Dardanelles) is called the Turkish Strait System (TSS) and exhibits rather complex hydrodynamic features (Figure 1). The most important particularity of this system is the formation of a two-layer current due to salinity gradient between the more saline (38psu) and dense waters of Mediterranean Sea and the less saline waters of the Black Sea (18 psu) flowing in opposite directions. Several studies helped establish the fundamentals of the Istanbul unique oceanography. It has long been understood that the Sea of Marmara is permanently and strongly salinity stratified, with a top layer only 10 to 30 m thick. The Black Sea is also stratified, but with a top layer over 100m thick. The upper layer in both these waters is nearly everywhere well oxygenated. The lower layer of the Marmara Sea lying below 30m depth, is not anoxic but suffers a persistent depression of dissolved oxygen to a concentration of the order of 1 to 2 mg/l. Although the lower layer is fed consistently from the Mediterranean via the Çanakkale Strait (Dardanelles), and water in the lower layer flows steadily toward the Istanbul Strait to pour northward in the Istanbul Strait under layer, currents in the sea itself are extremely sluggish whenever and wherever they have been measured. An intermediate layer is also formed between these two layers at approximately 10-15m depth at the southern sill and 40-45 m depth at the northern sill of the Istanbul Strait. Another important oceanographic feature is that the upper layer current flowing from the Black Sea towards the Sea of Marmara is controlling the ecological structure of the Sea of Marmara. All these aspects have been demonstrated in field surveys followed by scientific papers (Ünlüata *et al.* 1990; Beşiktepe *et al.* 1994; Gönenç *et al.* 1995; Polat *et al.* 1995a,b; Yüce *et al.* 1996a,b; Alpar *et al.* 1998; Sur *et al.* 2004). Figure 2 shows the salinity contours across the longitudinal transect of the Istanbul Strait with current vectors.

The oceanographic particularity of the Sea of Marmara and the Bosphorus has been taken into account in several studies mainly in the Master Plans developed for the sewerage system of the Greater Metropolitan Area of Istanbul (DAMOC 1971; IBRD 1993; ISKI 1999; ISKI 2002). Consequently, this feature has long been investigated and has been almost a guiding data for the selection of the disposal locations and adopted strategies for wastewater treatment and disposal for the Metropolitan Area of Istanbul. These investigations such as field surveys and modelling have been more concentrated on four key areas as follows and as shown on Figure 1).

- Sea of Marmara
- Istanbul Strait (Bosphorus)
- Istanbul Strait (Bosphorus)-Black Sea Junction
- Istanbul Strait( Bosphorus)-Sea of Marmara Junction

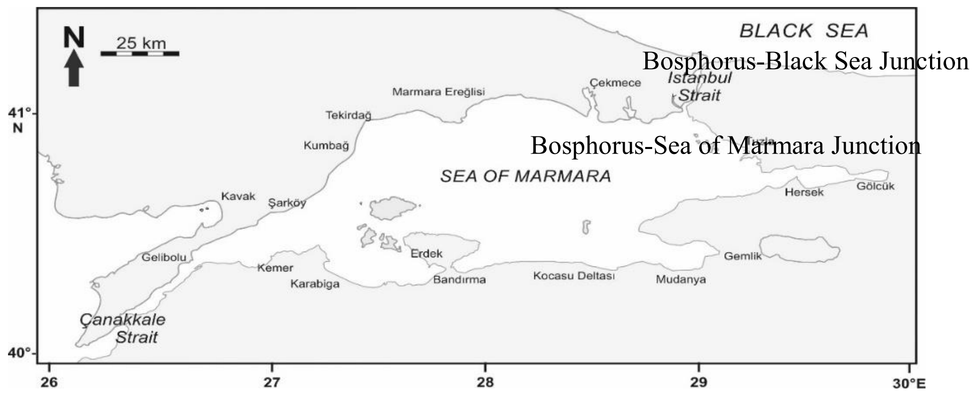


**Figure 1.** Turkish Strait System (TSS)

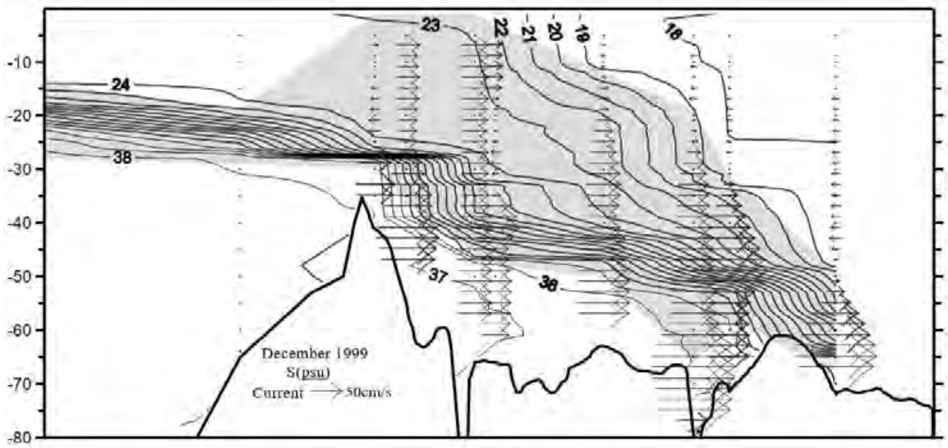


**Figure 2.** Salinity contours across the longitudinal transect of the Istanbul strait illustrated with current vectors

### 3. Land-based Pollution in the Marmara Region

### 3.1 Sources of land-based pollution and hot-spots

The land-based pollution generated in the Sea of Marmara is due to three major sources: a)domestic and industrial wastewater discharges from Istanbul and its surroundings, b)point source and diffuse pollution in the Southern Marmara Basin and c)nutrient load transported *via* the upper layer Black Sea current (Tuğrul *et al.* 1995).

When assessing land-based pollution disposal in the receiving media, it is necessary to address the question of what specifically are the pollution conditions along the coastline, as distinct from the offshore regions. The coastline is the location of most of the recreational activities (e.g. swimming, rowing, fishing) and aesthetic enjoyment of the sea, and important marine biological activity generally takes place in nearshore waters, yet until now most wastewater has been released, untreated, to the coastline, from where it can only be poorly dispersed to the sea. A reliable assessment of a sea pollution status must take into consideration, therefore, coastal and offshore areas separately.

The Marmara geographic region is the most developed region of the country in terms of industrialization and the most crowded in terms of population density as detailed in the abovementioned section. Pollution is generally most severe in semi-enclosed marginal seas and coastal waters bordering highly polluted and industrialized zones (Morkoç *et al.* 2001). The Sea of Marmara exhibits a very good example justifying this statement with large industries and cities that are located on the coast of the elongated semi-enclosed Izmit Bay, Gemlik and Bandırma bays which receive untreated or partially treated domestic and industrial wastewater (Burak *et al.* 2009). Figure 1 shows the location plan of the hot-spots in the Marmara region. During the preparation of the last Master Plan Study for Istanbul, land-based pollution load generated by major hot-spots in the Sea of Marmara was computed based on various field studies. Within the scope of the Master Plan Study, the major hot-spot was indicated as Istanbul having the 65% of the total input to the Sea of Marmara (DHI 1994).

### 3.2 Land-based pollution profile in Istanbul

The need of the above mentioned monitoring programs are due to high amount of land based discharges of pollutants to the marine environment. The metropolitan area of Istanbul has a total area of 5712 km2 and is bounded by the Sea of Marmara, Istanbul Strait, Golden Horn and Black Sea as shown on (Figure 3). The proportion of agricultural land in this area is minimal; therefore land-based pollution derives mainly from residential areas, industry and storm water. Additionally diffuse domestic pollution conveyed by creeks and streams discharging into the Sea of Marmara has caused local health and aesthetic concerns. This issue is still a concern even at present.

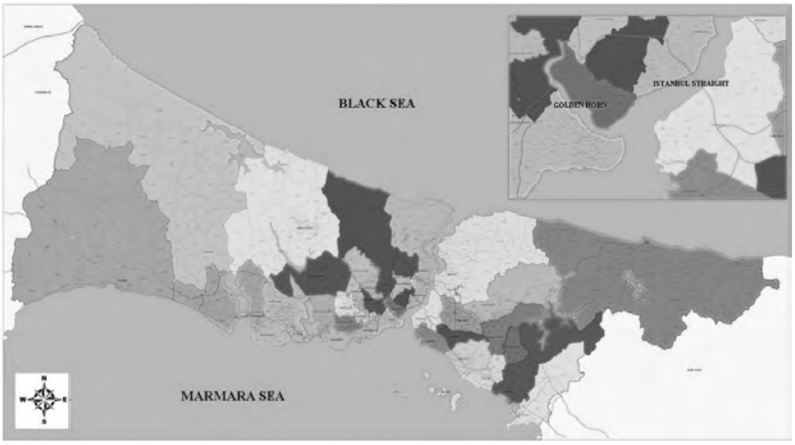


**Figure 3.** Istanbul Metropolitan Municipality area (www.ibb.gov.tr)

Daily domestic pollutant loads were computed based on the wastewater characterization study that was carried out with experimental data in Istanbul to indicate the unit emission rate for domestic sewage within the scope of the Istanbul Master Plan study (IMC 1993). Since no substantial changes have occurred in household customs, the same emission rates were taken as 40 (g/capita/d) for $BOD_5$; 45 (g/capita/d) for SS; 6.7 (g/capita/d) for TOT-N; 1.3(g/capita/d) for TOT-P respectively. The domestic pollution load discharged in the marine environment is given in Table 1, the details of the plants are given in Table 2. The corresponding load is 131210 tons/year for BOD5, 147610 for suspended solids, 23254 for total-N and 4515 for tot-P. The pollution load which was computed by the Master Plan Consortium estimates for 2040 a daily figure of more than 112 metric tons of nitrogen and 28 metric tons of phosphorus load input from the Istanbul discharges (ISKI 1999). In 1993, the domestic organic load generated by the Istanbul Metropolitan area was nearly the half of the whole organic load generated by the settlements of the entire Marmara region; that was 395tons/year and 565tons/year respectively.

Bacteriological contamination is another prominent issue for the Istanbul sewerage system since controlling storm water flow is not only difficult due to the topography of the city but also due to the fact that illegal connections may happen and this result by raw sewage discharges in the small creeks. More than 50 streams, effectively open sewers carry high domestic and industrial pollution loads. Although an extensive rehabilitation program was started to be implemented in parallel to the sewerage program after the 1990s, there are still creeks of various sizes with a total length of 500km that need to be rehabilitated (Burak 2008). A water quality monitoring study was carried out and experimental evidence of bacteriological pollution at the discharge location of these creeks was proven between 1998 and 2003 as shown on Figure 4.

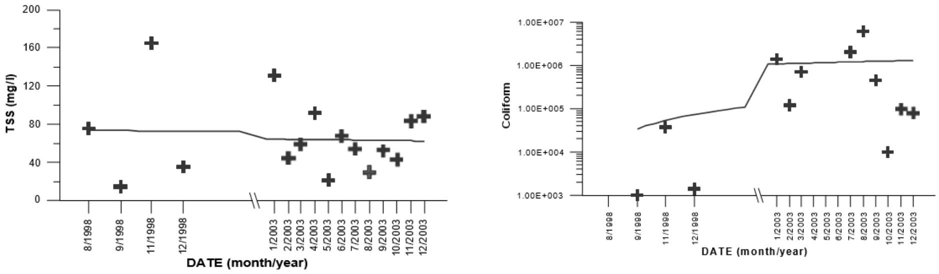


**Figure 4.** TSS and Coliform variations at the discharge area of Küçüksu creek between 1998 and 2003 (Burak 2008)

**Table 1.** Domestic Pollution Load Discharged in the Sea of Marmara and Istanbul Strait (Burak 2008)

| Sea Outfalls after primary treatment | Domestic pollution loads (tonxday$^{-1}$) | | | |
|---|---|---|---|---|
| | BOD | SS | Total | Total |
| Yenikapi | 100.00 | 112.50 | 16.75 | 3.25 |
| Baltalimanı | 60.00 | 67.50 | 10.05 | 1.95 |
| Büyükçekmece | 18.00 | 20.25 | 3.02 | 0.59 |
| Küçükçekmece | 24.00 | 27.00 | 4.02 | 0.78 |
| Üsküdar | 8.00 | 9.00 | 1.34 | 0.26 |
| Kadıköy | 89.20 | 100.35 | 14.94 | 2.90 |
| Küçüksu | 55.08 | 61.96 | 9.23 | 1.79 |
| Tuzla* | 5.20 | 5.85 | 4.36 | 0.85 |
| Total | 359.48 | 404.41 | 63.71 | 12.30 |

*The wastewater at the Tuzla plant is discharged after biological treatment, the $BOD_5$ load is computed on the assumption of 80 % removal rate of the organic pollution.

**Table 2.** Treatment Types, Capacities and discharge points of the Wastewater Treatment Plants in the Istanbul Metropolitan Area. (www.iski.gov.tr)

| NO | TREATMENT PLANT | | TREATMENT TYPE | CAPACITY $M^3$/DAY | POPULATION CAPACITY | DISCHARGE POINT |
|---|---|---|---|---|---|---|
| 1 | Yenikapı (1988) | | Primary - Physical Treatment | 873.000 | 3.160.000 | Treated wastewater is discharged to 64 m in depth, to the lower layer current, flows to the Black Sea. |
| 2 | Baltalimanı (1997) | | Primary - Physical Treatment | 625 000 | 3.000.000 | Treated wastewater is discharged to 70 m in depth undercurrent in the strait, 350 m away from the coast. |
| 3 | Büyükçekmece (1998) | | Primary - Physical Treatment | 155.120 | 620.000 | Treated wastewater is discharged to the 40 m depth of the Marmara Sea. |
| 4 | Üsküdar (1992) | | Primary - Physical Treatment | 77.760 | 350.000 | Treated wastewater is discharged into the 47 m in depth undercurrent of the Bosphorus, flows through to the Black Sea. |
| 5 | Kadıköy (2003) | | Primary - Physical Treatment | 1.420.000 | 3.000.000 | Treated wastewater is discharged into the 51,5 m in depth undercurrent of the Bosphorus, flows through to the Black Sea. |
| 6 | Küçükçekmece (2003) | | Primary - Physical Treatment | 350.000 | 1.400.000 | Treated wastewater is discharged to the 37,81 m depth of the Marmara Sea. |
| 7 | Küçüksu (2004) | | Primary - Physical Treatment | 640.000 | 1.400.000 | Treated wastewater is discharged into the 67 m in depth undercurrent of the Bosphorus, flows through to the Black Sea. |
| 8 | Ataköy (2010) | | Advanced Biological Treatment | 600.000 | 45.000 | Treated wastewater is discharged into the Marmara Sea by Ayamama Creek. |
| 9 | Tuzla | 1. Plant (1998) | Advanced Biological Treatment | 150.000 | 1.000.000 | Treated wastewater is discharged into the 46 m depth of the Marmara Sea. |
| | | 2. Plant (2009) | | 100.000 | 500.000 | |
| 10 | Paşaköy | 1. Plant (2000) | Advanced Biological Treatment | 125.000 | 500.000 | Treated wastewater is discharged into the Riva Creek by 6 km length tube and transmitted to the Black Sea by this way. |
| | | 2. Plant (2009) | | 125.000 | 500.000 | |
| 11 | Terkos (2000) | | Advanced Biological Treatment | 2.000 | 7.000 | Treated wastewater is transmitted to clean water tank and then discharged to the Terkos Lake Basin. |
| 12 | Bahçeşehir (2004) | | Biological Treatment | 7.400 | | Treated wastewater is discharged into the Küçükçekmece Lake Basin. |
| 13 | Paşabahçe (2009) | | Primary - Physical Treatment | 570.000 | 2.000.000 | Treated wastewater is discharged into the undercurrent of the Bosphorus. |
| 14 | Ambarlı (2012) | | Advanced Biological Treatment | 400.000 | 1.600.000 | Treated wastewater is discharged into the Marmara Sea. |

## 4. Overview of Wastewater Treatment and Disposal Strategies Adopted by the Metropolitan Municipality of Istanbul

It will be appropriate to remind some points related to ocean disposal strategy experienced in other World's great coastal cities in the recent past:

1. Use the sea: where a city is near the sea, it can be considered as part of its wastewater disposal system, to take strategic advantage of its assimilation capacity and its great spaces
2. Treatment: wastewater must be treated to some extent. There is no sea that can take the wastewater from so large a city as Istanbul without treatment. Industrial wastes bearing concentrated toxic chemicals such as heavy metals should be treated at their source
3. Discharge away from the shoreline: Treated wastewater discharged to the sea should be released into the optimum currents' location capable of assimilation and dispersion far from the coast. Discharge at the shoreline, or to poorly-flushed bays will be much less effective, because natural dispersion of wastes from the shoreline is very slow compared to offshore regions
4. Environmental impact: Furthermore, the shoreline is where people swim, walk and generally to enjoy the marine environment. The coastal environment is also a very important region for aquatic life and related food chain. The sustainability of the marine environment is of utmost importance as the coastal waters are shelter to aquatic species
5. Treatment plant location: It is desirable to locate a treatment plant in an area where there is sufficient space to provide adequate treatment to all wastewater to be handled there, both at the time of construction and in the future for extension, when flows may be greater and treatment requirements may be stricter

In Turkey, construction of up-to-the-standards sewerage facilities began in the late 1960's initiated by the Bank of Provinces, a governmental central agency (restructured in February 2011 as a joint stock company). New sewerage projects have been designed on separate systems taking into account land development projections. In urban areas more than 75% of the population is connected to the sewerage network on the average. Due to high investment costs, storm water collection systems have been constructed only in limited flood prone areas of big cities.

So far, in coastal settlements, the final disposal by deep-sea outfall of collected wastewater after preliminary treatment has been a common practice. The treatment level of domestic wastewater to be discharged into the receiving media has been assessed under three categories based on the population figures. The regulations prescribe a comprehensive list of effluent standards particular to domestic sewage treatment works discharging directly to watercourses and the sea and also individual industries. Areas of high ecologic importance and sensitive to environmental pollution must be given special importance as stipulated in the related clause of the Environment Act.

Advance treatment is gradually being introduced to the wastewater treatment plant design located in touristic coastal areas, special protected areas and water protection basins. After the accession process to the EU and harmonization of the standards, the adoption of the EC-WFD and its related daughter directives, related legislation and standards have been improved. One of the daughter directives that is put into force is the Urban Wastewater Treatment Directive (UWWTD) that obliges more stringent criteria and standards to be reached. This issue will be discussed in more details in Section 5.

In accordance with the first Master Plan finalized in 1971 and subsequent projects revised to accommodate changing circumstances, a comprehensive wastewater management program was launched in the 1980s for the Istanbul metropolis, envisaging treatment of an average daily wastewater discharge of 3.2-4.8 million $m^3$ for the horizon year 2020 equivalent to a population projection of 20 million (Burak 2008).

After the establishment of the Istanbul Water and Sewerage Administration (ISKI) in 1981, the wastewater collection and disposal strategies as proposed in the DAMOC Master Plan started to be implemented supported by a World Bank loan. The disposal strategy proposed in DAMOC, adopted deep sea outfall after primary treatment into the lower layer of the Bosphorus. This strategy was based on the hypothesis that the lower more saline Mediterranean current was reaching the Black Sea without significant infiltration to the upper layer less saline Black Sea current. The main argument behind this decision was the collection of wastewater urgently and disposal into the bottom layer current of the Istanbul Strait waters that flow northward from the Marmara Sea towards the Black Sea. The fact that the more saline lower layer current coming from the Mediterranean Sea discharges into the Black Sea and a less saline upper layer current flows southward in the opposite direction into the Mediterranean, was proven by several studies carried out along the Turkish Straits System (TSS) before the adoption of this strategy followed by its implementation (DAMOC 1971; Ünlüata *et al.* 1990; IBRD 1993; Gönenç 1994; Gönenç *et al.* 1995).

It was decided to launch an intensive program combining numerical modelling and field sampling providing answers to the abovementioned questions and finds a feasible, reliable and cost-effective treatment and discharge strategy.

The overall wastewater treatment and disposal strategies have the following targets:

1-Separate sewerage system in order to decrease the wastewater flow to be treated

2-Industrial wastewater must undergo preliminary treatment to the degree of domestic wastewater prior to be discharged into the municipal sewerage system
3-Discharge into the bottom of the receiving media that are either the Istanbul Strait or Marmara Sea
4-Wastewater is treated mechanically, biologically, tertiary where and when required and possible.
5- Phased approach with regard to the size of the plant (extension over time to cope with the equivalent population load) and treatment level (start with mechanical treatment and deep sea outfall as an urgent implementation and upgrade the treatment level over time)

The set strategy has been applied over time until present and has resulted with the phased implementation of 14 operating treatment plants. The treatment types, capacities and discharge locations of the wastewater treatment plants within the Istanbul Metropolitan Area, are given in Table 2.

Out of 14 operating wastewater treatment plants, six operate for biological and/or advanced (tertiary) treatment; the remaining ones operate as physical (primary treatment) plants. In the Istanbul Metropolitan Area, wastewater is discharged either into the lower layer of the semi-enclosed Marmara Sea or into the lower layer of Istanbul Strait which flow northward into the Black Sea via the lower layer current of the Istanbul Strait. Each treatment plant, either physical or biological, is complemented with a deep sea outfall.

Yenikapı primary treatment plant that was commissioned in 1988, Üsküdar in1992, and Küçüksu in 2004, discharge a load of 100 tons/day, 8 tons /day, and 55 tons/day respectively.

The location plan of the wastewater treatment plants are shown on Figure 3.

## 5. Assessment of Wastewater Treatment and Disposal Strategies

Selection of wastewater disposal strategy depends on several issues such as but not limited to the topography of the site, oceanographic features of the receiving media, the nature and the degree of the pollution and its fluctuation, environmental conditions of the surroundings and receiving waters, ruling pollution abatement criteria and ruling treatment mandatory standards and guidelines, transboundary pollution conditions etc. For the Istanbul Metropolitan Area, this has been difficult for decision makers and this becomes even more difficult and controversial in the face of the expanding metropolitan area which will necessitate most probably a revised master plan for Istanbul.


**Figure 3.** Locations of the Wastewater Treatment Plants in the Istanbul Metropolitan Area (www.ibb.gov.tr)

During the preparation phases of the latest Istanbul Master Plan completed after 2000, the assessment of disposal locations was focussed on the Marmara Outfalls, as their environmental situation was considered the most critical. Particular attention was given to whether the circulation in the Marmara lower layer would be adequate to disperse the large volumes of discharge from Tuzla and Küçükçekmece, in particular, after they have received biological treatment. Furthermore an assessment was made to whether tertiary treatment for nutrient removal would be of benefit for discharges to the Marmara lower layer. If treated, discharges could be released to the Marmara lower layer far from shore, investigations were made to establish how far from shore it would be necessary to convey the effluent achieve adequate dispersion and what benefit would be provided by biological treatment and by nutrient removal.

It was foreseen that the effluent from the Tuzla treatment facilities might have a critical impact on the local sub-surface marine environment, which was a naturally oxygen deficit sub-layer below the photic zone and in a bay with a very low residential circulation. The Küçükçekmece effluent was expected to cause similar problems. Together, these constituted the major environmental issues. Without judgement as to whether the precise sites chosen are optimal from an economic or structural point of view, it is clear that Istanbul growth patterns result in generation of major wastewater flows concentrated in these areas and acceptable disposal strategies had to be sought to serve them. Yet the logical disposal site, the Sea of Marmara, is a particularly problematic receiving water. Its shoreline has long been contaminated by simple coastal discharges of industrial and domestic wastewater. Disposal by conventional long deep sea outfall to discharge points sufficiently far from shore result in entrapment of the effluent in the fragile and very quiescent lower layer. Due to large quantities of effluent, even a highly treated discharge will threaten to consume the small but vital oxygen supply there. Anthropogenic pollution load constitutes a major environmental stress in the aquatic receiving media close to the discharge location, in particular. Indeed, as it was stipulated by (Albayrak *et al.* 2006), pollution effects slow down with increasing distance from the shoreline to distances with little to negligible anthropogenic pressures in the Sea of Marmara. However the assimilation capacity of the Sea of Marmara has been by far exceeded due to ever-increasing anthropogenic domestic pollution. Deep-sea outfalls for wastewater discharges will not be anymore a sufficient level for domestic pollution abatement efforts for the Istanbul Metropolitan Area. This has to be abandoned in favor of appropriate treatment in line with up-to-date regulations.

As stipulated in the abovementioned paragraph, and with regard to the commitment of Turkey for the adoption of the EC-WFD and its related daughter directives, one can analyze the extent of the problems. These relate mainly to the primary treatment plants located along the Istanbul Strait that need upgrade for biological treatment according to the UWWTD. At the time that these plants were constructed after the 1980's, the urgent need was to collect wastewater and discharge into the lower layer of the sea in order to protect the shoreline from pollution; moreover, the selected location of the plants was appropriate with regard to sea outfalls. But even from the beginning stage, there has been no room for biological treatment units along the Istanbul Strait, as these lands were already occupied; moreover, it is not environmentally, aesthetically and economically rational to locate large treatment plants along a recreational site having a scenic beauty.

To this end, it may be necessary to select a treatment site inland, where land may be less expensive and where the treatment plant will not occupy valuable coastal land, or dominate the waterfront. Land requirements can be greatly reduced by turning to increasingly popular compact, covered treatment works which can provide good biological or tertiary treatment within an area much smaller than conventionally required.

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## STATUS OF THE MARINE MAMMALS POPULATION OF THE SEA OF MARMARA

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### 1. Marine mammal species of the Sea of Marmara

In the Sea of Marmara there are three species of order Cetacea, common bottlenose dolphin *Tursiops truncatus* (Montagu, 1821), short-beaked common dolphin *Delphinus delphis* (Linnaeus, 1758), harbour porpoise *Phocoena phocoena* (Linnaeus, 1758). One species of order Pinnipedia, Mediterranean monk seal *Monachus monachus* (Hermann 1779) has been long been well known (Mursaloğlu 1984; Öztürk 1992; 1996). In addition, coupled with new records of two cetacean species striped dolphin *Stenella coeruleoalba* (Meyen, 1833) and Risso's dolphin *Grampus griseus* (Cuvier, 1812), totally six marine mammal species can be observed in the Sea of Marmara (Öztürk *et al.* 1999; Altuğ *et al.* 2011; Dede *et al.* 2013). These species can be classified according to Notarbartolo di Sciara and Birkun (2010); regularly sighted *D. delphis, T. truncatus* and *P. phocoena* as common, unusually sighted *S. coeruleoalba* (visitor) and *G. griseus* (vagrant) as occasional and *M. monachus* as very rare.

However, limited number of studies about the distribution, migration, population size, interraction with stressors such as fishing-marine traffic etc. are present. In the Saa of Marmara the presence of *T. truncatus*, *D. delphis* and *P. phocoena* (as *Delphinus phocaena*) was first described by Deveciyan (1926). A resident group of bottlenose dolphins in the Istanbul Strait was indicated by (Tezel 1958).

The Sea of Marmara constitutes an important migration pathway between the Aegean Sea and the Black Sea and called as Turkish Straits System (TSS) together with Çanakkale and Istanbul Straits. Dolphins use the area as a natural trap for feeding on migratory pelagic fishes. *T. truncatus* and *D. delphis* schools migrate through the Aegean Sea to the Sea of Marmara in April-May for feeding (Öztürk and Öztürk 1996). *D. delphis* migrate to the Black Sea in spring and back to the Aegean Sea in autumn (Berkes 1977). Above three species of cetaceans can be observed year round in the TSS mostly in spring and autumn. In the TSS the most common species is indicated as *D. delphis* followed by *T. truncatus* and rare or sporadic *P. phocoena* (Öztürk and Öztürk 1997). Besides, Mediterranean monk seals have no longer been observed since the mid 90's except an unusual sporadic observation in 2014 (Inanmaz *et al.* 2014).

In the Sea of Marmara, there had been no records on the presence of the striped dolphin *S. coeruleoalba* which is common in the Aegean and Mediterranean Seas, however, in 1998, two seperate individual strandings reported from the northeastern part of the Sea of Marmara (Öztürk *et al.* 1999). Besides, a recent study reports the first live sightings of striped dolphins in the Sea of Marmara (Altuğ *et al.* 2011). According to previous cetacean stranding studies, such as Öztürk *et al.* (1999) and Tonay *et al.* (2009), there had been no stranding of Risso's dolphins reported in the TSS., Recently, however, one stranded specimen of Risso's dolphin; *G. griseus* was recorded for the first time in the Sea of Marmara (Dede *et al.* 2013)

The situation of the harbour porpoise which is common in the Black Sea and Northern Atlantic Ocean and rare in the Sea of Marmara is not stable in the Mediterranean Sea. Between years 1980-2000, one live observation, one live stranding and three dead strandings were reported, four of which were from the Northern Aegean Sea (Frantzis *et al*. 2001). In addition, between 1997 and 2013, totally 28 strandings (24 dead, three live, one entangled) were reported from the Aegean Sea, during a survey in summer 2013, live harbour porpoises were observed on nine occasions and detected acoustically 16 times, with a total of 21 distinct encounters recorded in the Aegean Sea (Cucknell *et al*. 2016). Stranded harbour porpoises which genetically belong to the Black Sea population are strong evidence of the movements between Black Sea and Aegean Sea through the Sea of Marmara (Rosel *et al.* 2003; Tonay *et al.* 2016a).

A long term passive acoustic monitoring (PAM) survey in the Istanbul Strait by Dede *et al.* (2014) and Kameyama *et al.* (2014), and surveys on bottlenose dolphin behaviours in relation to marine traffic by Akkaya Baş *et al.* (2015) are noted as recently conducted studies in the cetacean critical habitat, the İstanbul Strait.

The only pinniped species of the Sea of Marmara is the Mediterranean monk seal which is facing danger of extinction in the world. Today, Mediterranean monk seals lost their original range of distribution and just survive in the Madeira Island and northwestern coast of Africa in the Atlantic, and the Mediterranean Sea (especially Turkish and Greek coasts) (IUCN 2016). World population of Mediterranean monk seals estimated about 300-700 while the Turkish population about 50-100 (Gücü *et al.* 2004; Güçlüsoy *et al.* 2004; Öztürk 2007; Karamanlidis *et al.* 2015). The species is also thought to be extinct or on the verge of extinction in the Marmara and Black Seas and the Adriatic coasts (Öztürk 1994; Kıraç and Savaş 1996; Öztürk and Dede 2002)

Above mentioned marine mammal species are under the protection in Turkey by national laws (Fisheries Law, Hunting Law etc.) and international conventions (such as Barselona Convention, 1976 and Bern Convention, 1979) ratified or signed by Turkish Government. These international conventions categorized them as "strictly protected species".

## 2. Population size and distribution

The only study exist on the abundance estimation of cetacean population in the Sea of Marmara which is just covered two delphinids; bottlenose and common dolphins. Seasonal line transect surveys between 1997 and 1999 on cetacean population in TSS indicated abundance estimations as follows (Dede 1999); 495 (203-1197 95% CI) *T. truncatus* and 773 (292-2050 95% CI) *D. delphis* in October 1997; 468 (184-1186 95% CI) *T. truncatus* and 994 (390-2531 95% Cl) *D. delphis* in August 1998; 359 (140-1020 95% CI) *T. truncatus* and 329 (110-990 95% CI) *D. delphis* in February 1999; 669 (189-2372 95% CI) *T. truncatus* and 1192 (468-2592 95 %CI) *D. delphis* in April 1999.

In the Istanbul Strait, monthly boat surveys between 2006 and 2008 were conducted to understand seasonal and spatial distribution of bottlenose dolphin, common dolphin and harbour porpoises. Higher sighting rates in the northern part of the strait where less urbanization than the southern part were reported. According to 60 boat based survey in the Istanbul Strait in 2006 which covered totally 257 hour survey effort (1800 nm), 387 sightings were recorded (42% harbour porpoise 39% bottlenose dolphin and 19% common dolphin). In general, common dolphin were sighted in spring and autumn, harbour porpoises between March and July while bottlenose dolphins were sighted throughout the year and each three species biased to peak together with pelagic fish migration (Dede *et al.* 2008; Öztürk *et al.* 2009).

Akkaya Baş *et al.* (2015) reported that bottlenose dolphin (or sighting density) density per km$^2$ as 322 in spring (March, April, May), 61.7 in summer (June, July, August), 79 in autumn (September, October, November), and 324.3 in winter (December, January, February) in the İstanbul Strait.

The harbour porpoise is the smallest cetacean species observed in the Sea of Marmara and Black Sea in the Mediterranean Basin. Deveciyan (1926) indicated the presence of the species as ‘’very rare’’ in the Mediterranean Sea. The hypothesis that harbour porpoise colonies were first formed in the Mediterranean Sea in the second half of the Pleistocene (600.000-21.000 years ago) and enter to the Sea of Marmara and Black Sea 21,000 or 150,000 years ago has been suggested while another hypothesis focused on the time of the merge of Mediterranean and Black Sea about 7000 years ago (Frantzis *et al.* 2001). Besides, scattering of the Mediterranean harbour porpoise populations triggered by warm mid-holocene about 5000 years before the end of the nutrient rich late glacial period has also been projected (Fontaine *et al.* 2010).

In the 90’s, the presence of harbour porpoises in the TSS was reported by Öztürk and Öztürk (1997), however, its population size remained unknown. Harbour porpoise sightings in the Marmara Island and off the Yenikapı were recorded by a seasonally conducted study between 2006 and 2007 (Altuğ *et al.* 2011). Harbour porpoises in the

Black Sea cannot migrate regularly to the Sea of Marmara due to todays anthropogenic stress of the Istanbul strait is conceivable. On the other hand, small group size, small body size and less conspicuous dorsal fin compared to the delphinids make them difficult to observe even in calm sea conditions.

The Mediterranean monk seal in the Sea of Marmara first described by Deveciyan (1926). The population size of the seals in the Sea of Marmara estimated as 25 by Berkes *et al.* (1979). The southwestern coast, Marmara Island, Paşalimanı Island, Ekinlik Island, Mola Island and Kapıdağ Peninsula indicated as important seal habitats of the Sea of Marmara and surviving two isolated seal individuals reported by Öztürk (1994).

Besides, studies in the 90's drew attention to low encounter probability of individuals living in the Black Sea, Sea of Marmara and Aegean Sea that will cause low genetic exchange and seals may going to be extinct in near future under these circumtances (Öztürk 1994; 1995; 1998). Fishermen's reports of a single animal in May 1994 (Güçlüsoy *et al.* 2004) and summer 1996 (Dede, 1999) were made in the Marmara and Paşalimanı Islands, respectively. There had been no regular sightings or habitat use of seals in the Sea of Marmara over the last two decades until a seal was occasionally seen in the southern Sea of Marmara in 2014 (Inanmaz *et al.* 2014).

### 3. Group size

Group size of the cetaceans depends on biogeography, food amount, diversty and availibity. Bottlenose dolphins usually forms groups of less than 10 individuals (Bearzi *et al.* 2008). Common dolphins usually forms groups of 50-70 individuals but schools of 100-600 individuals are also possible (Bearzi *et al.* 2003). Harbour porpoises form small groups of 1-3 individuals, infrequently 6-8, and rarely bigger groups (Bjørge and Tolley 2009). The common dolphin is the species that has biggest group size amongst the observed species in the TSS. In the Sea of Marmara, group size of the common dolphin is usually between 10-22 and schools of more than 100 individuals of observed around Asmalı Island and off the Marmara Island (southern Sea of Marmara). Bottlenose dolphin observed usually in groups of 5-18 individuals and bigger groups around 40 animals observed only in the Istanbul and Çanakkale Straits. Harbour porpoise observations show that group size varied between 2-9 in the Sea of Marmara and 2-15 in the İstanbul Strait. Because of few encounter on a survey, average group size for the harbour porpoise and Risso's dolphin could not be calculated. (Dede 1999; Dede *et al.* 2008; 2013).

Mediterranean monk seals are mostly observed solitary, pairs or groups. In the Sea of Marmara reported or sighted seals were usually single animals.

**4. Resident population**

Groups of less than 40 bottlenose dolphins seasonally observed both Istanbul and Çanakkale Straits evaluated as resident groups of straits and neighbour area. In the vicinity of southwestern Sea of Marmara islands and both straits oftenly encountered common dolphins pointed out a resident population of common dolphin that migrate through Aegean Sea to Black Sea and vice versa (Dede, 2010). However, detailed photo identification and genetic studies are deemed necessary to understand resident groups.

**5. Strandings**

In the TSS, between 1993 and 2008 totally 65 cetacean stranding were reported. These are 22 common dolphin (35%), 21 harbour porpoise (34%), 14 bottlenose dolphin (23%), 2 striped dolphin (3%), one delphinid (2%) and 2 unknown cetacean (Table 1). Cause of death of 7 harbour porpoise and 6 common dolphin out of strandings between 1999 and 2008 were identified as accidental net entanglement (by-catch) (Figure 1). These were all dead strandings.

**Table 1.** Cetacean strandings in the TSS (1993-2008) (P.p: harbour porpoise, D.d: common dolphin, T.t: bottlenose dolphin, S.c: striped dolphin, del.: Delphinid, U: unknown)

| Year | P.p | D.d | T.t | S.c | Del. | U | Total | Reference |
|---|---|---|---|---|---|---|---|---|
| 1993-1998 | 4 | 6 | 4 | 2 | - | - | 16 | Öztürk *et al.* 1999 |
| 1999-2008 | 17 | 17 | 12 | - | 2 | 2 | 50 | Tonay *et al.* 2009 |
| Total | 21 | 23 | 16 | 2 | 1 | 2 | 66 | |

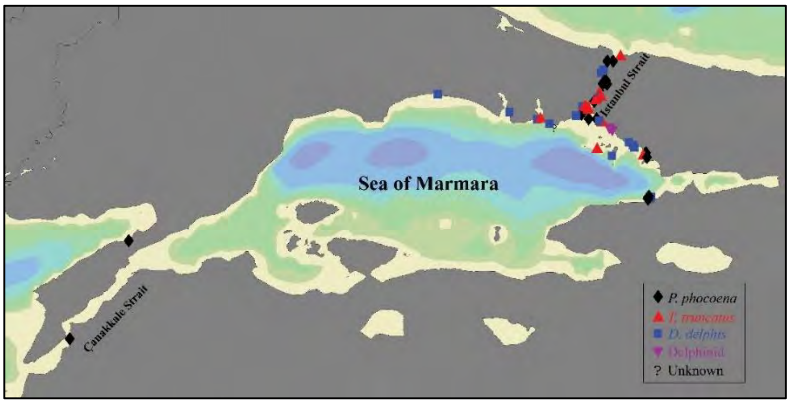


**Figure 1.** Strandings in the TSS during 1999-2008 (Tonay *et al.* 2009)

First stranding record of the striped dolphin in the Sea of Marmara were given by Öztürk *et al.* (1999), first stranding records of harbour porpoise in Çanakkale Strait were given by Tonay *et al*. (2009) and first stranding record of Risso's dolphin in the Sea of Marmara were given by Dede *et al*. (2013).

### 6. Population Genetics

It is well known that harbour porpoise population of the Black Sea and the Atlantic Ocean is morphologically (Kleinenberg 1956) and genetically (Rosel *et al.* 1995) different and isolated. The genetic studies on the Aegean Sea strandings pointed out that they are from the Black Sea population (Rosel *et al.* 2003; Tonay *et al.* 2016a). Besides, recently it is called as Phocoena phocoena relicta as a result of genetic studies on harbour porpoises which were strictly discriminate the Black Sea and Atlantic population (Fontaine *et al.* 2007; Viaud-Martinez *et al.* 2007). It's been assumed that few hundred individuals colonized the Black Sea as being the founder population by crossing Istanbul and Çanakkale Straits because environmental conditions became not suitable for this cold temperate species in the Mediterranean Sea around 8,000 ybp (Fontaine *et al.* 2012). Tonay *et al.* (2016a) indicated that the Marmara Sea harbour porpoise subpopulation was significantly differentiated from all of the other subpopulations by having an unique haplotype according to their mtDNA sequence variation, moreover, detecting the same haplotype in individuals from the same sea supports and strengthens the notion of its isolated (Uzun *et al.* 2016).

According to Tonay *et al.* (2016b), five new haplotypes of common dolphin were detected in the TSS and some degree of genetic connectivity was suggested from the common dolphins in the Turkish Black Sea and TSS waters to the Mediterranean and Atlantic populations.

### 7. Diet

In a study on stomach contents of one bottlenose dolphin and one common dolphin, *Pomatomus saltator* (blue fish) and *Trachurus trachurus* (horse mackerel) were the main prey items in both species while additionally *Sprattus sprattus* (sprat) found in common dolphin and *Belone belone* (garfish) found in bottlenose dolphin. Some plastics, fishing lines and nylon net parts also found in bottlenose dolphin stomach were indicated (Dede 1999). In the stomach contents of four by-caught harbour porpoises from the eastern Sea of Marmara in spring and autumn horse mackerel and sprat were the main prey items (Tonay *et al.* 2007).

There is no study about seal diet or stomach contents specificly for the Sea of Marmara. The Mediterranean monk seal is an opportunistic predator with their diet varying due to location, season and age of the seal as well as to the availability of food species (Gilmartin and Forcada 2009). The Mediterranean monk seal feeds in coastal areas on various fishes such as mullet, sea bream, bogues and mugil, cephalopods such as octopus and squid, and large crustaceans such as lobster and crabs (Öztürk 1994; Salman *et al.* 2001; Pierce *et al.* 2011; Karamanlidis *et al.* 2011; 2014).

**8. Migrations**

Instead of following prey fish herds dolphins also migrate for reproduction, wintering, nursing are known (Evans 1987; Öztürk 1996). *D. delphis* migrate to the Black Sea via the Sea of Marmara in spring and back to the Aegean Sea in autumn. *T. truncatus* and *D. delphis* move to Sea of Marmara from the Aegean Sea via Çanakkale Strait in April-May (Berkes 1977; Öztürk and Öztürk 1996; 1997). Dolphins are observed throughout the year, sightings peaked in between May-June and October-November (Dede 1999). Presence of dolphins correlated with the presence of migratory pelagic fishes in several studies (Berkes 1977; Öztürk 1996; Öztürk and Öztürk 1996; Dede *et al.* 2014).

Recent long term passive acoustic monitoring (PAM) study indicate that the cetacean presences in the Istanbul Strait related with feeding on the pelagic fish in spring when the fish migration has just started. Acoustic findings also suggest that they were feeding or socializing in spring and mostly travelling in the other seasons (Dede *et al.* 2014; Kameyama *et al.* (2014).

In the Mediterranean, long range movements by seals about 85-210 km were reviewed by Sergeant *et al*. (1978). In Turkish coasts about 36 km in one day was recorded by a marked seal (Mursaloğlu, 1984). Besides, Berkes *et al.* (1979) stated 40 km home range for the seals of the Bodrum Peninsula, southwestern Turkey. Although there is no any study on home range or movements pattern of seal in the Sea of Marmara, possible movements between northern Aegean Sea and southern Sea of Marmara via Çanakkale Strait is suggested because of historical seal sightings in the Çanakkale Strait.

**9. Threaths**

Main causes of the decline of the dolphin population briefly indicated as follows; accidentally caught by fishing net (by-catch), food shortage due to overfishing, habitat loss due to environmental degradation, over-urbanization and tourism, pollution, diseases, toxic affect of the chemicals (Öztürk 1996; Bearzi *et al*. 2004; Reeves and Notarbartolo di Sciara 2006). Cetacean population of the Sea of Marmara survive under various anthropogenic stressors such as heavy marine traffic, overfishing, pollution etc. (Öztürk 1995; Öztürk and Öztürk 1996; Dede *et al.* 2016).

The number of the large commercial or cargo transit ships is about 50.000 in a year, almost all of them also pass through the Çanakkale Strait. Domestic lines, small boats, daily tour boats etc. between the Asian and European coasts of the strait is about 2000-3000 (Poyraz and Paksoy 1998). Underwater noise made by marine vessels propeller cavitation and engine noise, seismic surveys, LF or MF sonars, and military exercises are mostly in low-frequency sounds and matched the sounds that many cetacean species use to communicate, feeding or mating and has negative effects (Pavan and Borsani 1997; Evans 2009; Würsig and Richardson 2009). Besides, intense traffic in the narrow strait can cause ship accidents that threat to human life, marine environment and ecosystem via oil spills etc. In 1994, eight *P. phocoena* and two *T. truncatus* individuals died in NASSIA oil tanker accident in the İstanbul Strait (Öztürk 1995). Recently marine traffic indicated as a significant source of disturbance to the bottlenose dolphin population in the Istanbul Strait (Akkaya Baş *et al.* 2015) and possibly affect cetacean diel movements pattern (Dede *et al.* 2014). Besides, increased densities of fishing vessels resulted in a drastic decline of dolphin sightings (Akkaya Baş *et al.* 2015) and possibly restrict dolphins to access feeding grounds (Dede *et al.* 2014) especially in autumn months.

The main causes for the decrease of the Mediterranean monk seal population are entanglement to fishing gear, deliberate killings, loss of habitat because of tourism (daily tours to seal habitats, recreational or cave diving etc.), coastal constructions and over-urbanisation, pollution, and lack of prey due to overfishing and illegal fishing, diseases (Sergeant *et al*. 1978; Reijnders *et al.* 1988; Israëls 1992; Panou *et al.* 1993; Johnson and Lavigne 1998; Bildt 2001; Öztürk and Dede 2002; Toplu *et al.* 2007; Karamanlidis *et al.* 2015). Main causes of disapperance of the seals from the Sea of Marmara are loss of habitat due to coastal over-urbanization, tourism, domestic and industrial pollution and coastal degradation (Öztürk 1994).

## 10. Dolphin Fishery History and Live capture

The early cetacean fishery records in the Marmara Sea goes back to 4th and 14th century (Tonay and Öztürk 2012). During the excavation of Theodosius harbour for Marmaray project, 90 specimens of dolphin (bottlenose and common dolphins) were identified, which have butchery marks on the surface of the remains (Onar *et al.* 2013; Onar 2016). Deveciyan (1926) mentioned about the cetacean fishery in the Black Sea, especially around Trabzon, but also in the Istanbul Strait and Marmara Sea during the Ottoman Period. Although there is no reliable statistic data on dolphin fishery, huge amount of dolphins were harvested between 1930 and the 1980's especially for oil. The only record for the Sea of Marmara mentioned by Berkes (1977) as 1.5 tonnes of dolphins (presumably total of all species) harvested in 1970. Turkey continued the dolphin fishery until 1983.

Dolphins, especially bottlenose dolphins, had been also captured for dolphinariums. In 2007, Turkish authorities gave permission for taking 30 wild dolphins for dolphinariums and so-called dolphin therapy companies which had been outcasted in most of the countries. Thus, Turkey violated Bern Convention, which lead to the official investigation.

### 11. Status and Conservation

Marine mammal species of the Sea of Marmara are listed in the IUCN Red List of Threatened Species (IUCN, 2016). Cetacean status listed as follows; Black Sea subpopulation of harbour porpoise is EN (Endangered), Mediterranean subpopulation of bottlenose dolphin is VU (Vulnerable), Black Sea subpopulation of bottlenose dolphin is EN, Mediterranean subpopulation of common dolphin is EN, Black Sea subpopulation of common dolphin is VU, Mediterranean population of striped dolphin is VU.

The Mediterranean monk seal listed as EN, “Endangered C2a(i) ver 3.1” by the IUCN (http://www.iucnredlist.org/details/13653/0, Karamanlidis and Dendrinos 2015). Previously, until 2013, the status was CR, “critically endangered” then change to “endangered” due to the world population trend assumed as increasing.

For the conservation of marine mammals, many international bodies such as IUCN, WWF, UNEP, RAC/SPA, and FAO-GFCM, governments, environmental NGO's and scientists have made elaboration to researches and conservation programmes in the last decades. Conservation action plans by international joint efforts are as follows;

- An Action Plan for the Conservation of the Mediterranean Monk Seal (UNEP/MAP 2009; UNEPRAC/SPA 2014).
- The Conservation Plan for Shortbeaked Common Dolphins in the Mediterranean Sea was prepared which mentioned Turkey waters as important Mediterranean common dolphin habitat (Bearzi *et al.* 2004).
- Draft Conservation Action Plan for the Mediterranean Bottlenose Dolphin published after Eighth Meeting of the Scientific Committee of the ACCOBAMS (Monaco, 13-15 November 2012) with the Turkish participation via contribution to ANNEX 8; AREA 10 – Aegean Sea (Turkey) & Area 11. Turkish Strait System.

The Action Plans for the conservation of the species mainly focused on *in situ* conservation measures as habitat protection especially on critical habitats, reduce interactions between marine mammals and fisheries, scientific research on marine mammals populations, education and public awareness campaigns and rescue/rehabilitation of orphaned or wounded marine mammals etc.

Turkey is the member of below international conventions consisting the protection of the Cetaceans and Mediterranean monk seal as follows;

- Convention for the protection of the Mediterranean Sea against Pollution (Barcelona Convention), 1976 (signed by Turkey 1981)
- Protocol concerning Mediterranean Specially Protected Areas (SPA) of the Barcelona Convention (Geneva 1982) (signed by Turkey 1988)
- Mediterranean Action Plan (MAP 1989) (signed by Turkey 1989)
- Convention on the Conservation of Migratory Species of Wild Animals, signed in Bonn Convention (June 23rd 1979).
- Convention on the conservation of European wildlife and natural habitats, signed in Bern on September 19th 1979. (signed by Turkey 1984)
- Convention on International Trade in Endangered Species of wild fauna and flora, signed in Washington, March 3rd 1973 (CITES). (signed by Turkey 1996)
- Convention on Biological Diversity, 1992 (signed by Turkey 1997)
- EEC Directive on the conservation of natural habitats and wild flora and fauna (Directive 9243 of May 21st 1992).
- Annex II of the European Union's Habitats Directive (92/43/EEC) which refer to designation of a Special Area of Conservation (SAC) for their protection.

The conservation of marine mammals is subject to governmental regulations since 1977 by Fisheries Law no 1381 which provides complete protection of cetaceans and Mediterranean monk seals in Turkish coasts. Other related Turkish national legislation are as follows; Forest Law, Hunting law, Law on the Protection of Cultural and Natural Assets, Environment Law No: 2872, Law on National Parks, Establishment of Authority for the Protection of Special Protection Areas.

For the conservation of the Mediterranean monk seal, a national seal committee was established for coordinating the conservation activities. The committee was coordinated by Ministry of Environment and it consists of government bodies, universities (İ.Ü., ODTÜ) and the NGO's (TUDAV, SAD, DHKD, TTKD). Fourteen (five of them most priority) important monk seal habitats in Turkish coasts were mapped and a list of problems threatening the species were prepared. The Sea of Marmara was excluded because of lack of current knowledge and sighting data. However, no further action has been implemented since then.

## 12. Discussion

Totally six marine mammal species; five cetacean species (bottlenose dolphin, common dolphin, harbour porpoise, striped dolphin and Risso's dolphin) and one pinniped (Mediterranean Monk Seal) can be observed in the Sea of Marmara. Recently observed new species for the Sea of Marmara the striped dolphins and the Risso's dolphins are commonly distributed in the Aegean Sea and they are known as forming mixed groups together in the Mediterranean Sea. Both species had been reported previously in the vicinity of Çanakkale Strait in the northern Aegean Sea, which suggests their possible short-term movement between the northern Aegean and the Sea of Marmara.

Although the dolphin fishery was banned since 1983 by Fisheries Law and dolphins are protected by national and international conventions, it is sad to witness that they are caught for the sake of commercial interests even they are endangered.

Turkey accedes to several international agreement except ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area). According to those agreements mammal species are listed as strictly protected species. Because of the dolphin takes strictly prohibited in most of the countries, the related companies tend to act in countries which has less prohibition measures or awareness. In the 2002-2010 conservation programme announced by IUCN Cetacean Expert Group, live capture of dolphins must be stopped unless complete scientific studies (abundance, reproduction, mortality) on wild dolphin population is available and fully evaluated (WDCS 2006).

In the Sea of Marmara, detailed studies are deemed necessary such as abundance estimation, population genetics, habitat preferences, home range estimation to update current knowledge on marine mammals. Meantime, a national stranding network for dead and live strandings or by-catch animals as well as a rehabilitation center for both cetaceans and pinnipeds should be established urgently.

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# OIL SPILL PREPAREDNESS AND RESPONSE IN THE SEA OF MARMARA

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## 1. Introduction

Oil Spills can arise from a number of different sources ranging from oil loading, unloading or pipeline operation, and from a collision or grounding of vessels carrying crude oil and product in local ports or coastal waters. They can also arise from tankers or barges operating on inland waterways, or from exploration and production operation and tankers operating in international waters. There are also other non operational sources such as urban runoff and natural seepage (Technical Guideline 2011).

Without a doubt the most crucial aspect of dealing with any emergency is to be repared.

Planning for an oil spill emergency helps minimized potential danger to human health and the environment by ensuring a timely and coordinated response. Well designed local, regional and national contingency plans can assist response personnel in their efforts to contain and clean up oil spill by providing information that the response team will need before, during and after spills, occur. Developing and exercising the plan provides opportunities for the response community to work together as a team and develop the interpersonal relationship that can mean so much to the smooth functioning of a response. Because the approached and methods for responding to oil spills are constantly evolving and each oil spill provides an opportunity to learn how to better prepare for future incidents, contingency plans are also constantly evolving and improving – ensuring increased protection for human health and environment from these accidents (Technical Guideline 2011).

Most of the marine pollution comes from land-based human activities. Accidental oil pollution contributes a comparatively small percentage of the total amount of oil entering the sea, but the consequences of a major accident resulting in an oil spill can be disastrous (Turan 2009).

Gradually increasing marine traffic also increases the accident and pollution risks in the Sea of Marmara. Large amounts of petroleum, which is dispersed in the marine environment as a result of tanker accidents, causes damage to water quality and greatly harms the flora and the fauna, and affects many species negatively, including humans, as it reaches shore-lines. Oil spills caused by vessel accidents also cause economical and social losses at serious levels (Birpınar *et al.* 2009).

The Turkish Straits System is comprised of the Sea of Marmara and the Straits of İstanbul and Çanakkale with coastlines shared by the continents of Europe and Asia. The Sea of Marmara has very special ecological conditions in terms of marine environment (atmospheric/oceanographic conditions, and biodiversity) and terrestrial environment. It also has roles as biological corridor and biological barrier between the Mediterranean Sea and the Black Sea and form an acclimatization zone for migrating species.

Turkey is a party to the IMO convention and most of the other conventions prepared by IMO to regulate the maritime safety and marine environmental protection. The national regulatory framework dealing with the prevention, preparedness and response of accidental oil pollution is shaped with the law 5312 "Pertaining to Principles of Emergency Response and Compensation for Damages in Pollution of Marine Environment by Oil and Other Harmful Substances" in Turkey. This is the legal framework dealing with the potential threats of accidental oil pollution along the coastal areas of the Turkey. Preparedness for the accidental oil pollution in Turkey, emergency response infrastructures and contingency plans are completed and have been available in an emergency situation (AMM 2008; AMP 2011).

## 2. Geography and Maritime Traffic

The Turkish Straits System (TSS) consists of the Marmara Sea and the Straits of İstanbul (Bosphorus) and Çanakkale (Dardanelles) located between the continents of Europe and Asia, and connecting the Mediterranean (Aegean) and Black Seas with contrasting physical and bio-chemical properties (Tuğrul *et al.* 2015). The Marmara Sea is located between 40 - 41.5°N and 27 - 30°E. It connects two large marginal basins of the Mediterranean and Black Seas through long and narrow straits: Çanakkale (length ~62 km, average width 4 km) and İstanbul (length 31 km, average width ~1.5 km) (Figure 1). The Marmara basin spans approximately 240 km in east-west and has 70 km north-south direction covering ~11500 km$^2$ surface area. In contrast with relatively shallow (~ 100m average depth) and wider (~33km) southern part, northern coast has narrower shelf area (10-13 km). Three depressions (1097, 1389, 1238 m. from west to east) separated by two sills (depth ~700 m) extend on a course parallel to the northern coast and is a part of North Anatolian Fault Zone. In the region of Marmara Sea-İstanbul Strait junction there exists a 70m deep canyon along the main axis the İstanbul Strait which eventually merges into the eastern depression. Submarine canyon at the Çanakkale Strait-Marmara Sea junction deepens gradually along the northeast direction in a triangular shape and reaches the western depression (Beşiktepe *et al.* 1994; Tuğrul *et al.* 2015).

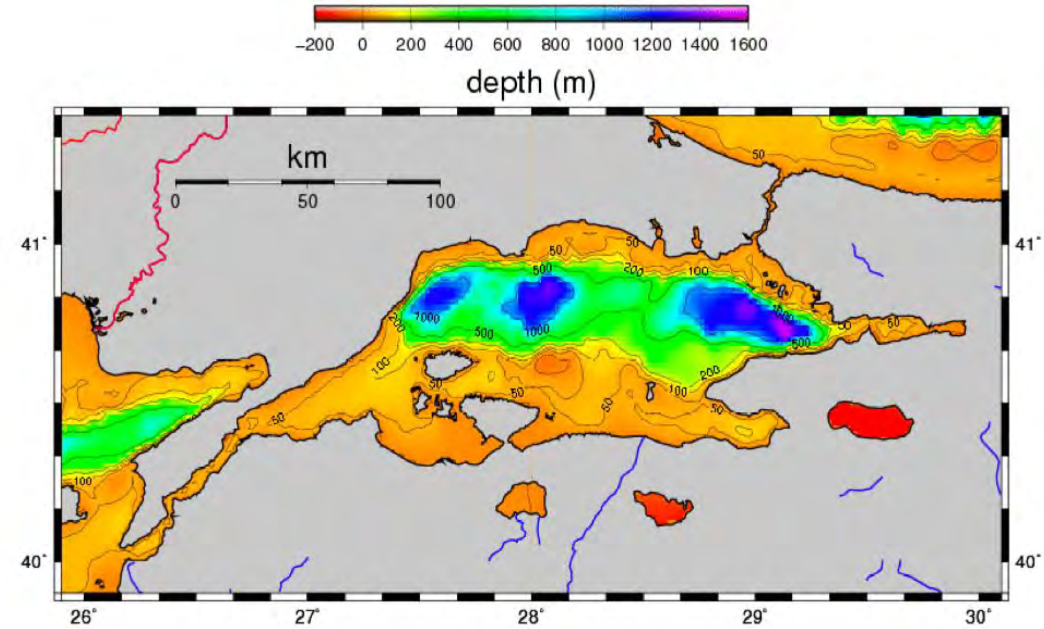


**Figure1.** Location and bathymetry of the Marmara Sea (Tuğrul *et al.* 2015)

The increased population and industrial activities in the Marmara region introduce large amounts of inorganic and organic pollutants to the TSS. Today there are over 43.000 ships passing through from Turkish Straits Systems to Black Sea (DGCS 2016). In addition, around 2500 vessel per day (over 700000 per year) sails randomly and approximately 2 million daily commuters cross the strait in ferries and private boats. International importance of the Sea of Marmara stands in the forefront even though it is an inland sea of Turkey and it deals with increasing ecological problems for the last 50 years. The pollution in the Sea of Marmara which threatens all living species cause dramatic falling in fishing potential. Increase in the volume of maritime traffic on the Strait and the Sea of Marmara have increased the risk of the maritime accidents over the years and since 1948 the number of ship accidents have been recorded as around 700. Furthermore, being on the transportation way of hazardous and dangerous materials pose environmental and safety hazards for the İstanbul Strait and the Marmara Sea with the surrounding residential areas (Birpınar *et al.* 2009).

The Turkish Straits System is one of the busiest natural channel with national and international maritime traffic and their loads are mainly dangerous goods like crude oil and its products, chemicals etc. geographic and oceanographic features of the İstanbul

Strait makes the navigation rather difficult and consequently the Strait has faced many casualties that caused severe environmental problems (Birpınar *et al.* 2009).

On the basis of AIS data a picture of the ship intensity in the Sea of Marmara is shown in Figure 2.

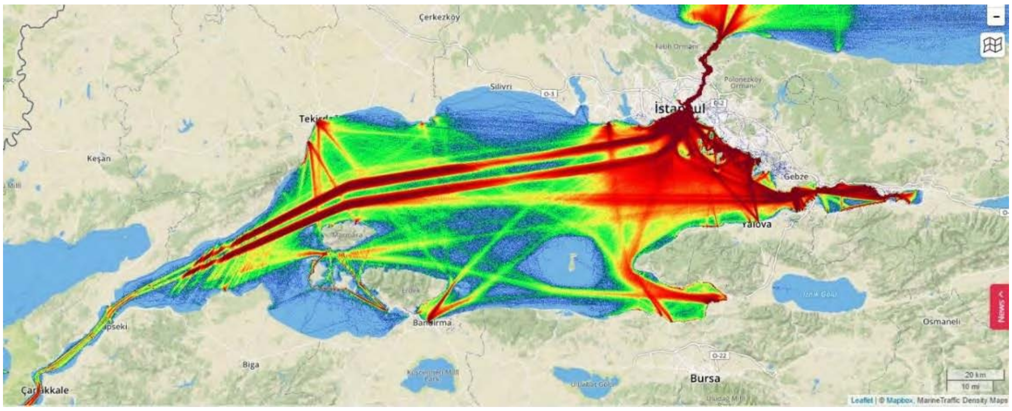


**Figure 2.** Intensity of ship traffic in the Marmara Sea (AIS 2015)

Many marine accidents resulting in oil spills in the Sea of Marmara had occured and there is always potential to experience a major oil spill especially in Turkish Straits System. Some of these accidents were severe incidents and caused serious environmental problems with many thousands tons of oil spill. Table 1 shows some of the major marine accidents occurred in the Sea of Marmara.

**Table 1.** Major marine accidents in the Sea of Marmara (Akten 2006)

| **accident** | **explanation** |
|---|---|
| World Harmony v. Peter Zoranic (1960) | 18.000 tons oil spilled (Kanlıca) |
| Lutsk v. Kransky Oktiabr (1964) | 1.850 tons oil spilled (Kızkulesi) |
| Independenta (1979) | Apr. 20.000 tons of crude oil spilled, 50.000 ton has burned |
| Jambur v. Da Tung Shan (1990) | 2.600 tons oil spilled (Sariyer) |
| Nassia and Ship Broker (1994) | 10.000 tons of oil spilled, commission established, (Bebek) |
| Volganeft 248 (1999) | Apr. 1600 tons of oil spilled, 7 km of coastline has been polluted |
| Semele and Şipka 1999 | 10 tons of oil spilled (Yenikapı) |
| Gotia (2002) | 25 tons of oil spilled, (Emirgan) |
| Svyatoy Panteleymon (2003) | 230 tons oil spilled (Anadolu Feneri) |

## 3. Legal Basis

Large oil spills will always capture the public's attention. The spills from the oil tankers and accidents (Figure 3) in the Sea of Marmara, first highlighted the critical need for appropriate preparedness and response programs to deal with significant environmental disasters.

Beginning in the 1970s, as the volume of maritime transportation has increased, the number of maritime accidents, which result in significant marine pollution, has increased in parallel. Turkey, suffering severe marine pollution in the aftermath of the Independenta accident on the Istanbul Strait, became a party to the OPRC agreement on September 18, 2003. Subsequently, Law 5312, was enacted on March 3, 2005. The application regulation, prepared on bases of law 5312 and the Environmental Law 2872, then took effect on October 21, 2006. The regulation, which provides the foundation for effective application of the provisions of law 5312, determines the principles, precautions, procedures, and the fundamentals of qualifications, tasks, and responsibilities specified in the law.

Law and regulations were adopted according to the national necessities and regional and international responsibilities.

Table 2 shows list of international and regional conventions in which Republic of Turkey is a signatory since joining the International Maritime Organization on 1958.

**Table 2.** International and Regional conventions

| **Convention** | | **Date of Acceptance** |
|---|---|---|
| **OPRC 1990** | International Convention on Oil Pollution Preparedness, Response and Co-operation 1990 | **18.09.2003** |
| **MARPOL 73/78** | International Convention for the Prevention of Pollution from Ships 1973, as Modified by the Protocol of 1978 | **24.06.1990** |
| **CLC 92** | International Convention on Civil Liability for Oil Pollution Damage 1969 and 1992 Protocol | **24.07.2001** |
| **FUND 92** | International Convention on the Establishment of an International Fund for Compensation for Oil Pollution Damage 1971 and 1992 Protocol | **18.07.2001** |
| **LLMC 76** | Convention on Limitation of Liability for Maritime Claims 1976 | **04.06.1980** |
| **Barcelona Convention** | Convention for the Protection Of The Mediterranean Sea Against Pollution | **31.10 1980** |
| **Bucharest Convention** | The Convention on the Protection of the Black Sea Against Pollution | **15.01.1994** |
| **Emergency Protocol** | The Protocol Concerning Cooperation in Combating Pollution of the Mediterranean Sea by Oil and other Harmful Substances in Cases of Emergency | **20.05.2003** |

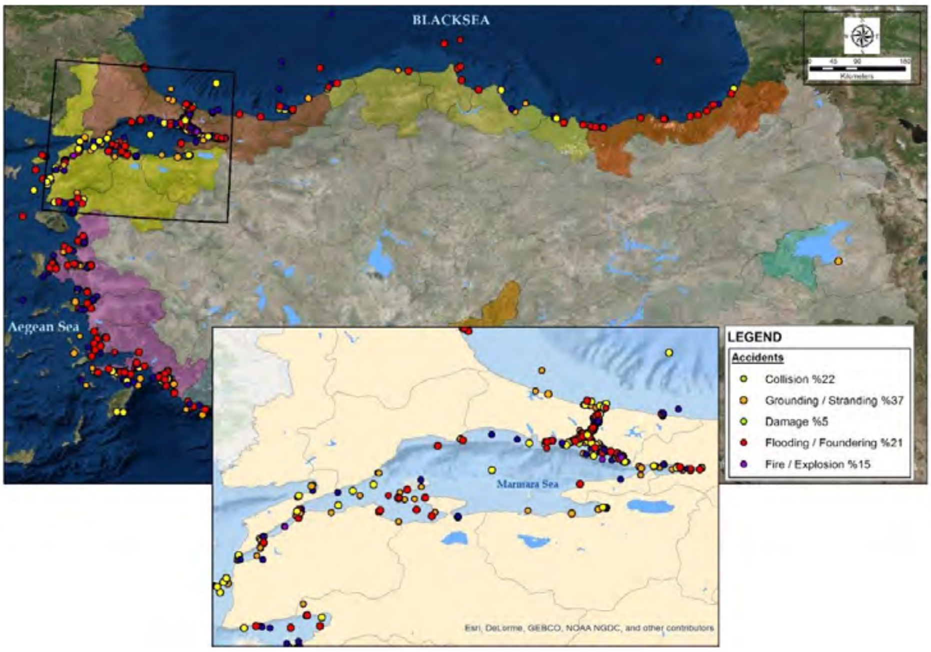


**Figure 3.** Ship accidents along the Turkish coasts and the Marmara Sea (AMM 2008)

**4. An oil spill contingency plan in the Marmara Sea**

The aims of oil spill response are both to minimize the immediate damage to environmental and socio-economic resources and to reduce the time for recovery of affected resources.

With law 5312, the duties of the related public enterprises and private organizations were regulated in case of accidental oil pollution in Turkey. According to this law preparedness activities are carried out and coordinated by Ministry of Transport Maritime Affairs and Communication (TM-TMAC). The application of laws and regulations is the responsibility of the Ministry of Environment and Urbanization (TM-EU).

Within the scope of the projects, constitution of the Emergency Response Centers and Determination of the Present Situation in Turkish Sea as a Feasibility Works (AMM) and National and Regional contingency plans (AMP) were finalized. (AMM 2008; AMP 2011).

The main aim of the contingency plans were to form the emergency response system; provide protection for the marine environment by effectively using public and private resources through facilitate coordination and cooperation.

National and regional contingency plans against pollution caused by petroleum and other harmful substances, in which all relevant government bodies would actively participate, were prepared on city basis.

In this contex; 8 province contingency plan were prepared for the Marmara Region (Figure 4).


**Figure 4.** Emergency response plan prepared provinces in Marmara Region

While law 5312 pertains only to emergency response for marine pollution caused by petroleum and other harmful substances, laws 5902* and 7269* cover all disasters and emergency situations. National and regional contingency plans were to be prepared considering all three acts.

*5902 "Organization and Functions of the Directorate of Disaster and Emergency Case Management."

*7269 "Measures and Assistances to be put into Effect Regarding Disasters Affecting the Life of the General Public"

The size, location and timing of an oil spill are unpredictable. Therefore, emergency response plans are based on tiered (gradual response strategy) approached

(AMP 2011). Example of Oil Spill Tier Level Descriptions (adapted API 2014) given below.

| Tier Level | Description |
|---|---|
| **Tier 1** | Response Small local spills, spills that are quickly controlled, contained and cleaned up using local (onsite or immediately available) equipment and personnel resources. |
| **Tier 2** | Response Medium spills, requiring activation of significant regional oil spill response resources |
| **Tier 3** | Response Large spills, Major spills requiring activation of large quantities and multiple types of response resources including those from out of the region, and possibly international sources. This will cover major incidents, the scale and scope of which is beyond the capabilities of the Tier 2 response. |

A contingency plan should cover each Tier and be directly related to the company's potential spill scenarios. The amount of equipment and trained personnel identified at each Tier will vary for each operation, depending on a variety of factors such as the risk, location, oil type and environmental or socioeconomic sensitivities under threat (AMP 2011).

The organizational chart were defined in contingency plan and in the event of an oil spill, this organizational chart shown in Figure 5 shall be followed (AMP 2011).

National Contingency Plan (NCP): is prepared to respond a third level (Tier 3) incident. It describes how to use national capabilities effectively in the case of major oil pollution and provide national and if necessary international cooperation and coordination mechanisms.

Regional Contingency Plans (RCP):plans for response to a second level (Tier 2) incident and are implemented by the responsible governor.

The contingency plan consists of the coordination and the operation units. The responsibilities of the units in the organization the procedures, and the principles were determined (AMP 2011). In a situation where the accident is on a national scale (Tier 3), the National Contingency Plan is activated, and general coordination is carried out by the Ministry of Environment and Urbanization.

An inventory of emergency response equipment and shoreline facilities owned by public and private organizations and institutions in the Marmara regions was also determined in the plan. The representatives from organizations and institutions, who takes part in contingency plans, were trained, and subsequently, theoretical and practical exercise, designed in Istanbul and Çanakkale.

Guidelines, which will be required during and after an emergency response, were prepared to provide support for the implementing parties.

These are:

- Definition of marine and shoreline response system and general shoreline cleaning methods,
- Determination of the rudiments regarding the acceptance of vessels into the places of refuge in accordance with national and international regulations,
- Definition and the suitability of the use of dispersants in emergency response situations,
- Definition of the transportation and elimination of waste materials,
- Termination of response operations and determination of rehabilitation operations,
- Procedure of compensation demand,
- Identified and documented an emergency response situation, communication among the teams and informing the public.

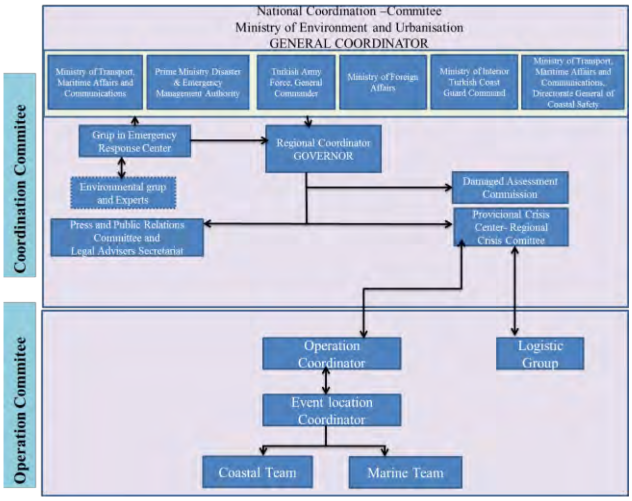


**Figure 5.** National and Regional Contingency Plan (AMP 2011)

National and Regional contingency plans were integrated into the Geographical Information System -based decision support system, named YAKAMOS.

With the application of law and regulations, according to the national necessities and regional and international responsibilities:

- Prepared the Regional and National Emergency Action Plan related to the oil spill and other hazardous substances;
- Determined the best place for the national emergency response centre (Tekirdağ), stock piles according to the risk analysis, number of personnel, quality and quantity of equipment and materials, etc.;

• Installed the GIS based decision support system (YAKAMOS) for decision makers to give most reliable action during intervention of the marine pollution;

• Natural protected areas, important economic activity areas and human settlement areas were identified and integrated into YAKAMOS;

• Analyzed accidental risk for the coastal areas by using related parameters such as, maritime traffic, previous accidents locations, importance of the coastline, bathymetry, distance from land and etc.;

• A semi-online Oil Spill Model was Installed into the YAKAMOS;

• Analyzed geomorphological structure of the Marmara Coasts according to the Environmental Sensitivity Index (ESI) for choosing the most suitable clean-up techniques during emergency response action;

• Determined background concentrations according to the "polluters pay for the petroleum hydrocarbons (polycyclic aromatic hydrocarbons (16 compounds)), along the Sea of Marmara. 22 stations in the Sea of Marmara were sampled from surface and 10 m depth, to define background concentrations of the areas (Table 3).

**Table 3.** Measured ranges of background pollutant concentrations in Sea of Marmara (AMM 2008)

| Parameters (µg/L) | Surface (min-max) | 10m (min-max) |
|---|---|---|
| Naphtalene | 0,001-0,66 | 0,001-0,91 |
| Acenaphtalene | 0,001-0,32 | 0,001-0,33 |
| Acenaphtene | 0,001-0,77 | 0,001-1,1 |
| Fluorene | 0,001-0,11 | 0,001-0,3 |
| Phenanthrene | 0,001-0,15 | 0,001-0,08 |
| Anthracene | 0,001-0,07 | 0,001-0,03 |
| Fluoranthene | 0,001-0,08 | 0,001-0,14 |
| Pyrene | 0,001-0,06 | 0,001-0,17 |
| Benz(a)anthracene | 0,001-0.056 | 0,001-0,09 |
| Chrycene | 0,001-0,06 | 0,001-0,04 |
| Benzo(b)fluoranthene | 0,001-0,12 | 0,001-0,04 |
| Benzo(k)fluoranthene | 0,001-0,129 | 0,001-0,03 |
| Benzo(a)pyrene | 0,001-0,10 | 0,001-0,04 |
| Dibenzo(a,h)anthracene | 0,001-0,06 | 0,001-0,5 |
| Benzo(g,h,i)perylene | 0,001-0,08 | 0,001-0,95 |
| Indeno(1,2,3-c,d)pyrene | 0,001-0,03 | 0,001-0,09 |
| **PAH (µg/L) (total of 16 compounds)** | **0,01-1,64-** | **0.003-2,6** |

## 5. Responce Techniques

The techniques which are considered and identified in the planning stage are drawn from the response toolkit. These tools include natural processes (i.e. biodegradation), the use of at-sea containment and recovery, chemical dispersants and controlled (in-situ) burning, as well as shoreline protection and clean-up. Table 4 summarizes the benefits and potential drawbacks of each technique (IPIECA, 2015).

**Table 4.** The benefits and potential drawbacks of the various oil spill response techniques (IPIECA 2015)

| Technique | Benefits | Description |
|---|---|---|
| **Mechanical recovery** | Removes oil with minimal environmental impact | Mechanical recovery can be inefficient, resource-intensive, and restricted by water conditions, with typically no more than 10–20 per cent oil recovery. |
| **Physical removal** | Selectively restores environmental and social value at specific locations using a variety of tools. | Aggressive or inappropriate removal methods may impact ecosystems and individual organisms. |
| **Natural processes** | Takes advantage of natural processes for oil removal, including biodegradation, and avoids intrusive clean-up techniques that may further damage the environment | Natural removal can take more time to return the environment to pre-spill use than other response techniques. |
| **Dispersant** | Removes surface oil that could harm wildlife and keeps oil from spreading to the shoreline; enhances natural biodegradation of oil and reduces vapours on the water surface. | Dispersed oil has the potential to initially affect local water column-dwelling wildlife and vegetation. |
| **Controlled (in-situ) burning** | Removes large amounts of oil rapidly via controlled (in-situ) burning.. | Burning presents a potential safety risk and localized reduction in air quality; burn residue can be difficult to recover. |

Turkish strategy for the responding accidental oil pollution is to respond as fast as possible on the sea with mechanical oil recovery techniques. The usage of the dispersant as a chemical recovery technique and in-situ burning in oil spill response is allowed with approval from the Authority Ministry of Environment and Urbanisation.

Methods for responding to oil spills are evolving and each oil spill provides an opportunity to learn how to better prepare for future incidents. Contingency plans should also regularly improve to ensure that increase protection for human health and environment from oil spill accidents.

With the implementation of the Law 5312, effective and quick response can be made in case of potential oil spills. With the preparation of the natioanal and regional contingency plans based on the risk assessments, it is expecting to have an effective response organization with qualified staff. By establishing emergency response centers at the regional/national level that would be equipped with the necessary trained personnel and response equipment to provide support to the response activities in case of an emergency. This will increase the quality of the oil spill removal and cleanup activities before giving substantial damage to the marine environments.

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## A PROPOSAL FOR THE INTEGRATED MANAGEMENT OF THE SEA OF MARMARA

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This management plan that was summarized here in macro dimensions and with general principles of an adaptive management was made the subject of an open debate by the Turkish scientific circles and non govermental organisations.

First of all, the Marmara Sea is the only Inland sea of Turkey. This fact should make us feel more sensitive and more responsible towards it. We owe this responsibility not to our country and people but this age we live in.

The Marmara Sea attracts masses of people as if embracing them. It's waters are neither too cold nor too warm. It's degree of saltness is neither too high nor too low. It's breezes are soft, it's coasts are relaxing. This sea lands its shores to Istanbul, that is the world's capital. The ecological problems of the Marmara Sea, that besides it's fishing, maritime transportation and touristic potential is also of major importance from the geopolitical aspect; have been inspected by many institutes and institutions during the last 20 years, even if with most irregular intervals. But the ecological problems that havereached gigantic dimensions in recent years make the adaption of amanegment plan aimed at conducting a regular and intensive research and follow-up of the Marmara Sea indispensible.

We need to be guided by the light of such a management plan, because the ecological problems of the Marmara Sea are currently examined at rather almost irregular intervals. These investigations that are disconnected, short range and mostly that are quite distant to all consuming approches directed to the solution of the problem.

The Marmara Sea suffers from land-based, ship-originated, athmospheric and transboundary pollution altogether. Furthermore, mostly ill-adapted and heavily applied land-reclamation processes along the Marmara Sea shoreline has been the major environmental concern related to the damage caused to the coastal ecosystems during the last decade.

Existing studies carried out in specific areas and/or hot-spots show that the rehabilitation of the Marmara Sea necessitates an integrated management policy encompassing remedial and/or preventive measures related to pollution and human-induced environmental damages as summarised in the above-mentioned section.

1. As expressed above, pressures on the Marmara Sea are various and have had complex environmental and ecological impacts. Besides, heavily planned human activities causing land and sea based pollution with chemicals, litter and nutrients, decrease of fishing potential, loss of habitats and biodiversity, increase of non-indigeneous species including invasives, noise and landscape pollution and loss of recreational habits, there are also impacts of climatic variability/change as well as Black Sea inputs. Even though treatment of effluents is on its way on and investments are ongoing and penalties are applied on illegal discharges with efforts of coastal mucipalities and the Black Sea inputs have decreased with actions taken by Danube basin countries, Marmara Sea ecosystem is becoming even more effected. This would focus us to the actions planning and the management model applied to the Sea and its overall basin.
2. An Integrated Management Plan, based on ecosystem approach and strongly supported with public incentives and political willingness with decisive steps, is the only tool to overcome the environmental problems and ecosystem damage of the Marmara Sea. This management is an adaptive one having certain steps to be applied in a consecutive manner. The main idea is setting targets for the achievement of good environmental status which needs to be defined for the region first. This has to consider all ecosystem components and all exerted pressures on the system. This needs a first assessment and initial targets for good status. Later monitoring and research has to be organized for science based assessments. Recommendations for programmes of actions provided and governing bodies take the actions identified. After the first cycle of management is completed (usually 5-6 yrs), targets are checked against new status based on monitoring data. So, new targets should be set if necessary (if there is recovery, targets can be set at higher levels, if not the analysis of the possible reasons of not achieving the targets should be made). This approach requires a new institutional organization for to succeed including a coordinating gorverning body and all other related actors.
3. This way of integrated management, was also proposed with the MEMPHIS Project for the Sea of Marmara in 2008. However, as not fully discovered yet the scientific complexity behind the implementation of ecosystem based adaptive management , we have to be cautious and should be keep away from pragmatic decisions.
4. To do so, all pressures need to be analyzed and considered with an integrated approach with participatory actions. Single-sectorial approaches are not any more enough for a prosperous management of the Sea. In other words, only the management of waste water discharges even with 0-discharge targets or the re-planning of coastal

land use and services with environmental friendly approaches are not enough any more for ecosystem recovery and sustainable management of the Sea. Instead, a pressure-impact matrix has to be established for the sea supported with a socio-economic analysis. These will be the key components of the initial assessment which has to include status and impact assessments as well.

5. Setting initial “good environmental satus” targets and their follow up with integrated monitoring are not easy and straightforward. While running the first cycle of implementation described above, we have to fill in a major gap. A coupled Marmara Sea Ecosystem model with hydrodynamics at one end and fishery management on the other, has to be establihed putting a research and development project in the pipeline. Previous several attemps of scientific community had failed because of rather weak support and understanding of the importance of it. Therefore, it has to be a voiced action again which must be cared by governing bodies and funding organizations. This is clearly an emergency step towards the integrated management of the Sea.

Integrated management of the Sea of Marmara necessitates a sea basin-scale approach to planning, including: (1) characterising sea basin; (2) setting goals and identifying solutions; (3)designing a basin development plan; (4) implementing basin plan; (5) designing implementation programme; (6) measuring progress and making adjustments; (7) building partnerships. The break-down of this approach can be as follows:

**Marmara Sea management plan (Macro dimensional)**

**Fist Step:** Regular research and monitoring program in all its ecological dimensions. (including Black Sea and the North Aegean Sea)

a. Interpratation and synthesis of the avaliable data.

b. Establishing of a data bank that is *confirmant to our purpose* (compliant with our purposes)

c. The management of all the research work from a single center by a civilian unit and creation of financial soources.

d.The forming of research and work groups. (Public, private, voluntary organisations)

c. Impacts of the Black Sea pollution load

d. Impacts of the riverian pollution load

e. Impacts of domestic and industrial effluents with different levels of treatment

**Second Step:** New protective strategies.

a. emergency measures. Protected areas ; Islands, habitats

b. Medium and long term measures and planning

**Third Step:** Planning of natural sources

a. The reviewing of cases of approaching, compliance with fishing prohibitings size and species restrictions. The prevention of over fishing.

b. The prevention of send removal, briging restrictions to the construction of second homes on the Marmara coastal strip, *the implementation of coastal law.*(the enforcement of the Coast Act)

c. New implementations for the oil pollution issue.

d. New implementation fort he waste and sewage problem.

e. The improvement of the public sector wastes.

f. Reviewing the improvement activities of the Golden Horn and other streams.

**Fourth Step:** Training

a. Mass training and comprehension programs (without taking advantage of rude politics and popülist approaches) directed towards educational goals in the subject of putting an and to the pollution of the Marmara Sea, it's protection and restoration.

b. Efforts oriented to have these mass comprehension programs to reach everyone.

c. Campaigns directed towards school age children living in the Marmara coast line.

**Fifth Step:** Legal measure  and institutional measures

a. Legal measures to have institutes and institutions concerned with this issue to work to reach the same target.

b. The adoption of measures regarding the coordination of the institutions.

c. The determination of legal loopholes in respect of this issue, their amendment or elimination.

d. Providing of equipment, materials and financial support to the inspecting organisations.

Finally, the policy actions should be split into these five categories and then corresponding pollution abatement measures and preventive actions should be set accordingly.

So far, field surveys, water quality monitoring and related researches have been sector-oriented, locally and intermittently implemented. Such studies have been carried out as need arose and in response to satisfy a specific need (e.g.DAMOC Master Plan, Istanbul Water Supply, Sewerage and Drainage, Sewage Treatment and Disposal Master Plan Study, MEMPHIS Project)

Although scattered in space with respect to the Sea of Marmara as a whole and distant in time, generating rather short time-series data, these field studies have been valuable undertakings for an initial assessment of the baseline situation of the Sea of Marmara.

However these studies might have been based on different methods which consequently may have given rise to biased interpretaion of the data/results.

Recently, the Ministry of Environment and Housing has launched a Project entitled "Integrated Pollution Monitoring in National SeasThe successful implementation of this Project in the Sea of Marmara is expected to satisfy the first two requirements of the Fisrt Step, (1)interpretation and synthesis of available data, Establishing of a data bank compliant with the set targets) .When a national Strategy has been approved by the government and is being implemented as this is the case for the"Integrated Pollution Monitoring in National Seas "The main question is "what are the components, mechanisms and arrangements for implementation. The so-called Project is expected to be long-lasting "technically" and "financially" with its components and mechanisms for implementation

The decision-making process depends on knowledge that can be ensured by monitoring, field surveys and researches which then must be assessed on a continous basis.

The implementation of the above mentioned plans and programmes and compliance with the set targets are expected to be achieved in case good governance and efficient follow-up can be established by all the stakeholders concerned.

## NATURA 2000 SITES PROPOSALS IN THE SEA OF THE MARMARA SEA

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### 1. Introduction

The Natura 2000 network shall include the special protection areas classified by the Member States pursuant to Directive 79/409/EEC.A coherent European ecological network of special areas of conservation shall be set up under the title Natura 2000. This network, composed of sites hosting the natural habitat types and the species' habitats concerned to be maintained or, where appropriate, restored at a favorable conservation status in their natural range. Each Member State shall contribute to the creation of Natura 2000 in proportion to the representation within its territory of the natural habitat types and the habitats of species, referred to in paragraph1.

Habitat directive or Council directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora issue is one of the poorly studied areas in Turkey. But this directive is extremely important for Turkey due to its accession process of the European Union. First of all, Turkey should conserve its unique natural heritage, richness and beauties for the prosperity of the citizens and next generations, whether it will join EU or not. Among these richness, marine and coastal diversity plays an important role, because the country is surrounded by four seas of different oceanographic characteristics. Although Turkey hosts very peculiar ecosystems, there is not much study for the inventory of Natura 2000 nor database for the future implementation.

The work has aimed to identify the potential Natura 2000 sites in order to prepare the inventory of all endangered plant/animal species and habitats in marine and coastal zones in the Sea Of Marmara. Flag species (*Monk seals, cetaceans, Posidonia oceanica* beds,) and some priority habitat types (caves, islets/islands, rocky reefs, coralligenous habitats, hydrothermal vents, hot springs and reef zone) in all coastal regions were proposed to be candidates to be included in Natura 2000.

Firstly, Natura 2000 areas and species were proposed for each sea according to the European Habitat Directive and using RAC/SPA action plans. Marine and coastal Natura 2000 implementations in the EU Member States Regulations were not homogeneous process and weak in terms of conservation. The EU member states were not reflected by this report due to inconsistency and different implementation stages they were at. Examining the European Natura 2000 process is already another subject of study.

## 2. Proposed Natura 2000 areas in the Sea of Marmara

Six different habitats and species have been proposed in the Marmara Sea to be candidates for Natura 2000. These are marine and coastal caves, small vulnerable island and, very small *Posidonia* beds, and coralligenous habitats. All these areas and species are under threat from heavy fishing pressure. Considering the size of the Marmara Sea, however, these areas are small and it cannot be impacted by fishing activities seriously. Some local fishermen may complain the *Posidoni*a beds for the fishing restriction but these protection measures may be useful for them in the long term period. (See the Table 1).

**Table 1.** Natura 2000 areas and predicted impacts on fisheries and tourism.

| Habitat Types | Species | Sea | Fisheries Impact | Tourism Impacts | Ref. |
|---|---|---|---|---|---|
| **Caves:** Tavşan Island | | MARMARA | NO | NO | (Ertek , 2010) |
| **Islands:** Kuş Adası, Sedef Adası, Fener Adası, Balıkçı Adası, Yassıada | | MARMARA | YES | YES | (Ertek,2010); Topçu and Oztruk (2013) |
| **Hydrotermal Vents:** Marmara Sea-Tekirdağ deep sea zone, Marmara Islands | | MARMARA | NO | NO | (Çağatay, 2010) |
| | **Catsharks:** Marmara Sea-Silivri deep sea zone | MARMARA | NO | NO | (Oral,2010) |
| | **Posidonia Beds:** Paşalimanı Island | MARMARA | YES | YES | (Yüksek and Okuş 2004); (Meinesz *et al,*2009) |
| **Coralligenous Habitats:** Sivriada, Yassıada, Laz Kayası, Marmara Adası, Ekinlik, Avşa, Hayırsız Ada | *Paramuricea clavata* *Eunicella cavolini* *Savalia savaglia* | MARMARA | YES | NO | (Öztürk *et al* 2004) |
| **Karabiga, Biga Peninsula** | *Monachus monachus* | MARMARA | YES | YES | (Dede, 2010) |
| **Pelagic Zone** | *Cetaceans* | MARMARA | YES | YES | (Dede ,2010) |

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# RIVER INPUTS PRESSURES ON MARMARA SEA

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The Marmara Sea is one of the most important seas to be protected as regards biodiversity and fishing in Turkey. It is an important inland sea for fishing not only in the Marmara region but also in the Black Sea and the Mediterranean basin.

Altough the Marmara Sea is an important area regarding biodiversity, it is exposed to ecosystem degredation due to different human pressures since more than 26% of the country's population lives there.  According to surveys, the average annual population growth rate expected for the period 2005-2030 is estimated at 1,65%. This shows that these pressures will grow further in the near future. These pressures are inputs from Black Sea, inland waste (domestic, industrial) and regional human activities performed at the sea (fishing, transportation, excavations and discharge Works, etc.). The environment is under heavy pressure as a result of sea-related human activity. A most important example is that the excavation works undertaken (such as within the scope of Marmaray Project) cause tons of marine sediments to mix with water. Another important pressure effecting the Marmara Sea ecosystem is the worsening of hypoxic conditions at deep water in the Marmara Sea, depending on hydrographic conditions, to below 15% saturation, due to pressures caused by human activity (Kunst 2007).

*Pressures Based on Geographical Location*

The Marmara Sea covers an area of 11,140 km$^2$ in a total basin of around 55,000 km$^2$. In other words, 20% of the basin area is covered with sea water.

The Marmara Sea is surrounded with the water basins listed below (Figure 2):

1. İstanbul and Bosphorus drainage area
2. İzmit Bay drainage area (as a whole)
3. Gemlik Bay drainage area (as a whole)
4. Susurluk River Basin
5. Gönen Stream Basin
6. Bandırma-Kapıdağ drainage area (as a whole)
7. Biga River Basin
8. Çanakkale Boğazı drainage area(as a whole)
9. Tekirdağ drainage area(as a whole)
10. Marmara Islandsdrainage area(as a whole)

*There are three main rivers reaching to Marmara Sea. These are:*

• Susurluk River: 3.000 million m3/year;

• Gönen River: 415 million m3/year;

• Biga River: 400 million m3/year.

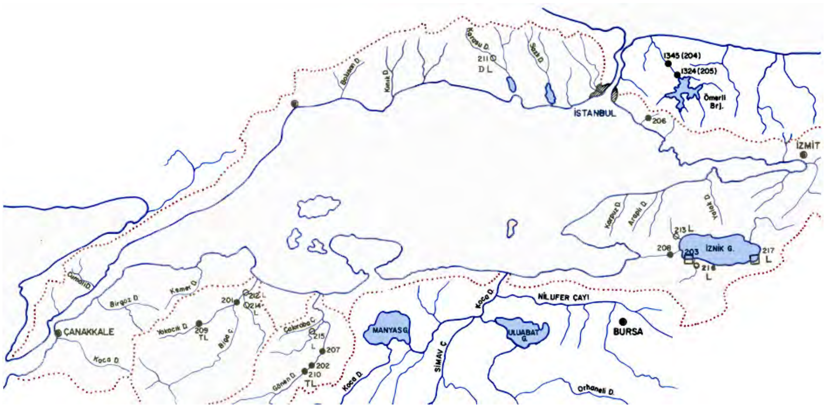


**Figure 2.** Marmara Region Basin map.

A sea ecosystem with two layers was formed as a result of water inter-change within the Turkish Straits System, which consists of the Marmara Sea and the Straits and connects the Black Sea to the Mediterranean. Infrahaline surface water (S: 17-18) with high concentrations of organic substances (carbon, nitrogen, phosphorous) streaming from the Black Sea forms the top layer of around 15m in the Marmara. High-salinity water (S:38.5-38.7) entering from Aegean Sea fills the whole basin under 30 meters; after a 7 years stay period some of them return by mixing with the upper layer, most of them carrying their chemical characteristics, and mix with the Black Sea intermediate layer by means of Bosphorous bottom currents. These two different bodies of water flowing in the opposite directions are separated from each other with a sharp halocline layer (salinity transition layer) formed between 15-30 m. This intermediate layer prevents oxygen transition from surface to bottom layers and low oxygen concentration is very significant in the deep water of the Marmara; in fact, in deep water of some polluted bays, oxygen concentration is too low (<0.5 mg/L). In the deep water of the middle zone of İzmit Bay, oxygen and nitrate ions are consumed completely and hydrogen sulphur is also observed at the end of summer months.

*Domestic and industrial disposals: Discharges*

Total population of the Marmara Sea basin is more than 16 million. It is equal to 25% of the total population of Turkey. Production of waste water in İstanbul, Bursa and İzmit is of therefore of high quantity, as would be expected.

Currently, only part of domestic wastewater is treated before disposal to surface water or the Marmara Sea basin. There are some places where no treatment is performed and at some places, tertiary level treatment meaning 70% nutrient (nitrogen and phosphorus) removal is applied. Those resources are shown in Figure 3 (Yüksek 2015).

Industries active in the region constitute approximately 50% of the total industry of Turkey in number and capacity. Industries in the Marmara Sea Basin can be divided into three categories based on their discharges. These are:

• Independent industries discharging their wastewater directly to receiving environment;
• Industries located in Organized Industrial Zones which discharge their wastewater together to receiving environment;
• Industries located in borders of municipalities which discharge their wastewater to municipality sewage systems.

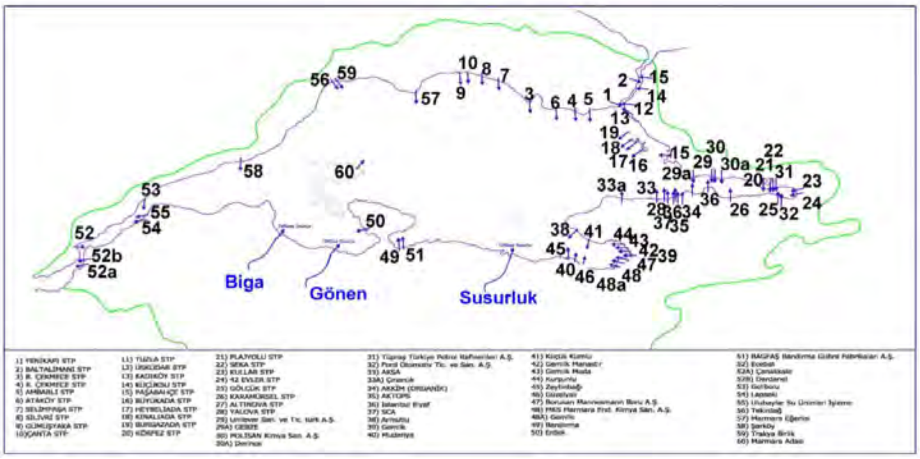


**Figure 3.** Marmara Sea Point and Distributed Polluted Areas

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## STATUS OF CARTILAGINOUS FISHES IN THE SEA OF MARMARA

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### 1. Introduction

The story of sharks and batoids, also known as cartilaginous or chondrichthyan fishes, in world's oceans started nearly 400 million years ago (Tricas *et al.* 1997). Since their first appearance, sharks and batoids occuppy a wide range of habitats, as a result of their diverse morphological or behavioural adaptations to their environment. Due to their life-history characteristics as k-selected species, *e.g.* large maximum body size, slow growth, late maturation and long lifespan (Camhi *et al.* 1998), sharks and batoids are two of the success stories of evolution, However, many shark and batoid species are now considered as vulnerable, threatened or endangered species, because of the same life-history traits.

According to a recent inventory study of cartilaginous fishes occurring in the seas of Turkey, 39 shark species and 30 batoid species occur in Turkish waters (Kabasakal 2002). The presence of 8 sharks and 2 batoids included in this previous inventory, need, however, to be confirmed. In the most recent checklist of marine fishes from Turkish waters, Bilecenoğlu *et al*. (2014) reported on the presence of 34 sharks and 30 batoids from the mentioned region.

The Sea of Marmara represents a peculiar ecosystem as a transitional zone between the Mediterranean and the Black seas, because of its geographical and hydrographical characteristics (Öztürk 2002). Since, it constitutes a barrier, a corridor or an acclimatization zone for marine organisms (Öztürk and Öztürk 1996), Sea of Marmara plays a significant and decisive ecological role in the dispersal of livings, and thus it can be defined as an "ecological gateway." Among the marine fishes came through this ecological gateway, several shark and batoid species are also included.

According to Kocataş *et al*. (1993), pioneering ichthyological studies in the Sea of Marmara dated back to 1910's. The unique fish fauna of this land-locked marine area has always been a point of focus of ichthyological studies since the dawn of 20$^{th}$ century (*e.g.* Ninni 1923; Deveciyan 1926; Ayaşlı 1937; Erazi 1942). According to a recent ichthyological list (Keskin and Eryılmaz 2010), the fish fauna of the Sea of Marmara holds 235 species. The common point of the historical and contemporary ichthyological lists of the Sea of Marmara is the low number of chondrichthyan species included in them. Furthermore, a remarkable characteristic of ichthyological research history of the Sea of Marmara throughout the 20th century is the paucity of shark- and batoid-specific studies.

In 2000, an extensive survey to clarify the status of sharks and batoids occurring in the seas of Turkey has been started, as an initiative of Ichthyological Research Society (IRS), a non-governmental and non-profit institution dedicated to research of cartilaginous fishes. One of the substudies of the main survey was to update the chondrichthyan fish fauna of the Sea of Marmara. Shark-specific results of this substudy was previously published (Kabasakal, 2003a) and recently updated (Kabasakal and Karhan, 2015). In the light of the data obtained over the last 16 years, our understanding about the shark and batoid fauna of the Marmaric waters was remarkably increased. Therefore, the aim of the present review is to provide an update on the status of the contemporary chondrichthyan fishes of the Sea of Marmara, based on available literature.

## 2. Historical and Contemporary Occurrence of the Marmaric Chondrichthyans

The oldest available information regarding the cartilaginous fishes of the Sea of Marmara is limited with a few anecdotal notes on two great white sharks, *Carcharodon carcharias*, which have been caught in southern part of the Bosphorus Strait by the bluefin tuna (*Thunnus thynnus*) handliners in February and November of 1881 (Kabasakal 2003b). Following this late 19th century incidents, Italian ichthyologist Emilio Ninni, whom has been carried out fisheries surveys on board of R/V L.F. Marsigli in waters of the fallen Ottoman Empire between 1921 and 1922, recorded 13 shark and 7 batoid species in the Marmaric waters (Ninni 1923). At the same time, former Ottoman ichthyologist Karakin Deveciyan published his monumentary book on fishes and fishery of Turkey’s waters, which is mostly based on fish species landed in Istanbul fish market and included 12 Marmaric sharks and 4 batoids (Deveciyan 1926). Seven years later, Ayaşlı (1937) published a detailed report on the fishes of Bosphorus Strait and mentioned the presence of great white shark and cat shark of *Scyliorhinus* sp., in the prebosphoric region of the Sea of Marmara. Finally, Erazi (1942) recorded 181 fish species in this small land-locked sea, with 7 species of sharks and 3 batoids, as well.

The search of shark- and batoid-specific or general ichthyology studies of the Sea of Marmara, as well as the daily newspapers, which have been published since the beginning of 1900’s and given information on the capture of sharks and batoids in the Marmaric waters, revealed the historical and contemporary occurrence of 22 shark and 15 batoid species in the Sea of Marmara (Tables 1 and 2). Contemporary occurrence of 13 of the 22 shark species in the Sea of Marmara is confirmed by recent studies or fishery records; however, due to absence in recent surveys or fishery records, 8 species are categorized as questionable or absent (Table 1). Status of the Marmaric sharks, based on current knowledge, is summarised in Table 1. On the other hand, in a recent inventory study of the Turkish marine fishes (Bilecenoğlu *et al.* 2014), 15 batoid species are occurred in the Sea of Marmara; however, since 5 of the 15 batoids were not mentioned in ichthyological lists published recently (Altuğ *et al.* 2011; Bök *et al.* 2011) or recorded during the recent field surveys (Yıldız *et al.* 2016), and therefore, these species considered as questionable. Contemporary batoid fauna of the Sea of Marmara is, thus, included 10 confirmed species (Table 2).

Contemporary presence of large sharks in the Sea of Marmara has always been a point of controversy, since most of the available pre-2000 records of them were based on historical records, e.g. Ninni (1923), Deveciyan (1926), or more recently Akşıray (1987). In a late 1990's ichththyological inventory study of Turkey's marine fishes, Mater and Meriç (1996) pointed out the absence of Hexanchus griseus (Figure 1a) in the Sea of Marmara; however, the reoccurrence of the species in the Marmaric waters was confirmed by Kabasakal (1998). In the Sixgill Shark Data Bank (SSDB) of Turkey, which includes the records of 150 specimens of H. griseus captured in Turkey's waters (Kabasakal 2013), 60 percent of them (90 specimens) have been captured in the Sea of Marmara between 1967 and 2013. Similarly, historical records of the common thresher shark, Alopias vulpinus, in the Marmaric waters are dated back to early 1920's (Ninni 1923; Deveciyan 1926; Akşıray 1987; Mater and Meriç 1996). Recent fishery records and surveys (Kabasakal 2007) confirm the contemporary occurrence of A. vulpinus in the Marmaric waters. In contrast to its congeneric species, the bigeye thresher shark, Alopias superciliosus, is one of the recent arrivals into Sea of Marmara. First record of A. superciliosus in the Sea of Marmara, is based on the capture of a female off the northern coast of the sea in 2007 (Kabasakal and Karhan 2007). Subsequent to this record, a second female has been entrapped in a commercial purse-seiner in the northern Sea of Marmara in 2011 (Kabasakal *et al.* 2011).

**Table 1.** Historical and contemporary records of shark species in the Sea of Marmara, and their current status of occurrence. P: present; A: absent; ?: questionable; A-M: Atlanto-Mediterranean; C: cosmopolitan; VU: vulnerable; EN: endangered; NE: not evaluated; DD: data deficient ; CR: critically endangered; NT: near threatened; LC: least concern. Historical records: Ninni (1923), Deveciyan (1926), Ayaşlı (1937), Erazi (1942).

| Species | Historical Records | Kabasakal and Karhan (2015) | Status | Distribution | IUCN Criterion |
|---|---|---|---|---|---|
| **Family HEXANCHIDAE** | | | | | |
| *Hexanchus griseus* (Bonnaterre, 1788) | + | + | P | C | NT |
| **Family LAMNIDAE** | | | | | |
| *Carcharodon carcharias* (Linnaeus, 1758) | + | – | A | C | EN |
| *Lamna nasus* (Bonnaterre, 1788) | + | – | A | C | CR |
| **Family ALOPIIDAE** | | | | | |
| *Alopias superciliosus* (Lowe, 1839) | – | + | P | C | DD |
| *Alopias vulpinus* (Bonnaterre, 1788) | + | + | P | C | VU |
| **Family SCYLIORHINIDAE** | | | | | |
| *Galeus melastomus* Rafinesque, 1810 | + | + | P | A-M | LC |
| *Scyliorhinus canicula* (Linnaeus, 1758) | + | + | P | A-M | LC |
| *Scyliorhinus stellaris* (Linnaeus, 1758) | + | + | P | A-M | NT |
| **Family TRIAKIDAE** | | | | | |
| *Galeorhinus galeus* (Linnaeus, 1758) | + | – | A | C | VU |
| *Mustelus asterias* Cloquet, 1821 | + | + | P | A-M | VU |
| *Mustelus mustelus* (Linnaeus, 1758) | + | + | P | A-M | VU |
| **Family CARCHARHINIDAE** | | | | | |
| *Carcharhinus* sp. | – | – | A | C | ? |
| *Prionace glauca* (Linnaeus, 1758) | + | – | A | C | VU |
| **Family OXYNOTIDAE** | | | | | |
| *Oxynotus centrina* (Linnaeus, 1758) | + | + | P | A-M | CR |
| **Family DALATIIDAE** | | | | | |
| *Dalatias licha* (Bonnaterre, 1788) | – | – | ? | C | DD |
| **Family CENTROPHORIDAE** | | | | | |
| *Centrophorus granulosus* (Bloch and Schneider, 1801) | – | – | ? | C | VU |
| *Centrophorus sp.* | – | – | ? | C | ? |

| | | | | | |
|---|---|---|---|---|---|
| **Family SQUALIDAE** | | | | | |
| *Squalus acanthias* Linnaeus, 1758 | + | + | P | C | EN |
| *Squalus blainville* (Risso, 1827) | + | + | P | C | NE |
| **Family ECHINORHINIDAE** | | | | | |
| *Echinorhinus brucus* (Bonnaterre, 1788) | + | + | P | C | DD |
| **Family SQUATINIDAE** | | | | | |
| *Squatina oculata* Bonaparte, 1840 | – | – | ? | A-M | CR |
| *Squatina squatina* (Linnaeus, 1758) | + | + | P | A-M | CR |

Historical occurrences of the great white shark, Carcharodon carcharias (Figure 1b), and the porbeagle shark, Lamna nasus, in the Sea of Marmara, were closely associated with the seasonal occurrence of the Atlantic bluenfin tuna, Thunnus thynnus, in the Marmaric waters (Ninni 1923; Deveciyan 1926; Akşıray 1987; Kabasakal 2003b). Following the collapse of tuna fishery in this sea in mid 1980's, no specimen of C. carcharias or L. nasus have been recorded in the area (Kabasakal, 2014; Kabasakal and Karhan 2015). Since, the two lamnid sharks have not been recorded neither in the recent studies nor in the fisheries records of the last 30 years, Kabasakal and Karhan (2015) concluded that they are apparently absent in the Marmaric waters.

**Table 2.** Historical and contemporary records of batoid species in the Sea of Marmara, and their current status of occurrence. P: present; ?: questionable; A-M: Atlanto-Mediterranean; E: Endemic; I: Indian Ocean; VU: vulnerable; DD: data deficient ; CR: critically endangered; NT: near threatened; LC: least concern. Historical records: Ninni (1923), Deveciyan (1926), Ayaşlı (1937), Erazi (1942).

| **Species** | **Historical Records** | **Bilecenoğlu *et al.* (2014)** | **Status** | **Distribution** | **IUCN Criterion** |
|---|---|---|---|---|---|
| **Family TORPEDINIDAE** | | | | | |
| *Torpedo nobiliana* Bonaparte, 1835 | - | + | ? | A-M | DD |
| *Torpedo marmorata* Risso, 1810 | + | + | P | A-M | LC |
| *Torpedo torpedo* (Linnaeus, 1758) | + | + | ? | A-M | LC |
| **Family RAJIDAE** | | | | | |
| *Dipturus batis* (Linnaeus, 1758) | + | + | ? | A-M | CR |
| *Dipturus oxyrinchus* (Linnaeus, 1758) | + | + | P | A-M | NT |
| *Leucoraja naevus* (Müller and Henle, 1841) | - | + | ? | A-M | NT |
| *Raja asterias* Delaroche, 1809 | - | + | P | E | LC |

| | | | | | |
|---|---|---|---|---|---|
| *Raja clavata* Linnaeus, 1758 | + | + | P | A-M | NT |
| *Raja miraletus* Linnaeus, 1758 | + | + | P | A-M, I | LC |
| *Raja montagui* Fowler, 1910 | - | + | ? | A-M | LC |
| *Raja radula* Delaroche, 1809 | - | + | P | E | DD |
| **Family DASYATIDAE** | | | | | |
| *Dasyatis pastinaca* (Linnaeus, 1758) | + | + | P | A-M | NT |
| *Dasyatis tortonesei* Capapé,1975 | - | - | P | E | VU |
| **Family GYMNURIDAE** | | | | | |
| *Gymnura altavela* (Linnaeus, 1758) | - | + | P | A-M | CR |
| **Family MYLIOBATIDAE** | | | | | |
| *Myliobatis aquila* (Linnaeus, 1758) | + | + | P | A-M | NT |

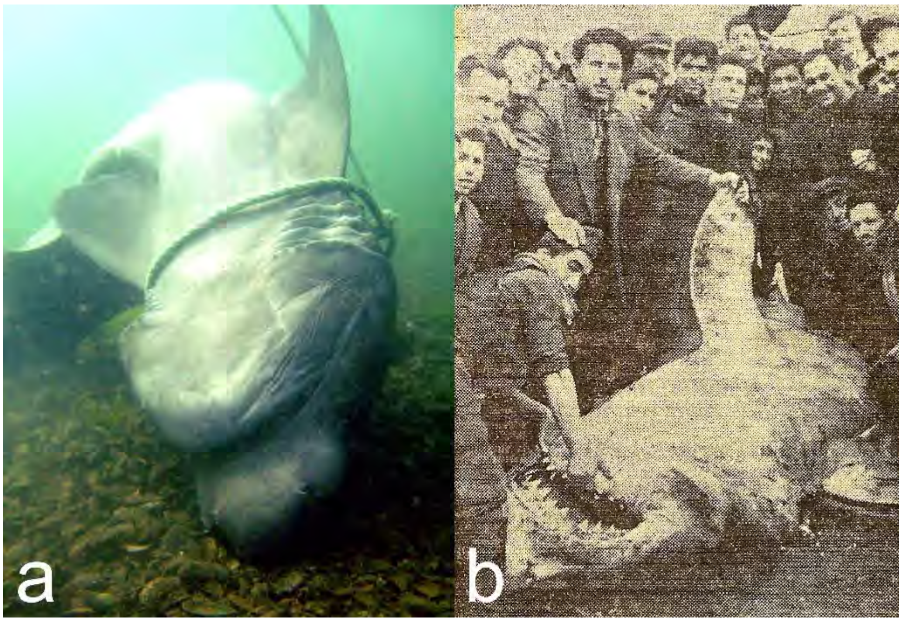


**Figure 1.** (a) discarded male specimen of *Hexanchus griseus* (400 cm TL), found on the bottom at a depth of 7 m off Ahırkapı coast on 17 September 2011; (b) great white shark, *Carcharodon carcharias* (450 cm TL), caught off the coast of Tuzla on 30 March 1954, by a tuna hand-liner.

Squaliforms, and triakid and scyliorhinid sharks are the well-known components of the shark fauna of the Sea of Marmara (Kabasakal and Karhan 2015). Scyliorhinid blackmouth catshark, *Galeus melastomus*, considered as a rare shark over the bathyal grounds in the northern slope of the Sea of Marmara by several authors (Meriç 1995; Uysal *et al*. 1996; Kabasakal 2003a), was recorded in very few numbers in the Marmaric waters. Although, available data confirms the rarity of the species in the Sea of Marmara, Kabasakal and Karhan (2015) emphasized the need of an extensive survey to clarify the status of *G. melastomus* over the Marmaric bathyal grounds. Similar to *G. melastomus*, large spotted catshark, *Scyliorhinus stellaris*, is another rare scyliorhinid shark of the Sea of Marmara (Keskin and Eryılmaz 2010; Kabasakal and Karhan 2015). Lesser spotted catshark *Scyliorhinus canicula*, has been recorded in recent ichthyological surveys on the Marmaric fish fauna more commonly than the congeneric *S. stellaris* (Karakulak *et al*. 2000; Keskin and Eryılmaz 2010; Altuğ *et al*. 2011). Several juvenile and adult specimens, as well as egg-cases of *S. canicula* were observed in southwestern Sea of Marmara, where rich growth gorgonians and black corals are forming a suitable spawning ground for the species (Kabasakal 2003a).

Regarding the triakids, tope shark, *Galeorhinus galeus* appears to be absent in the Sea of Marmara (Kabasakal and Karhan 2015). Contrary to tope shark, starry smoothhound, *Mustelus asterias,* and common smoothhound, *Mustelus mustelus* are contemporarily occurring in the region, although, the former species is quite rare in Marmaric waters (Kabasakal and Karhan 2015). Squaliform sharks is one of the major groups of Marmaric cartilaginous fishes, and the contemporary occurrences of the following species were confirmed in recent surveys by Kabasakal and Karhan (2015): *Oxynotus centrina, Squalus acanthias, Squalus blainville* and *Echinorhinus brucus*. Being one of the large sharks occurring in the Sea of Marmara, the enigmatic bramble shark, *Echinorhinus brucus*, has long been suggested possibly disappeared in the eastern Mediterranean (Hemida and Capapé 2002), Moreover, since no specimen of *E. brucus* recorded in the Sea of Marmara between late 1920's and mid 2000's, Kabasakal (2003a) concluded that *E. brucus* became absent in the Marmaric waters. However, during a seismic survey of the submarine part of the Northern Anatolian Fault Zone in the Sea of Marmara, a female bramble shark has been observed by a remotely operated vehicle at a depth of 1214 m in Tekirdağ Trench (Kabasakal *et al*. 2005), and subsequently four more specimens of *E. brucus* were recorded in the northern Sea of Marmara at the depths ranging from 100 to 700 m (Kabasakal and Dalyan 2011; Kabasakal and Bilecenoğlu 2014), confirming the presence of this rare shark not only in the Sea of Marmara, but in the eastern Mediterranean, as well.

The following squaliform sharks are considered with questionable occurrence in the Sea of Marmara (Kabasakal and Karhan 2015), since their records are based on previous studies carried out in 1990's (Benli *et al*. 1993; Meriç 1995): *Dalatias licha, Centrophorus granulosus* and *Centrohorus uyato,* which is not a valid species due its questionable taxonomic status (White *et al*. 2013).

To date, two squatinid sharks, *Squatina oculata* and *Squatina squatina* were recorded in the region (Meriç 1994; Kabasakal 2003a). Rarity of *S. squatina* in Marmaric waters was confirmed by Kabasakal and Kabasakal (2014), and *S. oculata* is a questionable species requiring confirmation (Kabasakal and Karhan 2015).

Historical evidences show that the blue shark, *Prionace glauca* has been occurred in the Sea of Marmara, at least in the first quarter of 20$^{th}$ century (Ninni 1923; Deveciyan 1926). Recently discovered photographical evidences also suggest that the requiem shark, *Carcharhinus* sp. has also been occurred in the Marmaric waters until 1950's (Kabasakal 2015). However, results of previous and recent ichthyological inventories of the Sea of Marmara suggest (Kabasakal 2003a; Keskin and Eryılmaz 2010), currently neither *Carcharhinus* sp., nor *P. glauca* are occurred in the Sea of Marmara.

Contrary to shark-specific studies carried out in the Sea of Marmara, specific studies on the occurrence and distribution of batoids of the same marine area is limited with remarkably low numbers of studies. Our knowledge on the occurrence and distribution of the Marmaric batoids are mostly based on the findings of general ichthyological inventories of the Sea of Marmara (*e.g*. Ninni 1923; Akşıray 1987; Keskin and Eryılmaz 2010; Altuğ *et al*. 2011; Bilecenoğlu *et al*. 2014). In one of the very few studies on Marmaric batoids, Uysal *et al*. (1996) reported on the distribution of two rare skates, *Leucoraja naevus* and *Dipturus oxyrinchus*, in the Sea of Marmara. Thereafter, Kabasakal and Ünsal (1995-1999) reported on the occurrence of *Raja radula* in Bosphoric waters, and the first record of the same species in the Sea of Marmara was accounted to the work by Yaka and Yüce (2006). Recently, Yıldız *et al*. (2016) reported on the first record of Tortonese's stingray, *Dasyatis tortonesei*, in the Sea of Marmara, based on 24 specimens caught in bottom trawl haulings in the northern Sea of Marmara.

## 3. Remarks on the Life History Traits of the Marmaric Chondrichthyans

Inventory studies of a certain marine area can only be a starting point of a better understanding of the species composition, and they should be followed by species-specific in-depth studies to reveal the life history traits of the identified species. From this perspective, the paucity of the studies on life history characteristics of the Marmaric sharks and batoids is obvious, and the available literature in this field can count something on the fingers of one hand.

Despite the low number of studies on the life-history traits of Marmaric cartilaginous fishes (Kabasakal 2004,2006,2009,2010a; Oral 2010; Bilecenoğlu and Ekstrom 2013; Yıldız *et al*. 2016), contents of the articles clarified the several aspects of the mentioned species. In two recent studies on the biology of the bluntnose sixgill shark, one of the largest species of the extant sharks, Kabasakal (2004, 2006) reported on the reproductive biology and stomach contents of *Hexanchus griseus*, based on specimens mostly captured in the Sea of Marmara. Kabasakal (2004) recorded 33 embryos with an average total length of 62.6 cm in a female (TL 450 cm) captured off

Hoşköy coast in 1997. According to Kabasakal (2004,2006), bony fishes were the main prey items of Marmaric sixgill sharks, although chondrichthyans (*Squalus* sp.), remains of marine mammals and cephalopods were also found in the stomach contents. Furthermore, Kabasakal (2006) also provided preliminary data on the length-weight relationship of the bluntnose sixgill shark, mostly based on Marmaric specimens. Oral (2010) reported on the feeding habits of *Galeus melastomus* trawled at the depths between 1024 and 1213 m in northwestern Sea of Marmara, and found crustaceans, *Calocaris macandreae* and *Sergestes robustus*, and the teleostean, *Engraulis encrasicolus*, were found in the examined stomach contents of black-mouth catshark. Recently, Yıldız *et al*. (2016) reported on the length-weight and disc width-weight relationships of *Dasyatis tortonesi*, bottom-trawled in the Sea of Marmara.

Release of the alive specimens is crucial for the survival of incidentally captured chondrichthyans; however, anthropogenic injuries and fishery-induced stress can negatively impact on the post-release survival rate of sharks and batoids (Figure 2). Post-release behavior and anthropogenic injuries observed on the specimens of *H. griseus*, mostly captured in the Sea of Marmara were examined by Kabasakal (2010a), and author concluded that injured sixgill sharks may be at risk from post-release disability or mortality, due to the possible long-term pathologic consequences of fishing gear induced scars.

**Figure 2.** Discarded specimen of *Oxynotus centrina*, found on the bottom off coast of Ahırkapı on 21st October 2012. Fishery-induced injuries are clearly seen on the body surface of the shark.

Locomotion patterns of the two Marmaric chondrichthyans, *Oxynotus centrina* and *Raja radula*, were investigated based on underwater videography (Kabasakal 2009; Bilecenoğlu and Ekstrom 2013). Observations on the patterns of movement of a female angular rough shark, ca. 60 cm of TL, revealed that, *O. centrina* is a carangiform swimmer and can use the posture of pectoral fins during maneuvering or hovering. In a similar study on pelvic fin walking and punting behaviour of *R. radula* imaged in the Sea of Marmara, Bilecenoğlu and Ekstrom (2013) provided the first *in situ* observation of pelvic fin locomotion for the species.

## 4. Chondrichthyan bycatches in the Sea of Marmara

Drastic reductions in the stocks of traditional commercially important sea fishes mean that sharks and batoids are now actively being considered as new opportunities for the survival of fisheries. Despite some attempts in the past, chondrichthyans are not subjected to a targeted commercial fishery in Turkey, but they are caught during the fisheries for other commercially important species.

Chondrichthyan landings in the Sea of Marmara are mostly comprised of incidentally captured specimens by commercial fishermen (Bayhan *et al*. 2006; Bök *et al*. 2011; Kabasakal 2013; İşmen *et al*. 2013). In an extensive survey on catch and bycatch composition of the shrimp fishery by beam trawl in the southeastern Sea of Marmara, Bayhan *et al*. (2006) recorded *Mustelus mustelus*, *Scyliorhinus stellaris*, *Oxynotus centrina* and *Raja* sp., and concluded that bycaught chondrichthyans comprised the 0.13 percent of the total catch of the shrimp fishery. During fishery surveys in northern Sea of Marmara, Bök *et al*. (2011), recorded *Mustelus asterias*, *Torpedo marmorata*, *Dipturus oxyrinchus*, *Raja clavata* and *Raja asterias* as bycatch chondrichthyans in beam-trawl fishery with a codend mesh opening of 40 mm, and reported that *R. clavata* and *R. asterias* represents 0.2% and 0.3% of the chondrichthyan bycatches, respectively, while each of *M. asterias*, *T. marmorata* and *D. oxyrinchus* comprised 0.03% of the total catch. According to Kabasakal (2013), sixgill shark, *Hexanchus griseus* is a common bycatch of commercial fishermen in the Sea of Marmara, where the highest number of captures in Turkish waters was recorded in this sea (90 specimens; 60% of total Turkish catches), mainly by purse-seiners. Chondrichthyan bycatches in the beam trawl shrimp fishery in the Sea of Marmara was also extensively investigated by İşmen *et al*. (2013), and *Squalus acanthias*, *Oxynotus centrina*, *Scyliorhinus canicula*, *Scyliorhinus stellaris*, *Torpedo marmorata*, *Raja clavata*, *Raja miraletus* and *Dasyatis pastinaca* were recorded as bycatch chondrichthyans. Regarding catch per unit of effort data (CPUE, kg/h), *R. clavata* (0.473) was the most abundant bycaught chondricthyan and *S. acanthias* was a seldom catch (0.002) (İşmen *et al*. 2013).

## 5. Conservation issues

IUCN criterion of the following shark and batoid species, which are also occurred in the contemporary chondrichthyan fauna of the Sea of Marmara, are defined as follows (Cavanagh and Gibson 2007): *Hexanchus griseus*, near threatened; *Alopias superciliosus*, data deficient; *Alopias vulpinus*, vulnerable; *Scyliorhinus stellaris*, near threatened; *Mustelus asterias*, vulnerable; *Mustelus mustelus*, vulnerable; *Oxynotus centrina*, critically endangered; *Centrophorus granulosus*, vulnerable; *Squalus acanthias*, endangered; *Squalus blainville*, not evaluated; *Echinorhinus brucus*, data deficient; *Squatina squatina*, critically endangered; *Torpedo marmorata*, least concern; *Dipturus oxyrinchus*, near threatened; *Raja asterias*, least concern; *Raja clavata*, near threatened; *Raja miraletus*, least concern; *Raja radula*, data deficient; *Dasyatis pastinaca*, near threatened; *Dasyatis tortonesei*, vulnerable; *Gymnura altavela*, critically endangered; *Myliobatis aquila*, near threatened (Tables 1 and 2). Regarding the severe decline of chondrichthyans in the Mediterranean Sea due to by-catch pressure of commercial fisheries, saving the sharks and batoids of the Sea of Marmara is also vitally important for the conservation of several Mediterranean chondrichthyans. Slow growth, late sexual maturity, low fecundity and long life of chondrichthyan fishes, resulting in low rates of population increase (Camhi *et al.* 1998). Such life histories make these species highly vulnerable to overexploitation and slow to recover once their populations have been depleted. From this perspective, capture of pregnant females create a significant threat to the survival of the Marmaric sharks and batoids. Thus, before the implementation of evidence-based measures for the conservation, and even a ban on the fishing of certain chondrichthyans in the Sea of Marmara, promoting fishermen to release live specimens, appears to be an urgent, feasible first step for the protection of these fishery-sensitive species. This land-locked marine area could provide a sanctuary for chondrichthyan fishes, if conservation and management measures were implemented.

## 6. Conclusions

The remarkable increase in the research efforts on the chondrichthyan fishes of the Sea of Marmara for the last 25 years resulted with a better understanding and several reoccurrences of the apex predators of this land-locked small marine area, as well as with a number of new arrivals. For example, *E. brucus*, once has been accounted in the historical studies (Ninni 1923; Deveciyan 1926) and then supposed to be absent in the Sea of Marmara, due to its absence in the ichthyological records of this sea in late 20$^{th}$ century, reoccurred in Marmaric bathyal, following a series of deep sea imaging surveys in mid 2000's (Kabasakal *et al*. 2005). The discovery of *A. superciliosus* in the Sea of Marmara, which was considered as a rare or occasional shark in the Mediterranean Sea (Serena, 2005), was also the consequence of the recent shark surveys in Marmaric waters (Kabasakal and Karhan 2007).

According to one of the recent ichthyological inventories (Keskin and Eryılmaz 2010), the fish fauna of the Sea of Marmara includes 235 species, of which 13 shark species and 10 batoids with confirmed contemporary occurrence (Tables 1 and 2) representing the 9.78 percent of the total ichthyofauna. According to Serena (2005), 49 shark species and 34 batoids occur in the entire Mediterranean Sea. Thus, the Marmaric chondrichthyans with confirmed contemporary occurrence represent the 27.71 percent of the total Mediterranean chondrichthyan fauna.

An extensive pelagic fish survey is necessary in order to clarify the contemporary status of the highly migratory shark species, *e.g. Carcharodon carcharias*, *Lamna nasus* and *Prionace glauca*, which could enter the Sea of Marmara in pursuit of pelagic bait fish. Occurrence of several lamniforms including *C. carcharias* and *L. nasus*, as well as *P. glauca* near the vicinity of southern entrance of Dardanelles Strait (Kabasakal 2010b, 2014), the gateway between Mediterranean and Marmara seas, emphasize the importance of such a survey in Marmaric waters.

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# ENDANGERED SPECIES OF THE MARMARA SEA

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## 1. Introduction

The Census of Marine Life (CoML) indicates the presence of approximately 250,000 valid marine species (excluding microbes), with an estimated at least 750,000 more species remaining to be described. Such taxonomical information is very important from the viewpoint of conservation biology, since we may not predict how many species we are losing without knowing how many we already have. Until 2008, IUCN (International Union for Conservation of Nature) experts evaluated the threat of extinction of only 1.2% of the marine biota, but as of March 2015, 13,500 species (corresponding to 5.4% of the global marine biodiversity) have now been assessed under the IUCN Red List Categories and Criteria (GMSA 2016). Despite of this remarkable progress, one may easily recognize that extinction risk of almost 95% of the marine species are still unknown, so an unpredictable number of species may even become extinct without ever having been identified or assessed.

By recent scientific research focused on the marine life of the Mediterranean Sea, crucial data on the structure and spatial distribution of the biota is obtained, together with vital information on the principal factors having negative influence on the diversity. Independent from ecological and hydrological differences between its basins and sub-basins, the most important threats affecting the entire Mediterranean Sea ecosystem at present are habitat loss and degradation, followed by fishing impacts, pollution, climate change, eutrophication, and the establishment of alien species (Coll *et al.* 2010). With reference to the priority objectives and goals of the Turkish National Biological Diversity Strategy and Action Plan (2007), marine biodiversity of Turkey has been revealed for the first time in its history through a series of papers published lately (see section 2 - status of endangered species). By this recent taxonomical knowledge expansion, we now have the opportunity to better specify conservation strategies and assess the threat status of species distributing along the Turkish coastline. Supported by TÜDAV (Turkish Marine Research Foundation), a list of endangered species of the Aegean Sea was previously published (Bilecenoğlu and Çınar 2015) and we hereby deal with the endangered marine life of the Sea of Marmara.

Situated on the border of Europe and Asia, the Sea of Marmara truly exhibits oceanic features, despite of its lake-like small dimensions. Via the physical connections with the Black and Mediterranean Seas, the Sea of Marmara complex (including Turkish straits systems) exhibits vital ecological roles as a biological corridor/barrier and an acclimatization zone. Such an unmatched hydrological characteristic simply denotes that the health of the Sea of Marmara is substantial in the protection of marine biodiversity of adjacent ecosystems (Öztürk 2002). Scientific research performed so far has revealed that biota of the Sea of Marmara is highly under negative influence of various anthropogenic activities (coastal development, untreated wastewater discharges, dumping, agricultural run-off, illegal/unreported/unregulated fishing, overfishing, marine litter, shipping etc.) (Topçu and Öztürk 2015) and natural pressures (i.e. hypoxia in the bottom layer) (Yüksek *et al.* 2013). These unfavorable conditions are clear signs of a suffocating ecosystem, in which urgent measures must be taken to ensure its revival. In the present review, the endangered marine species distributing along the coast of the Sea of Marmara are examined, by taking into consideration the IUCN Red Lists and international treaties signed by Turkey.

## 2. Status of Endangered Species

The Sea of Marmara is unquestionably one of the most vibrant marine environments throughout the entire Mediterranean basin, in which the occurrence of approximately 3000 marine species were reported, including 507 plants (Aysel *et al.* 2000), 63 poriferans (Topaloğlu and Evcen 2014), 115 cnidarians (Çınar *et al.* 2014), 398 annelids (Çınar *et al.* 2014), 787 arthropods (Bakır *et al.* 2014), 537 molluscans (Öztürk *et al.* 2014), 64 echinoderms (Öztoprak *et al.* 2014), 258 other invertebrate species (such as bryzoans, sipunculans, ascidians etc., Açık Çınar 2014; Çınar 2014; Koçak and Önen 2014), 257 cartilaginous and bony fishes (Bilecenoğlu *et al.* 2014), 36 marine birds, 2 reptiles and 6 mammals (Güçlüsoy *et al.* 2014). The examination of appendices of the international treaties (Barcelona and Bern conventions) and the regional Red Lists (IUCN) have revealed the presence of 115 endangered marine species inhabiting the Sea of Marmara (for full account, see the Appendix and Table 1).

The Bern Convention constitutes an instrument of major importance for the conservation and sustainable use of biological diversity at the regional level, whose main objective is to conserve wild flora and fauna and their natural habitats, especially those requiring the co-operation of several states. With reference to marine species occurring in the Sea of Marmara, 67 species are currently covered by the Bern Convention. There are only 7 marine plants included in the Appendix I (4 algae species and 3 flowering plant species), while majority of the strictly protected species (Appendix II) are animal taxa (39 sp.) and exploitation of 21 more species are to be regulated (Appendix III).

**Table 1.** The number of endangered species in taxonomic groups in the Sea of Marmara and their proportions as a percentage of the relevant local diversity.

| | **Number of Endangered Species** | **% of Local Diversity** |
|---|---|---|
| Plantae | 19 | 3.7 |
| Porifera | 8 | 12.7 |
| Cnidaria | 8 | 7.0 |
| Arthropoda | 4 | 0.5 |
| Mollusca | 5 | 0.9 |
| Echinodermata | 3 | 4.7 |
| Pisces | 40 | 15.6 |
| Reptilia | 2 | 100 |
| Aves | 36 | 55.6 |
| Mammalia | 6 | 100 |

The Barcelona Convention comprises 22 contracting parties that are aimed to protect the marine and coastal environment of the Mediterranean Sea, while focusing to achieve sustainable development by boosting regional and national plans. By the recent revisions made (UNEP/MAP 2013), the Barcelona convention now includes 87 protected species inhabiting the Sea of Marmara. The Appendix II (that lists endangered plant and animal species) includes 67 species, while 20 species were mentioned in the Appendix III (species whose exploitation is regulated).

IUCN is the world's main authority for the conservation status of species, and the red lists of threatened species prepared are the most comprehensive inventory of the global conservation status of organisms, assessing the risk of extinction of species. The regional red lists include 39 (critically endangered: 9, endangered: 11, vulnerable: 19) species. It should be noted that, majority of the taxa has not yet evaluated by the IUCN experts or covered by appendices of treaties, so the proportion of endangered species as a percentage of the relevant local diversity is quite low (Table 1) - for example, out of 537 marine molluscans inhabiting the Sea of Marmara (Öztürk *et al.* 2014), only five species appear within the red lists or appendices of other conventions.

### 2.1. Marine Algae and Seagrasses

Among marine algae and seagrasses of the Sea of Marmara, none of the species existed in the threatened categories of IUCN Red Lists, but 3.7% of the flora were listed in the appendices of Bern and Barcelona conventions. *Cystoseira* species made up the majority of the endangered taxa, which are among the most important marine ecosystem-engineers forming extended canopies and indicators of pristine coastal waters. By the recent revision of the Barcelona convention, all *Cystoseira* species (except for *C. compressa*) were listed as endangered (Appendix II), corresponding to 11 species reported from the Sea of Marmara (Taşkın *et al.* 2008).

Seagrass meadows are one of the most important primary producers of the infralittoral zone of the Sea of Marmara. Three of the species (*Cymodocea nodosa*, *Zostera marina* and *Z. noltei*) are widely spread throughout the basin (Aysel *et al.* 2000;

Yüksek and Okuş 2004) (Figure 1), while distribution of *Posidonia oceanica* is sparse and restricted to Dardanelles, Erdek Bay and Paşalimanı Island (Yüksek and Okuş 2004; Meinesz *et al.* 2009). Among their distribution ranges, all four seagrass species are subjected to combined negative impacts of coastal development, urban and industrial wastes, mechanical (human mediated) damages and nutrient increase.

**Figure 1.** Seagrasses may be found even in very shallow shores of the Sea of Marmara (above), which makes them vulnerable to coastal originated impacts. Anywhere they occur, seagrasses always support a rich marine life, such as the endangered sea horses as seen below (Photos: Murat Bilecenoğlu).

## 2.2. Marine Invertebrates

There are 28 endangered invertebrate species inhabiting the Sea of Marmara, in which poriferans and cnidarians comprise more than half of the endangered species (8 species each), followed by molluscans, crustaceans and echinoderms.

Several poriferan species of the world suffer from epidemic diseases and (direct/indirect) effects of global warming (Webster 2007), but threatening factors at the Sea of Marmara are most probably associated with anthropogenic impacts such as the alteration of coastal ecosystems, untreated water discharge, etc. The severe epidemic observed in the Mediterranean during 1986 (till 1990) was resulted by the mass mortality of sponges in several countries, which immediately led Turkey to ban sponge fisheries (see Fishery Bulletins of General Directorate of Fisheries and Aquaculture). The population structure and abundance of the Sea of Marmara's sponges are currently almost unknown, and immediate scientific research must be done to fill this information gap.

The endangered molluscs of the Sea of Marmara are either negatively impacted by illegal activities (such as the collection of cowry shells, or the damage of *Pinna nobilis* by bottom trawlers and/or their collection by divers) or anthropogenic disturbances (such as habitat degradation, influencing the reef forming vermetid gastropod *Dendropoma petraeum*). The population of endangered edible molluscs (*Lithophaga lithophaga* and *Pholas dactylus*) are currently unknown in the Sea of Marmara, and harvesting for consumption (which is the main threat throughout their distribution ranges) is quite unlikely in the region.

Until now, only nine threatened cnidarians were listed under various international treaties regarding the Mediterranean Sea ecosystem, which has currently risen to 17 species by the recent local red list assessments. According to IUCN (2016), the Mediterranean anthozoans mainly suffer from the effects of accidental damage by various fishing techniques and gears (bottom trawling and dragging nets), followed by commercial collection, climate change, pollution, increased sedimentation, seawater eutrophication and human disturbance. Deep sea species are threatened also by drilling, dumping, mining activities and anchorage. From eight threatened cnidarians inhabiting the Sea of Marmara, one was listed by the Barcelona Convention (Appendix II), three were listed by the Bern Convention (Appendix II) and six by the Mediterranean local red list of IUCN including *Paramuricea clavata* (Figure 2).

Four crustaceans are listed in the Appendix III of the Bern and Barcelona Conventions, while only *Palinurus elephas* was categorized as "vulnerable" by the red list. The spiny crab (*Maja squinado*) forms relatively a dense population (1-2 specimens.10m$^{-2}$) at some places (pers. observ., Figure 3). Indeed, they are all under pressure of over- and illegal fishing, and will likely to become extinct in the Sea of Marmara because of inefficient governmental regulations. An annual fishery ban should be taken into consideration by the General Directorate of Fisheries and Aquaculture (Ministry of Food, Agriculture and Livestock), before their populations rapidly approach to the critical levels.

Biological data on sea urchins of the Sea of Marmara are very limited. *Paracentrotus lividus* is quite a common species in the region (Figure 3), while distribution ranges and abundances of *Asterina pancerii* and *Centrostephanus longispinus* should be scientifically examined.

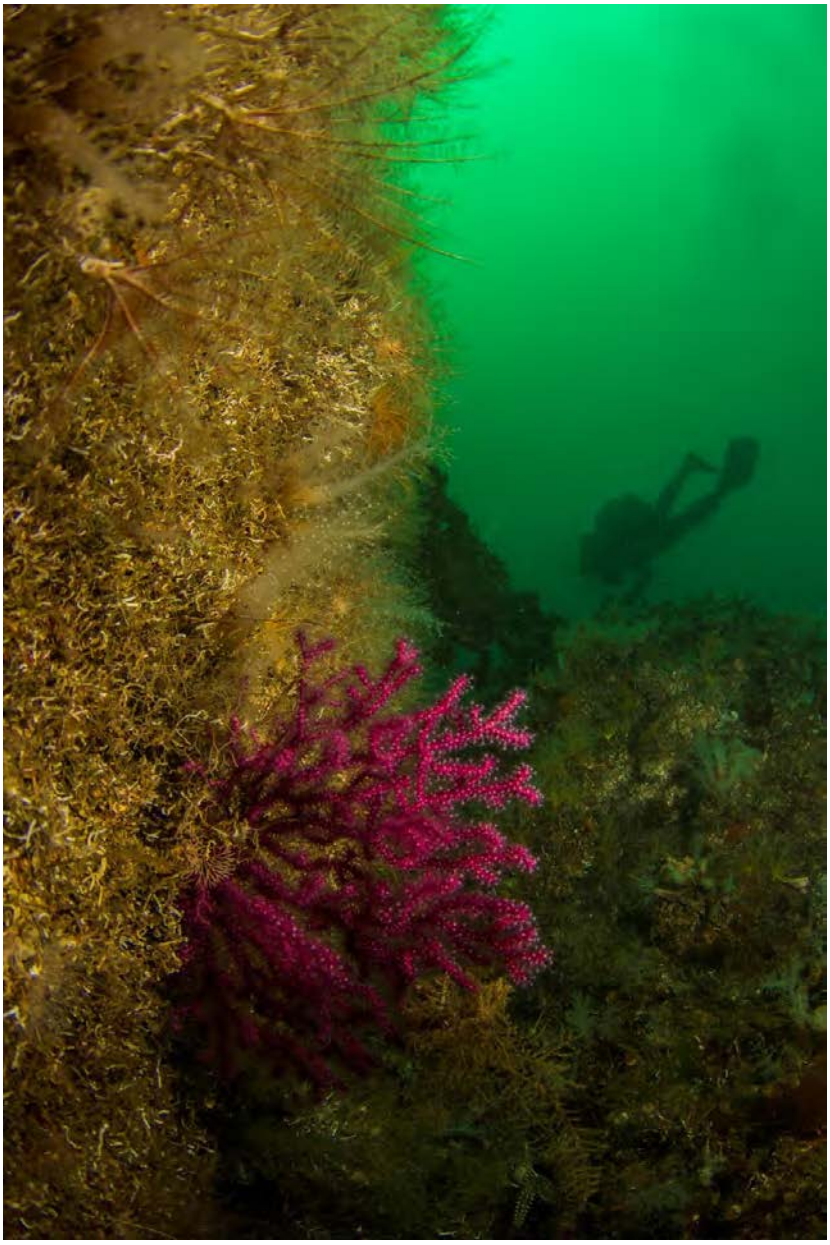

**Figure 2.** *Paramuricea clavata* colony from Neandros/Prince Islands (Photo: Recep Şen).

**Figure 3.** Examples of threatened invertebrate species from the Dardanelles Strait. Togetherness of *Paracentrotus lividus* with the fan mussel *Pinna nobilis*, in the vicinity of a weak *Posidonia oceanica* population (above). A close up view of *Maja squinado* is given below (Photos: Murat Bilecenoğlu).

### 2.3. Marine Vertebrates

Among 36 cartilaginous fish occurring at the Sea of Marmara ecosystem (Bilecenoglu *et al.* 2014), 20 were considered to be threatened in the red lists and appendices of the international conventions. Exactly half of the sharks and rays in the region were previously assigned to the red list categories (6 species for each of CR, EN and VU), which is clearly a higher percentage in comparison to the global scale and the Mediterranean itself (Cavanagh and Gibson 2007). With the exception of annual national fishery ban for a few cartilaginous species, the existing governmental regulations are currently ineffective for the conservation of sharks and rays (i.e. *Raja radula*, see Figure 4). The recommended measures to be taken are reinforcing fishing regulations, creating new marine reserves, reducing pollution and reviewing fishing quotas - in particular the number of captures allowed for threatened species (Abdul-Malak *et al.* 2011).

A greater number of bony fish species more than those listed in the Appendix are definitely threatened in the Sea of Marmara. There are several species not appearing in the appendices of the international treaties and/or in the red lists, which require urgent conservation action by the governmental involvement (Table 2, Figure 4).

**Table 2.** A list of bony fish species occurring at Sea of Marmara that requires immediate conservation action

| Species | Existing (Main) Threats |
|---|---|
| *Conger conger* (Linnaeus, 1758) | Habitat degradation, coastal development, spearfishing |
| *Merluccius merluccius* (Linnaeus, 1758) | Overfishing, illegal fishing (bottom trawlers) |
| *Merlangius merlangus* (Linnaeus, 1758) | Overfishing, illegal fishing (bottom trawlers) |
| *Zeus faber* Linnaeus, 1758 | Overfishing, inefficient fishery regulations |
| *Pomatomus saltator* (Linnaeus, 1766) | Overfishing, inefficient fishery regulations |
| *Umbrina cirrosa* (Linnaeus, 1758) | Overfishing, spearfishing |
| *Chelidonichthys lucerna* (Linnaeus, 1758) | Overfishing, illegal fishing |
| *Scophthalmus rhombus* (Linnaeus, 1758) | Overfishing, illegal fishing |

Only two sea turtles occur in the Sea of Marmara - *Chelonia mydas* and *Caretta caretta*; the Mediterranean subpopulation of the latter is currently assessed as "least concern" by IUCN. Despite of some increased observations of sea turtles in the region, their abundance is currently unknown (Güçlüsoy *et al.* 2014). All 20 seabird species were mentioned in the Bern Convention (19 species in Appendix II and one species in Appendix III), 14 of which were also listed in the Barcelona Convention appendices.

All cetacean and pinniped species are protected by law in Turkey (Fishery Bulletin nos. 4/1 and 4/2 of General Directorate of Fisheries and Aquaculture). Negative impact of pollution and the reduced food availability caused by overfishing are likely to be main threatening factors for the Sea of Marmara's cetaceans, while the Mediterranean Monk Seal suffers from the combination of coastal degradation, habitat loss, reduced food availability, marine pollution and disturbance from maritime traffic (IUCN 2012).

**Figure 4.** Examples of threatened fish species of the Sea of Marmara. *Raja radula* (above), *Chelidonichthys lucerna* (below) (Photos: Recep Şen).

## 3. Conclusive Remarks

At present, about 4% of Turkey's territorial waters is protected by law, with an estimated 346.138 hectares of marine area under legal protection within 31 Marine and Coastal Protected Areas (see www.mpa.gov.tr). There is no doubt that all these areas are very important ecosystems for several bioecologically fragile habitats and species (i.e. seagrass meadows, coralligenous habitats, seabirds, cetaceans, monk seals, marine turtles, endangered sponge and coral species etc.), but "protection" status of the selected Turkish marine area do not prevent or decelerate direct and indirect human impact (for example coastal urbanization, fishing activities, pollution etc.) (Bilecenoğlu and Çınar 2015).

The most important steps to be taken are: 1) Determining abundance and distribution of all endangered species, together with a meticulous research on their key biological and ecological characteristics (i.e. spawning areas). The governmental financial support mechanism for basic sciences should be substantially reviewed and improved, since such kind of research effort certainly requires large funds reinforced by the government, as also defined by the convention of biological diversity (CBD). 2) The Sea of Marmara fulfills the first six criteria of EBSA'S (Ecologically or Biologically Significant Marine Areas) with “high” category (Yüksek *et al.* 2013) and there is an urgent need for defining ecological boundaries for potential Marine Protected Areas. At present two marine areas (İstanbul islands and Marmara islands) were proposed by TÜDAV as MPA's (Öztürk 2012). 3) An effective pollution prevention plan should be designed and any sources contributing to the pollution of Sea of Marmara must be largely diminished. 4) The other key threats such as habitat destructions, sea embankments, shallow-water and deep-sea dumping activities, over-fishing and the introduction of alien species should be controlled and regulated. Preparation of Action Plans for each seas surrounding Turkey will be a key step in integrated ecosystem conservation.

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**Appendix.** Endangered species in the Sea of Marmara. Red List Categories: CR - critically endangered, EN - endangered, VU - vulnerable. Description of the Bern Convention Appendices – Appendix I (App.I): strictly protected flora species; AppendixII (App.II): strictly protected fauna species; Appendix III (App.III): protected fauna species. Description of the Barcelona Convention Appendices - App.II: List of endangered and threatened species; App.III: List of species whose exploitation is regulated.

| | Barcelona | Bern | Red List |
|---|---|---|---|
| **PLANTAE** | | | |
| **Magnoliophyta** | | | |
| *Cymodocea nodosa* (Ucria) Ascherson, 1870 | App.II | App.I | - |
| *Posidonia oceanica* (Linnaeus) Delile, 1813 | App.II | App.I | - |
| *Zostera marina* Linnaeus, 1753 | App.II | App.I | - |
| *Zostera noltei* Hornemann, 1832 | App.II | - | - |
| **Heterokontophyta** | | | |
| *Cystoseira barbata* (Stackhouse) C.Agardh, 1820 | App.II | - | - |
| *Cystoseira corniculata* (Turner) Zanardini, 1841 | App.II | - | - |
| *Cystoseira crinita* Duby, 1830 | App.II | - | - |
| *Cystoseira elegans* Sauvageau, 1912 | App.II | - | - |
| *Cystoseira foeniculacea* (Linnaeus) Greville, 1830 | App.II | - | - |
| *Cystoseira funkii* Schiffner ex Gerloff & Nizamuddin, 1976 | App.II | - | - |
| *Cystoseira mediterranea* Sauvageau, 1912 | App.II | App.I | - |
| *Cystoseira sauvageauana* Hamel, 1939 | App.II | - | - |
| *Cystoseira spinosa* Sauvageau, 1912 | App.II | App.I | - |
| *Cystoseira tamariscifolia* (Hudson) Papenfuss, 1950 | App.II | - | - |
| *Cystoseira zosteroides* C.Agardh, 1820 | App.II | App.I | - |
| *Laminaria rodriguezii* Bornet, 1888 | App.II | App.I | - |
| *Sargassum acinarium* (Linnaeus) Setchell, 1933 | App.II | - | - |
| *Sargassum hornschuchii* C.Agardh, 1820 | App.II | - | - |
| **Rhodophyta** | | | |
| *Gymnogongrus crenulatus* (Turner) J.Agardh, 1851 | App.II | - | - |
| **ANIMALIA** | | | |
| **Porifera** | | | |
| *Aplysina aerophoba* Nardo, 1843 | App.II | - | - |
| *Axinella cannabina* (Esper, 1794) | App.II | - | - |
| *Axinella polypoides* Schmidt, 1862 | App.II | App.II | - |

| | | | |
|---|---|---|---|
| *Geodia cydonium* (Jameson, 1811) | App.II | - | - |
| *Hippospongia communis* (Lamarck, 1814) | App.III | App.III | - |
| *Sarcotragus foetidus* Schmidt, 1862 | App.II | - | - |
| *Spongia officinalis* Linnaeus, 1759 | App.III | App.III | - |
| *Tethya aurantium* (Pallas, 1766) | App.II | - | - |
| **Cnidaria** | | | |
| *Cladocora caespitosa* (Linnaeus, 1767) | App.II | - | EN |
| *Funiculina quadrangularis* (Pallas, 1766) | - | - | VU |
| *Paramuricea clavata* (Risso, 1826) | - | - | VU |
| *Parantipathes larix* (Esper, 1788) | App.II | - | - |
| *Pennatula phosphorea* Linnaeus, 1758 | - | - | VU |
| *Pennatula rubra* Ellis, 1761 | - | - | VU |
| *Pteroeides spinosum* (Ellis, 1764) | - | - | VU |
| *Savalia savaglia* (Bertoloni, 1819) | App.II | App.II | - |
| **Mollusca** | | | |
| *Dendropoma petraeum* (Monterosato, 1884) | App.II | App.II | - |
| *Erosaria spurca* (Linnaeus, 1758) | App.II | App.II | - |
| *Lithophaga lithophaga* (Linnaeus, 1758) | App.II | App.II | - |
| *Pholas dactylus* Linnaeus, 1758 | App.II | App.II | - |
| *Pinna nobilis* Linnaeus, 1758 | App.II | - | - |
| **Crustacea** | | | |
| *Homarus gammarus* (Linnaeus, 1758) | App.III | App.III | - |
| *Maja squinado* (Herbst, 1788) | App.III | App.III | - |
| *Palinurus elephas* (Fabricius, 1787) | App.III | App.III | VU |
| *Scyllarus arctus* (Linnaeus, 1758) | App.III | App.III | - |
| **Echinodermata** | | | |
| *Asterina pancerii* (Gasco, 1870) | App.II | App.II | - |
| *Centrostephanus longispinus* (Philippi, 1845) | App.II | App.II | - |
| *Paracentrotus lividus* (Lamarck, 1816) | App.III | App.III | - |
| **Elasmobranchii** | | | |
| *Alopias superciliosus* Lowe, 1841 | - | - | EN |
| *Alopias vulpinus* (Bonnaterre, 1788) | App.III | - | EN |
| *Carcharodon carcharias* (Linnaeus, 1758) | App.II | App.II | CR |
| *Centrophorus granulosus* (Bloch & Schneider, 1801) | App.III | - | CR |
| *Centrophorus uyato* (Rafinesque, 1810) | - | - | VU |

| | | | |
|---|---|---|---|
| *Dalatias licha* (Bonnaterre, 1788) | - | - | EN |
| *Dasyatis pastinaca* (Linnaeus, 1758) | - | - | VU |
| *Echinorhinus brucus* (Bonnaterre, 1788) | - | - | EN |
| *Galeorhinus galeus* (Linnaeus, 1758) | App.II | - | VU |
| *Gymnura altavela* (Linnaeus, 1758) | App.II | - | CR |
| *Lamna nasus* (Bonnaterre, 1788) | App.II | App.III | CR |
| *Mustelus asterias* Cloquet, 1821 | App.III | - | - |
| *Mustelus mustelus* (Linnaeus, 1758) | App.III | - | VU |
| *Myliobatis aquila* (Linnaeus, 1758) | - | - | VU |
| *Oxynotus centrina* (Linnaeus, 1758) | App.II | - | VU |
| *Prionace glauca* (Linnaeus, 1758) | App.III | App.III | - |
| *Raja radula* Delaroche, 1809 | - | - | EN |
| *Squalus acanthias* (Linnaeus, 1758) | App.III | - | EN |
| *Squatina oculata* Bonaparte, 1840 | - | - | CR |
| *Squatina squatina* (Linnaeus, 1758) | App.II | App.III | CR |
| **Actinopteri** | | | |
| *Acipenser gueldenstaedtii* Brandt & Ratzeburg, 1833 | - | - | CR |
| *Acipenser sturio* Linnaeus, 1758 | App.II | App.II | - |
| *Alosa fallax* (Lacepede, 1803) | App.III | App.III | - |
| *Anguilla anguilla* (Linnaeus, 1758) | App.III | - | CR |
| *Dentex dentex* (Linnaeus, 1758) | - | - | VU |
| *Epinephelus marginatus* (Lowe, 1834) | App.III | App.III | EN |
| *Hippocampus guttulatus* Cuvier, 1829 | App.II | App.II | - |
| *Hippocampus hippocampus* (Linnaeus, 1758) | App.II | App.II | - |
| *Huso huso* (Linnaeus, 1758) | App.II | App.III | - |
| *Labrus viridis* Linnaeus, 1758 | - | - | VU |
| *Pomatoschistus marmoratus* (Risso, 1810) | - | App.III | - |
| *Pomatoschistus minutus* (Pallas, 1770) | - | App.III | - |
| *Ponticola syrman* (Nordmann, 1840) | - | App.III | - |
| *Sciaena umbra* (Linnaeus, 1758) | App.III | App.III | - |
| *Scophthalmus maximus* (Linnaeus 1758) | - | - | VU |
| *Syngnathus abaster* Risso, 1827 | - | App.III | - |
| *Thunnus thynnus* (Linnaeus, 1758) | App.III | - | - |
| *Umbrina cirrosa* (Linnaeus, 1758) | App.III | App.III | VU |
| *Xiphias gladius* (Linnaeus, 1758) | App.III | - | - |

| | | | |
|---|---|---|---|
| *Zosterisessor ophiocephalus* (Pallas, 1814) | - | App.III | - |
| **Reptilia** | | | |
| *Caretta caretta* (Linnaeus, 1758)* | App.II | App.II | - |
| *Chelonia mydas* (Linnaeus, 1758) | App.II | App.II | EN |
| **Aves** | | | |
| *Calonectris diomedea* (Scopoli, 1769) | App.II | App.II | - |
| *Chlidonias hybrida* (Pallas, 1811) | - | App.II | - |
| *Chlidonias leucopterus* (Temminck, 1815) | - | App.II | - |
| *Chlidonias niger* (Linnaeus, 1758) | - | App.II | - |
| *Chroicocephalus genei* (Brème, 1839) | App.II | App.II | - |
| *Gavia arctica* (Linnaeus, 1758) | - | App.II | - |
| *Gavia immer* (Brünnich, 1764) | - | App.II | VU |
| *Gavia stellata* (Pontoppidan, 1763) | - | App.II | - |
| *Gelochelidon nilotica* (Gmelin, JF, 1789) | App.II | App.II | - |
| *Hydroprogne caspia* (Pallas, 1770) | App.II | App.II | - |
| *Ichthyaetus audouinii* (Payraudeau, 1826) | App.II | App.II | - |
| *Ichthyaetus melanocephalus* (Temminck, 1820) | App.II | App.II | - |
| *Larus armenicus* (Buturlin, 1934) | App.II | App.III | - |
| *Microcarbo pygmaeus* (Pallas, 1773) | App.II | App.II | - |
| *Pelecanus crispus* (Bruch, 1832) | App.II | App.II | - |
| *Pelecanus onocrotalus* (Linnaeus, 1758) | App.II | App.II | - |
| *Phalacrocorax aristotelis* (Linnaeus, 1761) | App.II | App.II | - |
| *Puffinus yelkouan* (Acerbi, 1827) | App.II | App.II | - |
| *Sternula albifrons* (Pallas, 1764) | App.II | App.II | - |
| *Thalasseus sandvicensis* (Latham, 1787) | App.II | App.II | - |
| **Mammalia** | | | |
| *Delphinus delphis* Linnaeus, 1758 | App.II | App.II | VU |
| *Grampus griseus* (G. Cuvier, 1812) | App.II | App.II | - |
| *Monachus monachus* (Hermann, 1779) | App.II | App.II | CR |
| *Phocoena phocoena* (Linnaeus, 1758) | App.II | App.II | EN |
| *Stenella coeruleoalba* (Meyen, 1833) | App.II | App.II | VU |
| *Tursiops truncatus* (Montagu, 1821) | App.II | App.II | EN |

# ICZM AND THE SEA OF MARMARA: THE ISTANBUL CASE

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## Introduction

Coastal areas are the most attractive places of the planet. The shores occupy less than 15% of the Earth's surface and they shelter more than 40% of the world's population. The number of people expected to reside in the coastal zone in 2025 will constitute 75% of the world's population. The coastal areas are rich sources for producing goods and services and most of them relate to commercial/industrial activities. Coastal areas have important natural, socio-cultural, and economic potential. As a natural result, throughout the history these areas have been the centre of many human activities and today they account for around 60 sectoral activities. The ever-increasing pressure generated from urbanization and economic activities on coastal areas coupled with environmental problems, required the adoption of new approaches on Integrated Coastal Zone Managements (ICZM).

To combat the environmental pollution on coastal areas, "coastal management" notion has been developed and later it evolved into a more comprehensive "integrated coastal zone management" concept. Over time, countries started to implement their administrative and legislative regulations and especially in Europe many countries prepared and started the implementation process of national strategy plans.

It is clear that Turkey has much to achieve in this regard when compared with the U.S. and European countries. The latest integrated coastal zone management programmes developed by the Ministry of Environment and Urban Planning and municipalities on the selected areas by using European models as an example did

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achieved only partial success mainly because of the legal statute that has not been fully identified. Lack of administrative structuring and unfamiliarity with coastal and marine environment are the other reasons for.

In this chapter, Turkey's general situation with regard to ICZM will be discussed and the problems emerging from lack of coastal planning on the coasts of the Sea of Marmara with Turkey's most important coastal city, İstanbul, will be analysed.

**The Notion of Coast**

The main problem related to coastal regions on national and international level is the lack of understanding and the definition of "coast". Besides the geographic and morphologic approaches, a multidisciplinary definition on coast was not being made for a long period of time. Today the coast has been redefined by 12 different disciplines. It is also a subject of law because of the socio-economic importance accumulated in time as it is subject to geomorphology, geography, ecology etc. as it is a natural part of earth's surface (Akın, 1998;). The boundary of the coast is the area where land meets the sea, lake or river and its width depends not only on meteorological events but also on social factors.

The contradiction in terms on the definition of coast is continually generating problems in practice. In different academic researches and articles, "Coast" has been defined and also elaborated in similar ways. Coast, except the flooding cases, is a development where sea, natural or artificial lake or river hits the land and creates a sandy, gravel, rockiness, swamp, or stony ground, is a biological richness which requires ecological security, and is a land in which sea and land ecosystems meet and both systems affect each other. In terms of justice system, Coast is defined as 'the area between coast line and the coast edge line' in the Coastal Law and the Management Contract. The conceptual discrepancies about the coast have always been a problem in the implementation. Coastal area needs to be defined not only that it covers the nautical areas but also the area that is on the land side. Even though an agreement was made about the definition of the coast, current definitions don't reflect a general and multi-dimensional area concept.

It is not possible to talk about the management and planning of a concept of which the definition is not proper and agreed upon. Since it is an area in which the water and the land conjoin, this area's bottom line according to water and the top line according to land must be identified and both areas must be included in the management process. Although the Supreme Court defined the coast not just a line but an area, it was not considered as such in the implementations. The coast, for which the conceptual definitions were made in different science fields, must be presented to the society as a part of the social life with a multidisciplinary approach and it should meet today's expectations. The conceptual definition of the coast for today, due to the fact that it brought a lot of problems in terms of usage and implementation, must be made again to be able to get the support of different science fields. Otherwise every sector will make their own definition for their own benefit and the success of any plan or implementation will decrease.

### The Concept of Coastal Planning and Management

Coastal planning and management is the sum of technical and legal tools, with the aim to preserve and improve the sustainability of the coastal areas that provide balance between different social divisions which aim to benefit from coastal areas for their social, cultural, economic, needs.

***Coastal planning;*** coastal planning is a flexible, dynamic and guiding tool which defines the use of coastal areas from a sustainability and public benefit framework based on coastal law and construction zoning law. The planning process should be according to law, unbiased, participatory and free from political concerns and including urban planning strategies (Akkaya, 2004). Basic principle in coastal planning is to assure sustainability of the coastal area.

***Coastal management;*** coastal zones are areas where human activities are concentrated because of the various resources they offer. The heavy use of coastal areas leads conflicts among the activities on the use of those resources and for that reason, requires a management action.

***Integrated Coastal Zone Management (ICZM);*** Until the 80's, the approach on managing coastal areas had a unilateral character. Problems regarding the coastal areas were addressed individually and their interconnections and their effects were often neglected. Another dimension of the problem is the presence of multiple institutions related to ICZM. The main reasons are; (1) Overlapping of the authority and the work field of the institutions. (2) Unawareness of other institutions undergoing efforts. (3) Competition between the institutions. (4) Different perspectives and educational background.

The difficulties made it clear of all the shortcomings of the unilateral approach and made path for a new "integrated" approach. Integrated Coastal Zone Management represents a wide spectrum approach including every activity affecting coastal areas and their resources together with environmental concerns. After 80's, many developed countries started to implement their integrated coastal management plans while in Turkey the same process is far from being achieved. Management problems, especially related to sustainability, on coastal areas will remain most likely unresolved without its implementation.

Turkey is a country with important and rich coastal areas. The Anatolian Peninsula, together with the Thrace Peninsula in the northwest, constitutes the land of Turkey. The Turkish land borders the Black Sea in the north, the Aegean in the west and the Mediterranean in the south. In addition to these three seas Turkish land encloses a very important inland sea, the Sea of Marmara. Human activities in the coastal regions however, with the exception of those on the Black Sea coast, only intensified during the second half of the 20th century, especially after the 1970s. There are several reasons why Turkey's coastal areas have been historically neglected. Among these, low levels of industrialization and urbanization within the country, very modest demands from tourism and for recreational activities, the weakness of the private sector, limited private ownership of coastal lands, and the geomorphologic characteristics of the coastal areas are the most significant ones (PAP/RAC 2005).

During the Ottoman period, coastal areas were the property of the empire with the subsequent imposition of written laws of the Sultan. The young republic (in 1923) has continued to apply many laws and one of the most important of these is the coastal law. The coastal related laws and practices, which were included in the preliminary development law, became an independent law later. Although it has been subject to change many times, the priorities that the coastal state is the property of the state and must be open to everyone's use have not changed. Articles 43 of the 1982 Constitution and the principle of the use of the coasts in the public interest have been registered. The Coastal Law No. 3086, adopted in accordance with this constitutional provision, entered into force on 01.12.1984. The legislation currently in practice is the Coastal Law No. 3621, amended by Law No. 3830, and the Implementing Regulations published in 1992 and 1994. A substantial part of the coastal areas of Turkey, including forests, are still state owned in the year 2016. This state ownership has caused several problems for the development of coastal areas. For example, the illegal occupation of state-owned coastal lands (and forests) by villagers and the use of these lands for agriculture and farming is a long-lasting issue that still needs to be solved. This problem gained a new dimension when the inhabitants of large cities flooded the coastal areas in large numbers starting in the 1980s, in search of an attractive new home after their retirement. In 2003, the Turkish Government passed a law regulating the selling of ex-forest areas that have lost their forest character (e.g. land which had been subject to deforestation) to the occupiers of these lands. Despite having an independent coastal law, over time, various institutions and organizations have gained competence with more than major 25 different legal arrangements related to the coast. The situation has made it almost impossible to manage the coasts.

Arrangements that allow the allocation of some important and special zones for tourism development have been carried out in Marmara Region, preferably for industrialization. The problem of state-ownership of the coastal lands and its discouragement of private sector investment has been resolved by the long-term leasing of these lands to the developers at very modest rental fees. Several examples of coastal industry and marine facilities exist that have been developed on public land following a leasing agreement with the State. A significant total of the tourism facilities that have been erected after the end-1980s have also utilized lands leased by the state for a period of 50 years, as it was envisaged by the Tourism Incentives Law enacted in 1983. The rapid growth of Turkish tourism, which has multiplied fifteen fold in terms of the number of incoming tourists over a period of more than thirty years, has been paralleled by the very rapid urbanization of coastal resorts. In this period investment preferences for the Marmara Region concentrated on industrialization. In this context Marmara Region was not benefited from the related arrangements for tourism.

Following the intensification of human development and activities in the coastal zone after the 1980s, Turkey has gained considerable experience in the planning and management of coastal activities and developments in several sectors. For example marine transportation, fisheries, urbanization, and conservation of natural and cultural heritage are the traditional sectors that have been dealt with in the coastal zone for a long time. Over the last two decades, several new sectors such as tourism and recreation, aquaculture facilities, technical agriculture gained in importance. According to Özhan 2004); however, the management of coastal development in Turkey has been strongly central and clearly sectoral, although there have been several efforts since the late 1980s (discussed later in the report) to bring in "integrated" management and to decentralize the planning and implementation authority by transferring responsibilities to local administrations (municipalities and provincial governorates). Emerging transportation networks and socio-economic development in Bursa-Izmit have changed the central concept of Istanbul with regard to the Marmara Region. At present, Istanbul expands beyond its limits set by the law. We could talk about the management of the ICZM of Istanbul and the Marmara Region, starting from Tekirdağ in the west and continuing to reach Izmit and further in the east. Some investments, such as the motorway and the third airport, which have been passing through northern Istanbul since 2010, are expected to carry further extension of Istanbul to the north. The archaeological excavations of Yenikapı proves that Istanbul has been an uninterrupted settlement since 8000 years ago and that it has been spoken and spread on the coasts of the Sea of Marmara and that life has been shaped by coastal resources since its first settlers (Algan *et al.* 2011). Istanbul, especially starting from the Roman era, is a port city that has been shaped as a commercial centre for the Black Sea and Anatolian.

### Istanbul ICZM Applications

Istanbul is of the world's major cities connecting Asia to Europe. With around 15 million of inhabitants it is also one of the most populated cities in the world. 647 km of coastal length of Istanbul and the Istanbul Strait connecting Black Sea to the rest of the world, makes it also an important coastal city. The surface area of Istanbul is 5.313 $km^2$ with a population density of 2.759 people per square kilometre.

**Land use on coastal areas of Istanbul**

The strait of Istanbul, its surroundings and coasts has always been an important social, cultural and strategic area throughout the history and continues to preserve its importance. The activities on the coastal area can be listed as; transportation, industrial, residential, touristic, recreational and other.

***Transportation;*** As the Straits of Istanbul divides the city longitudinally and also connecting Black Sea ports to the rest of the world, the sea around of Istanbul experiences a heavy mixed traffic of international sea trade and city commuting. Consequently many facilities and areas like ports, piers, passenger terminals, anchoring areas, and traffic control stations like radars occupy coastal areas.

***Industry;*** Proximity to transportation hubs, economic centres, raw materials and work force is important aspects for the development of industry. Apart from that, port facilities and their storage areas, the water needed as a coolant for machinery and the sea as an economic and easy way for waste disposal resulted the industrialization of the coastal areas of Istanbul.

***Urbanization and housing politics;*** Countries that lagged behind in industrialization and urbanization couldn’t meet the needs of their ever growing population. Population surge in cities resulted in urban sprawl and eventually caused decay on historical and natural assets. Aesthetics values have been disregarded to provide much needed housing. This process is one of the most criticized topics in Turkey. After 50’s, rapid urbanization in Turkey resulted the much criticized urban aesthetic decay in İstanbul (Akyüz, 2016). Housing need and the rapid urbanization also resulted unplanned and unlawful land reclamation on coastal areas by municipalities. Apart from the necessity, the potential of political and economic gains were also in play and motivating for excessive land reclamation.

***Tourism;*** Because of less favourable climatic conditions, Marmara region is ranked in 3rd place in terms of tourism investments after Aegean and Mediterranean regions. Towns like Yalova, Çınarcık, Gemlik, Erdek on the southern coast of Marmara and coasts of Tekirdağ on the North are ideal locations for and filled with many summer houses. The islands of Avşa and Marmara are also popular destinations during summer. The tourism attraction of Istanbul is mainly cultural and historic.

***Recreational;*** the Straits of Istanbul coasts attract many people day and night for various recreational activities as it's a very unique and beautiful landscape. Most popular activities are fishing and sea side restaurants.

***Other uses*;** Apart from these purposes there are other types of use like military, raw material procurement, food production and waste disposal. Some coasts and coastal areas have military value and dedicated for military training and/or occupied with military facilities for naval activities. Golden Horn is another area known for bad practices on waste disposal in recent history.

**The Usage of the Land in Artificial Coastal Areas in Istanbul**

Coasts are sometimes being shaped by the human effects as they are being shaped by the natural occurrences. Land fill coastal areas are the best examples of that. Every type of permanent structure made on the sea side of the coastal edge line is called land fill coast (reclaimed area). Land fill coastal areas can be classified based on the construction type, the filling material or the usage purpose. Land fill areas are being made for reclamation, security, transportation, recreational activities, housing, maintenance, social facility. The coastal areas that are being filled for all those purposes mentioned above are also being shaped by the usage of the land. The most common remarkable usage of the land fill areas is recreational activities. The main purpose of the filling is the public interest. Even though the public interest concept has been defined differently by different authorities, the main objective is to make public interest sustainable. While we can say it is for the public interest to establish a port in Istanbul coastal area which will help the development of trading and naval and not possible to establish in another area, it is not possible to mention about the public interest when building a hotel in Istanbul land fill coastal area. Additionally, the concept of public interest will vary based on the area that the project will be established and the time. This dilemma is a serious issue for Istanbul landfills coastal areas. It cannot be argued that public interest is taken into consideration unless integrated coastal zone management principles are met and applied properly.

It is vital to save the natural sources and preserves the coasts and coastal areas. Projects that are planned to be implemented on coastal areas such as construction of building, establishments or institutes should be realised with regard to public interest and absolute demand by the local residents. If there is an essential need or absolute necessity to start an establishment or construction project, all the aspects must be considered or surveyed in detail in order to avoid causing a negative effect in the ordinary lives of residents of the area. After the examination of the projects that took place in Istanbul, none of them related to land reclamation is compatible with the new act and regulations. (Akkaya et al; 1998). Concerning land filling projects that took place in Istanbul, it is clear that construction companies have taken advantage from the loopholes that exist between two consecutive sequences of abrogation and promulgation of laws.

Provisions regarding protection plans for conservation purposes of the Law on the Protection of Cultural and Natural Assets numbered 2863 in the coastal and landfill sites and coastal lines are not applied. "The arrangement of the sea, the coastal area and the land area is completely ignored whereas; coastal areas are a natural continuum of land but separate zones. Evaluation is not possible in terms of geomorphological, hydrodynamic and ecological aspects with regard to the coasts. For this reason, landfilling should be allowed in case the appropriateness of the coastal and marine areas to be reclaimed by drying out the marshlands and the areas protected by the Law on the Protection of Cultural and Natural Assets (Law No. 2863) is assessed from the scientific (geomorphological, hydrodynamic and ecological) point of view. These assessments are required to be designed in accordance with "conservation zoning plans", taking into consideration the integrated approach and principles of the use of areas to be acquired by filling and by drying out marshlands protected by law. Unfortunately, all these activities that we can call coastal fillings need to be followed carefully, but all the existing laws and practices are being bypassed and applied directly on the coasts.

Istanbul, the Sea of Marmara and its surroundings close to the borders and coasts of Trakya, comprising also; Büyükçekmece, Avcılar, Bakırköy, Zeytinburnu, Fatih and Eminönü districts' coastal areas have been subject to land filling projects, recently. The coastal line between Ahırkapı area and Florya has been selected to start constructions to create recreational areas. Land filling projects around the Sea of Marmara and Trakya coasts will continue intwo different directions; Avcılar and Büyükçekmece. Istanbul Maltepe and Yenikapı land-filling project is known as the most important and complicated land filling project (Döker, 2006).

Due to the fact that, there is a fast growing construction projects and poorly designed structures, most people feel like they have to live in squeezed areas between concrete walls. In order to leave room for relaxation and an area for people which want to take time with their family, constructing recreational areas and districts close to sea coasts by land filling projects could be a remedial approach. Most land filling projects have always been dedicated to produce recreational area that will serve all community members of the society. Land filling projects must be taken into consideration more seriously and should not be seen as an option to dump all the extra concrete waste that was produced by urban transformation of the city of Istanbul (Küçükakça *et al.* 2014). Uncontrolled land filling projects could result in serious and irreversible damages in the sea ecosystem and also can affect residents of urban area in long term (Küçükakça, *et al.* 2014). The idea or belief that every member of society including construction companies and municipalities actually benefits from the land filling project and recreational projects, may create an illusion for disregarding long term possible negative and harmful effects. Also transportation and parking problems, besides poor accessibility for disabled citizens are rooted by approval of undetailed Project proposals lack adequate project proposals for transportation and parking and accessibility for disabled citizens. While we still have the images of the 1999 earthquake happened in the Sea of Marmara in our minds, starting new construction on the borders of Yenikapı and Maltepe generates serious concerns. If a project has no environmental protection and maintenance plans besides positive support for the society, it could create bigger shortcomings that would be difficult to handle in the future.

In the end, it can be clearly seen that as potential recreational areas and green areas are occupied and owned by construction companies and real estate, recreational and green areas are generated on reclaimed lands on the coast in response to the need of the citizens. In other words this coastal reclaimed land replaces the exerted natural green areas which once existed within the city itself.

However statistical studies carried out during a recent study proved that public opinion is biased with regard to the implementation and consequences of land reclamation along the Sea of Marmara. The results of the statistical analyses show that 35% of the population prefers recreational areas realized on reclaimed land; whereas 65% of the population prefers unchanged coastline and having direct access to the sea.

The conclusion of the study pointed out that the polemic with regard to land reclamation will still be an issue unless the provisions of the Coast Act cover satisfactorily all the required and relevant parameters and corresponding enforcement. (Burak and Küçükakça, 2015)

**Istanbul's Historical Coastline**

Since 1963, Istanbul’s coastline change has been followed and documented. Moreover, historical buildings close to the sea border has been used as a reference point for these research projects. The ruins of Byzantine and Ottoman Empire have been also used as reference points to be able to clarify the alignment of the borders of coastline. An Ancient City wall at the borders of Trakya has been used as evidence. The Ahırkapı Light House of 40 meters height that was built in 1857 by Sultan Abdülmecit is also an evidence that has been chosen. Sis Düdük Light House has also survived and it is still standing. There are clear and visible remains of the old sea and land borders by that light house. There is no significant change starting from Yeşilköy Çiroz and Küçükçekmece Lake line which would reach Avcılar. To be able to prevent possible problems about urbanization progress of Istanbul, land filling has been accepted as a solution by most companies and municipalities. The changes which were caused due to that urbanization projects, has actually started in the 1960s. The coastline of Istanbul has been subject to changes many times due to ongoing land filling construction projects (Figure 1; Döker, 2006). During the years following the change of the reconstruction and zoning law in 1984, the natural shoreline of Istanbul has changed rapidly.

**Figure 1.** Istanbul natural coastline and landfill areas (Döker 2006).

### Earth Movements or Earthquakes and Probable Real Estate Problems in the land-sea border ranges

Existence of fault lines and the 1999 Gölcük earthquake also caused hazard on some buildings at Yeşilköy, Avcılar, Küçükçekmece and Büyükçekmece. In case of an earthquake as strong as in Gölcük, there is a high risk of collapse and destruction that may affect the landfill areas. Also, there is no record of how the sea and land or coastlines have been affected after Gölcük earthquake. Therefore, using land filling just for recreation or transportation reasons seems more suitable and safe for the society. (YTÜ Research Team, 2013) This new construction of recreation area was expected to increase the quality of the land-sea connection and bring more charm; instead it lowered the quality of the land-sea areas due to lack of planning and architecture defects which did not consider natural life balance

### Istanbul Coasts and 'Canal Istanbul' Project

The Strait of Istanbul Management preliminary zone is governed by a special law and a directorate. For this reason, the standard ICZM model and approaches should be considered separately. The project that was planned to become an alternate route for maritime transportation via Turkish Straits, Canal Istanbul, in other words the 'Crazy Project' has been mentioned frequently in national and international platforms. Canal Istanbul is the 'artificial water route' project that is expected to relieve the traffic that goes through the Black Sea and the Mediterranean Sea. The length of the canal is 40-45 km, width of the canal on the surface is 145-150 m, at the bottom 125 m, and the depth of the water will be 25 m. There will be two new cities established until 2023 where the canal and the Sea of Marmara meet. This project includes Avcılar, Bağcılar, Bakırköy, Arnavutköy, Başakşehir, Esenler, Eyüp and Küçükçekmece in Istanbul. Canal Istanbul is very important for the Küçükçekmece Lake and it will make a change on the land by the river basin. It is a vital issue to evaluate this project in terms of socio-economic and justice system as it falls in the research topics of many scientific disciplines. The Canal Istanbul project that is being planned to become an alternate route for the Turkish Straits must be analysed with regard to the Istanbul coastal management (Öymen, 2014). It is possible to evaluate the expected effects of the Canal Istanbul Project. The first approach enumerates the positive impacts and the second approach relates to the adverse impacts of the projects. Those are;

***Positive approach;*** it is important to put Canal Istanbul into practice to make Istanbul Strait more secure. Çanakkale and Istanbul Straits are the natural canals, and they were formed thousands of years ago. Moreover, there are artificial canals such as Panama and Suez Canals which are the projects that have been implemented in order to to decrease the costs of travel and save time with the development of the global trading. Canal Istanbul will be the 'artificial water route' project that is expected to relieve the traffic that goes through the Black Sea and the Mediterranean Sea. Entire freight traffic will go from North to South without going through the Straits of Istanbul. With the Canal Istanbul Project, both tourism and the trading activities will increase in Istanbul which is one of the leading cities of history, culture and trading. The Canal Istanbul is considered to save the Strait of Istanbul from oil tanker traffic. A canal that will be constructed in Istanbul will protect the Strait of Istanbul, and the community from a big danger. Around 10 thousands of tankers which are almost equal to a nuclear bomb threat will be diverted to Canal Istanbul which then will remove this threat. All these positive approaches must be analysed with the reasons behind it.

***Negative Approach;*** generally, focuses on an environmental disaster and Montreux Agreement may become a current issue.

It is planned that once the Canal Istanbul Project is operational, all cargo ships that carry hazardous material must be banned for using the Istanbul Strait and diverted to Canal Istanbul routing. That is the main expected success of the Canal Istanbul Project. However this enforcement is against the Montreux Convention. Even if the agreement is terminated, it will still be against international law. Under such circumstances, the peace that was established by Montreux may be put in danger.

Although the exact location is yet to be disclosed final it is planned that Canal Istanbul's length will be around 45-50 km, the width 400 m and the depth 25 m and it will split the European side into two. Considering this project as just a canal project will be a mistake as it will bring many global infrastructural projects and it has a potential to create a new Istanbul with 30 000 ha land and around 2.5-3 million people. Additionally, in the development plan of Istanbul Municipality in 2006 and 2009, there is no provision for it. Therefore since there is no legal basis for this project, the sustainability for land-use planning will be further in danger.

### Istanbul Coasts and Subsidiarity Principle

Since the last quarter of 20th century, central management and local management started to change intensively. This change process has resulted in the consequent changes of local values which became more prominent than general approaches.. Change process puts both globalization and subsidiarity; responsibilities and the power of local administrations become more of an issue. Subsidiarity Principle is being considered as the main axis of subsidiarity since it facilitates to solve the local problems, and local administration is responsible for the public issues. The functionality of this principle can be found in the practices of the Municipality of Istanbul with regard to the coasts. It is possible to mention the success of the local administration with regard to the surrounding seas of Istanbul, coast and marine saving, prevention of marine pollution, rehabilitation and improvement of the coast usage. However, it must be remembered that 39 municipalities under the Istanbul Metropolitan Municipality have the authority when it comes to management of the coastal areas.

### Istanbul Coastal Areas and 'Public Interest' Principle

Especially the Sea of Marmara and the Istanbul Coastal area have gained a wide range of usage with its features and potential generated throughout centuries. The usage of these areas that is interesting and attractive has been arranged by the laws for the community in order to benefit from them and prevent from ill-adapted practices any abuse by the enforcement of the legal framework. The main purpose must be the one that is mentioned in the constitution for the usage of coastal areas. Due to limited coastline, the use among sectors should be made as fair as possible. In order to make an equitable use of it, environmental and public benefits should be given priority compared to commercial company's benefits and gains. Benefits, gains and earnings that will be made via recreational projects realized on reclaimed areas should have positive impacts on both urbanization and socio-cultural aspects (Aşan *et al.* 2014).

Socio-cultural benefits should also be supported with appropriate infrastructure that is implemented according to the design based on local requirements. It does not mean that when a place is left to public, it will be open to any kind of use for public. Values of the coastline and improvement on the matter create benefits to public in many aspects. Personal benefits and social benefits of coastal lines are two independent subjects which should not be accepted or treated at the same way. Benefits of one Title Company or just one institute cannot account for public interest even though the company or institute provides services to the society. Especially, quickly growing rant, property and land values of Istanbul has a big impact on the added value of the coastlines. The pressure and competition between private properties and public or government properties creates injustice in the progress of urbanization. There are two main conflicts regarding the utilization of coastlines: -First conserving of coastlines and their resources related to public should not be an obstacle for the urbanization plans and projects, on the other hand, while urbanization starts, it should not affect daily lives and benefits of the local residential areas located on these coastlines.

### Importance of Coastal Cadastral Survey at Istanbul with regard to ICZM Evaluation

Projects located along the Sea of Marmara like Galataport, Zeyport; Kanal Istanbul, Yenikapı Landfilling, Tunnel Path are very essential ones therefore further attention and detailed work is needed. The system which is used for cadastral issues should also be applied or a new cadastral system should be created for sub-sea or coastlines. Marine areas should be mapped and also one has to consider managing these areas like land cadastre. Management and control of marine areas of Turkey seems very insufficient and this issue becomes an obstacle when sub-sea projects are to be proposed for implementation. If a new law or could be promulgated and put into force in order to clearly define the property rights of the prospective owners or project candidates with a follow-up system and control database which can create reports that would provide more efficiency during the management process of sub-sea or coastline of cadastre. All the rights of sub-sea or coastline of cadastral survey should be clearly defined and bring solution for possible conflicts could happen between border neighbours. Collecting records and keeping this data to use sub-sea or coastline of cadastre is a very essential and fragile issue that requires serious attention. Construction of any kind of institute or establishment should not be permitted until all infra-structure issues have been completed and inspected carefully.

**Figure 2.** Yenikapı Landfill

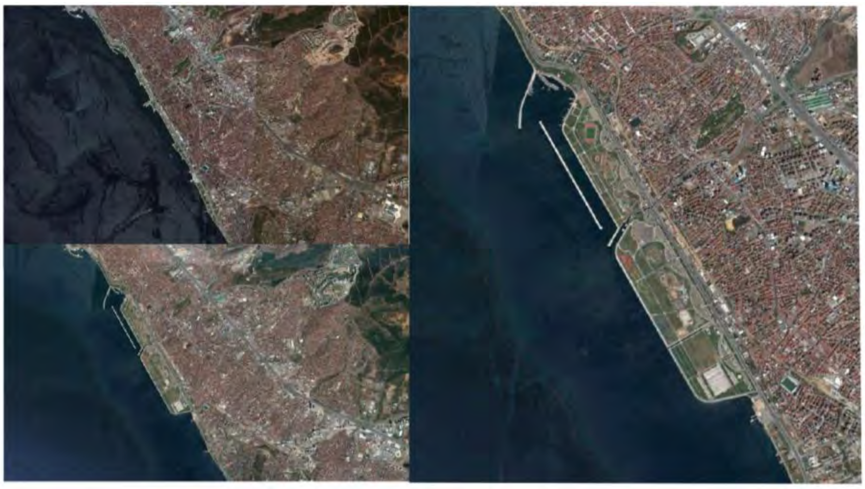

**Figure 3.** Maltepe Landfill.

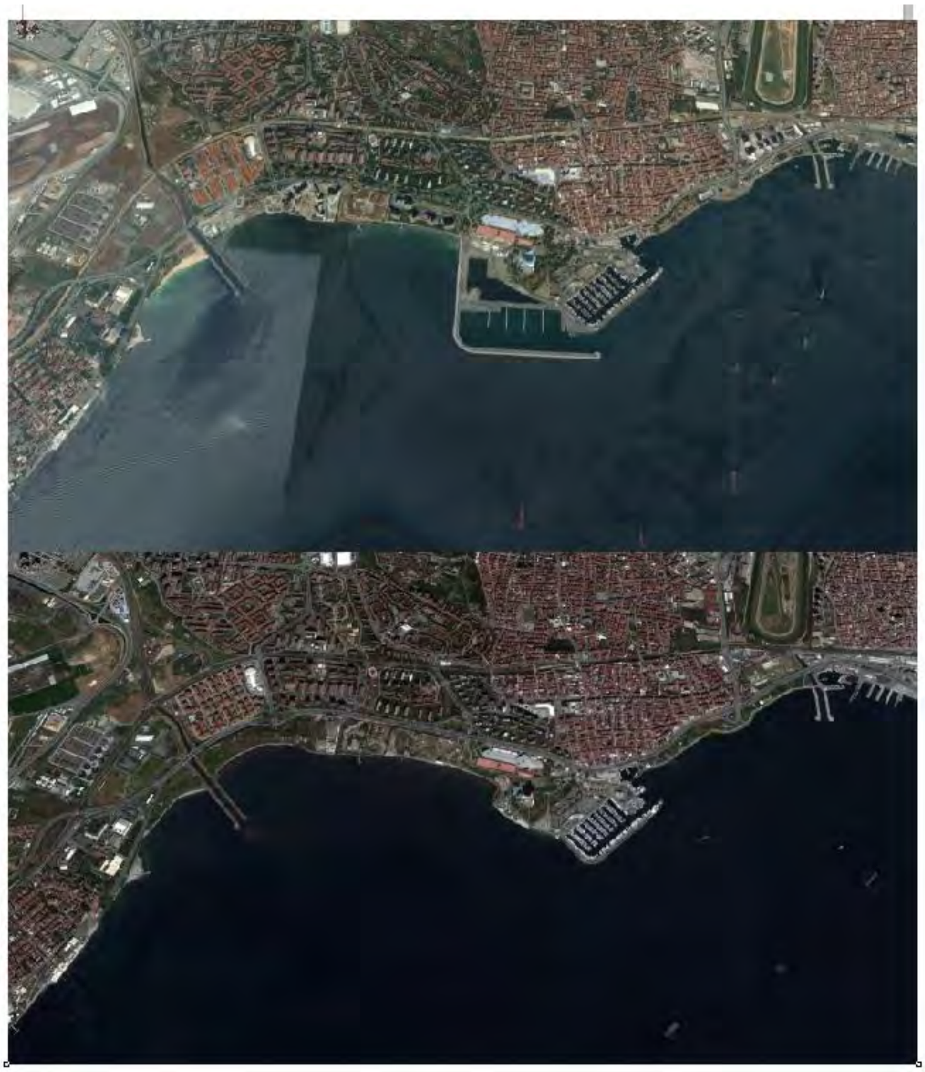

**Figure 4.** Ataköy Marina Landfill.

**Figure 5.** Hersek Shipyard Landfill

If we consider that mainly around the Sea of Marmara, the Istanbul Strait and the Golden Horn palaces, large condos and mansions have been all built on the coasts or close to the coastline, one can easily realize the level of the importance that has been given to the value of the coastal area throughout centuries. An especially fast growing suburbanization project has brought many concrete buildings as close as 15-20 meters to the coastline. We need to start seeking solutions to the mistakes that have already been made and also stop ever-complaining about previous mistakes..

Turkish ports hold a very strategic position within the East Mediterranean and Black Sea Merchant Lines and at the intersection point of East-West and North-South directional international transport corridors. They are in an advantageous position to attract transhipment/transit cargoes. Ports in all regions of Turkey are so located that they can serve different transportation nets. Mediterranean and Aegean ports are located with higher distances compared to the Sea of Marmara ports and have ability to attract Asian-European main shipping lines cargoes passing through the Mediterranean. As a result of growing trade and transport volume in the Black Sea, which is the most important means of access for trading among the blocked-in Asian countries with Europe, the importance of Turkish ports has increased. Marmara Region, which is an important crossroads in the global trade network, must take the necessary precautions, especially coastal zones, against the trade intensity which is known to be increasing. The development of industrialization and maritime dimensions along the Sea of Marmara is making it possible to develop in the ship-building industry. In particular, the coastal zones and the effects on transportation of the ship-building industry clustered around the Tuzla and Yalova coasts require a comprehensive plan. It is highly probable that marina industry and yachting, which develop with the increase of financial development, will generate a significant income source for Istanbul and Marmara coasts and hinterlands.

To stay code and conduct oriented and provide meaningful solutions for the problems, the first thing that should be done is earning knowledge about the local area and the residents, etc. Ongoing increase in the number of population of Istanbul, has already caused some irreversible damage to the coastlines and still creating unhealthy situations for the residents. There is an essential need for a database system to be set and to be used for coastline management. All the institutes such as public or private must provide data and let inspections to be made for accurate data collection. Moreover, all the institutes that have relation with coastline of cadastral needs to accept to work cooperatively to be able to create accurate data collection or analyses. The main reason for the lawsuit filed due to conflicts mostly happen due to lack of existence of clear code and conducts, bills and law orders. General purpose of the management and control system of coastline of cadastral survey must be like listed below:

- Current and designed usage of the coastal areas and their interaction between each other, needs to be clearly defined and more focused on those subjects. -Lack of detailed analyses of benefit or earning and also cost or warrants data management causes stress and conflicts regarding the cadastral survey of the coast.
- The main principles of coastal management should be set at central level in order to avoid biased and conflicting enforcement between local authorities and sectors. But these main principles must be applied according to the requirements of each coastal area and developed on ecosystem-based approach.
- More importantly Canal Istanbul, Northern Cities, Third Airport projects need to be or have to be inspected in every stages and milestones of the projects and the same rules must be applied to all of them.

• Pollution, erosion, loss of resources and damage on the habitable zones and lands should be surveyed under constant surveillance in order to make better progress during project management.

• All the members and residents of the areas that will be urbanized must be presented in every stage of decision making process and meetings.

• Benefits of society and environment must come first. -There should be a system to inspect, guide and create ongoing reports and records that can follow dynamic structure of urbanization progress.

• It is finally understood clearly and realized that coastline issues and problems cannot be handled without an institute. - Coastline Control Model which is being used by the European Union can be used as a reference in order to create a new and compatible system that will work for our country. There is a need to establish General Coastal Councils and Local Coastal Councils. -Istanbul would be the most appropriate and suitable to test a system as expected.

The Marmara Region is located on the Northern Anatolian Fault Zone (NAFZ) which is one of the most active fault zones in the world. In addition to this, it has been proven in many recent studies that the Sea of Marmara coasts and bottom morphology are shaped by NAFZ (İmren *et al.* 2001; Gazioğlu *et al.* 2002; Gökaşan *et al.* 2002). Since the greatest effect of the active seismic properties of the zone will be on the coasts, the coasts must be assessed and managed. It should never be forgotten that the coastal fillings can be tested by nature, as it is in the example of Gölcük at the time of the Marmara Earthquake in 1999. The active seismic features and probable large-scale Earthquake are the tsunami wave at one of the destructive effects (Alpar *et al.* 2003). There is numerous Tsunami evidence, especially on the coasts of the Sea of Marmara. In particular, planning should be carried out in accordance with the maximum tsunami wave height to be calculated in low coastal areas (Hebert *et al.* 2005). Besides this, it may cause submarine landslides in the Sea of Marmara shelf areas of earthquakes that are not destructive, causing unexpected tsunami waves to harm the coasts (Gazioğlu *et al.* 2005).

The Sea of Marmara and its borders, which are located in the middle of the Black Sea and Mediterranean basins, the basins where global climate change can be most effective, will be affected rapidly by climate change (Alpar *et al.* 1997). Salinity, flooding and extreme atmospheric conditions, especially in low coastal areas, will be first observed natural phenomena (Direk *et al.* 2012; Şeker *et al.* 2013). It is thought that the developments that will occur at the water levels in the following phases will cause destructive effects on Marmara Sea coasts (Gazioğlu *et al.* 2010; Simav *et al.* 2013). The tracks belonging to the first settlements in archaeological excavations in the Yenikapı district were found 8 meters deeper than the sea level today. Since the last glacial era, the Sea of Marmara water levels have repeatedly oscillated and are now in the “0” position. This level is not a final level but is entirely governed by global climate change.

The irregular and rapid urbanization phenomenon especially in Istanbul in recent years has also affected the coastal areas. With these urbanization movements, the Istanbul coast was quickly exerted and started to settle on the shore 15-20 meters from the area. The intensive settlements in the coastal areas have taken place in the recreational areas that have to be naturally in the coastal areas. According to Döker 2006) the recreation areas lost on the coast were filled by the Istanbul Metropolitan Municipality for the purpose of creating a new area. This situation revealed a new contradiction. With the misuse, the natural beauties of the coast were destroyed, and with the spatial problems brought about by these destroyed areas, there was resentment in the field of filling. Although there are many reservations about coastal filling the amount of green area on the area acquired from the sea with the coastal filling areas extending from Büyükçekmece to Tuzla constitutes 14%±3 of the amount of Istanbul green area.

Considering the Sea of Marmara and borders of Istanbul as an initial reference, we may set-up an efficient control and management system that would be easily applied to any other city due to the fact that Istanbul has the most complicated structure and large land or resources and this fact can be used as a valuable experience.The research about establishing a new system which is going to follow, guide, give permissions or put limits considering all the items above and creating a model for General Environmental Plans and Projects for City Urbanization progress of Istanbul, was made by YTÜ academicians 2011-2013). These studies must be utilized and taken as reference for the benefit of urbanization progress.

## Suggestions: urgent action plan for the Sea of Marmara coastal area management

Several ICZM experiments have produced an asset of policies, depending on the natural situation, national context and the main prospective beneficiaries in each case, in addition to the problems they were trying to deal with. Despite their instantaneous progress, the directions taken by these various creativities can be schematically identified with a research for new forms of management on the one hand and the development of capabilities to manage information and scientific data on the other. Regular research and monitoring programs should be launched without ignoring the interaction between the Mediterranean and the Black Sea via the Aegean Sea in all its ecological dimensions:

- Interpretation and synthesis of existing information needs to be evaluated by a scientific platform other than decision makers.

- Establishment of a shared, integrated and effective information bank in accordance with ICZM model,
- Recognizing the diversity of a territory,
- All research can be managed from a single centre, an independent civilian and/or semi-civilian and independence unit,
- Necessary to develop partnerships, co-ordination and inclusion of all factors.
- A non-hierarchical up-to-date approach should be developed. Long-term climate change problems are likely to create problems for the long-horizon, science-based model should be developed for the Sea of Marmara and also an ICZM model should be developed at the Marmara Region scale.
- Giving a large role to all participations for long-term plan.

**New Protection** Buffer Zones **for the ICZM of the Sea of Marmara:**

- Considering the active seismic threats, the ICZM model for the Sea of Marmara coasts should be developed.
- Emergency research
- Medium and long term investigation and plans

**Natural Resource Planning:**

- Prevention of sand extraction and coastal destruction, restriction of secondary houses on the Sea of Marmara coast, application of coastal law. Revision of coastal fillings and difficulty of new fillings.
- New applications for garbage and sewage problems.
- The prohibition of fishing (snatching, obeying fishing prohibitions, size, kind, etc.), the prevention of over-fishing,
- The gardening of land-based clerics,
- The rehabilitation of the Golden Horns and the Gulfs and all the streams discharging into the Sea of Marmara.

**Legal Framework**

- Despite the existence of an up-to-date and comprehensive coastal law, the construction of the locus-based conceptual model in the ICZM dimension,
- Ensuring that supervisory bodies are involved in the management of the coastal areas

**Managing demographic structure**

- Measures to prevent the increasing rate of population growth on the Sea of Marmara Coasts,
- Sea of Marmara and its surroundings management of industrial investments,
- The protection and sustainable use of first grade agricultural land.

The sources of pollution in the Sea of Marmara are domestic, industrial and ship-originated. Domestic pollution is the most intense among these. Industrial pollution management should be improved. The ICZM philosophy should be developed taking into account the oceanographic characteristics. The objectives, how and where the pollution abatement measures are to be used must be clearly defined. The Sea of Marmara-ICZM should be equipped with human-focused and subsidiarity principle. Although the Sea of Marmara is an inland sea, it could not be taken away from the Mediterranean-connected Aegean Sea and the Black Sea.

Among these several ICZM policies, it can be seen that none of them represents the true or real approach to admit and accept, to the exclusion of all the others. According to the structure of the ICZM model there is no single solution to suggest for the Sea of Marmara ICZM. Developing new modes of governance for the coastal ecosystems of which human beings are an integral part cannot be managed by a single policy, but rather requires control of a mixed bag of policies related to the ecological, social, economic and cultural conditions in the territory of territories which require to be managed. The result of the pioneering work for the Mediterranean bell can be used within the Turkish coasts to create a suitable road map. It is natural that there are differences in the ICZM approach since it is a business of governance. In addition, different approaches for each geographical region need to be developed. In addition to this, subsidiarity prevails today in central governance. The integration initiative embodied in the Protocol on ICZM in the Mediterranean will thus be expressed through territorial plans which, by having components that interlock at various levels, and pooling experiences, will help build national strategies and achieve sustainable development of the coastal areas in the Mediterranean basin.

As authors, we consider that it should be never forgotten that the Sea of Marmara, in terms of its geographic location, and characteristics, is a member of both the Mediterranean and the Black Sea basins, whilst at the same time it exhibits many features that clearly separate it from both of these two basins.

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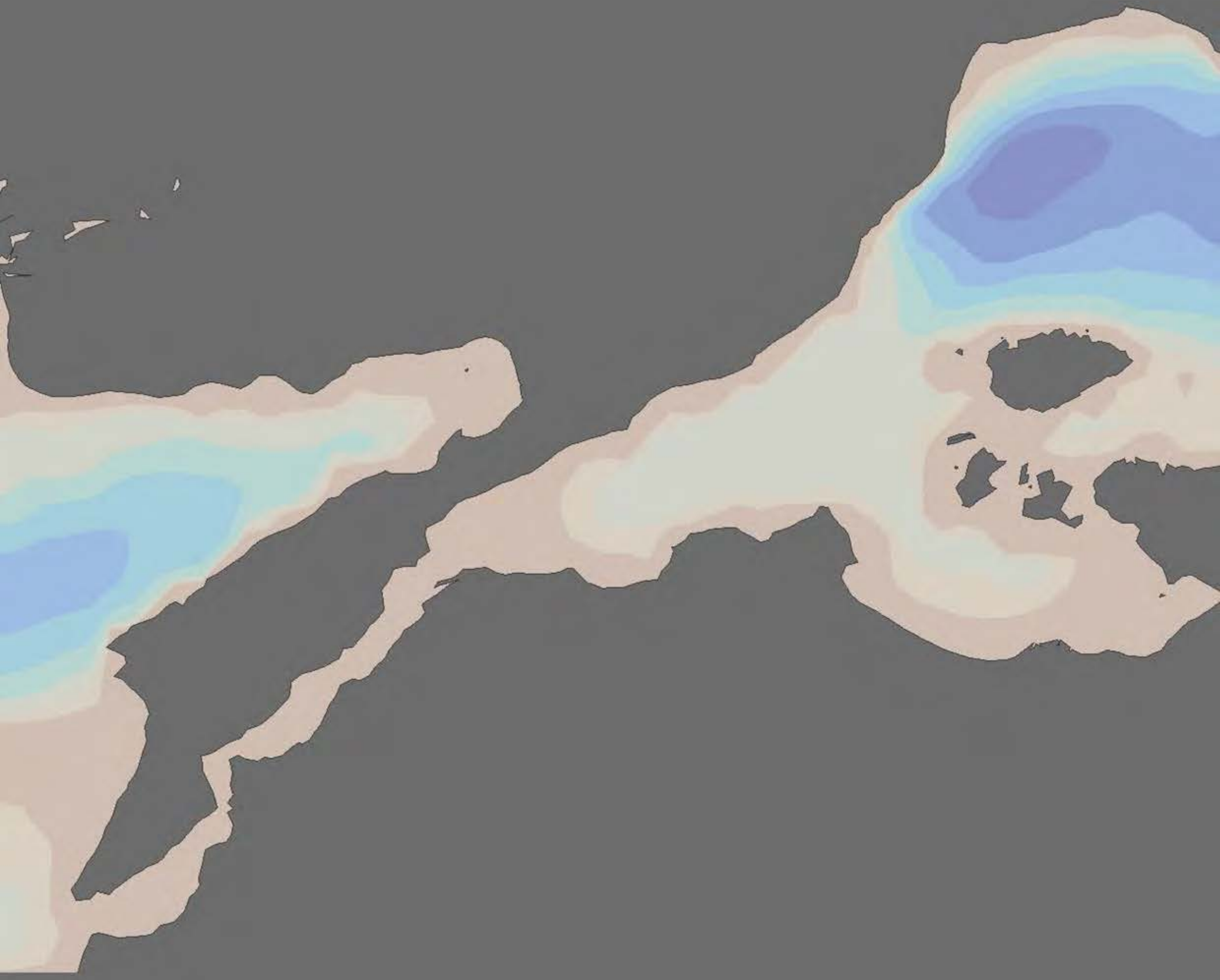

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