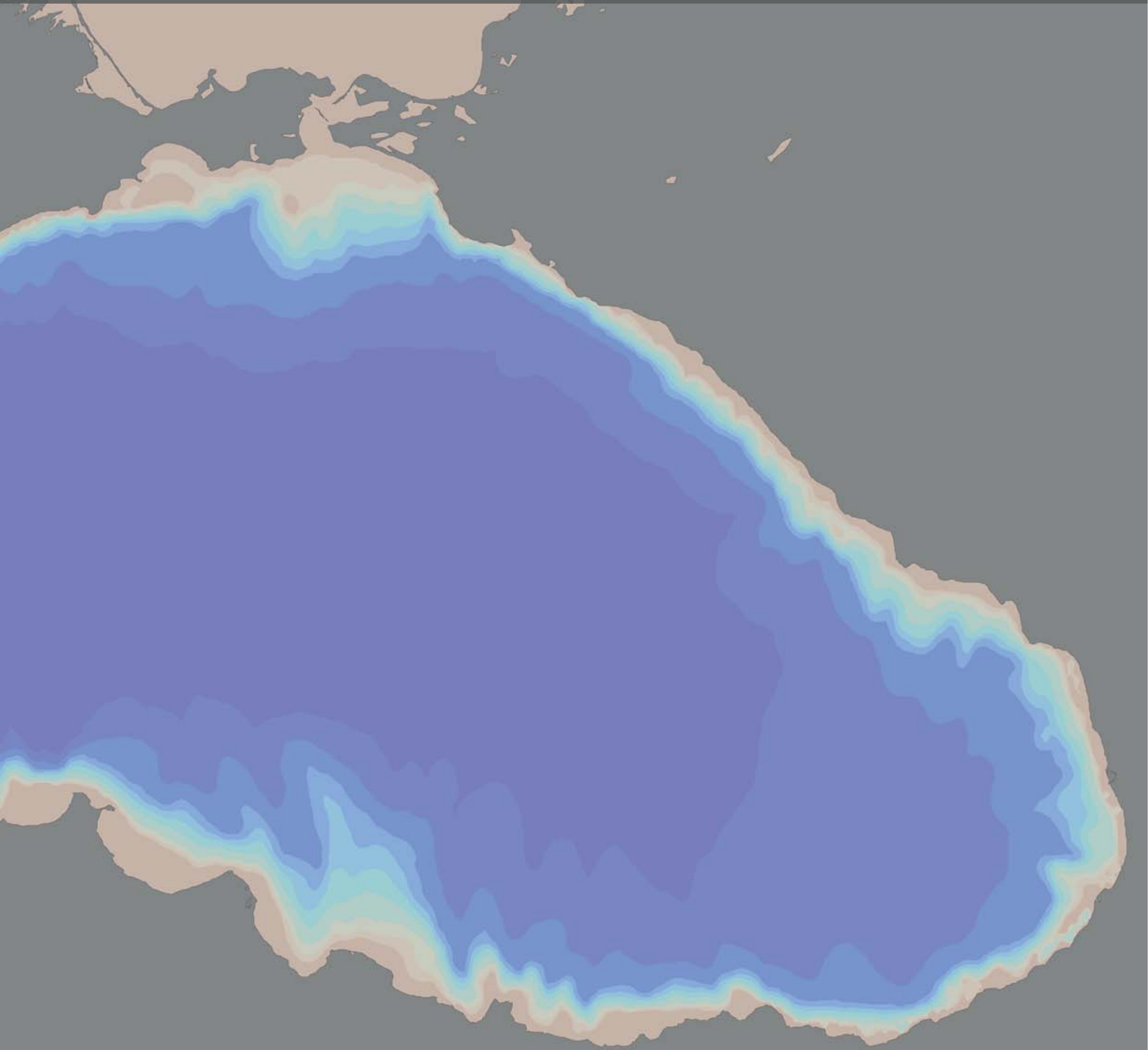
BLACK SEA MARINE ENVIRONMENT:
THE TURKISH SHELF

EDITORS: MURAT SEZGİN, LEVENT BAT, DERYA ÜRKMEZ, ELİF ARICI, BAYRAM ÖZTÜRK



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Edited by

Murat SEZGİN – Sinop University

Levent BAT – Sinop University

Derya ÜRKMEZ – Sinop University

Elif ARICI – Sinop University

Bayram ÖZTÜRK – Istanbul University

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Turkish Marine Research Foundation (TÜDAV)
P.O. Box: 10, Beykoz / Istanbul, TURKEY
Tel: +90 216 424 07 72
Fax: +90 216 424 07 71
E-mail: tudav@tudav.org
www.tudav.org

This book is dedicated to the memory of

PROFESSOR DR. MURAT SEZGİN

our sad loss,
who was the leading editor of this work,
and
a brilliant scientist with studies on marine biology and ecology of the Black Sea.

"The Black Sea will never forget your footprints..."
Editors

PREFACE

The Black Sea is one of the major water bodies and a famous inland sea of the world. It is a connecting link between six different countries sharing its coasts with the boundaries of Turkey, Bulgaria, Romania, Ukraine, Russia and Georgia. The Black Sea has extraordinary natural conditions as the largest water body with a meromictic basin. This means that, the interaction between the oxygen rich surface waters and the Black Sea's deeper areas tends to be very limited compared to anywhere else in the world. This leads to a layering structure being created which affects the diversity of the organisms within the Black Sea.

This book aims to be a good compilation bringing together articles focusing on the Black Sea looking at its ecosystem from different aspects. It goes without saying that the Black Sea is like a special kind of living organism which should be known in detail to be protected and saved. And, we deeply recognize that, during the last 50 years, its ecosystem changed extensively making it more vulnerable to anthropogenic effects. Marine resources have declined as a consequence of over-fishing, unplanned development of coastal zones and intense maritime traffic. Therefore, we believe that such kind of a compilation effort with an output can draw a general outline of the picture and help in concentrating attentions on such a special area.

“Black Sea Marine Environment: The Turkish Shelf” is the latest of the series of Turkish Marine Research Foundation (TÜDAV), which covers 29 articles under 4 main chapters (oceanography, biodiversity, pollution and conservation and science and policy) written by 61 authors from various universities and institutions working under different disciplines and who have studies in the Black Sea.

We truly appreciate the contributions of the authors and the editors to this book. We are sure that this publication will serve as an exchange of knowledge with the other bordering countries in the Black Sea and also provide a brief insight to this fragile water body targeting all the readers who care for the better understanding, conservation and sustainable development of the Black Sea.

Prof. Dr. Bayram ÖZTÜRK
Director, Turkish Marine Research Foundation (TÜDAV)
December 2017

CONTRIBUTORS

Ahmet ÖZER
Faculty of Fisheries, Sinop University, Sinop, Turkey
E-mail: aozer@sinop.edu.tr

Ali KARAÇUHA
Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
E-mail: ali_karacuha@hotmail.com

Ali Muzaffer FEYZİOĞLU
Faculty of Marine Sciences, Karadeniz Technical University, 61530 Camburnu, Turkey
E-mail: muzaffer@ktu.edu.tr

Arda M. TONAY
Faculty of Aquatic Sciences, Istanbul University, Ordu St., No: 8, 34134, Laleli, Istanbul, Turkey
E-mail: atonay@istanbul.edu.tr

Arzu GÜRSOY ERGEN
Faculty of Science Literature, Ondokuz Mayıs University, Samsun, Turkey
E-mail: agursoy@omu.edu.tr

Ayaka Amaha ÖZTÜRK
Faculty of Aquatic Sciences, Istanbul University, Ordu St., No: 8, 34134, Laleli, Istanbul, Turkey
E-mail: ayakamaha@hotmail.co.jp

Ayhan DEDE
Faculty of Aquatic Sciences, Istanbul University, Ordu St., No: 8, 34134, Laleli, Istanbul, Turkey
E-mail: aydede@istanbul.edu.tr

Ayşah ÖZTEKİN
Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
E-mail: aysahvisne@gmail.com

Barış BARLAS
Istanbul Technical University, Department of Naval Architecture, Istanbul, Turkey
E-mail: barlas@itu.edu.tr

Barış SALİHOĞLU
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: baris@ims.metu.edu.tr

Bedri ALPAR
Istanbul University, Institute of Marine Sciences and Management, 34134 Vefa, Istanbul, Turkey
E-mail: alparb@istanbul.edu.tr

Bettina A. FACH
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: bfach@ims.metu.edu.tr

Beyhan TAŞ
Ordu University, Faculty of Arts and Sciences, Department of Biology, Cumhuriyet Campus, Altınordu, Ordu, Turkey
E-mail: beyhantass@gmail.com

Ceren GÜRASLAN
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: ceren@ims.metu.edu.tr

Cihangir AYDÖNER
TUBITAK- MRC, Institute of Environment and Cleaner Production, Gebze, Kocaeli, Turkey
E-mail: cihangir.aydoner@tubitak.gov.tr

Çolpan POLAT BEKEN
TUBİTAK Marmara Research Centre, Environment and Clean Technology Institute Gebze, Kocaeli, Turkey
E-mail: colpan.beken@tubitak.gov.tr

Derya ÜRKMEZ
Scientific and Technological Research and Application Center, Sinop University, Sinop, Turkey
E-mail: deryaurkmez@gmail.com

Devrim TEZCAN
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: devrim@ims.metu.edu.tr

Dilek EDİGER
Istanbul University, Institute of Marine Sciences and Management, 34134 Vefa, Istanbul, Turkey
E-mail: dilek.ediger@istanbul.edu.tr

Ebru OLGUN EKER
Ministry of Enviroment and Urbanization of Turkey, General Directorate of Environmental Impact Assessment Permits and Control/Dept. of Laboratory, Measurement and Monitoring Gölbaşı, Ankara, Turkey
E-mail: ebru.olgun@csb.gov.tr

Ekin AKOĞLU
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: ekinakoglu@gmail.com

Elif ARICI
Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
E-mail: elfkarakas@gmail.com

Emine Şükran OKUDAN
Faculty of Fisheries, Dept. of Hydrobiology, Akdeniz University, Antalya, Turkey
E-mail: okudanes@gmail.com

Ersan BAŞAR
Marine Sciences Faculty, Karadeniz Technical University, Çamburnu, Sürmene, Trabzon, Turkey
E-mail: ebasar@ktu.edu.tr

Ertuğ DÜZGÜNEŞ
Marine Sciences Faculty, Karadeniz Technical University, Çamburnu, Sürmene, Trabzon, Turkey
E-mail: ertug@ktu.edu.tr

Ertuğrul AĞIRBAŞ
Recep Tayyip Erdogan University, Faculty of Fisheries, Rize, Turkey
E-mail: ertugrul.agirbas@erdogan.edu.tr

Evrim SÖNMEZ
Sinop University, Faculty of Education, Sinop, Turkey
E-mail: esonmez@sinop.edu.tr

Fatih ŞAHİN
Faculty of Fisheries, Department of Hydrobiology, Sinop University, 5700 Sinop, Turkey
E-mail: fsahin@sinop.edu.tr

Fatma TELLİ KARAKOÇ
Marine Sciences Faculty, Karadeniz Technical University, Çamburnu, Sürmene, Trabzon, Turkey
E-mail: fatma.tellikarakoc@ktu.edu.tr

Funda ÜSTÜN
Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
E-mail: fustun@sinop.edu.tr

Güley KURT-ŞAHİN
Faculty of Arts and Sciences, Dept. of Biology, Sinop University, Sinop, Turkey
E-mail: gkurtsahin@sinop.edu.tr

Günay ÇİFÇİ
Institute of Marine Sciences and Technology, Dokuz Eylül University, Izmir, Turkey
E-mail: gunay.cifci@deu.edu.tr

Hacer SAĞLAM
Marine Sciences Faculty, Karadeniz Technical University, Çamburnu, Sürmene, Trabzon, Turkey
E-mail: hacersaglam@ktu.edu.tr

Hacer SELAMOĞLU ÇAĞLAYAN
Ministry of Enviroment and Urbanization of Turkey, General Directorate of Environmental Impact Assessment Permits and Control/Dept. of Laboratory, Measurement and Monitoring Gölbaşı, Ankara, Turkey
E-mail: hacer.caglayan@csb.gov.tr

Hakan ATABAY
TUBITAK- MRC, Institute of Environment and Cleaner Production, Gebze, Kocaeli, Turkey
E-mail: hakan.atabay@tubitak.gov.tr

İ. Noyan YILMAZ
Istanbul University, Institute of Marine Sciences and Management, Istanbul, Turkey
E-mail: noyan@istanbul.edu.tr

İbrahim TAN
TUBITAK- MRC, Institute of Environment and Cleaner Production, Gebze, Kocaeli, Turkey
E-mail: ibrahim.tan@tubitak.gov.tr

Koray ÖZHAN
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: koray@ims.metu.edu.tr

Korhan ÖZKAN
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: okorhan@metu.edu.tr

Levent BAT
Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
E-mail: leventbat@gmail.com

Melek İŞİNİBİLİR
Faculty of Aquatic Sciences, Istanbul University, Istanbul, Turkey
E-mail: melekis@istanbul.edu.tr

Mine ÇARDAK
School of Applied Science Canakkale, Department of Fisheries Technology, Canakkale 18 Mart University, Canakkale, Turkey
E-mail: mine_bio98@hotmail.com.tr

Murat SEZGİN
Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
E-mail: msezgin@ sinop.edu.tr

Mustafa MANTIKCI
TUBITAK- MRC, Institute of Environment and Cleaner Production, Gebze, Kocaeli, Turkey
E-mail: mustafa.mantikci@tubitak.gov.tr

Mustafa YÜCEL
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: myucel@ims.metu.edu.tr

Nebil YÜCEL
Faculty of Marine Sciences and Technology, Iskenderun Technical University, Iskenderun, Turkey
E-mail: nebilyucel@gmail.com

Nelli G. SERGEEVA
Institute of Marine Biological Research of Russian Academy of Sciences, 2, Nakhimov ave., Sevastopol 299011, Russia
E-mail: nserg05@mail.ru

Pelin S. ÇİFTÇİ TÜRETKEN
Faculty of Aquatic Sciences, Istanbul University, Istanbul, Turkey
E-mail: pciftci@istanbul.edu.tr

Selma ÜNLÜ
Istanbul University, Institute of Marine Sciences and Management, 34134 Vefa, Istanbul, Turkey
E-mail: su@istanbul.edu.tr

Serap KANTARLI
Ministry of Enviroment and Urbanization of Turkey, General Directorate of Environmental Impact Assessment Permits and Control/Dept. of Laboratory, Measurement and Monitoring Gölbaşı, Ankara, Turkey
E-mail: serap.kantarli@csb.gov.tr

Serdar BEJİ
Istanbul Technical University, Department of Ocean Engineering, Istanbul, Turkey
E-mail: sbeji@itu.edu.tr

Sinan ARKIN
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: sinan.arkin@ims.metu.edu.tr

Sinan MAVRUK
Fisheries Faculty, Department of Marine Biology, Cukurova University, Adana, Turkey
E-mail: smavruk@cu.edu.tr

Süleyman TUĞRUL
Institute of Marine Sciences, Middle East Technical University, Erdemli, Mersin, Turkey
E-mail: tugrul@ims.metu.edu.tr

T. Ahmet ERTEK
Istanbul University, Faculty of Letters, Department of Geography, Istanbul, Turkey
E-mail: taertek@istanbul.edu.tr

Temel OĞUZ
Middle East Technical University, Institute of Marine Sciences, Erdemli, Mersin, Turkey
E-mail: temeloguz@gmail.com

Türkay ÖZTÜRK
Faculty of Fisheries, Sinop University, Sinop, Turkey
E-mail: tozturk@sinop.edu.tr

Ülgen AYTAN
Faculty of Fisheries, Recep Tayyip Erdogan University, Rize, Turkey
E-mail: ulgen.kopuz@erdogan.edu.tr

Yakup ERDEM
Faculty of Fisheries, Sinop University, Sinop, Turkey
E-mail: yakuperdem@gmail.com

Yeşim AK ÖREK
Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
E-mail: yesimak@ims.metu.edu.tr

Yılmaz ÇİFTCİ
Department of Fisheries Technology Engineering, Faculty of Marine Sciences, Ordu University, 52400 Fatsa, Ordu, Turkey
E-mail: yciftci@odu.edu.tr

CONTENTS

II. BIODIVERSITY

PHYSICAL OCEANOGRAPHY

Temel OĞUZ

Middle East Technical University, Institute of Marine Sciences,
Erdemli, Mersin, Turkey
temeloguz@gmail.com

1. Introduction

The Black Sea is a nearly enclosed and zonally elongated basin with the zonal dimension of about 1200 km and the meridional dimension varying from 500 km on the western side to 250 km towards the eastern side (Figure 1). With a surface area of 423,000 km^2, it is approximately one-fifth of the surface area of the Mediterranean. It has a limited interaction with the Aegean Sea through the Turkish Straits System. Its main bathymetric feature is the presence of a narrow shelf (generally less than 20 km) and steep topographic slope (generally less than 30 km) around deep interior basin having maximum depths of 2200m (Figure 1). The north-western part of the sea, occupying ~20% of the total area, is characterized by a fairly wide shelf and its connection to the deep western basin through a wider topographic slope zone. The width of the western shelf gradually reduces towards south and finally terminates to the east of the Bosphorus Strait exit region (Figure 1). The Black Sea receives fresh water inflows all around the basin but the important ones (Danube, Dnieper and Dniester) discharge into the north-western coastal waters. The River Danube being one of the largest rivers in Europe introduced dramatic effects on the Black Sea ecosystem.

2. Physical characteristics

2.1. Stratification characteristics

The Black Sea is a strongly stratified system; its stratification within the upper 100 m layer (10% of the entire water column) varies up to $\sigma_t \sim 5$ kg m^{-3} (Figure 2) and is an order of magnitude greater than, for example, in the neighbouring Mediterranean Sea. The pycnocline corresponding to the density surface $\sigma_t \sim 16.2$ kg m^{-3} approximately conforms to 100-150 m depth within the interior cyclonic cell or may extend to 200 m within coastal anticyclones. The deep homogenous layer that has a thickness of 2000 m within the abyssal plain of the sea possesses almost vertically uniform characteristics below 200 m within the range of values of T ~ 8.9-9.1ºC, S ~ 22-22.5, $\sigma_t \sim 17.0$-17.3 kg m^{-3}. The deepest part of the water column approximately below 1700 m involves homogeneous water mass formed by convective mixing due to the bottom geothermal heat flux during the last several thousands of years (Murray *et al.* 1991).

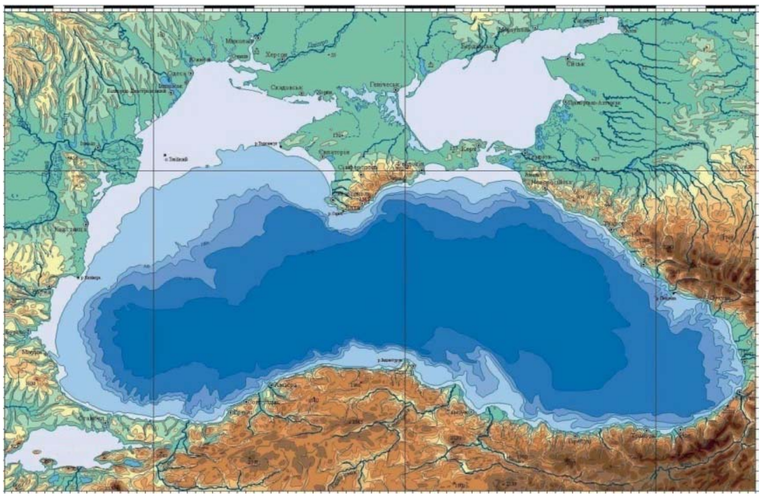

Figure 1. The location and bathymetry of the Black Sea

The upper 50-60 m is homogenized in winter with T~6-7 ^{o}C, S ~18.5-18.8, σ_t ~14.0-14.5 kg m^{-3} when the north-western shelf and near-surface levels of the deep basin exposed to strong cooling by successive cold-air outbreaks, intensified wind mixing, and evaporative loss. As the spring warming stratifies the surface water, the remnant of convectively-generated cold layer is confined below the seasonal thermocline and forms the Cold Intermediate Layer (CIL) of the upper layer thermohaline structure. Following severe winters, the CIL may preserve its structure for the rest of the year, but it may gradually warm up and loose its character in the case of warm winter years. Stratification in summer months comprises a surface mixed layer with a thickness of 10-20 m with T~22-26^{o}C, S~18-18.5 and σ_t ~10.5-11.5 kg m^{-3}.

A distinct feature of the SST is the strong spatial variability as inferred by the long-term mean distribution (Figure 3). The temperature difference as high as 3^{o}C extends diagonally from its lowest values (~13.5^{o}C) within the north-western shelf region and relatively higher values (~16.5^{o}C) within the eastern part of the eastern basin. This is related to the more frequent exposition of the western part to the cold air outbreaks from the continental Europe. On the contrary, the eastern basin is protected from such cold outbreaks by the mountain chains along the southern and eastern coastlines. Thus, the eastern basin favours milder winters and warmer winter temperatures in the surface mixed layer. Thus the decadal warming signature was felt more pronouncedly in the eastern basin during the 1990s. The relatively deep interior part of the sea is also slightly cooler than the peripheral zone due to the persistent upwelling motion associated with the cyclonic circulation system.

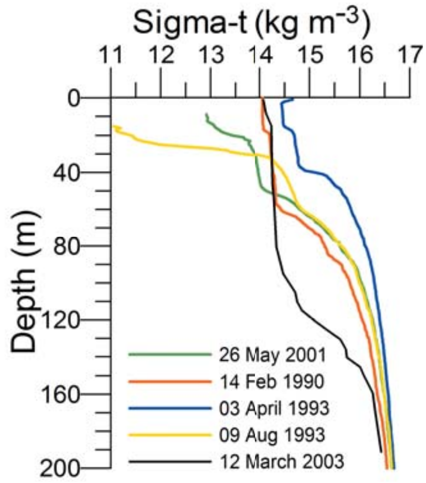

Figure 2. Vertical variations of density (expressed in terms of sigma-t, kg m^{-3}) at various locations of the interior basin during different months representing different types of vertical structures

An important feature of the upper layer physical structure is the intensity of diapycnal mixing that controls ventilation of the CIL and oxygen deficient zone and nutrient entrainment from its subsurface source in winter months. According to the recent microstructure measurements (Gregg and Yakushev 2005 and Zatsepin *et al.* 2007), the vertical diffusivity attains its maximal values on the order of 10^{-3}–10^{-4} m^2 s^{-1} in the surface mixed layer (0–15 m), but decreases to 10^{-5}–10^{-6} m^2 s^{-1} across the seasonal thermocline (15–30 m). An increase in the diapycnal diffusivity is observed in the CIL to the range 2–6 x 10^{-5} m^2 s^{-1}. Below the base of the CIL, it rapidly decreases to its background values of 1–4×10^{-6} m^2 s^{-1}. Consequently, turbulent fluxes near the base of CIL are too weak to renew the oxygen deficient Suboxic Layer (SOL).

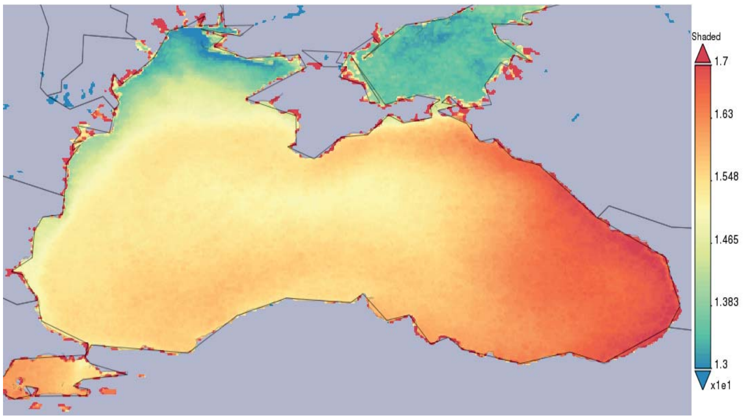

Figure 3. Time averaged (2002-2016) SST distribution over the Black Sea provided by the 4km resolution monthly mean MODIS satellite products

The Mediterranean underflow that is characterized typically by T~13-14 ^{o}C and S~35-36 upon issuing from the Bosphorus modifies considerably by mixing with the upper layer waters and enters the shelf with T~12-13 ^{o}C and S~28-30. In the shelf, its track is regulated by small scale topographic variations. As it spreads out as a thin layer along the bottom, it is diluted by entrainment of relatively colder and less saline CIL waters and is barely distinguished by its slight temperature and salinity differences from the ambient shelf waters up on issuing the shelf break. The modified Mediterranean water is then injected in the form of thin multiple layers at intermediate depths (150-250 m) (Hiscoock and Millero 2006, Glazer *et al.* 2006). Signature of the Mediterranean inflow within the interior parts of the basin can be best monitored up to 500 m, where the residence time of the sinking plume varies from ~10 years at 100 m depth to ~400 years at 500 m (Ivanov and Samodurov 2001, Lee *et al.* 2002).

On the basis of available data since the 1920s (Ilyin *et al.* 2005), the total river discharge and precipitation into the sea show weak but opposite trends that compensate each other and therefore their sum remain uniform at ~550 km^3 y^{-1}. Evaporation varied slightly around 400 km^3 y^{-1} up to the mid-1970s (except 15% increase in the 1940s), and then decreased steadily to ~300 km^3 y^{-1} during the subsequent 15 years and stabilized at this value afterwards. The net fresh water flux into the sea, therefore, revealed an increasing trend from ~120 km^3 y^{-1} in the early 1970s to ~300 km^3 y^{-1} in the mid-1990s. This freshwater excess is balanced by the net outflow through the Bosphorus defined as the difference between the transports of its two layers and implies a nearly two-fold change from the 1960s to the 1990s.

2.2. Climatic variations

The physical characteristics of the upper layer water column above the base of the permanent pycnocline experienced distinct decadal-scale oscillations (Oguz *et al.* 2006, Piotukh *et al.* 2011). The sea surface temperature (SST) is used here as a proxy for describing climatic variability. It indicates a relatively mild cooling phase (0.5^{o}C) during 1960-1980 and a subsequent more pronounced cooling phase identified by the winter (December-March) mean sea surface temperature (SST) changes as high as 1.5^{o}C during 1980-1993 (Figure 4). Similar variations are also observed in the summer-autumn (May-November) mean subsurface cold intermediate layer (CIL) temperature field (Figure 4). They are followed by an equally pronounced warming phase during 1993-2014. They imply a clear signal of climatic changes within the upper 100m water column above the permanent pycnocline. The climate-induced temperature changes are related to strengthening of the NAO; its positive phase resulting in colder, drier, and more severe winters contrary to the simultaneous wetter, warmer, and milder winters over the north-western Europe and the Eastern North Atlantic Ocean (Oguz *et al.* 2006). The subsequent warming trend starting by 1993 up to 2001 increases the SST and CIL temperature back to their former levels prior to the 1980. Afterwards, both SST and CIL temperature undergoes to a decadal scale oscillation with an amplitude of ~1.5^{o}C between the minimum at 2005-2006 and the maximum at 2010-2011, followed by a decreasing trend.

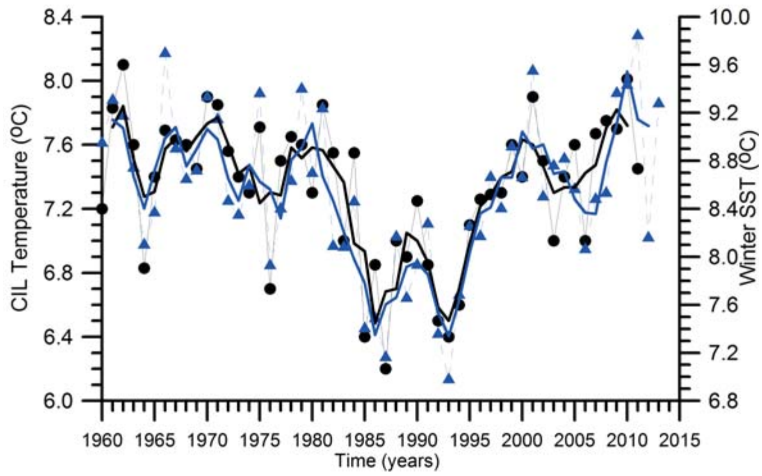

Figure 4. Long term variations of the winter (December-March) mean sea surface temperature and the summer-autumn (May-November) mean Cold Intermediate Layer (CIL) temperature below the seasonal thermocline. The thin lines with symbols refer to the original data whereas the thick lines represent their smoothed variations by three point running averaged

Sea level changes provide best response of the physical climate to atmospheric forcing, because the link includes an overall response of the changes in the surface atmospheric pressure through the inverse barometer effect, water density changes in response to temperature and salinity variations (steric effects), precipitation, evaporation and river runoff. The detrended sea level anomaly time series at Poti tide gauge site located at the south-eastern corner of the sea (Figure 5) reveals higher (lower) SLA values coinciding with the warm (cold) cycles of the SST and exhibits a rising trend up to the mid-1999 (~3 cm y^{-1}) followed by -3.0 cm y^{-1} declining trend 07/1999–12/2008 in consistent with the cooling phase indicated by the winter SST data and a rising trend afterwards. Good agreement between the SLA changes and the temporal variation of the Danube discharge suggest its predominant role on the basin-scale sea level oscillations.

The general consistency between periods of positive (negative) NAO index and relatively low (high) sea surface and air temperatures, higher (lower) surface air pressures supports the presence of a teleconnection between the regional atmospheric conditions and the NAO-driven large scale atmospheric motion (Oguz *et al.* 2006, Kazmin and Zatsepin 2007). In terms of duration and intensity of events, the sequence of mild and severe winter cycles follows the temporal pattern of the negative and positive NAO cycles, respectively. In particular, the strong cooling trend during 1980-1993 characterizes an extended strongly positive NAO phase. The subsequent warming trend in SST coincides with the weakening of positive NAO index and its decreasing trend. The NAO climatic control of the Black Sea may be further modulated by the EAWR oscillation (Oguz *et al.* 2006).

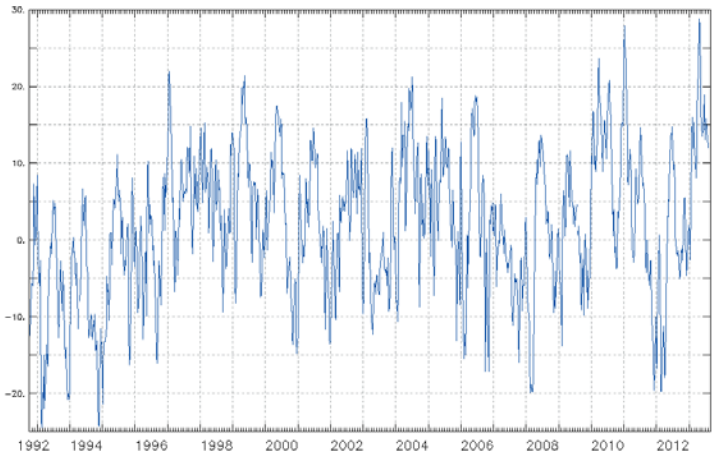

Figure 5. The sea level anomaly time series at Poti tide-gauge site located at the south-eastern corner of the sea

3. Circulation characteristics

The upper layer (100-150m) water column of the Black Sea above the permanent pycnocline reveals a complex, eddy-dominated circulation (Figure 6). It comprises different types of structural organizations of water masses within the interior cyclonic cell, the Rim Current jet is confined mainly along the abruptly varying continental slope and margin topography around the basin, and a series of anticyclonic eddies along its onshore side (Oguz *et al.* 1994, Besiktepe *et al.* 2001, Blockhina and Afanasyev 2003, Korotaev *et al.* 2003, Zatsepin *et al.* 2003, Kubryakov and Stanichny 2015). The interior circulation consists of several sub-basin scale gyres, each of which is formed by several cyclonic eddies. They evolve continuously by interactions among each other, as well as with meanders and filaments of the Rim Current. The overall basin circulation is primarily forced by the curl of wind stress throughout the year, and further modulated by the seasonal evolution of the surface thermohaline fluxes and mesoscale features arising from the basin's internal dynamics. The strong topographic slope together with the coastline configuration of the basin governs the main pattern of the Rim Current system. It changes seasonally from a more coherent structure in the winter and spring to more a turbulent, eddy-dominated structure in the late summer and autumn.

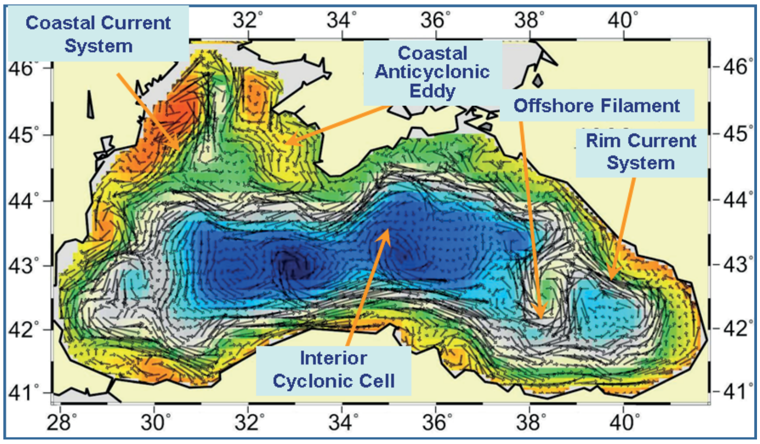

Figure 6. A typical structure of the upper layer circulation field deduced from a circulation model using assimilation of altimeter sea level anomaly data as described by Korotaev *et al.* (2003)

Larger scale characteristics of the upper layer circulation system possess a distinct seasonal cycle (Korotaev *et al.* 2003, Poulain *et al.* 2005). The interior cyclonic cell in winter months involves a well-defined two-gyre system surrounded by a rather strong and narrow jet without much lateral variations. This system gradually transforms into a multi-centred composite cyclonic cell surrounded by a b roader and weaker Rim Current zone in summer. The interior flow field finally disintegrates into smaller scale cyclonic features in autumn (September-November) in which a composite Rim Current system is hardly noticeable. The turbulent flow field is rapidly converted into a more intense and organized structure after November-December.

The circulation is accompanied by a well-defined, meandering salinity front separating relatively less saline and dense coastal waters from more saline and denser interior basin (Figure 7). The fresh water discharge from the Danube contributes to buoyancy-driven component of the basin-wide cyclonic circulation system. Baroclinic instability processes are responsible by introducing considerable variability of the Rim Current in the form of eddies, meanders, filaments, offshore jets that propagate cyclonically around the basin. Over the annual time scale, westward propagating Rossby waves further contribute to the complexity of basin wide circulation system. Eddy dynamics and mesoscale features evolving along the periphery of the basin as part of the Rim Current dynamic structure appear to be the major factor for the shelf-deep basin exchanges. They link coastal biogeochemical processes to those beyond the continental margin, and thus provide a mechanism for two-way transports between nearshore and offshore regions.

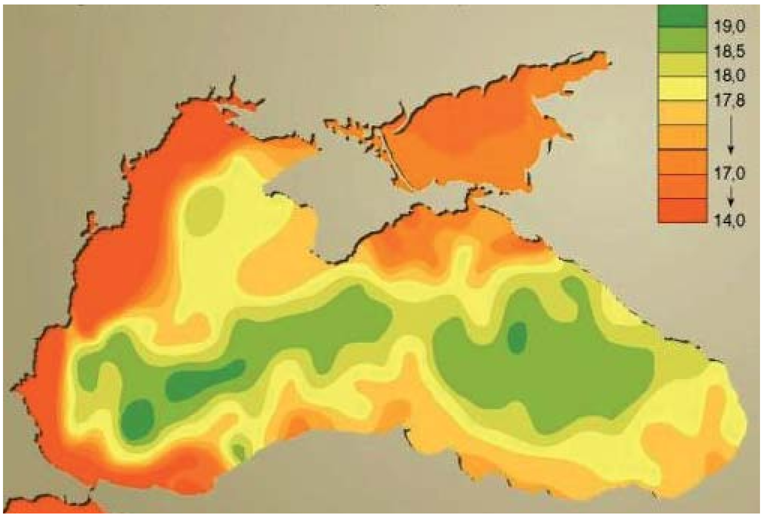

Figure 7. Surface salinity distribution determined by the July 1992 multi-ship basin wide survey. The distribution possesses a meandering frontal structure between the relatively high interior basin salinity (>18.0 psu) compared to lower salinity values around the basin maintained by the coastal fresh water discharges and outflow from the Azov Sea

The Ship mounted Acoustic Doppler Current Profiler (ADCP) and CTD measurements in the western Black Sea (Oguz and Besiktepe 1999), carried out soon after an exceptionally severe winter conditions in 1993, has shown a vertically uniform current structure in excess of 50 cm/s (maximum value ~100 cm/s) within the upper 100 m layer, followed by a relatively sharp change across the pycnocline (between 100 and 200 m) and the vertically uniform sub-pycnocline currents of 20 cm/s (maximum value ~40 cm/s) up to 350 m being the approximate limit of ADCP measurements. The cross-stream velocity structure exhibited a narrow core region (~30 km) of the Rim Current jet that was flanked by a narrow zone of anticyclonic shear on its coastal side and a broader region of cyclonic shear on its offshore side. Such exceptionally strong sub-pycnocline currents of the order of 20-40 cm/s should be largely related with the severity of the winter conditions that was indeed one of the most severe winters of the last century (Oguz *et al.* 2006). The corresponding geostrophically-estimated currents from the CTD measurements were relatively weak due to the lack of ageostrophic effects and barotropic component of the current.

Lagrangian subsurface current measurements by the autonomous profiling floats deployed into the intermediate layer and deep layers provided direct, quantitative evidence for strong currents and a well-organized flow structure, which changed the traditional views built on a rather sluggish deep circulation of the Black Sea (Korotaev *et al.* 2006). The data suggested active role of mesoscale features on the basin-wide circulation system at 200m similar to the case observed in the upper layer (<100m) circulation system. The currents reach a maximum intensity of 15 cm s^{-1} along the Rim Current jet around the basin, which is consistent with the findings of ADCP measurements (Oguz and Besiktepe 1999).

The magnitudes of deep currents may reach to 5 cm s^{-1} at 1500 m depth along the steep topographic slope (Korotaev *et al.* 2006). The combination of float and altimeter data suggests that deep currents are steered by the steep topographic slope and well-correlated with the structure of surface currents at seasonal and longer time scales. The deep layer currents flow along the strong topographic slope following constant potential vorticity isoclines due to the topographic β-effect. The wind stress, as the main driving force, can introduce a barotropic flow on the order of 5 cms^{-1} as further supported by the numerical modelling studies (Stanev 1990, Oguz *et al.* 1995, Stanev and Beckers 1999). The floats at the intermediate (750 m) and deep (1550 m) layers also delineate the importance of mesoscale eddies on the flow field.

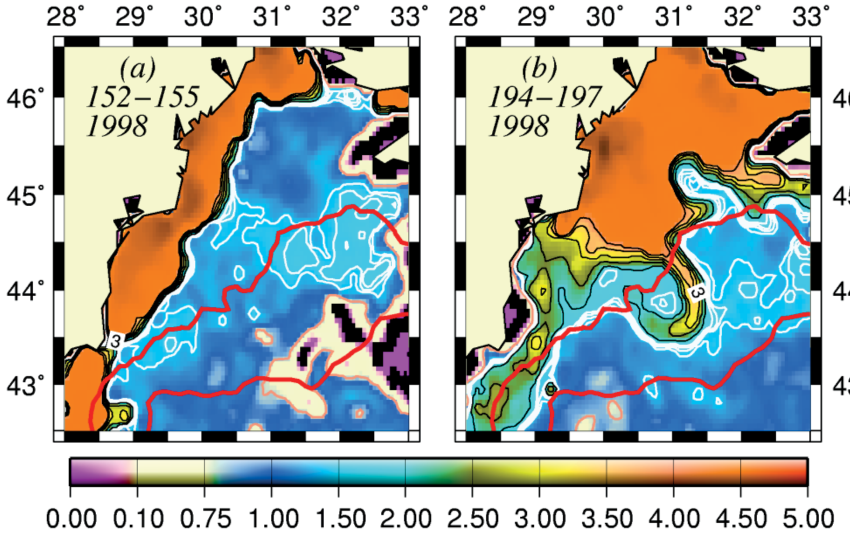

Figure 8. SeaWiFS chlorophyll distributions showing two alternative forms of circulation structure in the north-western shelf; (a) a southward coastal current system during days 152-155 (early June) and (b) a closed circulation system confined into its northern sector during days 194-197 (mid-July), 1998 (taken from Oguz *et al.* 2002).

The basic mechanism which controls the flow structure in the surface layer of the north-western shelf is spreading of the Danube outflow. Wind stress is an additional modifier of the circulation. The Danube anticyclonic eddy confined within a narrow band along the coast between Odessa and Constanta and often introduced by the wind forcing prevails for almost half of the year during spring and summer months (Figure 8). It sometimes expands and occupies almost the whole NWS region (Figure 8b). The Constanta and Kaliakra anticyclones located further south have a typical lifespan of 50 days are observed for about 190 days per year. An alternative configuration of the River Danube plume is the southward coastal current system (Figure 8a). The leading edge of this plume protrudes southward (*i.e* downstream) as a thin baroclinic boundary current along the western coastline. The flow system is separated from offshore waters by a well-defined front as inferred from the large contrast between the chlorophyll concentrations in the figure. Its offshore flank may display unstable features, exhibits meanders and spawns filaments extending across the wide topographic slope zone (Figure 8b). Except such small scale features, there is almost no exchange between shelf and interior basin.

All available finding of the Black Sea circulation system suggest that the most notable quasi-persistent and/or recurrent features of the circulation system include (i) the meandering Rim Current system cyclonically encircling the basin, (ii) two cyclonic sub-basin scale gyres comprising four or more gyres within the interior, (iii) the Bosphorus, Sakarya, Sinop, Kızılırmak, Batumi, Sukhumi, Caucasus, Kerch, Crimea, Sevastopol, Danube, Constanta, and Kaliakra anticyclonic eddies on the coastal side of the Rim Current zone, (iv) bifurcation of the Rim Current near the southern tip of the Crimea; one branch flowing south-westward along the topographic slope zone and the other branch deflecting first north-westward into the shelf and then contributing to the southerly inner shelf current system, (v) convergence of these two current systems near the southwestern coast, (vi) presence of a large anticyclonic eddy within the northern part of the north-western shelf.

References

Besiktepe, S.T., C.J. Lozano, and A.R. Robinson. 2001. On the summer mesoscale variability of the Black Sea. J. Mar. Res. 59: 475-515.

Blokhina, M.D. and Y.D. Afanasyev. 2003. Baroclinic instability and transient features of mesoscale surface circulation in the Black Sea: Laboratory experiment, J. Geophys. Res. 108(C10): 3322.

Glazer, B.T., G.W. Luther III, S.K. Konovalov, G.E. Friederich, R.E. Trouwborst, and A.S. Romanov. 2006. Spatial and temporal variability of the Black Sea suboxic zone. Deep Sea Res. II, 53: 1756-1768.

Gregg, M.C. and E.V. Yakushev. 2005. Surface ventilation of the Black Sea's cold intermediate layer in the Middle of the Western Gyre. Geophys. Res. Lett. 32: L03604.

Hiscock, W.T. and F.J. Millero. 2006. Alkalinity of the anoxic waters in the Western Black Sea. Deep Sea Res. II, 53: 1787-1801.

Ilyin, Y.P. and L.N. Repetin. 2005. Long-term climatic trends in the Black Sea region and their seasonal features. Proceedings of The First Biannual Scientific Conference: Black Sea Ecosystem 2005 and Beyond, organized by Commission on the Protection of the Black Sea Against Pollution, May 2006, Istanbul.

Ivanov, L.I. and A.S. Samodurov. 2001. The role of lateral fluxes in ventilation of the Black Sea. J. Mar. Syst. 31: 159-174.

Kazmin, A.S. and A.G. Zatsepin. 2007. Long-term variability of surface temperature in the Black Sea, and its connection with the large-scale atmospheric forcing. J. Mar. Syst. 68: 293-301.

Korotaev, G.K., T. Oguz, A. Nikiforov, and C.J. Koblinsky. 2003. Seasonal, interannual and mesoscale variability of the Black Sea upper layer circulation derived from altimeter data. J. Geophys. Res. 108: 3122.

Korotaev, G., T. Oguz, and S. Riser. 2006. Intermediate and deep currents of the Black Sea obtained from autonomous profiling floats. Deep Sea Res. II, 53:1901-1910.

Kubryakov, A. and S. Stanichny. 2015. Seasonal and interannual variability of the Black Sea eddies and its dependence on characteristics of the large-scale circulation, Deep-Sea Res. I, 97: 80-91.

Lee, B-S., J.L. Bullister, J.W. Murray, and R.E. Sonnrup. 2002. Anthropogenic chlorofluorocarbons in the Black Sea and the Sea of Marmara. Deep-Sea Res. I, 49: 895-913.

Murray, J.W., Z. Top, and E. Ozsoy. 1991. Hydrographic properties and ventilation of the Black Sea. Deep-Sea Res., 38 (2A): 663-690.

Oguz, T., D.G. Aubrey, V.S. Latun, E. Demirov, L. Koveshnikov, H.I. Sur, V. Diacanu, S. Besiktepe, M. Duman, R. Limeburner, and V.V. Eremeev. 1994. Mesoscale circulation and thermohaline structure of the Black sea observed during HydroBlack'91. Deep Sea Research I, 41: 603-628.

Oguz, T., P. Malanotte-Rizzoli, and D. Aubrey. 1995. Wind and thermohaline circulation of the Black Sea driven by yearly mean climatological forcing. J. Geophys. Res. 100: 6846-6865.

Oguz, T. and S. Besiktepe. 1999. Observations on the Rim Current structure, CIW formation and transport in the western Black Sea. Deep Sea Research I, 46: 1733-1753.

Oguz, T., A.G. Deshpande, and P. Malanotte-Rizzoli. 2002. On the role of mesoscale processes controlling biological variability in the Black Sea: Inferrences from SeaWIFS-derived surface chlorophyll field. Continental Shelf Research, 22: 1477-1492.

Oguz, T., J.W. Dippner, and Z. Kaymaz. 2006. Climatic regulation of the Black Sea hydro-meteorological and ecological properties at interannual-to-decadal time scales. J. Mar. Syst. 60: 235-254.

Piotukh, V.B., A.G. Zatsepin, A.S. Kazmin, and V.G. Yakubenko. 2011. Impact of the winter cooling on the variability of the thermohaline characteristics of the active layer in the Black Sea. Oceanology, 51: 221-230.

Poulain, P-M., R. Barbanti, S. Motyzhev, and A. Zatsepin. 2005. Statistical description of the Black Sea near-surface circulation using drifters in 1999-2003. Deep-Sea Res. I, 52: 2250-2274.

Stanev, E.V. 1990. On the mechanisms of the Black sea circulation. Earth-Sci. Rev., 28: 285-319.

Stanev, E.V. and J.M. Beckers. 1999. Numerical simulations of seasonal and interannual variability of the Black Sea thermohaline circulation. J. Mar. Syst. 22: 241-267.

Zatsepin, A.G., A.I. Ginzburg, A.G. Kostianoy, V.V. Kremenitskiy, V.G. Krivosheya, S.V. Stanichny, and P-M. Poulain. 2003. Observations of Black Sea mesoscale eddies and associated horizontal mixing. J. Geophys. Res. 108: 3246.

Zatsepin A.G., N.N. Golenko, A.O. Korzh, V.V. Kremenetskii, V.T. Paka, S.G. Poyarkov, and P.A. Stunzhas. 2007. Influence of the dynamics of currents on the hydrophysical structure of the waters and the vertical exchange in the active layer of the Black Sea. Oceanology, 47(3): 301-312.

COASTAL GEOMORPHOLOGY OF THE BLACK SEA COAST OF TURKEY

T. Ahmet ERTEK

Istanbul University, Faculty of Letters, Department of Geography, Istanbul, Turkey
taertek@istanbul.edu.tr

1. Coastal Geomorphology of Black Sea Coasts of Turkey

The Black Sea coast of Turkey extends between the Rezve Creek on the western border of Bulgaria and the Sarp Creek on the border of Georgia to the east, as shown by the arrows on the location map (Figure 1 and 2). In general, the east-west direction of the mountain range in the north of Turkey was formed as a result of tectonic movements that occurred during the Alpine orogeny. Therefore, the Turkish Black Sea coast comprises a Pacific-type (longitudinal-type) coast in that it borders the mountain chain lying to the south (Ardel 1967-1968, İnandık 1958). The length of the Turkish Black Sea coast is 1695 km along which large indentations and protrusions (Figure 3) do not exist. The shelf area is very narrow and stretches 5-20 km from the coastline with the exception of the traverse-aligned coastal area lying near Cape Baba in Zonguldak-Eregli due to presence of local tectonic lines. It is possible to see that the ultrabasic magmatites extend along the Black Sea coast, especially along with coast of the Eastern Black Sea of Turkey.

According to plate tectonics, the best theory explaining the origin of the Anatolian Plate rising to the Tethys surface i.e., the level today of the Mediterranean, the African Plate moved to the north towards the Eurasian Plate in the Upper Miocene. At the end of this movement, the Anatolian Plate began to move to the west and southwest. At that moment, two large transformational faults occurred; one of which is the North Anatolian Fault (NAF) and the other is the East Anatolian Fault (EAF) (Şengör 1980, Şengör and Yılmaz 1981). Here, the Arabian Plate compresses to the north. The east of the country is mostly a contractional regime in Eastern Anatolia, a high plain regime in Central Anatolia shaped as if moving to the west, and an extensional regime in West Anatolia (Şaroğlu *et al.* 1992a, b). For this reason, in general, the mountains on the eastern shores of the Black Sea reach an altitude of almost 4000 m (Kaçkar Mountain summit: 3932 m). This value gradually reduces in the Western Black Sea and decreases to 2019 m in the Küre Mountains. Further to the west, on the Kocaeli Peninsula, the elevation almost reaches sea level and turns into an average plateau of 200-250 m. In the Thrace coastal zone, this value is repeated, but in the massive mountainous region of the Strandja Mountains, the altitude again reaches 1019 meters.

Eastern Black Sea Coast: The issue of basin development, which is usually encountered in inland seas, is one of the most important problems faced in the Black Sea. The traces of this are clearly present here. One of them is the shelf, which is very narrow under the sea due to tectonic activity, and the steep descent to the 2000 m abyssal bottom at an average of 10 km offshore from the coast. This appears as fault scarps on the ground. For this reason, the Turkish Black Sea coast forms a broad protrusion to the north on the coast of Kerempe, two broad bays, and in the south Black Sea coast. This overall pattern intensifies in several places. These are: Cape Fener, Cape Yasun, Çarşamba and Bafra deltas and İnceburun Peninsula, the city of Sinop is located. On the other hand, the middle of the western coast has the exit of the Bosphorus, which is connected to the Sea of Marmara.

When looked at the coast of the Eastern Black Sea of Turkey, which lies in between Sarp Stream and Çarşamba Plain, due to the effect of tectonics, steep and cliff-like high coastlines have developed. However, the sections corresponding to the mouths of rivers such as the Fırtına, İyidere, Yanbolu, Değirmendere, Harşit, Aksu and Melet creeks have a low shore or narrow coastal plains and beaches. These coastal plains are located at the mouths of rivers such as the Aksu, Melet, Harşit, İkizdere, Değirmendere, Fırtına, etc. These low areas and coastal plains are formed as a result of alluvial deposition. The other areas are mostly steep and high cliffs between these low coasts (Ardel 1963).

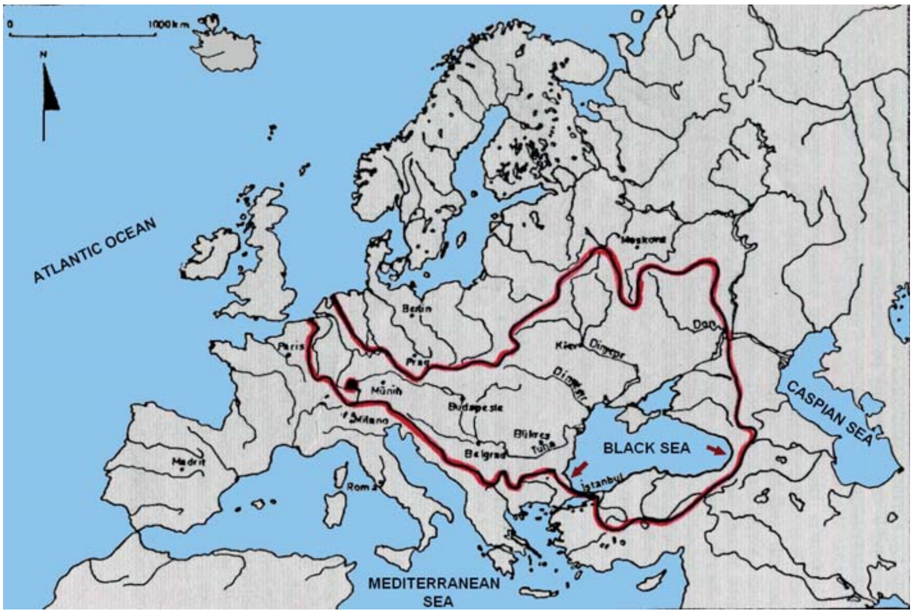

Figure 1. Location map of the Black Sea Basin (Complied by Mater *et al.* 1994)

Figure 2. Location map of the Black Sea (from google earth).

Today, the traces of Pleistocene glacialization in particular are visible on the Eastern Black Sea mountains. They are found at between 2400 and 3500 m on active valley glaciers, glacial valleys or cirques and moraines on the eastern coastal range mountains, which form the summits of Mount Kaçkar, Hunut, and Verçenik on the Altıparmak, Bulut, Soğanlı, Gavur and Giresun mountains (Erinç 1952, Kurter 1991, Çiner 2004, Akcar and Schluchter 2005, Sarıkaya *et al*. 2011). These active glaciers, according to our observations in 2014, (for example, the Kaçkar glaciers) are now on the wastage stage, based on global climate change.

The rise of the old sea levels caused the formation of marine terraces based on the compression of Eastern Anatolia. These are also observed in the vicinity of Trabzon (Ardel 1943, Erol 1952, Solmaz 1990). Trabzon Airport is on a 15-20 m marine terrace, Karadeniz Technical University 60-100 m above sea level, and KTÜ Farabi Hospital at 110-160 m is also located on a marine terrace. It can be said that marine terraces have also increased during the continuation of the squeezing of Eastern Anatolia.

Marine terrace levels according to the climate change in Pleistocene around Trabzon (Ardel 1943) are as follows:
1.Level: 2-8 m
2.Level: 15-40 m
3.Level: 60-100 m

4.Level: 110-135 m
5.Level: 160-180 m and at the farthest back of the plateau surface in the form of abrasion surfaces up to 200 m above sea level.

In general, the shape of Turkey's Black Sea coasts is partially reorganized by anthropogenic effects. The harbors of Hopa, Rize, Trabzon, Perşembe, Samsun, Sinop, Zonguldak and Şile, Kıyıköy were built during the Republican Period in Turkey. However, the Ordu-Giresun Airport (Figure 4), which was opened to service in 2015, due to the fact that it is the third airport built in the world on the sea, partially deteriorates the dynamism of the coastal current.

Middle Black Sea Coast: There are two important protrusions here. Their formation and development constitute an important morphological problem of these shores. Both of these deltas, which are exceptional low coastal types on the northern Anatolian coast, were formed by the Kızılırmak and Yeşilırmak, two large rivers of Anatolia. They enter a class of mixed delusions that form the crown of a crescent and offer common features of crescent-shaped and lobed deltas known as the Bafra Plain. Çarşamba Plain, formed by the River Yeşilırmak, has the same characteristics. The difference between them is due to the shaped irregularities that the Yeşilırmak has formed due to meanderings in its plain (Erkal 1983). Indeed, the Kızılırmak Delta is a more uniform triangle; the west coast is crescent-shaped, and the eastern coast is lobed but triangular in shape (İnandık 1955, 1957a, b). There are many lagoons in the delta lakes such as Balık Lake in the Kızılırmak Delta and Semenlik Lake in the Yeşilırmak Delta. Because of the dams built on the Yeşilırmak and Kızılırmak, all the alluvium is held within the reservoirs of the dam, and these deltas have started to decline in the direction of the land in the last 30 years (Zeybek *et al.* 2012).

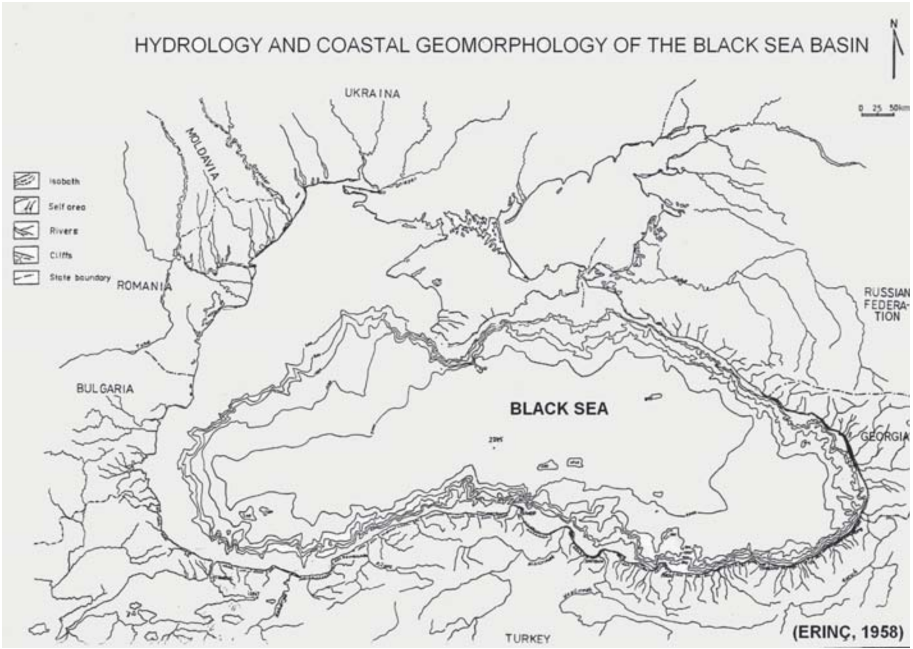

Figure 3. Hydrology and geomorphology map of the Black Sea (Erinç 1958)

Figure 4. Landsat view of Ordu-Giresun Airport (from Google Earth)

The gorge between the Canik Mountains is the greatest power stage in the Yeşilırmak's energy production. In 1981, 35 km south of Çarşamba Plain, the Hasan Uğurlu Dam (also called the Ayvacık Dam) was constructed for electricity production. This dam, which is located in the province of Samsun, is of rock-fill type, and the body height is 175 meters. There is a hydroelectric power plant with 1217 MW power and the dam lake has an area of 23 km². The Suat Uğurlu Dam (also known as Balahor Dam) was built on the Yeşilırmak to the north. This dam, located in the province of Samsun, was also opened in 1981 and is used for power generation and irrigation at a 273 MW power plant. The body height is 51 m and it has a dam lake, which occupies an area of 10 km² (*dsi.gov.tr*).

Altınkaya Dam was built on the River Kızılırmak in 1988 and is located in the province of Samsun. It is of the rock-fill type and its 700 MW power is for power generation and energy purposes. The body height is 195 m and it has a dam area of 118 km^2 (*dsi.gov.tr*).

The Samsun coast is located between the Bafra and Çarşamba deltas. It is 10 m above the present Black Sea level west of the River Mert, 5-10 m west of Ünye, 10 km west of Ünye and 5-10 m of Gölevi (Quaternary) marine sediments are encountered (Yalçınlar, 1958). In addition to the lower terrace, Bilgin also mentions 20-25 m marine terraces at the top (Bilgin 1963). As a result, the level of the marine terraces in the Central Black Sea Region is slightly lower than in the east (Uzun 1995).

Western Black Sea Coast: Here, the city of Sinop is located to the east of the connection which is the neck of an old island and was later connected to the land by a tombolo. In addition, Cape Baba is an important extension into the Black Sea (Akkan 1975).

Hamsilos Cove at the mouth of the Karasu Stream is the most typical type of "Ria coast" on the Turkish Black Sea coast. Although it is referred to as such in some studies, Hamsilos cannot be a fjord, because the Pleistocene glaciation did not affect the Black Sea coasts of Turkey.

The shores of Sinop are encountered in valleys in the direction of the slope, especially experiencing landslides and earthslides in coastal areas due to the effect of rainfall on the low- settled Eocene flysch land. The most typical of these is the "Çiftlik Landscape" on the 10th km of the Sinop-Gerze highway, a rescue site with landslide prevention work carried out by our team (Ertek *et al.* 1993).

The marine terraces seen on the Sinop Peninsula at a height of 40-50 m (Erinç and İnandık 1955, Akkan 1975, Barka and Sütçü 1993) and 80-100 m (Erinç and İnandik 1955), where old Karangat fossils are found, are actually 6-16 m (Erol 1979). Therefore, it can be said that the ground on the Sinop Peninsula is about 85 m higher than the terraces, which cannot rise to such high values. According to the age determination of the coastal terraces on the northern and eastern coast of the Black Sea; Karangat fossiliferous deposits extending from 8-20 m on Cape Karangat in the Crimea are 80-100,000 years old; while for the Ashe terraces corresponding to a level of 45 m in front of the Caucasus coast, 139,000 years has been given by U/Th aging (Tchepalyga *et al.* 1997). On the basis of these data, local tectonic activity continues on our Black Sea coasts (Ertek and Aytaç 2001, Yıldırım *et al.* 2013).

The western Black Sea mountain ranges (*i.e.* the Küre Mountains) form a folded system parallel to the shore and generally form coastal, cliff-like and steep coasts between Sinop-Cide. However, the Ayancık and Devrekani creek mouths, for example, are drowned and low coastal features like the Eastern Black Sea coasts of Turkey.

The same high coastal features occur between Filyos Creek mouth and Cide. The mouth of Filyos Creek and Bartın Creek turn into a coastal plain. Also, due to local tectonism and anticline and syncline lines in the Cape Baba site at Ereğli, a different shore emerges due to the north-south direction of the fold lines. These shores take the form of transverse coastal features.

The coast from Akçakoca gradually takes the shape of a low coast to the west. In addition to marine processes, there is also a large contribution by the Sakarya River. With the alluvial deposits carried by the Sakarya River, it first filled the Adapazarı Plain in Quaternary. Then the Sakarya River opened the Mağara Gorge to the north of its plain and later transported its waters into the Black Sea. Here, in the presence of such an obstacle as the Adapazarı Basin in front of the river carrying alluvium, the submarine topography is deep and a delta in its mouth has not developed due to the narrowness of the shelf (İnandık 1961, Algan *et al.* 2002). However, with the help of the coastal currents, the alluvium first spread to the coastal area and in front the Akçakoca-Karasu Beach was formed 30-50 meters wide. With the contribution of marine processes, this alluvial material has been transported to the interior under the influence of wind. As a result, a sand dune of 2-3 km width and 10-12 km length was formed from Karasu towards the east and west towards Cebeci region.

The Black Sea coast of Turkey does not have large islands as on the Marmara and Aegean coast of Turkey. Except for the Amasra islands, there is no life on the others. Kefken Island, with a small area of 1 km^2, is the largest island in the Black Sea due to the presence of resistant andesitic rocks. Giresun Island and Hoynat Island in Ordu Perşembe, Tavşan Island in Amasra, Ocakli Island, Zeytinli Island, Dış Island, Uzun Island, Yelken Island and Aya Ana I and Aya Anna II islands (except for Ocaklı Island, Dış Island and Küçük Island, the others are connected to the land by anthropogenic factors) (Ertek and Evren 2005) are the main islands on the Turkish Black Sea coast.

The areas where the cities of Giresun and Sinop are situated and the places they are located are tombolo. Also, to the west are Eşek Island in Şile and Tavşan Island in Riva, which are miniature areas with a tombolo characteristic.

The Black Sea Coast of Istanbul: The province of Istanbul named the “Çatalca-Kocaeli Peneplain” is the shoreline of a plateau area of average 200-250 m elevation, which is utilized land up to almost sea level (Ertek 1995). Here, due to the presence of different rocks, the Black Sea coast of Istanbul also presents itself as a drowned coastal feature (Ertek 1992). However, in general, the West Black Sea Fault (WBF) is bounded in a northwest-southeast direction (Oral interview with Yücel Yılmaz 2016) due to the fact that Istanbul's Black Sea coasts have a flat or nearly-flat extension.

A mature shore type emerges on the Şile shores. Because of the presence of erosive soft rocks in front of the cliffs, the development of the beach is observed from low to high, and the connection of the cliffs to the sea is cut off due to accumulation on the coast. As a result, the active cliffs have now become "dead cliffs". They have large beaches in front of them. The 1km long Ağva Beach, Kumbaba Beach and Sofular-Sahilköy Beach are lowlands of Şile and like Riva Beach, are narrow and long sandy beaches. At the back of these beaches, there are sand dunes between Kumbaba and Sofular-Doğancılı-Sahilköy (Figure 5).

Figure 5. Most important dune areas of the northern part of Turkey (DHKD 1996)

In addition, between the Doğancılı-Alacalı coasts on the western side of Şile, there are coquinites (beachrocks with coquinite fossil shells) and eolianites (fossil dunes). These are the Quaternary fossil deposits of Şile (Ertek 2001). The studies of Erginal indicate that paleosoils were deposited on the surface at a depth of 2-9 meters. The eolianites occurred between 174-772,000 years ago, showing the prevailing winds that swept northwest and east-southeast based on the existing cross-stratification. The age of the coquinites on the eolinites corresponds to MIS 6 between 163-187,000 years ago (Polimeris *et al.* 2012, Erginal *et al.* 2013a, Erginal 2016, Erginal *et al.* 2016). Within the eolinites (*i.e.* fossil dunes), fossil plant roots have been dated by our team to 105-127,000 years ago (Polimeris *et al.* 2016). These are areas where the coastal zone of Şile could be a geopark and be included in the World Heritage List (Photo 1).

Photo 1. Coquinite and eolianite deposits in the Doğancılı coast of western Şile (Ahmet Ertek archive 2014)

The exit of the Bosphorus is 3 km wide and with the flow of water to the north, an old river valley formed the Istanbul Strait as a result of the sea flooding it. The east and west coasts at the exit of the Bosphorus are mainly composed of volcanic rocks, high and steep coasts. The Yavuz Sultan Selim Bridge, the third Bosphorus Bridge, was opened in 2016 and was built at the exit of the Istanbul Strait but not in the Black Sea (Photo 2).

Photo 2. Yavuz Sultan Selim Bridge exit of the Istanbul Strait (*sabah.com.tr*)

Black Sea Coast of Thrace: These coasts extend in a northwest-southeast direction. This direction is parallel to the direction of the massive character of the Strandja Mountains. However, Cape Iğneada should be excluded as a cape. It is generally composed of high, steep and cliff-like shores. Small river mouths and rocks liable to erosion are found especially in Kilyos and Yalıköy where there are low coasts with beaches, dead cliffs, Quaternary deposits of coquinites in Karaburun region (Erginal *et al.* 2012) and beachrock in Kıyıköy (Erginal *et al.* 2013b). There are several lagoons such as Kocagöl and Hamam Lake in the district where İğneada is located (Kurter 1963). The easternmost of these lagoons is Terkos Lake to the north of Istanbul. The south shore of Terkos Lake represents the former Black Sea coast, but it has become a lagoon with a shoreline consisting of alluvial matter carried by marine processes. The lake is 39 km^2 in area and the deepest part is 11 meters.

2. Submarine Morphology of Black Sea Coasts of Turkey

Both the bathymetric and geophysical character of the submarine morphology of the Black Sea are divided into three parts, in terms of which it resembles a miniature ocean (Erinç 1954, 1958, Çekunof and Riyabin 1973, Erinç 1973, 1984, 2001) (Figure 6,7,8,9).

1. A shelf which resulted almost everywhere, around -90 m (37%).
2. A continental slope, whose outer edge lies between -90 m and -2000 m (39%).
3. An almost flat abyssal base extending between -2000 m and -2200 m in depth (24%).

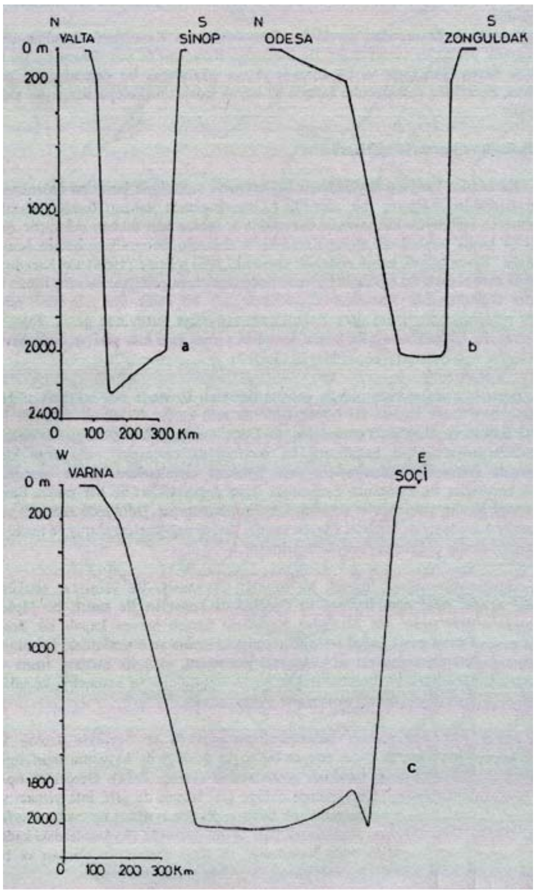

Figure 6. North-south and east-west bathymetric profiles of the Black Sea (Mater *et al.* 1994)

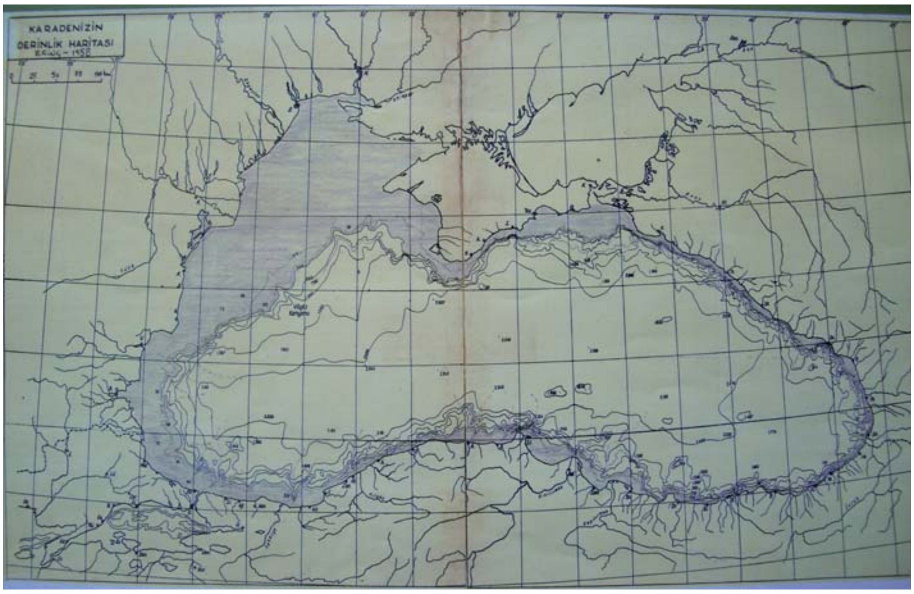

Figure 7. Bathymetry map of the Black Sea (from Erinç 1958)

Figure 8. Bathymetry map of the Black Sea (according to Ross *et al.* 1974 from Algan *et al.* 2002)

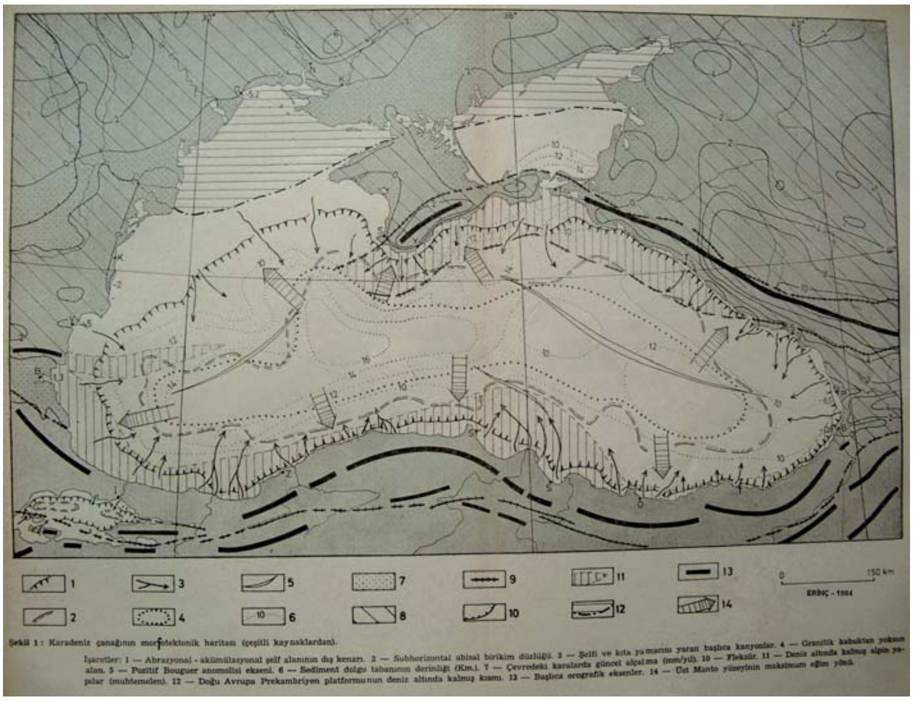

Figure 9. Morpho-tectonic map of the Black Sea (Erinç 1984)

The abyssal base, which occupies close to half of this entire basin, is located in the central part of the depression. This central depression is covered by sediments, of which there are almost no deformations, extending from 10 to 16 km in thickness, most of which belong to the Oligocene, Neogene and Quaternary. On the other hand, seismocarotaige data reveal that the continental slope of the Anatolian and Caucasian borders displays a folded and faulted structure and the existence of displaced masses with landslides.

One of the most interesting features of the Black Sea basin in terms of geomorphology and neotectonics is that the shelf and the continental slope are separated by numerous submarine valleys. Most of these are submerged in the waters of these submarine valleys or canyons, which are located in front of the estuaries of major rivers and show the same dandritic drainage pattern as the drainage network on land behind. The relative depth of the submarine canyons or the size of the cleavage is 75-250 m on the shelf and 700-800 m on the continental slope boundary. The longitudinal profile of each is a typical bending profile, consisting of two different parts, convex at the top and concave at the bottom. These canyons are followed up to 2000 m in front of the western

Black Sea coast of Turkey, 1500 m in front of the Black Sea coast of Turkey and the Caucasus coast, and 1000 m deep in the western part of the Black Sea basin.

These morphological observations provide us with some conclusions about the type and age of the movements that led to the formation of the Black Sea basin and which affected it until recently. As a result of a subsidence movement expanding from the centre of the influence of the submarine canyon to the periphery of submarine canyons, as long as the formations between the lower boundaries of the submarine canyons that exist presently are taken into consideration, these movements are of different kinds and consequently the southern and south-eastern parts were further deepened. On the other hand, according to the geological and geophysical findings, it is believed that this subsidence continued throughout the entire Quaternary, especially since Oligocene. Geomorphological observations allow the age of recent movements to fall within the scope of neotectonics. As mentioned above, the submarine canyons are connected to the river network formed on the land at the end of the Miocene or at the beginning of the Pliocene due to rivers descending from the north, i.e. the newly elevated Pontids. This means that they must be of the same age in terms of occurrence. Accordingly, the neotectonic movements leading to today's bathymetric conditions must have occurred after the Pliocene.

On the other hand, the fact that the shelf is at the same depth (-90 m) around almost all the surrounding the Black Sea basin indicates that large deformations did not occur except for one or two cuts after the formation of the shelf. The level indicated by the outer edge of the Black Sea shelf corresponds to the last glacial period, without any doubt.

According to this scenario, it may be concluded that the main movements that led to the present character of the Black Sea basin came into play between the beginning of the Pliocene and the last glacial. The sea level dynamics were around 2.5-5 m in the case of oscillations on the coast of Turkey. As seen on the shores of the Sea of Marmara and especially on the terraces of Hora Lighthouse to the west of Tekirdağ, the sea did not reach 100-120 meters in depth. Here, too, the area underwent young tectonic movements whereby the land rose and the Black Sea basin sunk.

References

Akçar, N. and C. Schlüchter. 2005. Paleoglaciations in Anatolia: A Schematic Review and First Results. Eiszeitalter und Gegenwart, Hannover. 55: 102-121.

Akkan, E. 1975. Geomorphology of Sinop Peninsula, (in Turkish). Ankara Univ. DTC. Fac. Publ. No: 261.

Algan, O., E. Gökaşan, C. Gazioğlu, Z.Y. Yücel, B. Alpar, C. Güneysu, E. Kirci, S. Demirel, E. Sari, and D. Ongan. 2002. A high-resolution seismic study in Sakarya Delta and Submarine Canyon, southern Black Sea shelf. Continental Shelf Research, 22: 1511-1527.

Ardel, A. 1943. Observations on the morphology of Trabzon and its surroundings (in Turkish). Turkish Geographical Review, 1: 71-82.

Ardel, A. 1963. Geographical observations in the coastal zone between Samsun and Hopa, (in Turkish). Review of I.U. Geography Institute, 13: 36-49.

Ardel, A. 1967-1968. Collective overview of the occurrence and evolution of the Turkish Coasts, (in Turkish). Turkish Geographical Review, 20-21: 24-25.

Barka, A. and Sütçü, F.Y. 1993. Properties and tectonic interpretation of late Pleistocene (Karangat) sediments in surrounding of the Sinop Peninsula, (in Turkish). ITU Mining Faculty, Turkey Quaternary Workshop Abstracts, pp: 41-42.

Bilgin, T. 1963. Akçay Pleistosen terraces in western Ünye, (in Turkish). Review of I.U. Geography Institute, 13: 159-163.

Çekunof, A.V. and L.İ. Riyabin (Translate by S. Erinç). 1973. Some occurence problems of Black Sea basin and geotectonic properties of neogene and anthropogen. Review of I.U. Geography Institute, 18-19: 231-252.

Çiner, A. 2004. Turkish glaciers and glacial deposits, p. 419-429. In J. Ehlers and P.L. Gibbard [eds.], Quaternary Glaciations: Extent and Chronology, Part. I: Europe. Elsevier Publishers, Amsterdam.

DHKD (Doğal Hayatı Koruma Derneği=Association of Natural Life Protection), (in Turkish). 1996. Most important dune areas of northern part of Turkey, brochure.

Erginal, A.E., Y.L. Ekinci, A. Demirci, E. Kırcı Elmas, and H. Kaya. 2012. First note on Holocene coquinite on Thrace (Black Sea) coast of Turkey. Sedimentary Geology, 267-268: 55-62.

Erginal, A.E., N.G. Kiyak, Y.L. Ekinci, A. Demirci, A. Ertek, and T. Canel. 2013a. Age, composition and paleoenvironmental significance of a late *Pleistocene eolianite* from the western Black Sea coast of Turkey. Quaternary International, 296: 168-175.

Erginal, A.E., Y.L. Ekinci, A. Demirci, M. Bozcu, M.Z. Ozturk, M. Avcioglu, M.Z. Oztura. 2013b. First record of beach rock on Black Sea coast of Turkey: Implications for Late Holocene sea-level fluctuations. Sedimentary Geology, 294: 294-302.

Erginal, A.E. 2016. Eolinite Occurrence and Dune Paleogeography in Şile (in Turkish). Çantay Bookstore, 124 p.

Erginal, A.E., N.G. Kıyak, M.Z. Öztürk, H.H. Selim, Y.L. Ekinci, A. Demirci, E. Kırcı Elmas, T. Öztürk, Ç. Çakır, and M. Karabıyıkoğlu. 2016. Eolianite and coquinite as evidence of MIS 6 and 5, NW Black Sea coast, Turkey. Aeolian Research, 25: 1-9.

Erinç, S. 1952. The present glaciation in Turkey. General Assembly and 17th International Congress of the International Geographical Union, p. 326-330. 8th Proceedings, August 8-15, Washington, D.C.

Erinç, S. 1954. Relations between the morphological evolution of the Black Sea and its environment and the pleistocene climate change, (in Turkish). Review of I.U. Geography Institute, 5-6: 46-94.

Erinç, S. and H. İnandık. 1955. Les Dèpôts Pleistosenes Observes Sur La Cote Nord De La Turquie. I.U. Review No: 2, Istanbul.

Erinç, S. 1958. Submarine morphology of the Black Sea. Review of I.U. Geography Institute, 9: 103-114.

Erinç, S. 1973. The role of neotectonic and geomorphological geodynamic associations in the occurrence of Turkey, (in Turkish). Journal of Geomorphology, 5: 15-25.

Erinç, S. 1984. Geomorphological and structural properties and morphometry of the Black Sea basin, (in Turkish). I.U. Marine Science and Geography Institute, Bulletin, 1: 15-22.

Erinç, S. 2001. Geomorphology II (3rd Press), (in Turkish). (Updated by: A. Ertek and C. Güneysu). DER Publ. No: 294.

Erkal, T. 1983. Geomorphology of Yeşilırmak Delta and its environment, (in Turkish). Journal of Geomorphology, 20:13-28.

Erol, O. 1952. A note about Trabzon Terraces, (in Turkish). Ankara Univ. Journal of Language and History-Geography, 1/2: 125-136.

Erol, O. 1979. Quaternary, (in Turkish). AU. DTCF. Publ. No: 289, Ankara.

Ertek, T.A. 1992. Geomorphological investigations in northwest Anatolian coasts (Şile-Kefken), (in Turkish). Turkish Geographical Review, 27: 139-154.

Ertek, T.A., H. Turoğlu, and B. Mater. 1993. Çiftlik landslide (Sinop, Northern Turkey), (in Turkish). Turkish Geographical Review, 28: 181-188.

Ertek, T.A. 1995. Geomorphology of Northeastern Part of Kocaeli Peninsula. (in Turkish) Çantay Bookstore, Istanbul.

Ertek, T.A. 2001. Neo-tectonic movements and beachrock occurence on the coast between Şile-Sahilköy, (in Turkish). Workshop of Turkish Quaternary, 21-22 May 2001, pp: 24-31, İTÜ Avrasya Inst.

Ertek, T.A. and A. Aytaç. 2001. The correlation of the marine terraces in Black Sea Coasts of Turkey, p. 70-74. Workshop of Turkish Quaternary, 21-22 May, İTÜ Avrasya Inst., Istanbul.

Ertek, T.A. and E.N. Evren. 2005. A Geographical Area Analysis: Şile District, (in Turkish). Güven Publishing House. 295 p.

İnandık, İ. 1955. Morphological study of the coasts between Sinop and Terme, (in Turkish). Turkish Geographical Review, 15-16: 21-42.

İnandık, İ. 1957. Morphological study of the coasts between Sinop and Terme, (in Turkish). Turkish Geographical Review, 17: 51-69.

İnandık, H. 1957. Main morphological problems of Turkey's coasts, (in Turkish). Review of I.U. Geography Institute, 8: 67-77.

İnandık, H. 1958. Overview of Turkish coasts, (in Turkish). Review of I.U.Geography Institute, 9: 50-72.

İnandık, H. 1961. Sakarya Delta, (in Turkish). Review of I.U. Geography Institute, 13: 83-98.

Kurter, A. 1963. Morphological Study of Strandja Mountain, (in Turkish). I.U. Geography Institute, Doktora Thesis (Unpublished), Istanbul.

Kurter, A. 1991. Glaciers of Middle East & Africa – Glaciers of Turkey. In R.S. Williams and J.G. Ferrigno [eds.], Satellite Image Atlas of the World, USGS Prof. Paper 1386-G-1, 1-30.

Mater, B. 1994. The impact of land pollutants on the Black Sea in countries with Turkey's coasts. Black Sea and its problems, (in Turkish). Marmara Univ. Publ. No: 553: 27-48.

Mater, B., T.A. Ertek, E. Gürpınar, B. Gönençgil, H. Turoğlu, and M. Uludağ. 1994. The dimensions of environmental problems in the Black Sea, (in Turkish), p. 71-88. KTU. Architecture Regional City Planning Division. 4th National Regional Science / Regional Planning Congress Presentations, Trabzon.

Polymeris, G.S., A.E. Erginal, and N.G. Kiyak. 2012. A comperative morphology, compositional as well as TL study of Bozcaada (Tenedos) and Şile aeolianites, Turkey. Mediterranean Archaeology & Archaeometry, 12(2): 117-131.

Polymeris, G.S., G. Kitis, N.G. Kiyak, E. Theodosoglou, N.C. Tsirliganis, A. Ertek, and A.E. Erginal. 2016. Dating fossil root cast (Black Sea coast, Turkey) using thermoluminescence; implications on windblown drift of shelf carbonates during MIS 2. Quaternary International, 401: 184-193.

Sarıkaya, M.A., A. Çiner, and M. Zreda. 2011. Quaternary glaciation of Turkey. Develeopments in Quaternary Science, 15: 393-403.

Solmaz, F. 1990. Morphology and terraces of Vakfıkebir-Yomra shoreline, (in Turkish). I.U. Social Science Institute Post-graduate Thesis, Istanbul.

Şaroğlu, F., Ö. Emre, and İ. Kuşçu. 1992a. Active Fault Map of Turkey, MTA Publ., Ankara.

Şaroğlu, F., Ö. Emre, and İ. Kuşçu. 1992b. The east Anatolian fault zone of Turkey. Annales Tectonicea, 6: 99-125.

Şengör, A.M.C. 1980. Principles of Turkey's Neotectonics, (in Turkish). Turkish Geological Society, 40.

Şengör, A.M.C. and Y. Yılmaz. 1981. Tethyan evolution of Turkey a plate tectonic approach. Tectonophysics, 75: 181-241.

Tchepalyga, L.A., A.M.C. Şengör, and Y. İslamoğlu. 1997. Late pleistocene marine terraces on the Anatolian coast of the Black Sea. The Late Quaternary in the Eastern Mediterranean International Symposium, pp. 1-4, MTA Ankara.

Uzun, A. 1995. Geomorphology of Gerze-Alaçam coastal region, (in Turkish). Öz Eğitim Publ. No: 3, Konya.

Yalçınlar, İ. 1958. Neogene and quaternary coastal deposits of Samsun Region, (in Turkish). Review of I.U. Geography Institute, 9: 11-21, Istanbul.

Yildirim, C., D. Melnick, P. Ballato, T.F. Schildgen, H. Echtler, A.E. Erginal, N.G. Kıyak, and M.R. Strecker, 2013. Differential uplift along the northern margin of the Central Anatolian Plateau: Inferences from Marine Terraces. Quaternary Science Reviews, 81: 12-28.

Zeybek, H.İ., A. Uzun, C. Yılmaz, and S. Özdemir. 2012. Consequences of coastline changes in Kızılırmak Delta, (in Turkish). Samsun Symposium. 13-16 Oct. 2011, Samsun Governorship Publ. 2: 885-896.

GEOLOGY AND GEOPHYSICS OF THE SOUTHERN SHELF OF THE BLACK SEA

Devrim TEZCAN [1], Mustafa YÜCEL [1] and Günay ÇİFÇİ [2]

[1]Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
[2]Institute of Marine Sciences and Technology, Dokuz Eylül University, Izmir, Turkey
devrim@ims.metu.edu.tr

1. Introduction

The Black Sea is one of the largest anoxic basins in the world. It is surrounded by the North Anatolian Mountains in the south, and the Caucasus and Crimea Mountains in the east and north. It covers an area of 422,000 km^2 with a volume of 534,000 km^3. The Black Sea basin can be divided into four physiographic provinces: the shelf represents about 29.9% of the total area of the sea, the basin slope about 27.3% of the total area, the basin apron, with 30.6%, and the abyssal plain 12.2% (Panin 2008).

The Black Sea is shared between six countries: Bulgaria, Romania, Ukraine, Russia, Georgia and Turkey. The total length of the Black Sea coastline is about 4869 km. The longest coastline is the Turkish coast with a total length of 1700 km from İğneada in the west to Sarp in the east (Stanchev *et al*. 2011).

2. General Settings

The Black Sea is located between the Eurasian plate in the north and the African-Arabian plates in the south. It is generally accepted that the Black Sea formed as a result of a back-arc extension during the Cretaceous in connection with the northward closure of the Tethys Ocean (Robinson 1997, Spadini *et al.* 1996, Nikishin *et al.* 2003). The Black Sea, as a result, is surrounded by Cenozoic orogenic belts: the Pontides in the south, the Caucasus in the east, and the Balkanides in the west and the Crimean Mountains in the north (Robinson *et al.* 1996).

The Black Sea basin has two sub-basins, western and the eastern. The sub-basins are separated by a basement uplift, the Mid Black Sea Ridge that consists of the Andrusov Ridge in the north and the Archangelsky Ridge in the south.

Both sub-basins are tectonically active as a result of the ongoing northward movement of the Arabian plate that causes the westward escape of the Anatolian block along the North and East Anatolian Faults (Rangin *et al.* 2002, Shillington *et al.* 2008).

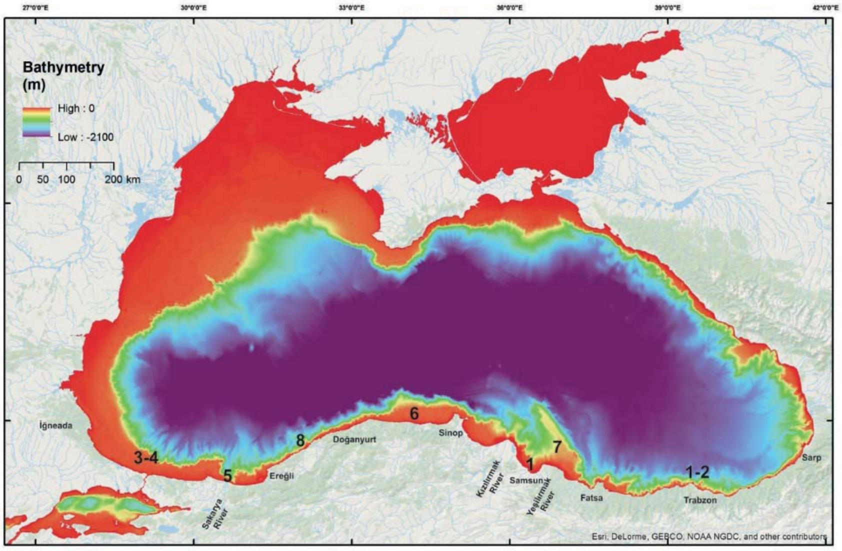

Figure 1. Bathymetry of the Black Sea. The numbers indicate the locations of geological and geophysical survey areas: (1) Okyar *et al.* 1994; (2) Okyar and Ediger 1999; (3) Demirbağ *et al.* 1999; (4) Aksu *et al.* 2002b; (5) Algan *et al.* 2002, 2007; (6) Duman *et al.* 2006; (7) Dondurur and Çifçi 2007, 2009; (8) Dondurur *et al.* 2013

3. Oceanography

The Black Sea is a semi-enclosed basin connected to the Mediterranean Sea via the Turkish Straits System (Bosporus Strait, Marmara Sea and Dardanelles). The water exchange between the Black Sea and the Marmara Sea is restricted by the shallow (32 m) Bosphorus Strait.

The Bosphorus strait is the only source for warm and salty Mediterranean seawater that flows into the Black Sea. Meanwhile, rivers such as Danube, Dniester, Dnieper that have a drainage basin covering almost a third of Europe supply high rates of fresh water fluxes to the Black Sea. This fresh water input forms a surface layer with a low salinity. Due to the salinity gradient of almost 4 units between surface and sub-pycnocline deep waters, the water column is strongly stratified with respect to density (Latif *et al.* 1991). The pycnocline between 100 and 200 m water depth separating surface water with salinity of about 18‰ from the deep saline water (about 22.5‰) restricts vertical mixing (Murray *et al.* 1991). As a result of the vertical stratification, limited ventilation of the deep basin and high amounts of organic matter fluxes, the deep Black

Sea is anoxic and contains high sulfide concentrations (Murray *et al.* 1989, Murray *et al.* 1991) while the surface layer remains well-oxygenated.

The vertical stratification forms a density driven two-layer flow exchange system in the Bosphorus Strait (Ünlüata *et al.* 1990, Özsoy and Ünlüata 1997, Oğuz *et al.* 2004). The surface layer carries the less dense water to the Sea of Marmara, and saltwater from the Mediterranean flows in the basin as a lower layer (Oğuz *et al.* 1990, Özsoy *et al.* 1993).

The saline water from Marmara Sea creates a sub-aqueous saline exchange flow (gravity current) through the Bosphorus Strait into the southwest Black Sea (Latif *et al.* 1991, Özsoy *et al.* 2001, Oğuz 2005, Flood *et al.* 2009, Parsons *et al.* 2010).

4. Rivers

The north-western part of the Black Sea basin receives input from the largest Europeans rivers: the Danube, the Dnieper, the Dniester and the Southern Bug. The Danube is the largest, with an 817,000 km^2 of drainage basin.

The southern coast of the Black Sea abounds with rivers. Most of them are small ephemeral streams, mostly fed by snow and rainwater. The major rivers are Yeşilırmak, Kızılırmak and Sakarya from east to west, respectively. The Yesilırmak is 519 km long and has a catchment area of 36,129 km^2. A delta has been formed at the mouth of Yeşilırmak near Çarşamba. The Kızılırmak, 1 355 km long with a catchment area of 78 646 km^2, is the largest Turkish river flowing into the Black Sea. It flows through a wide coastal plain and reaches the sea near Bafra. The Sakarya River is the second largest Anatolian river discharging into the Black Sea with a drainage area of 56,504km^2 and a length of 824 km.

The north-western part of the Black Sea is the main depocentre for sediment supply from Central Europe via the Danube River (Popescu 2004). However, Dnieper, Dniester and Southern Bug are not significant suppliers of sediments because they discharge their sedimentary load into lagoons separated from the sea by beach barriers (Panin 2008).

Although the contribution of Anatolian rivers to the total freshwater discharge is only 8%, they provide 33% of the total sediment input into the Black Sea (Panin 2008). A distinct feature of the rivers draining to the southern Black Sea is that they bring weathering products from a mostly high-relief, mountainous, humid terrain, which may constitute an unknown but important material source to the Black Sea that may shape the basin’s biogeochemical cycles.

5. Bathymetry and Morphology

The Turkish coastal plain has three regions based on physical geography: the coastal North Anatolian Highland (Pontides) province in the east, the lowlands of the Kocaeli peninsula, from Sakarya to the Bosporus; and the hilly terrain of the Çatalca peninsula (Jaoshvili 2011).

The southern margin of the Black Sea is both morphologically and geologically different from the northern margin (Algan *et al.* 2007). Compared to the north-western shelf that includes the Romanian, Ukrainian and northern part of the Bulgarian Shelf (comprising about 25 % of the total area of the sea), the southern shelf is significantly smaller.

The Turkish coast is generally characterized by a narrow continental shelf (Figure 2). The total surface area of the Turkish shelf is about 28 000 km^2. The shelf break occurs between 110 and 120 m water depth with slopes dipping steeply (5–9^o) to the Black Sea abyssal plain at about 2200 m (Figure 2).

The southwestern shelf that extends from the western boundary of Turkey to the Sakarya delta is generally flat (<1°). This is the largest (36%) shelf along the Turkish coast with an area of 13, 000 km^2. The shelf width reaches 65 km off İğneada. The width decreases gradually towards the Sakarya delta. Off the Bosphorus, the shelf width is about 42 km, and it diminishes to 25 km to the east. Here, the Sakarya submarine canyon dissects the shelf. The heads of the canyon are located at very short distances from the shoreline (Figure 2).

After the heads of the Sakarya Canyon, the shelf width increases to 25 km in the vicinity of the Sakarya delta.

To the east, from Ereğli to Doğanyurt, the shelf progressively narrows, ranging between 3 and 12 km. In this area the slope of the shelf also increases (1-3°). Further east, the shelf area widens to more than 35 km from Doğanyurt to the Kızılırmak delta near Bafra. The minimum width of 10 km is located off the Sinop peninsula. In front of the the Kızılırmak river mouth, the head of Kızılırmak submarine canyon, situated 3 km to the coast, cuts the shelf. Further east, the shelf width has an average of 10 km, but after the Yeşilırmak delta, the width increases to 22 km. Near Fatsa, the shelf is dissected again by a submarine canyon that extends to the shore as close as 1 km (Figure 2).

The coast in the east is partly dominated by steep rocky cliffs due to the presence of North Anatolian Highlands. Thus, eastwards of Fatsa, the shelf becomes narrower until the Georgia border with a maximum width of 8 km. Here in most areas, the shelf edge generally is delineated by the 100 m isobath (Okyar *et al.* 1994).

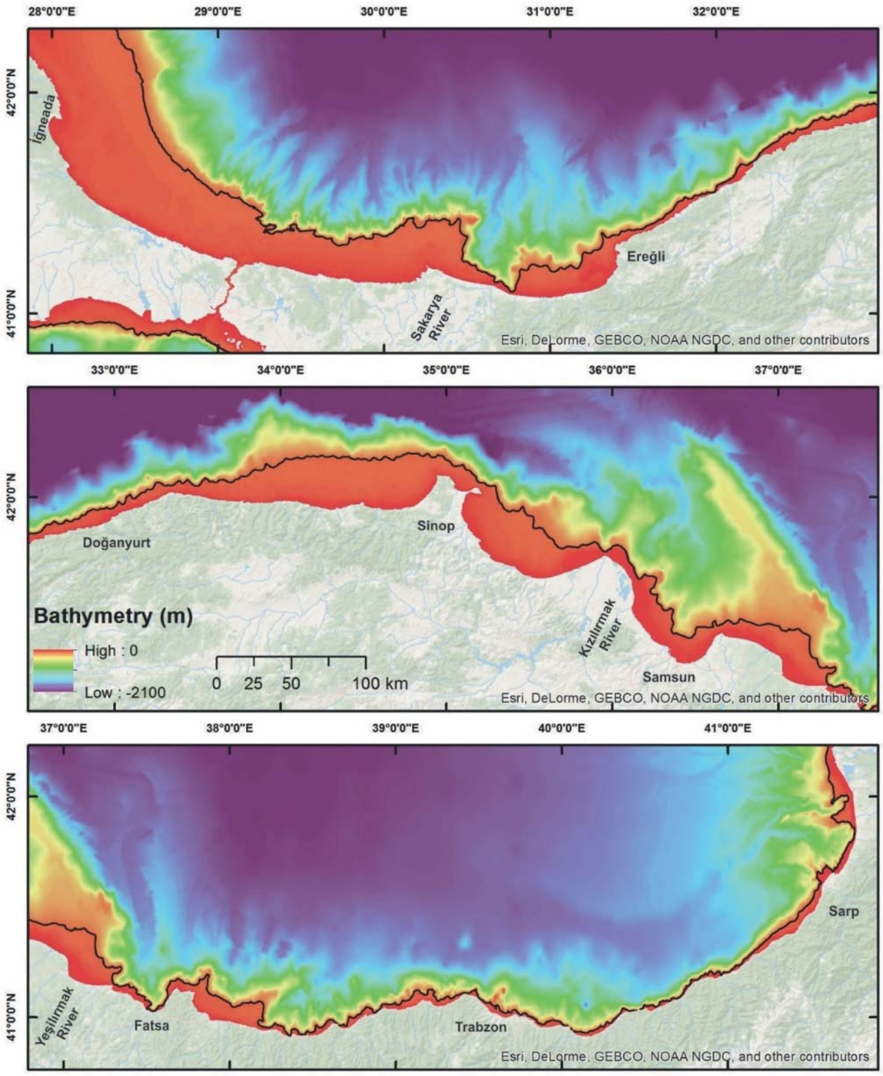

Figure 2. The southern shelf of the Black Sea. The black line shows the 100-meter depth contour

6. Submarine Canyons

The continental shelf edge occurs approximately at the 110 m isobath along the southern Black Sea. The slope is crossed by numerous submarine canyons and gullies extending from shelf to deep water depths of about 2000 m. Major submarine canyons along the Turkish coast of the southern Black Sea are located offshore the Bosphorus strait, the Sakarya River and Kızılırmak River.

The Sakarya Canyon is located off the mouth of the Sakarya River which is the second largest Anatolian river discharging into the Black Sea. Algan *et al.* (2002) have reported that the Sakarya submarine canyon has two heads: one immediately in front of the Sakarya Delta and the other to the east. Both of the canyon heads dissect the Sakarya delta to a water depth of less than 50 m with V-shaped profiles (Algan *et al.* 2002). The eastern head shows a relatively asymmetric profile, but the western canyon displays a relatively symmetric profile. As the canyon dissects all the seismic unit and the erosional surface, Algan *et al.* (2002) have claimed that the Sakarya canyon formed as a result of both tectonic and submarine processes.

The Bosphorus submarine canyon is located 30 km north east of the Black Sea exit of the İstanbul/Bosphorus Strait. The shelf between the canyon and the coast is cut by a channel (Bosphorus channel) that is 200-500 m wide and 10-25 m deep (Aksu *et al.* 2002b). The channel extends in the north east direction for 10 km, then curves towards northwest. After this bend, the main channel splits into many smaller channels. One small channel changes its orientation to northeast and reaches the Bosphorus canyon. The other channels continue 35 km northwest through the shelf to reach the shelf edge.

7. Seismic Stratigraphy

In contrast to the extensive studies in the north-western shelf area, only a few studies (Okyar *et al.* 1994, Okyar and Ediger 1999, Demirbağ *et al.* 1999, Görür *et al.* 2001, Aksu *et al.* 2002a, Algan *et al.* 2002) have been performed to determine the seismic stratigraphy of the narrow Turkish shelf. The study areas are shown in Figure 1.

8. Seismic Units

The stratigraphy of the late quaternary deposits in the south-eastern shelf of the Black Sea have been investigated by Okyar *et al.* (1994). They used high resolution seismic profiles, borehole and sedimentological data to describe the seismic facies and stratigraphy, thickness, and major sedimentary sequences. Seismic data were acquired by an Uniboom seismic system in two study areas located off Samsun and Trabzon (Figure 1).

Okyar *et al.* (1994) has shown that the shelf is formed by two distinct depositional sequences, A and B, which are separated by an erosional surface (Reflector R; Figure 3). They describe Sequence A as simple (parallel), complex (prograding sigmoid) and lenticular stratified reflectors in the sub seafloor of Samsun area. In the nearshore zone off Trabzon, Sequence A is commonly characterized by parallel-subparalel and prograding sigmoidal reflectors similar to that in Samsun. They interpreted the prograding sigmoid configuration of Sequence A in the wedge shaped external form, as being of a deltaic or shallow water origin and possibly related to the high sediment input from the adjacent coastal rivers. The lower depositional sequence B that is characterized by chaotic reflectors is defined either as strata deposited in a variable, relatively high energy setting, or as initially continuous strata that have been deformed (Okyar *et al.* 1994). They claim that the presence of some parallel-sub-parallel reflections within sequence B denote its original stratified character. The erosional unconformity (reflector R) that separates the sequences A and B is defined as a surface formed by falling sea level at the time of the Last Glacial Maximum (Okyar *et al.* 1994; Figure 3).

In the southwestern shelf of the Black Sea, Demirbağ *et al.* (1999) investigated the effects of the opening of the Strait of Istanbul (Bosporus) on the shelf using a sparker seismic system (Figure 1).

They identified five different seismic stratigraphic units based on their seismic reflection configurations on high resolution shallow seismic data collected from the southwestern shelf. The units A, B and C that belong to the Upper Cretaceous–Eocene, Oligocene–Miocene and Early Quaternary (prior to Holocene) sediments, constitute the basement for the Quaternary deposits (Units D and E).

They defined unit D as a depositional unit that had been deposited on a truncated surface. The truncation surface underlies the units A, B and C. They indicate that Unit D covers units B and C with onlap at the shelf edge. Although they did not observe on their seismic data because of the lack of vertical resolution, they assume that a thin layer (Unit E) should be present on top based on the cores and higher resolution seismic data from other studies (Alpar *et al.* 1997, Ryan *et al.* 1997). Demirbağ *et al.* (1999) also argue that the recent sediments of the Strait of Istanbul must have been simultaneously deposited with the unit D.

Another study in the southwestern shelf of the Black has been carried out by Aksu *et al.* (2002b). Using a single channel seismic reflection system, Huntec deep-tow boomer and sparker profiles, they identified five distinct seismic stratigraphic sequences (Unit 1, 2, 3, 4 and 5 from younger to older, respectively) separated by four unconformity surfaces (α, β, γ and δ).

They have reported that the southwestern Black Sea shelf is formed by a protracted shelf - edge progradation since the Miocene-Pliocene. The youngest sequence Unit 1 is defined as the last phase of the progradational history that deposited during the last glacial lowstand and Holocene.

Unit 1 is divided into four subunits: Subunit 1A is interpreted as a lowstand systems tract, 1B and 1C are interpreted as a transgressive systems tract, and Subunit 1D is interpreted as a highstand systems tract (Figure 3). They associated the transgressive systems tract units with the last Glacial-Holocene sea level rise.

Overlying all older units, Unit 1 deposited over a major shelf-crossing unconformity (α), identified by a strong and regionally distinctive reflector on seismic profiles. This unconformity is recognized across the entire width of the southwestern Black Sea shelf extending into the shelf-slope break at 100-120 m.

Further east, off the Sakarya river mouth, Algan *et al.* (2002) studied the submarine delta and the canyon to determine the sedimentary evolution of the Sakarya delta and the Sakarya submarine canyon.

They have reported the presence of three units based on the analysis of high-resolution seismic profiles: Unit 1, 2 and 3 (Figure 3).

Unit 1 is a progradational seismic unit composed of seawardly dipping reflectors which show parallelism and concordance in regions proximal to the Sakarya River mouth and downlap and offlap terminations in distal areas. This unit is interpreted as the present-day compound deltaic complex of the Sakarya River. Unit 2 is described as a lowstand deposit located at the edge of shelf break that is overlain only with a thin drape, where Unit 1 is absent. It has an oblique-parallel progradational internal configuration. Unit 3 is the oldest unit lying beneath Unit 1 in the shelf area and Unit 2 at the shelf edge. The boundary between Unit 3 and Unit 1 is a major erosional surface. Unit 3 is formed by locally folded and faulted acoustically reflective strata. Unit 3 has inclined parallel internal reflectors, but they are highly deformed in active fault zones. It is interpreted as an extension of land basement units consisting of Upper Cretaceous limestone, volcanogenic sedimentary rocks, and also Oligocene- Lower Miocene sedimentary sequences (Oktay *et al.* 1992, Yılmaz *et al.* 1997).

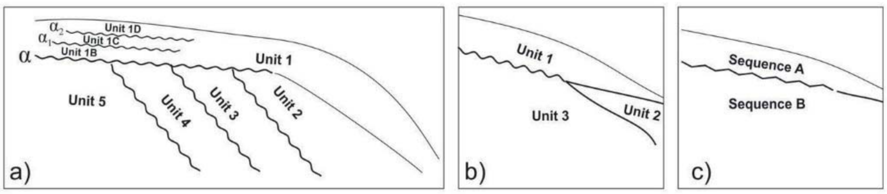

Figure 3. Schematic illustration of the relationships between seismic-stratigraphic units: (a) Aksu *et al.* 2002b, (b)Algan *et al.* 2002, (c) Okyar *et al.* 1994

9. Erosional Surface

Several seismic surveys on the shelf of Black Sea in many locations have identified a major unconformity surface on seismic data. It is widely accepted that this surface on the shelf is formed under the sub-aerial conditions when the shelf was exposed during the latest glaciation.

This erosional surface was reported on the Romanian shelf (Popescu *et al.* 2004, Lericolais 2001, Lericolais *et al.* 2003, Lericolais *et al.* 2007), on the Bulgarian shelf (Coleman and Ballard 2007, Dimitrov and Peychev 2005, Genov *et al.* 2004, Dimitrov 1982, Khrischev and Georgiev 1991).

Many authors observed a similar surface on seismic data on the Turkish margin of the Black Sea (Aksu *et al.* 2002b, Algan *et al.* 2002, 2007, Demirbag *et al.* 1999, Okyar and Ediger 1999, Okyar *et al.* 1994).

Off Samsun and Trabzon in the south-eastern shelf of the Black Sea, Okyar and Ediger (1999) and Okyar *et al.* (1994) have reported an erosional unconformity surface (reflector R) that is probably caused by falling sea level at the time of the Last Glacial Maximum. This surface exhibits a toplap termination with the seaward dipping reflectors of the underlying sequence at 91 m depth that indicates a stillstand of sea level during the Last Glacial Maximum.

In the southwestern shelf of the Black Sea, Demirbağ *et al.* (1999) have described the boundary between the depositional unit (Unit D) and the older units as a palaeoshoreline during the low stand in the Early Holocene. They observed the first onlap on the older units at about 105 m depth indicating the ancient shoreline prior to the drowning of the Black Sea shelf.

In another study on the southwestern shelf, Aksu *et al.* (2002b) identified a strong and regionally distinctive reflector (α), which is interpreted as a major shelf-crossing unconformity extending into the shelf-slope break at 100-120 m.

In the Sakarya delta plain, Algan *et al.* (2002) have defined a major erosional surface separating the deltaic complex of the Sakarya River from the older units. They claim that the sedimentary wedge of Unit 2, located at the shelf edge, the shelf area must have been exposed to subaerial erosion. This erosional surface between Units 3 and 1 in the shelf extends to shelf edge where it overlies Unit 2. They conclude that the paleoshoreline of this lowstand period was at a water depth of 105 m.

10. Sedimentology

Although little is known about the sedimentology of the shallow shelves along the southern Black Sea (Duman *et al.* 2006), it is generally accepted that most of the sediments accumulated on continental shelves are generated inland and transported by fluvial systems (Lericolais *et al.* 2010), while a contribution from the local organic matter production and deposition of the planktonic debris is also an important factor.

In the southwestern Black Sea shelf, sediments are mainly transported by the two major rivers which are the Sakarya River and Filyos River (Duman *et al.* 2006).

Duman *et al.* (2006) collected 85 surface sediment samples from the shelf of south-central Black to investigate the contemporary sedimentary processes and the sources of these surficial sediments. The seafloor sediment samples were collected in areas representing anoxic, suboxic and oxic conditions. The grain size analysis show that the surface sediments in the study area on the shelf and upper slope consist of clayey silts and silty clays (Duman *et al.* 2006). The sediment trend analysis based on the grain size parameters (size, sorting and skewness) indicates that the main sediment transport is largely eastward along the southern central Black Sea shelf.

Yücesoy and Ergin (1992) collected 47 surface sediment samples along the southern shelf and upper slope of the Black Sea. Based on the grain size analysis, the samples consist of a wide variety of textural classes, from mud to sandy gravel. They indicate that the sediments off the mouth of major rivers (Sakarya, Yeşilırmak and Kızılırmak) are characterized by relatively high mud portions mainly due to the high sediment loads from these rivers. Coarser sediments are found off the Bosphorus and Rize indicating high-energy conditions in these areas.

11. Mass Wasting

Like many other locations in Black Sea, few mass wasting events also have been reported along the southern shelf of the Black Sea.

Okyar *et al.* (1994) have demonstrated mounded seismic facies on seismic data acquired off Trabzon. They suggest that this conical to asymmetrical features which start immediately beyond the slope are the indication of slump masses.

Ergün *et al.* (2001) and Çifci *et al.* (2003) showed that several slump and slide features are located approximately at a depth of 300 m off Yeşilırmak delta.

Ballard *et al.* (2001) have reported a complex bottom morphology at north of Sinop formed as a result of massive slumps and landslides.

Algan *et al.* (2002) highlighted some irregularities in the Sakarya submarine canyon walls which have possibly formed by mass movement as a result of both tectonic and submarine processes.

Dondurur *et al.* (2013) investigated intensely the western Turkish margin in Black Sea using multi-channel seismic, multibeam bathymetry and Chirp high resolution seismic data due to its potential for petroleum. They have identified four slides and four buried debris lobes in an unstable area offshore of Amasra what they named "Amasra mass failure zone". They suggest that all kind of mass movements that they observed in the area are probably triggered by earthquake activities.

12. Gas Occurrence

Different kinds of gas occurrences on the Black Sea floor have been studied for a long time. As a result of these studies many gas related features such as gas seepages, submarine mud volcanoes and gas hydrates have been reported in many places in Black Sea (*e.g.*, Ginsburg *et al.* 1990, Limonov *et al.* 1994, Ivanov *et al.* 1996, Ivanov and Woodside 1996, Woodside *et al.* 1997, Kruglyakova *et al*. 2004)

Similarly, a number of researcher have demonstrated the evidences for shallow gas in marine sediments in the southern Black Sea.

Okyar and Ediger (1999) have observed anomalous zones on high-resolution seismic profiles collected on the south-eastern shelf. They have interpreted these anomalies as acoustic turbidity zones formed due to the presence of gas in the sediments.

The gas accumulation in the sediments of the upper unit (Sequence A in Okyar *et al.* 1994) has been observed as rising to within 2-15 m of the seabed without reaching the surface.

They have concluded that the gas in sediments is mainly methane of biogenic origin based on seismic and previous geochemical evidence. They haven't observed any gas seepages in the seismically surveyed areas.

Aksu *et al.* (2002) have highlighted the existence of mud volcanoes on the southwestern shelf. They have imaged the mud volcanoes using high resolution seismic and side-scan sonar. The volcanoes are 200-300 m in diameter, reach 20-25 m in height above the seafloor. They are predominantly found at 90-120 m water depths.

Çifci *et al*. (2003) have reported circular and elongated pockmarks on the overlying plateau of the Archangelsky Ridge off the Yeşilırmak delta, between 180 and 300 m water depths. They have identified several buried pockmarks in vertically stacked form in the deeper sedimentary strata indicating that the migration of gas is repeated periodically over certain periods of time rather than a continuous gas migration to the seabed.

Dondurur and Çifci (2009) have observed pockmarks and several strong reflections on deep-towed, high resolution sub-bottom profiler data in the Turkish shelf and upper slope of the Eastern Black Sea at the water depths of 250 to 700 m. They have claim that the strong reflections located at the subsurface depths of 25-60 metres below the sea floor might be similar to the reflectors observed by Woodside *et al.* (2003) in the Sorokhin Trough in central Black Sea, where gas hydrates were also sampled using a gravity corer.

In the south-western Black Sea margin, off Amasra, Dondurur *et al.* (2013) have observed acoustic turbidity zones and bottom simulating reflector (BSR) on multichannel seismic profiles in approximately 180 metres below the sea floor, especially below the slide zones. They have argued that the BSRs might be the base of gas hydrate accumulation zone. They also have identified some possible gas accumulations and gas chimneys beneath the headwalls of the slides. They have concluded that gas occurrence in the form of shallow gas accumulation, gas seepage and gas hydrate dissociation as one of the factors that control the slope stability along the margins.

13. Re-Connection

The Black Sea is connected to the Mediterranean Sea by the shallow straits, Bosphorus and Dardanelles, with sill depths of 32 and 70 meters, respectively. Therefore, during the global sea level lowstands in glacial periods, the Black Sea was isolated and the water exchange between the Black Sea and the Mediterranean was interrupted. Following the Last Glacial Maximum (LGM) sea level rose and connected the Black Sea to the Mediterranean.

The last reconnection of the Mediterranean with the Black Sea has been a hot topic of research for the last two decades. It is still a matter of debate how this connection happened.

Ryan *et al.* (1997) have proposed that when the Mediterranean water reached the level of the Bosphorus, the water level in Black Sea was about 100 m below the present sea level. Then they argue that the Mediterranean waters flowed in to the Black Sea as a rapid flooding. They also suggest that this catastrophic flooding might be related to the origins of the Biblical Noah's Flood story.

The main evidence of the hypothesis of catastrophic flooding was based on a seismic survey on the northern continental shelf of Black Sea (Ryan *et al.* 1997). The seismic profiles reveal an erosional surface underlying a thin, uniform, transparent mud drape. They claim that there is no evidence of transgressive features that can be associated with a slow rise in sea level. The same erosion surface was reported at many different Black Sea shelf locations (see above). The authors also showed the lowstand shorelines characterized by wave-cut terraces in different areas of the Black Sea as another evidence of their hypothesis (Dimitrov 1982, Ryan *et al*. 1997, 2007; Ballard *et al*. 2000, Lericolais *et al*. 2003, 2007).

A number of researchers have supported this view (Siddall *et al*. 2004, Gökaşan *et al*. 2005, Algan *et al*. 2007, Eriş *et al*. 2007, 2008, Lericolais *et al*. 2007). However, several other researchers have rejected the hypothesis of catastrophic flooding (Aksu *et al*. 1999, 2002a, b, Görür *et al*. 2001, Hiscott and Aksu 2002, Hiscott *et al.* 2002, 2008; Yanko-Hombach *et al*. 2007, 2014).

Using seismic data obtained on the shelf off the Bosphorus, Aksu *et al.* (2002b) showed that the top unit (Unit 1) overlying the erosional surface (α) has transgressive systems tract components that are associated with the last Glacial-Holocene sea level rise. They suggested that the Black Sea level rose gradually since the LGM. Moreover, it has been claimed that an outflow from the Black Sea into the Marmara Sea via Bosphorus strait exists since ~10.5 ky BP. Until ~8.5 ky BP there was only one-way flow through the strait; the two-way flow system has been established since ~8.5 ky BP (Hiscott *et al.* 2007).

Some other authors also suggested a gradual rise of the sea level in an oscillating manner and some alternative connections, Izmit Bay–Sapanca Lake–Sakarya River, between Black Sea and the Marmara Sea (Yanko-Hombach *et al.* 2007).

Since there are many studies on this subject, the reader is referred to books with compilation of different hypotheses entitled: "The Black Sea Flood Question. Changes in Coastline, Climate and Human Settlement", edited by Yanko-Hombach *et al.* (2007) and "Geology and Geoarchaeology of the Black Sea Region: Beyond the Flood Hypothesis" edited by Buynevich *et al.* (2011).

14. Future Research Directions

The southern part of the Black Sea shelf is a morphologically complex area that combines a unique set of seafloor features such as submarine canyons, river deltas, smoothly deepening slopes and pockmarks. Detailed bathymetric maps of certain economically important sections of the shelf still needs to appear in scientific publications. Targeted coring, with both long gravity cores and short cores, is needed to resolve how this unique seafloor section of the Black Sea influences the turnover of material and biological fluxes.

References

Aksu, A.E., R.N. Hiscott, P.J. Mudie, A. Rochon, M.A. Kaminski, T. Abrajano, and D. Yaar. 2002a. Persistent holocene outflow from the Black Sea to the eastern Mediterranean contradicts Noah's flood hypothesis. GSA Today, 12(5): 4-10.

Aksu, A.E., R.N. Hiscott, D. Yasar, F.I. Isler, and S. Marsh. 2002b. Seismic stratigraphy of Late Quaternary deposits from the southwestern Black Sea shelf: evidence for non-catastrophic variations in sea-level during the last 10000 yr. Marine Geology, 190(1-2): 61-94.

Algan, O., E. Gökaşan, C. Gazioğlu, Z.Y. Yücel, B. Alpar, C. Güneysu, E. Kirci, S. Demirel, E. Sari, and D. Ongan. 2002. A high-resolution seismic study in Sakarya Delta and Submarine Canyon, southern Black Sea shelf. Continental Shelf Research, 22(10): 1511-1527

Algan, O., M. Ergin, E. Keskin, E. Gökasan, B. Alpar, D. Ongan, and E. Kirci-Elmas. 2007. Sea-level changes during the Late Pleistocenee Holocene on the southern shelves of the Black Sea, pp. 603e631. In: V. Yanko-Hombach, A.S. Gilbert, N. Panin, P.M. Dolukhanov [eds.], The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, New York (USA).

Alpar, B., M.A. Danisman, E. Gökagan, E. Dogan, V. Gainanov, and A. Zverev. 1997. Design of a single channel high resolution digital seismic system and some geological results. Turk. J. Mar. Sci. 3(2): 49-63.

Ballard, R.D., D.F. Coleman, and G.D. Rosenburg. 2000. Further evidence of abrupt Holocene drowning of the Black Sea shelf. Marine Geology, 170: 253-261.

Ballard, R.D., T.H. Fredrik, F.C. Dwight, C. Ward, J. S. Smith, K. Willis, B. Foley, K. Croff, C. Major, and F. Torre, 2001. Deepwater Archaeology of the Black Sea: The 2000 Season at Sinop, Turkey. American Journal of Archaeology, 105(4): 607-623.

Cifci, G., D. Dondurur, and M. Ergun. 2003. Deep and shallow structures of large pockmarks in the Turkish Shelf, Eastern Black Sea. Geo-Marine Letters, 23: 311-322.

Coleman, D. and R.D. Ballard. 2007. Submerged paleoshorelines in the southern and western Black Sea–implications for inundated prehistoric archaeological sites, pp. 671. In V. Yanko-Hombach, A.S. Gilbert, N. Panin, P.M. Dolukhanov [eds.], The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, New York (USA).

Demirbag, E., E. Gökasan, F.Y. Oktay, M. Simsek, and H. Yüce. 1999. The last sea level changes in the Black Sea: evidence from the seismic data. Marine Geology, 157(3-4): 249-265.

Dimitrov, P.S. 1982. Radiocarbon datings of bottom sediments from the Bulgarian Black Sea Shelf: Bulgarian Academy of Science. Oceanology, 9: 45-53.

Dimitrov, P. and V. Peychev. 2005, Changes of the area, capacity and average depth of the Black Sea during Quaternary period: Proceedings of Oceanology, 5: 135-143.

Dondurur, D. and G. Cifci. 2007. Acoustic structure and recent sediment transport processes on the continental slope of Yesilirmak River fan, Eastern Black Sea. Marine Geology, 237(1-2): 37-53.

Dondurur, D. and G. Cifci. 2009. Anomalous strong reflections on high resolution seismic data from the Turkish shelf of the Eastern Black Sea: possible indicators of shallow hydrogen sulphide-rich gas hydrate layers. Turkish Journal of Earth Sciences, 18(2): 299-313.

Dondurur, D., M. Küçük, and G. Çifçi. 2013. Quaternary mass wasting on the western Black Sea margin, offshore of Amasra. Global and Planetary Change, 103.

Duman, M., S. Duman, T.W. Lyons, M. Avcı, E. Izdar, and E. Demirkurt. 2006. Geochemistry and sedimentology of shelf and upper slope sediments of the south-central Black Sea. Marine Geology, 22 (1-2): 51-65.

Ergün, M, G. Cifci, and D. Dondurur. 2001. High resolution seismic and sonar characteristics of the Eastern Black Sea Turkish Continental slope. In 36^{th} CIESM Congr, Monaco. Rapp Comm Int Mer Mediterranee, 36.

Eriş, K.K., W.B.F. Ryan, M.N. Çağatay, U. Sancar, G. Lericolais, G. Menot, and E. Bard. 2007. The timing and evolution of the post-glacial transgression across the Sea of Marmara shelf south of Istanbul. Mar. Geol., 243: 57-76.

Eriş, K., W.B.F. Ryan, M.N. Çağatay, U. Sancar, G. Lericolais, G. Menot, and E. Bard. 2008. Reply to comment on "The timing and evolution of the post-glacial transgression across the Sea of Marmara shelf south of Istanbul" by Hiscott *et al.* Mar. Geol., 248: 228-236.

Flood, R.D., R.N. Hiscott, and A.E. Aksu. 2009. Morphology and evolution of an anastomosed channel network where saline underflow enters the Black Sea. Sedimentology, 56: 807-839.

Genov, I., K. Slavova, and P. Dimitrov. 2004. Geological events as result from the climatic changes in the Black Sea Region during the period 20000-7000 calendar years BP, pp. 577-584. In Proceedings of the International Symposium of Earth System Science (8-10 Sept 2004, Istanbul University), organized by Istanbul University, the Institute of Marine Sciences and Management, and the Department of Geography, Kelebek and Grafika Grup, Istanbul.

Geology and Geoarchaeology of the Black Sea Region: Beyond the Flood Hypothesis, 2011. In I.V. Buynevich, V. Yanko-Hombach, A. Gilbert, R.E. Martin [eds.], Special Paper 473, The Geological Society of America.

Ginsburg, G.D., A.N. Kremlev, M.N. Grigorev, G.V. Larkin, A.D. Pavlenkin, and N.A. Saltykova.1990. Filtrogenic gas hydrates in the Black Sea. Soviet Geology and Geophysics, 31: 8-16.

Gökaşan, E., H. Tur, B. Ecevitoglu, T. Görüm, A. Türker, B. Tok, F. Çağlak, H. Birkan, and M. Şimşek. 2005. Evidence and implications of massive erosion along the Strait of Istanbul (Bosphorus). Geo.Mar. Lett., 25(5): 324-342.

Gorur, N., M.N. Çağatay, Ö. Emre, B. Alpar, M. Sakınç, Y. İslamoğlu, O. Algan, T. Erkal, M. Keçer, R. Akkök, and G. Karlık. 2001. Is the abrupt drowning of the Black Sea shelf at 7150 yr BP; a myth? Marine Geology, 176(1-4): 65-73.

Hiscott, R.N. and A.E. Aksu. 2002. Late Quaternary history of the Marmara Sea and Black Sea from high-resolution seismic and gravity-core studies. Marine Geology, 190: 261-282.

Hiscott, R.N., A.E. Aksu, D. Yaşar, M.A. Kaminski, P.J. Mudie, V.E. Kostylev, J.C. MacDonald, F.I. Isler, and A.R. Lord. 2002. Deltas south of the Bosphorus Strait record persistent Black Sea outflow to the Marmara Sea since 10 ka. Marine Geology, 190: 95e118.

Hiscott, R.N., A.E. Aksu, P.J. Mudie, F. Marret, T. Abrajano, M.A. Kaminski, J. Evans, A.I. Çakıroğlu, and D. Yaşar. 2007. A gradual drowning of the southwestern Black Sea shelf: evidence for a progressive rather than abrupt Holocene reconnection with the eastern Mediterranean Sea through the Marmara Sea Gateway. Quaternary International 167-168: 19-34.

Hiscott, R.N., A.E. Aksu, and P.J. Mudie. 2008. Comment on "The timing and evolution of the post-glacial transgression across the Sea of Marmara shelf south of Istanbul" by Eriş *et al.* Mar. Geol., 248: 228-236.

Ivanov, M.K. and J.M. Woodside.1996. Shallow gas and gas hydrates on the Crimean continental margin, Black Sea, p. 46. Gas Hydrates: relevance to world margin stability and climatic change symposium, Gent, Belgium.

Ivanov, M.K., A.F. Limonov, and T.C.E. Van Weering. 1996. Comparative characteristics of the Black Sea and Mediterranean ridge mud volcanoes. Marine Geology, 132: 253-271.

Jaoshvili, S. 2011. The rivers of the Black Sea. European Environment Agency, Technical Report, No: 71.

Khrischev, K.G. and V.M. Georgiev. 1991. Regional washout on the Pleistocene-Holocene boundary in the western Black-Sea depression: Comptes Ren- Dus De L'academie Bulgare Des Sciences, 44(9): 69-71.

Kruglyakova, R.P., Y.A. Byakov, M.V. Kruglyakova, L.A. Chalenko, and N.T. Shevtsova. 2004. Natural oil and gas seeps on the Black Sea floor. Geo-Mar. Lett., 24: 150-162.

Latif, M.A., E. Özsoy, T. Oğuz and Ünlüata, Ü. 1991. Observations of the Mediterranean inflow into the Black Sea. Deep Sea Research, 38 (2): 711-723.

Lericolais, G. 2001. La catastrophe du Bosphore. Pour la Science 284: 30-37.

Lericolais, G., I. Popescu, N. Panin, W.B.F. Ryan, and F. Guichard. 2003. Last rapid flooding in the Black Sea, p. 39. In S. Uscinowicz, J. Zachowicz [eds.], Rapid transgressions into semi- enclosed basins. IGCP 464. Polish Geological Institute, Gdansk.

Lericolais, G., I. Popescu, F. Guichard, S.M. Popescu, and L. Manolakakis. 2007. Water-level fluctuations in the Black Sea since the Last Glacial Maximum, pp. 437-452. In V. Yanko-Hombach, A.S. Gilbert, N. Panin, P.M. Dolukhanov [eds.], The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer.

Lericolais, G., F. Guichard, C. Morigi, A. Minereau, I. Popescu, and S. Radan. 2010. A post younger dryas Black Sea regression identified from sequence stratigraphy correlated to core analysis and dating. Quaternary International, 225(2): 199-209.

Limonov, A.F., J.M. Woodside, and M.K. Ivanov. 1994. Mud volcanism in the Mediterranean and the Black Seas and shallow structure of the Eratosthenes seamount. UNESCO Reports in Marine Sciences 64.

Murray, J.W., H.W. Jannasch, S. Honio, R.F. Anderson, W.S. Reeburgh, Z. Top, G.E. Friederich, L.A. Codispoti, and E. Izdar. 1989. Unexpected changes in the oxic/anoxic interface in the Black Sea. Nature (London), 338(6214): 411-413.

Murray, J., W.Z. Top, and E. Özsoy, 1991. Hydrographic properties and ventilation of the Black Sea. Deep-Sea Res., 38(2): 663-689.

Nikishin, A.M., M.V. Korotaev, A.V. Ershov, and M. Brunet. 2003. The Black Sea basin: tectonic history and Neogene–Quaternary rapid subsidence modeling. Sedimentary Geology, 156: 149-168.

Oğuz, T., E. Özsoy, M.A. Latif, H.I. Sur, and Ü. Ünlüata. 1990. Modeling of hydraulically controlled exchange in the Bosporus strait. Physical Oceanography, 20(7): 945-965.

Oğuz, T., S. Tugrul, A.E. Kideys, V. Ediger, and N. Kubilay. 2004. Physical and biogeochemical characteristics of the Black Sea, pp. 1331-1369. In A.R. Robinson, K.H. Brink [eds.], The Sea, Volume 14B: The Global Coastal Ocean: Interdisciplinary Regional Studies and Synthesis. Harvard University Press, Cambridge, MA.

Oğuz, T. 2005. Hydraulic adjustments of the Bosphorus exchange flow. Geophys. Res. Lett. 32: L06604.

Oktay, F.Y., R.H. Eren, and M. Sakınc. 1992. Sedimentary geology of the eastern Thrace Oligocene basin in the region of Karaburun-Yeniköy (Istanbul) (in Turkish). Proceedings of the 9th Petroleum Congress of Turkey, Ankara, 17–21 February 1992, 92–101

Okyar, M., V. Ediger, and M. Ergin. 1994. Seismic stratigraphy of the southeastern Black Sea shelf from high-resolution seismic records. Marine Geology, 121: 213-230.

Okyar, M. and V. Ediger. 1999. Seismic evidence of shallow gas in the sediment on the shelf off Trabzon, southeastern Black Sea. Continental Shelf Research, 19: 575-587.

Özsoy, E., U. Ünlüata, and Z. Top. 1993. The Mediterranean water evolution, material transport by double diffusive intrusions, and interior mixing in the Black Sea. Prog. Oceanogr., 31: 275-320.

Özsoy, E. and Ü. Ünlüata. 1997. Oceanography of the Black Sea: a review of some recent results. Earth Sci. Rev., 42: 231-272.

Özsoy, E., D. Di Iorio, M.C. Gregg, and J.O. Backhaus. 2001. Mixing in the Bosphorus Strait and the Black Sea continental shelf: observations and a model of the dense water outflow. J. Mar. Syst., 31: 99-135.

Panin, N. 2008. General Oceanographic Properties: Geography, Geology and Geochemistry, 421 pp. In T. Oguz [ed.], BSC, 2008. State of the Environment of the Black Sea (2001-2006/7). Publications of the Commission on the Protection of the Black Sea Against Pollution (BSC) 2008-3, Istanbul, Turkey.

Parsons, D.R., J. Peakall, A.E. Aksu, R.D. Flood, R.N. Hiscott, Ş. Beşiktepe, and D. Mouland. 2010. Gravity-driven flow in a submarine channel bend: direct field evidence of helical flow reversal. Geology, 38: 1063-1066.

Popescu, I. G. Lericolais, N. Panin, A. Normand, C. Dinu, and E. Le Drezen. 2004. The Danube Submarine Canyon (Black Sea): morphology and sedimentary processes. Marine Geology, 206(1-4): 249-265.

Rangin, C., A.G. Bader, G. Pascal, B. Ecevitoglu, and N. Gorur, 2002. Deep structure of the Mid Black Sea High (offshore Turkey) imaged by multi-channel seismic survey (BLACKSIS cruise). Marine Geology, 182(3-4): 265-278.

Robinson, A.G., J.H. Rudata, C.J. Banksa, and R.L.F. Wilesa. 1996. Petroleum geology of the Black Sea. Marine and Petroleum Geology, 13(2): 195-223.

Robinson, A.G. 1997. Regional and petroleum geology of the Black Sea and surrounding region. Memoir, 68. American Association of Petroleum Geologists, Tulsa, USA.

Ryan, W.B.F., W.C. Pitman, C.O. Major, K. Shimkus, V. Mokalenko, G.A. Jones, P. Dimitrov, N. Görür, M. Sakinç, and H. Yüce. 1997. An abrupt drowning of the Black Sea shelf. Marine Geology, 138(1-2): 119-126.

Ryan, W.B.F. 2007. Status of the Black Sea flood hypothesis, pp. 63-88. In V. Yanko-Hombach, A.S. Gilbert, N. Panin, P.M. Dolukhanov [eds.], The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement.

Shillington, D.J., N. White, T.A. Minshull, G.R.H. Edwards, S.M. Jones, R.A. Edwards, and C.L. Scott. 2008. Cenozoic evolution of the eastern Black Sea: a test of depth-dependent stretching models. Earth and Planetary Science Letters, 265: 360-378.

Siddall, M., L.J. Pratt, and K.R. Helfrich. 2004. Testing the physical oceanographic implications of the suggested sudden Black Sea infill 8400 years ago. Paleoceanography, 19: 1-11.

Spadini, G., A.G. Robinson, and S.A.P.L. Cloetingh. 1996. Western versus eastern Black Sea tectonic evolution: pre-rift lithospheric controls on basin formation. Tectonophysics, 266: 139-154.

Stanchev, H., A. Palazov, M. Stanceva, and A. Apostolov. 2011. Determination of the Black Sea area and coastline length using gis methods and landsat 7 satellite images. Geo-Eco-Marina, 17: 27.

Ünlüata, Ü., T. Oğuz, M.A. Latif, and E. Ozsoy. 1990. On the physical oceanography of the Turkish Straits, pp. 25-60. In L.J. Pratt [ed.], The Physical Oceanography of Sea Straits. NATO/ ASI Series. Kluver, Dordrecht.

Woodside, J.M., M.K. Ivanov, and A.F. Limonov. 1997. Neotectonics and fluid flow through sea floor sediments in the eastern Mediterranean and Black Seas-Parts I and II. UNESCO Reports. Marine Sciences, 48.

Woodside, J.M., D.I. Modin, and M.K. Ivanov. 2003. An enigmatic strong reflector on subbottom profiler records from the Black Sea-the top of shallow gas hydrate deposits. Geo-Marine Letters, 23: 269-277.

Yanko-Hombach, V., A.S. Gilbert, and P. Dolukhanov. 2007. Controversy over the great flood hypotheses in the Black Sea in light of geo- logical, paleontological, and archaeological evidence. Quaternary International, 167-168: 91-113.

Yanko-Hombach, V., A.S. Gilbert, N. Panin, and P. Dolukhanov. (eds.) 2007. The Black Sea Flood Question: Changes in Coastline, Climate, and Human Settlement. Springer, Yanko-Hombach, V., P.J. Mudie, S. Kadurin, and E. Larchenkov. 2014. Holocene marine transgression in the Black Sea: new evidence from the northwestern Black Sea shelf. Quaternary International, 345: 100-118.

Yılmaz, Y., O. Tüysüz, E. Yiğitbaş, S.C. Genç, and A.M.C. Şengör. 1997. Geology and Tectonic evolution of the Pontides, pp. 183-226. In A.G. Robinson [Ed.], Regional and Petro- leum Geology of the Black Sea and Surrounding Region: AAPG Memoir 68, Tulsa, Oklahoma.

Yücesoy, F. and Ergin, M. 1992. Heavy-metal geochemistry of surface sediments from the southern Black Sea shelf and upper slope. Chem. Geol., 99: 265-287.

NUTRIENTS, CHLOROPHYLL-*A* AND DISSOLVED OXYGEN DYNAMICS IN THE COASTAL WATER BODIES AND MARINE WATERS OF THE SOUTHERN BLACK SEA

Çolpan POLAT BEKEN [1], Hakan ATABAY [1], Mustafa MANTIKÇI [1], İbrahim TAN [1], Süleyman TUĞRUL [2], Dilek EDİGER [3], Cihangir AYDÖNER [1], Hacer SELAMOĞLU ÇAĞLAYAN [4], Ebru OLGUN EKER [4] and Serap KANTARLI [4]

[1]TUBITAK- MRC, Institute of Environment and Cleaner Production, Gebze, Kocaeli, Turkey
[2]Middle East Technical University Institute of Marine Science, Erdemli, Mersin, Turkey
[3]Istanbul University Institute of Marine Science and Management, Vefa, İstanbul, Turkey
[4]Ministry of Enviroment and Urbanization of Turkey, General Directorate of Environmental Impact Assessment Permits and Control/Dept. of Laboratory, Measurement and Monitoring Gölbaşı, Ankara, Turkey
colpan.beken@tubitak.gov.tr

1. Introduction

Black Sea has been one of the best studied part of the world oceans, attracting researchers from all over the world besides its own experts. This is not only because of its natural peculiarities but also the dramatic consequences of the pressures exerted on it for almost half a century. Large fresh water inputs versus limited saline water intrusion from the Bosphorus (İstanbul) Strait as well as the response of the hydrological system to the climatic variability are the main factors controlling the spatial and temporal changes of the hydrochemistry of the water column and the surface waters (Sorokin 2002, Oguz 2008, Konovalov and Murray 2001, Oguz and Velikova 2010).

The main characteristics of the water column are the permanent halocline, seasonal surface cooling and the formation of a cold intermediate layer (CIL) during spring-summer. Existence of suboxic layer (SOL) between oxygenated upper layer and anoxic/sulphidic deep waters covering all over the basin approximately deeper than 125-200 m are also key characteristics. SOL formed below the main oxycline has been defined (firstly by Codispoti *et al.* 1991, Tuğrul *et al.* 1992 and Murray *et al.* 1989, 1995) as a layer where dissolved oxygen (DO) is less than 20 µM and sulfide is less than 1 µM. Thickness of SOL and its establishment at certain density layers have also been investigated for a better understanding of the processes effecting the water column biogeochemistry (including redox chemistry) and also the effects of eutrophication in the water column. Assuming that the physical properties of the permanent halocline located below the winter mixing zone have remained unchanged during the last several decades, density (sigma-t) dependent depth profiles have served as an unifying approach for bio-chemical data analysis, such that all over the basin to assess long term changes in the chemical properties from the winter mixing zone boundary down to the upper depths of the anoxic layer formed below the permanent halocline. In this sense, the upper layer down to 14.5-15.0 density surface is subject to winter cooling which leads to the CIL formation, in the layer between 14.5-15.6 (oxycline-nitracline), and effect of winter mixing weakens with depth allowing oxygen diffusion downward but nutrient flux upward. The water layer between the 15.6-16.2 density surface has a relatively longer residence time (Konovalov and Murray 2001) and therefore rate of oxygen intrusion is not sufficient for aerobic oxidation of particulate organic matter (POM) sinking from the euphotic zone, leading to the formation of suboxic condition, denitrification processes and formation of phosphate minimum zone via redox dependent processes in the lower depths of the SOL. The entire water column is anoxic in the deep basin below 16.2 density surface (BSC 2008, Mikaelyan *et al.* 2013, Tuğrul *et al.* 2014). Cyclonic basin-wide rim current and the CIL formations ventilate the oxycline formed in the upper halocline depths (Oguz *et al.* 1993, Özsoy and Ünlüata 1997, Capet *et al.* 2012); this feature is relatively thin and appears at greater density surface (upper boundary: 14.5) in the cyclonic gyres, enlarging and deepening in the coastal waters, and anti-cyclonic eddies and appears at smaller density surface (14.2-14.3). It is clear that the upper boundary of chemocline appears at smaller density surfaces but greater depths in the coastal and anti-cyclonic eddies over the Black Sea. Moreover, the intrusion of the Bosphorus plume modifies the chemical features in the depth of upper suboxic/anoxic interface of the SW coastal zone and Rim current (Codispoti 1991, Konovalov *et al.* 2006, Tuğrul *et al.* 2014).

The surface/upper layer chemistry is highly influenced by fresh water inputs from major rivers at regional and local scales where this is the main nutrient source for the surface waters. North western rivers have had major contributions to the riverine nutrient loads (Teodoru *et al.* 2007, BSC 2008) and the second important reservoir is the Turkish main river inputs discharging to the southern Black Sea coast. At regional scale, atmospheric wet and dry depositions may likely play an important role on the long-term nutrient enrichment of the Black Sea (BSC 2008, Medinets *et al.* 2012) whereas Black Sea sub-regions might be subject to different levels of atmospheric pressures (Koçak *et al.* 2014). Upwelling along the coastal rim current and eddies as well as the inputs from point sources and from the Marmara Sea at lower depths are the other pathways of nutrients.

In fact, published work based on long-term Black Sea data sets at regional scale from various projects and regional expeditions have been efficiently evaluated to understand the Black Sea characteristics since 1970s (quite well revised and updated by Tuğrul *et al.* 2014) until now, lastly discussed by Capet *et al.* (2016) on the decline of Black Sea oxygen inventory. New data is needed and, in this case, the present status during the last two winter and three summer periods of 2014-2016 has been assessed.

However, this data set is not enough to evaluate off-shore marine waters despite the fact that limited number of marine water stations' water column characteristics were also examined and compared with previous findings. Presented data was collected within the scope of the “Integrated Pollution Monitoring Programme: 2014-2016” of the Ministry of Environment and Urbanization (MoEU).

2. Methods

Turkish coastal and territorial waters (up to 12 nm) have been monitored since 2004 with the support of Ministry of Environment and Urbanization. In this paper, the data of the last 3 years (2014-2016) is presented for two winter and three summer seasons and compared with the previous periods and other published studies.

Nutrient and chlorophyll-*a* (Chl-*a*) levels of the surface layer of 16 coastal water bodies (CWB: 1-16 W-E) and 5 marine assessments units (MAU: 1-5 W-E) as defined in DEKOS Project (TUBITAK-MRC and MoEU-GDEM 2014) were assessed as well as the vertical profiles of nutrients and dissolved oxygen in deeper waters with respect to typical physical features of the water column.

Surface water levels were presented as upper 10 m averages for each CWB and MAU for both seasons and all units. Vertical features were investigated at deeper waters up to 12 nm only at one summer period (2015) at two selected stations in the western and eastern MAU1 & 5 respectively at stations SAD and AYD (see Figure 1).

For trends, historical data collected since 2004 within the monitoring projects of MoEU were also assessed only for the western part since better data sets are available there and only significant trends are presented in this paper.

CWBs were also assessed for pressures and impacts with the use of land use index and Chl-*a* values (LUSI/LUSIVal) (Flo *et al*. 2011, Romero *et al*. 2013, Ediger *et al*. 2015, Tan *et al*. 2017).

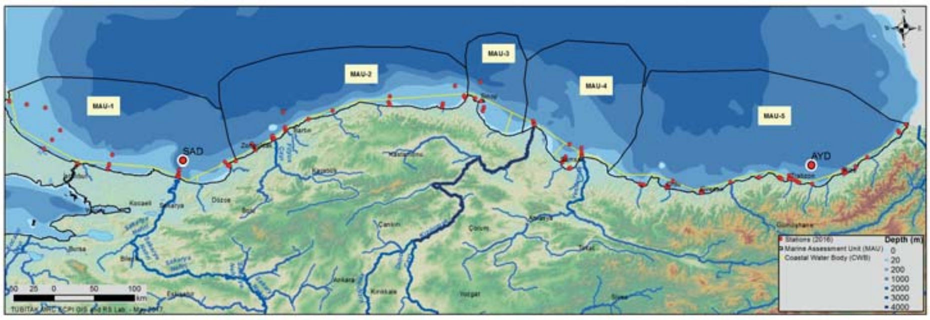

Figure 1. Map of the study area

3. **Surface layer (0-10 m) distribution of nutrients and Chl–a in the Turkish near-shore waters**

3.1. Nitrogen concentrations

Surface NO_2+NO_3-N (NO_x) concentrations varied from 0.56 to 1.78 µM in winter and from 0.06 to 0.92 µM in summer in the coastal water bodies (Figure 2a). Surface NO_x in the open waters varied from 0.49 to 1.06 µM in winter, decreasing to 0.14-0.32 µM levels in summer (Figure 2b).

The NO_x displays apparent seasonal variations, increasing about four times in winter and then consumed by photosynthesis during summer when the internal and external inputs are insufficient. Higher winter concentrations indicate apparent contribution of terrestrial inputs to the surface nutrient pool of the coastal regions. As clearly shown in Figure 2, the external pressure becomes more apparent in winter due to higher input rates of nutrients, exceeding its consumption in photosynthesis under light-limited winter conditions.

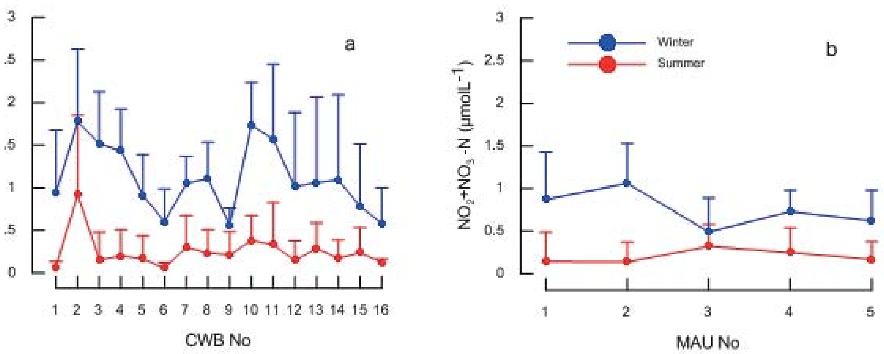

Figure 2. Average surface layer (0-10 m) values of 2014-2016 winter (blue circles) and summer (red circles) NO_2+NO_3-N (NO_x) concentrations at the coastal water bodies (CWB; a) and the marine assessment units (MAU; b)

NH_4^+ concentrations in the surface layer, as an external pressure indicator due to lack of ammonia in the winter mixing zone of the Black Sea, varied from 0.35 to 0.90 µM in winter and from 0.30 to 0.61 µM in summer in the coastal water bodies (Figure 3). Surface layer concentrations of ammonium in the open waters varied from 0.19 to 0.58 µM in winter and from 0.32 to 0.41 µM in summer (Figure 3). Spatial and seasonal variability in ammonia concentration is less pronounced, implying limited external inputs to the studied coastal and off-shore areas of the southern Black Sea.

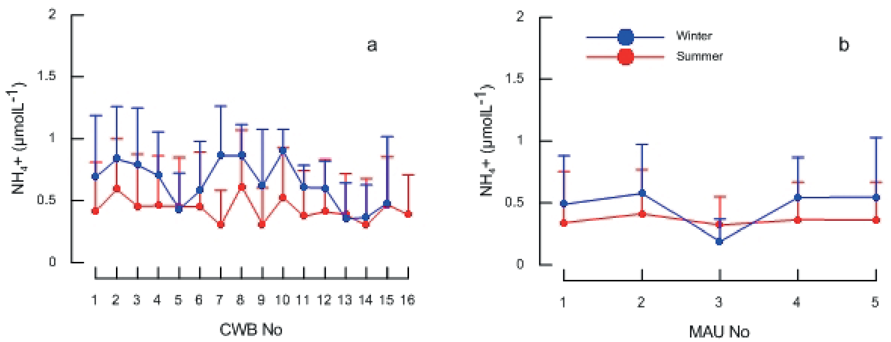

Figure 3. Average surface layer (0-10 m) values of 2014-2016 winter (blue circles) and summer (red circles) NH4+ concentrations at the coastal water bodies (CWB; a) and the marine assessment units (MAU; b)

3.2. Reactive Phosphorus (phosphate; PO_4^{3-}) concentrations

Surface layer PO_4^{3-} concentrations varied from 0.05 to 0.31 µM in winter and from 0.02 to 0.12 µM in summer in the coastal water bodies (Figure 4a). Phosphate concentrations in the open waters varied slightly between 0.03 and 0.06 µM in winter and summer period, displaying no significant seasonal variability (Figure 4b). The coastal and offshore concentrations of phosphate were almost similar, except CWB no:10 point fed by P-polluted Yeşilırmak river waters. Higher NO_x but limited phosphate concentrations (leading to high N/P ratios) in winter and very low phosphate values in summer strongly suggest a P-limited algal production especially during spring bloom period. P-limitation of Black Sea coastal waters has also been shown by limiting nutrient studies conducted during 2009 (Kuzyaka *et al*. 2011) within the scope of SINHA Project (Avaz *et al.* 2011).

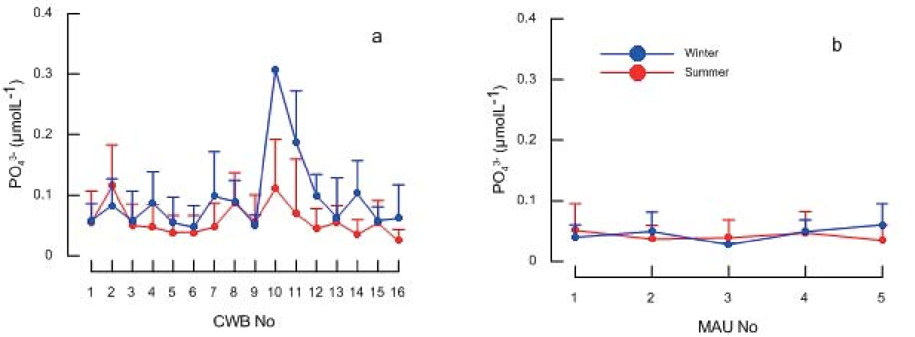

Figure 4. Average surface layer (0-10 m) values of 2014-2016 winter (blue circles) and summer (red circles) PO_4^{3-} concentrations at the coastal water bodies (CWB; a) and the marine assessment units (MAU; b)

3.3. Silicate (Si) concentrations

Silicate concentrations in the coastal surface layer were markedly high in winter, varying between 2.46- 5.36 µM and decreased to 0.69 from 2.47 µM in summer (Figure 5a). Surface Si concentrations in the open waters varied from 1.53 to 3.11 µM in winter and then decreased to the levels of 0.43-0.89 µM in summer (Figure 5b). The highest Si was observed at CWB no: 10 as seen in other nutrients. Seasonal variation of Si at the visited locations are identical to that in NO_x, indicating that high-silicate regions were highly influenced by the Si and NO_x laden river flows in winter, resulting in diatom-dominated primary production in the nutrient-enriched coastal Black Sea in winter and early spring. Not unexpectedly, the Si concentrations displayed a spatial decreasing trend from the western coastal waters to the south eastern Black Sea (Figure 5), reflecting impact of reduced Si loads to the sea via regional rivers having a series of dams constructed in recent years. Si-limitation of the Black Sea coastal waters has also been shown by limiting nutrient studies conducted during 2009 (Kuzyaka *et al*. 2011).

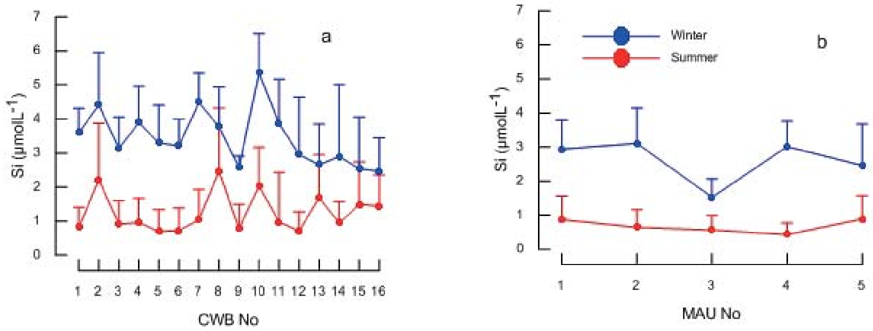

Figure 5. Average surface layer (0-10 m) values of Si concentrations for the 2014-2016 winter (blue circles) and summer (red circles) periods in the coastal water bodies (CWB; a) and the marine assessment units (MAU; b) of the southern Black Sea.

3.4. Nutrient ratios

Molar ratios of Si/N (Si/NO_x) in the surface layer varied from 2.3 to 10.7 in winter and from 2.7 to 51.0 in summer in the coastal water bodies (Figure 6) whilst the offshore ratio varied slightly between 3.2 and 6.6 in winter but from 1.7 to 36.3 in summer (Figure 6). The average coastal ratios of Si/N display less seasonality than the offshore ratios. Silicate limitation is expected to occur in phytoplankton production in late-spring- summer period as the surface Si concentrations decline below 1.0 µM and a similar decreasing trend appears in the surface Si/N ratio of the southern Black Sea.

Molar ratios of N/P (NO_x/PO_4^{3-}) in the coastal surface layer were highly variable, ranging from 2.8 to 85.9 in winter and from 1.9 to 14.2 in summer (Figure 6). Surface layer ratios of N/P in the open waters were relatively high in winter, ranging between 15.6 and 33.9 and then decreased markedly in summer to levels of 3.8-7.3 (Figure 6). Since the river inflows were highly rich in NO_x, the winter N/P ratios in the southern Black Sea were higher in the water bodies fed by NO_x laden river inflows; then river influences decreased in summer period due to increasing nutrient uptake rates in photosynthesis compared to the rates of nutrient supply to the surface layer. Consequently, depletion of NO_x during summer and identical phosphorus concentrations in both seasons as well as low N/P ratios (below Redfield ratio-16) during summer suggest that primary production the Turkish Black Sea coastal and open waters are N limited in summer.

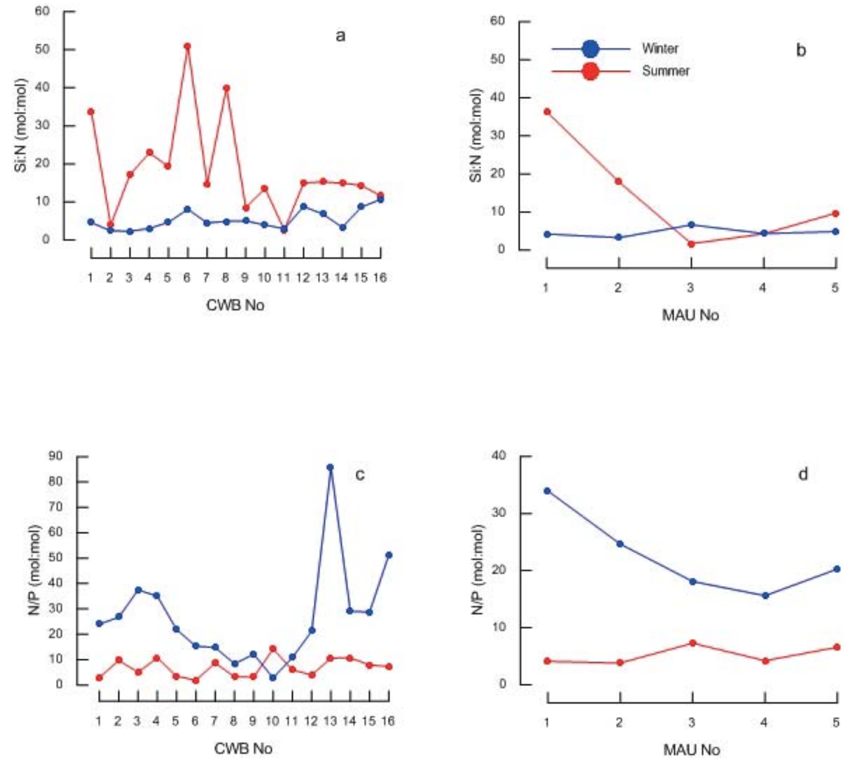

Figure 6. Average surface layer (0-10 m) values of Si/N ratios for the 2014-2016 winter (blue circles) and summer (red circles) periods in the coastal water bodies (CWB; a) and the marine assessment units (MAU; b) of N/P ratios for the same period in the coastal water bodies (CWB; c) and the marine assessment units (MAU; d)

3.5. Chlorophyll-a concentrations

Surface Chl-*a* concentrations (phytoplankton biomass indicator) varied from 0.51 to 1.23 μgL^{-1} in winter and slightly decreased in summer to 0.20- 1.20 μgL^{-1} levels in the coastal water bodies (Figure 7). Surface layer Chl-*a* concentrations in the open waters varied from 0.53 to 0.90 μgL^{-1} in winter and from 0.22 to 0.45 μgL^{-1} in summer (Figure 7). Overall, winter concentrations were about 2 times higher than the summer measurements. Relatively high Chl-*a* concentrations (≥ 1 μgL^{-1}) in the coastal waters were observed at CWB no: 2-8-9-10-14-16 water bodies influenced by the regional river discharges.

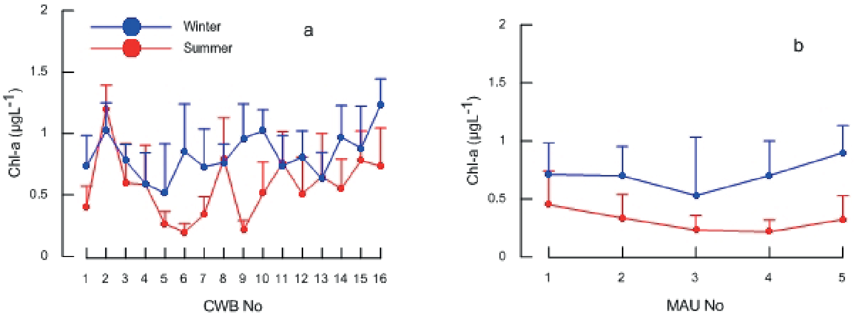

Figure 7. Average surface layer (0-10 m) values of 2014-2016 winter (blue circles) and summer (red circles) Chl-*a* concentrations at the coastal water bodies (CWB; a) and the marine assessment units (MAU; b)

Concentrations of Chl-*a* in winter and summer periods in the coastal and the open waters are presented in Table 1. Seemingly, Chl-*a* concentrations are higher in the coastal water bodies than in the marine waters and summer values are lower than winter values. Both cases are acceptable considering the seasonality in nutrient inputs and pimary production. However, this might remind us again two issues; firstly spring period could not be included because of the existing monitoring scheme, secondly limiting nutrient conditions (especially of P and Si) might be inhibiting the primary production levels.

Table 1. Mean surface layer Chl-*a* concentrations in the CWBs and the MAUs during winter and summer seasons of 2014-2016

Water type - season	Chl-*a* concentrations (µg/l)				
	No of obs.	mean	std dev.	min	max
Coastal (CWB) Winter (2015, 2016)	205	0.79	0.31	0.08	1.50
Coastal (CWB) Summer (2014, 2015, 2016)	259	0.52	0.31	0.10	1.47
Open (MAU) Winter (2015, 2016)	85	0.74	0.28	0.08	1.35
Open (MAU) Summer (2014, 2015, 2016)	109	0.36	0.24	0.08	1.14

Significant Spearman correlation coefficients of Chl-*a* with nutrients in summer were observed both in the open waters {0.42(n=108, <0.0001) for PO_4^{3-} and 0.29(n=109, <0.0001) for Si} and in the coastal waters {0.15(n=250, <0.015) for PO_4^{3-}, 0.25(n=257, <0.0001) for Si} and no significant correlation (p>0.05) was observed between Chl-*a* and NO_x neither in the coastal nor in the open waters. This is supported with the limiting nutrient experiments (Kuzyaka *et al.* 2011) and higly consumed levels of Si and PO_4^{3-} and ratios presented above. During winter, correlations were much less significant and there was a positive significant correlation between Chl-*a* and PO_4^{3-} (0.30; n=83, <0.006) only for the open waters. In both seasons, there was a negative correlation between salinity and Chl-*a*, being more pronounced during summer. This is an expected result of increased primary production due to land based nutrient inputs.

4. Vertical distribution of nutrients and dissolved oxygen

Summer NO_x concentrations were very low in the surface layer. In the upper halocline between sigma-t 15.0-15.6 layer, the NOx reached a maximum value of about 2.5-3 µM over the coastal basin (Figure 8). The NOx maximum values were greater in the offshore water as discussed extensively elsewhere (Tuğrul *et al*. 2014, Konovalov and Murray 2001). In the coastal waters, PO_4^3- and Si concentrations increased gradually with increasing depth and sigma-t and reached their maximum in the anoxic bottom waters. NH_4^+ concentrations were consistently low in the surface oxic and suboxic waters. However, it increased sharply in the anoxic water layer below sigma-t 16.0 density surface due to anaerobic oxidation of POM sinking from the surface. In the coastal waters, the concentration reached to about 15 µM levels at depths of the 17.0 density surface.

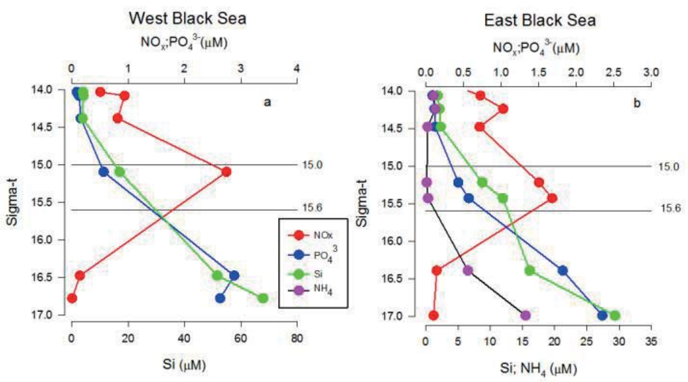

Figure 8. Density-dependent vertical profiles of NO_x, PO_4^{3-}, NH_4 and Si in the South Western Black Sea (a) and the South Eastern coastal Black Sea (b)

Summer dissolved oxygen (DO) concentrations in the mixed upper layer (euphotic zone) were about 250-330 µM of both the East and the West Black Sea (Figure 9), displaying a small maximum below the seasonal thermocline. The upper layer was saturated in DO down to the winter mixing zone. Then a stable oxycline was formed in the upper halocline depths between sigma-t: 14.0-15.7 surfaces. In this zone, the DO decreased sharply to 30-50 µM levels and then declined gradually to undetectable levels (<3 µM) below the depths of sigma-t:16.0.

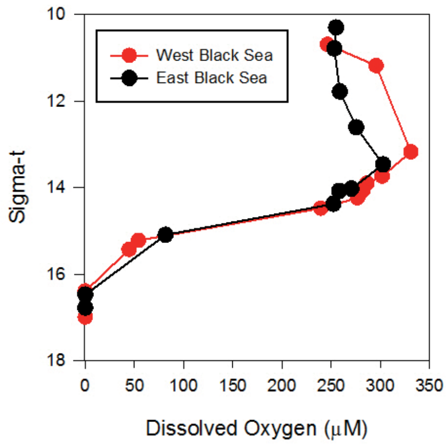

Figure 9. Density dependent vertical profiles of dissolved oxygen (µM) in the Western Black Sea and the Eastern Black Sea water columns

5. Trends of surface layer nutrients and Chlorophyll-*a*

Historical data for the trend analysis was only available at the western coast of the Black Sea. Although winter concentrations of nutrients were higher than summer concentrations as shown above, the available data only included March-November period. Therefore the results should be interpreted with caution as nutrients could possibly be consumed by primary production during this period and that the data could not be representative of current nutrient pool of given years. Linear regression analysis of long-term data suggests that the surface layer NO_x concentrations decreased significantly ($p<0.05$) from 1986 to 2015 (Figure 10a), whereas Si showed a parabolic pattern (Figure 10b). Si peaked during 2001 then decreased until 2015, suggesting that the Si stock of the surface layer enhanced between 1995-2005 period as the NO_x displayed a decreasing trend by 2000. Then NO_x has remained almost at similar levels as the Si stock of the upper layer has decreased by photosynthesis and consequently particulate-Si has been exported to greater depths below the euphotic zone.

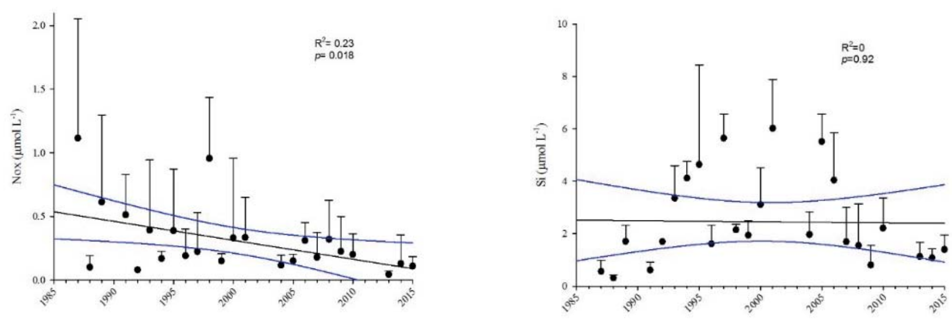

Figure 10. Trend analysis of NO_x (a) and Si (b) between 1986 and 2015 at the Marine Assessment Unit No:1 (West Black Sea). Error bars shows standard deviation of yearly mean values

Linear regression analysis of Chl-*a* levels suggests that there was a significant (p<0.05) decreasing trend from 2004 to 2015 which is in parallel with decreasing pattern of NO_x in the western Black Sea (Figure 11).

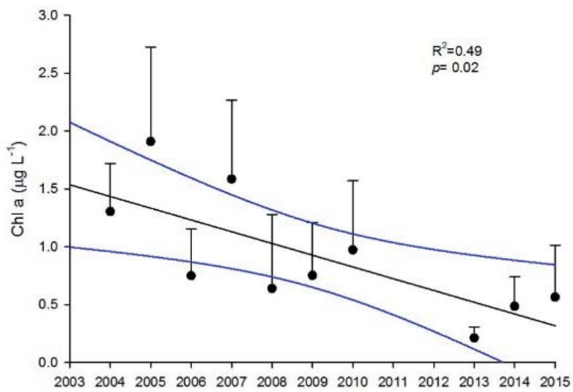

Figure 11. Trend analysis of Chl-*a* between 2004 and 2015 at the Marine Assessment Unit No:1 (West Black Sea). Error bars shows standard deviation of yearly mean values

6. Relations of pressures and impacts in CWBs

The result of the LUSIVal showed that there was a significant (R^2=0.37; ρ<0.05) positive linear relationship between LUSIVal and Chl-*a* in the CWBs as shown in Figure 12 which was based on earlier monitoring data evaluated in DEKOS Project. It had been concluded that this was a useful tool to better understand the relation between pressures and the expected impacts in the marine environment (TUBITAK-MRC and MoEU-GDEM 2014, Ediger *et al.* 2015, Tan *et al*. 2017).

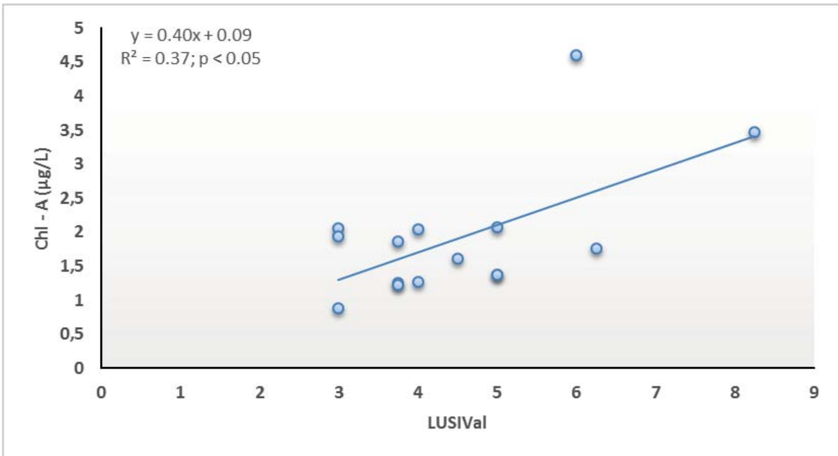

Figure 12. The relationship between LUSIVal and Chl-*a* in the CWBs of the Black Sea

Pressure on the eastern part was higher than the western part of the Black Sea according to the LUSIVal results (see Figure 13). However, the impact of the North-western shelf waters and the river Danube were not included in the analysis of LUSIVal. CWBs (No. 7, 8, 9, 10) which are under the pressure of Kızılırmak & Yeşilırmak Rivers as well as the Samsun province, were found as the highest source of pressure area. Since, the Chl-*a* vs LUSIVal showed (Figure 12) a significant positive correlation, and the pressure map well present the most impacted areas (Figure 13).

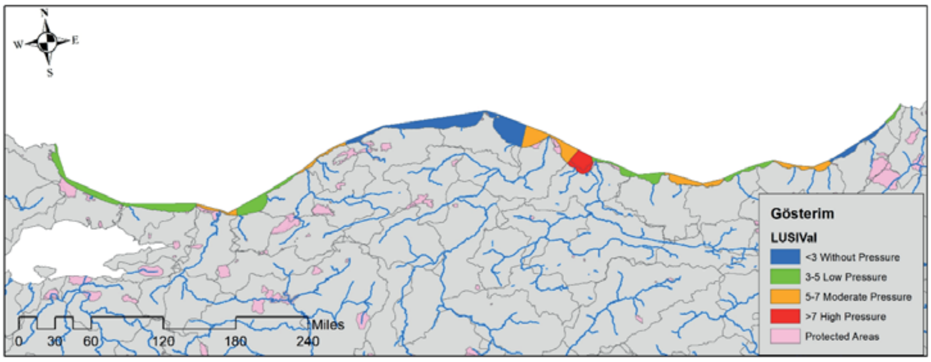

Figure 13. The map of the Black Sea pressure analysis LUSIVal index results

7. Discussion

Evaluation of long-term surface nutrient data from Rim current and central gyre of western basin of the Black Sea (Tugrul *et al.* 2014) indicate sharp decreases in the surface silicate concentrations after the mid 1970's, decreasing to very low levels (0.1-0.5 µM) in the summer periods of 1988, 1991 and 2005. This change expectedly reduced the Si/NO_x ratio dramatically from 100-500 levels in the 1960's to below <1.0) in the western coastal and Rim currents in the 1980's, when the NO_x and TP inputs by the Danube reached the highest levels, leading to marked decreases in Si/NO_x levels as the dammed river waters flowing into NW shelf (Oguz *et al.* 2008). This phenomenon was also observed in the study period both for the western and eastern coastal and open waters being more emphasized during summer.

Also the increased inputs of DIN (nitrite+nitrate+ammonia) from rivers and precipitation enhanced reactive consumption in the upper layer and changed the Si/NO_x ratio dramatically. High N/P ratios developed in the surface layer of western shelf waters fed the Danube discharges in last 4 decades, and this strongly suggest P-limited algal production (Oguz *et al*. 2008). However, in the SW Basin, the low N/P ratios (<10) in the surface waters of the Rim Current and central gyre during spring-autumn period after the mid 1990's indicate both P and nitrate-limited algal production in the open sea.

Comparison of density-dependent vertical distributions of the major chemical features in the oxygen gradient zone (oxycline) and SubOxic Layer (SOL) of the deep basin and Rim Current allows us to assess long-term changes in the upper layer (oxic-suboxic) chemistry (Tugrul *et al.* 2014). The density-dependent chemical profiles are principally similar over the deep basin; however, they are situated at greater depths in the SW coastal basin and Rim Current (depth > 200 m), depending on the circulation patterns, the intensity of shelf-basin interactions and chemical factors. The oxygenated Bosphorus plume supplies DO into the suboxic layer and upper depth of sulphidic water (Konovalov *et al.* 2003, Tugrul *et al.* 2014). In the study area, SOL was located almost at the same sigma-t layer (between 14.4 and 15.4) values where the depths are ~ 25 m shallower at the western basin (between 75-100 m) than in the eastern basin.

The increased nutrient inputs and excess POM production in the surface layer, drastically enhanced POM export below the euphotic zone, leading to seasonal/decadal changes in the boundaries of the nutricline and main oxycline and altered the upper boundary of the SOL over the deep basin (Murray 1989, Codispoti *et al.* 1991, Tugrul *et al.* 1992, 2014). Excess POM export has altered the boundaries of the oxycline and thus, SOL in the deep basin by 10-30m after 1970's (Tugrul *et al.* 2014).

Chl-*a* concentrations exhibited difference both temporally and spatially throughout the study period (Figure 7). Chl-*a* concentrations for the coastal stations were higher than the offshore stations and the highest concentrations were obtained during winter. On the other hand, mean (0-10m) concentrations were relatively low (<l μg L^{-1}) during the study period in both offshore areas.

The distribution of Chl-*a* for different regions of the southern Black Sea has been well documented by different research groups (Yılmaz *et al.* 1998, Çoban-Yıldız *et al.* 2000, Yayla *et al.* 2001, Yunev *et al.* 2002, Ağırbaş *et al.* 2014, Ediger *et al.* 2015). In the seasonally stratified surface waters of the Black Sea, Chl-*a* profiles display a sub-surface maximum at the base of the euphotic zone (Çoban-Yıldız *et al.* 2000). The concentrations in the euphotic zone were generally reported as relatively low (<0.5 μg L^{-1}) and varied from 0.1 to 1.5 μg L-1 in the southern Black Sea during spring-autumn period of 1995–1996 (Yılmaz *et al.* 1998). Chl-*a* concentrations during the spring-autumn period of 1995–1996, ranged between 0.1 and 0.6 μgL^{-1} for the Batumi anticyclone region whilst the concentrations in the western cyclone region, the Bosphorus region and off Sinop ranged from 0.3 to 1.5 μgL^{-1} (Yayla *et al.* 2001). The highest average 10 years time series Chl-*a* (~1 μg L^{-1}) was reported by Ediger *et al.* (2015) in winter, spring and autumn, for the central and eastern (>30m) Black Sea surface water. This would indicate favourable conditions for phytoplankton during these seasons. Chl-*a* concentrations ranged between 0.16-2.75 μg L^{-1} in South Eastern and between 0.07-4,29 μg L^{-1} in the South Central Black Sea (Ediger *et al.* 2015).

The spatio-temporal distributions of Chl-*a* in the open areas of the basin reveal large discrepancies between sub-regions in regard to sampling intensity and coverage for the different interannual periods. Monitoring of the coastal areas and comparison of the coastal water bodies (16) in the entire Black Sea has been carried out for the first time in this study. Chl-*a* concentrations measured in the present study showed similar pattern with other studies even though the locations and sampling period were different. CWBs under the influence of rivers and the main cities showed increased mean values.

In order to show this relation, a pressure-impact assessment approach (Land use index vs. Chl-*a*) was used in this study. The chloropyll-a vs LUSIVal showed a significant positive correlation in the Black Sea. Effect of coastal pressure and vertical mixing could be seen as higher concentrations in the coastal than in the open waters. Kızılırmak & Yeşilırmak Rivers (MAU 4) and Samsun province were found to be as the highest source of pressure area.

Human-induced pressures (inputs) have altered ecological properties of the entire Blcak Sea after the 1970's. Therefore, the pristine conditions in the 1950-1960's could not be achieved in the future under the present input rates and changing climate conditions. In addition, the enhanced DIN in Si-poor wet precipitation has further enhanced POM production in the sea and thus decreased Si/NO_x ratios in the surface layer. Reduced silicate (Si) inputs by the river discharges with lower Si/DIN ratio (<1.0) should be compensated by the Si input from internal source (the lower layer waters by winter mixing and upwelling processes). However, this internal input may still be insufficient to compensate the Si loss from the surface layer by diatom production especially in shelf waters due to the large DIN inputs from anthropogenic sources with low Si/DIN ratios.

Therefore, "new" reference conditions and tolerable limits of nutrients for setting "G*ood Environmental Status*" (GES) targets are needed for the Black Sea ecosystem. For the achievement of GES objectives, DIN inputs from both rivers and precipitation should be reduced to the threshold levels that can only be estimated by N-P-Si multi-metric basin wide ecosystem models fed by reliable data from basin wide studies and systematic measurements in the major rivers and precipitation. The new GES target defined for NO_x should keep the surface Si to remain excess in the upper layer, and also to observe improvement in the trophic state of the system. The present nutrient conditions in the Rim Current and in the open sea indicate that it is likely to observe a gradual increase in Si inventory of the upper layer as experienced in the mid 1990's, by reducing NO_x inputs by the major rivers.

Trend analysis approach as studied in this paper is also an important indicator to assess the time dependent changes in the system that is also required by the Black Sea Integrated Monitoring and Assessment Program (BSIMAP 2017-2022) in relation to BS SAP (2009) ecosystem quality objective: reduction of eutrophication.

Future monitoring studies planned for 2017-2019 by the Ministry of Environment and Urbanization will include both coastal and offshore marine areas with a better coverage of the open sea than the previous programme and the trends will be continued to be investigated. In these studies, detailed water column samplings will be conducted in the open waters of the five marine assessment units identified in view of the circulation and the hydrochemical properties of the Turkish Black Sea marine area.

References

Agirbas, E., A.M. Feyzioglu, and U. Kopuz. 2014. Seasonal changes of phytoplankton chlorophyll-a, primary production and their relation in the continental shelf area of the south eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 713-726.

Avaz, G., V. Tüfekçi, H. Tüfekçi, *et al.* 2011. Urban wastewater management along coastal areas of Turkey: Reidentification of hot spots&sensitive areas, determination of assimilation capacities by monitoring and modelling and development of sustainable urban wastewater investment plans (in Turkish). (TÜBİTAK TARAL 1007) (SINHA), Final report project code 506G207.

BSC, 2008. State of the Environment of the Black Sea (2001 - 2006/7). pp. 448. In T. Oguz [Chief Ed], Publications of the Commission on the Protection of the Black Sea against Pollution (BSC) 2008-3, Istanbul, Turkey.

Capet, A., A. Barth, J.M. Beckers, and M. Grégoire. 2012. Interannual variability of Black Sea's hydrodynamics and connection to atmospheric patterns. Deep-Sea Res. Pt. II, 77-80: 128-142.

Capet, A., E.V. Stanev, J.M. Beckers, J.W. Murray, and M. Grégoire. 2016. Decline of the Black Sea oxygen inventory. Biogeosciences, 13: 1287-1297.

Coban-Yildiz, Y., S. Tugrul, D. Ediger, A. Yilmaz, and S.C. Polat. 2000. A comparative study on the abundance and elemental composition of POM in three interconnected basins: the Black, the Marmara and the Mediterranean Seas. Mediterranean Marine Science, 1: 51-63.

Codispoti, L.A., G.E. Friederich, J.W. Murray, and C.M. Samatamota. 1991. Chemical variability in the Black Sea: implications of data obtained with a continuous vertical profiling system that penetrated the oxic/anoxic interface. Deep-Sea Res. 38(2): 691-710.

Ediger, D., Ç.P. Beken, M. Feyzioğlu, F. Şahin, and İ. Tan. 2015. Establishing boundary classes for the quality classification of southeastern Black Sea using phytoplankton biomass. Turkish Journal of Fisheries and Aquatic Sciences, 15: 727-736.

Flo, E., J. Camp, and E. Garcés. 2011. Assessment pressure methodology, Land Uses Simplified Index (LUSI), BQE Phytoplankton; Spain-Catalonia.

Koçak, M., N. Mihalopoulos, E. Tutsak, K. Violaki, C. Theodosi, P. Zarmpas, and P. Kalegeri. 2014. Atmospheric Deposition of Macronutrients (Dissolved Inorganic

Nitrogen and Phosphorous) onto the Black Sea and Implications on Marine Productivity, Journal of the Atmospheric Sciences.

Konovalov, S.K. and J.W. Murray. 2001. Variations in the chemistry of the Black Sea on a time scale of decades (1960–1995). J. Mar. Syst, 31: 217-243.

Konovalov, S.K., G.W. Luther, G.E. Friedrich, D.B. Nuzzio, B.M. Tebo, J.W. Murray, T. Oguz, B. Glazer, R.E. Trouwborst, B. Clement, K.J. Murray, and A.S. Romanov. 2003. Lateral injection of oxygen with the Bosphorus plume-fingers of oxidizing potential in the Black Sea. Limnol. Oceanogr. 48(6): 2369-2376.

Konovalov, S., J.W. Murray, G. Luther, and B. Tebo. 2006. Processes controlling the redox budget for the oxic/anoxic water column of the Black Sea, Deep-Sea Res. Pt. II, 53: 1817-1841.

Kuzyaka, E., V. Tüfekçi, H. Tüfekçi, G. Avaz, and S. Tuğrul. 2011. Assessment of limiting nutrients at Marmara and Black Sea coasts in terms of eutrophicaton: 1. Environmental pollution and its management at coastal areas (in Turkish) Tekirdağ, 17-20 November.

Medinets, S. and V. Medinets. 2012. Investigations of atmospheric wet and dry nutrient deposition to marine surface in western part of the Black Sea. Turkish J. Fish. Aquat. Sci, 12: 497-505.

Mikaelyan, A.S., A.G. Zatsepin, and V.K. Chasovnikov. 2013. Long-term changes in nutrient supply of phytoplankton growth in the Black Sea. Journal of Marine Systems, 117-118: 53-64.

MoEU-DGEIAPI and TUBITAK-MRC. 2014. Integrated Marine Pollution Monitoring Project (2014-2016). ECPI 5148704, Report No. ÇTÜE.14.201 (The Black Sea Final Report, 2014), April 2015, Gebze-Kocaeli.

Murray, J.M., L.A. Codispoti, and G.E. Freiderich. 1995. Oxidation-reduction environments: the suboxic zone in the Black Sea, p. 157-176. In C.P. Huang, C.R. O'Melia, and J.J. Morgan [eds.], Aquatic Chemistry, ACS Advances in Chemistry Series.

Murray, J.W., H.W. Jannasch, S. Honjo, R.F. Anderson, W.S. Reeburg, Z. Top, G.E. Friederich, L.A. Codispoti, and E. Izdar. 1989. Unexpected changes in the oxic/anoxic interface in the Black Sea. Nature, 338: 411-413.

Oguz, T., V.S. Latun, M.A. Latif, V.V. Vladimirov, H.I. Sur, A.A. Markov, E. Ozsoy, V.V. Kotovshchikov, V.V. Eremeev, and U. Unluata. 1993. Circulation in the surface and intermediate layers of the Black Sea. Deep Sea Res. I, 40, 1597–1612.

Oguz, T. 2008. General oceanographic properties: physico-chemical and climatic features, pp. 448. In T. Oguz [ed.], State of the Environment of the Black Sea (2001-2006/7). Publications of the Commission on the Protection of the Black Sea against Pollution (BSC) 2008-3, Istanbul, Turkey.

Oguz, T. and V. Velikova. 2010. Abrupt transition of the northwestern Black Sea shelf ecosystem from a eutrophic to an alternative pristine state. Mar. Ecol. Prog. Ser. 405: 231-242.

Özsoy, E. and Ü. Ünlüata. 1997. Oceanography of the Black Sea: a review of some recent results. Earth-Sci. Rev. 42: 231-272.

Romero, I., M. Paches, R. Martinez-Guijarro, and J. Ferrer. 2013. Glophymed: An index to establish the ecological status for the Water Framework Directive based on phytoplankton in coastal waters. Marine Pollution Bulletin, 75: 218-223.

Sorokin, Y.A. 2002. The Black Sea: Ecology and Oceanography. 875 pp. Biology of Inland Waters. Backhuys, Leiden, The Netherlands.

Tan, İ., Ç.P. Beken, and S. Öncel. 2017. Pressure-Impact analysis of the coastal waters of Marmara Sea. Fresenius Environmental, 26-40 (4): 2689-2699.

Teodoru, C. R., G. Friedl, J. Friedrich, U. Roehl, M. Sturm, and B. Wehrli. 2007. Spatial distribution and recent changes in carbon, nitrogen and phosphorus accumulation in sediments of the Black Sea. Marine Chemistry, 105, 52-69.

TUBITAK-MRC and MoEU-GDEM. 2014. Marine and Coastal Waters Quality Determination and Classification Project (DeKoS). ECPI 5118703, Report No. ÇTÜE.13.155 (Final Report), February 2014, Gebze-Kocaeli, Turkey.

Tugrul, S., Ö. Basturk, C. Saydam, and A. Yılmaz. 1992. Changes in the hydrochemistry of the Black Sea inferred from water density profiles. Nature, 359: 137-139.

Tugrul, S., J.W. Murray, G.E. Friederich, and I. Salihoglu. 2014. Spatial and temporal variability in the chemical properties of the oxic and suboxic layers of the Black Sea. J. Marine Syst., 135: 29-43.

Vinogradov, M., E. Shushkina, A. Mikaelyan, and N.P. Nezlin. 1999. Temporal (seasonal and interannual) changes of ecosystem of the open waters of the Black Sea. P. 109-129. In S.T. Beşiktepe *et al.* [eds.], Environmental Degradation of the Black Sea: Challenges and Remedies. Kluwer Academic Publishers.

Yayla, M., A. Yilmaz, and E. Morkoc. 2001. The dynamics of nutrient enrichment and primary production related to recent changes in the ecosystem of the Black Sea. Aquatic Ecosystem Health and Management, 4: 33-49.

Yilmaz, A., S. Tugrul, C. Polat, D. Ediger, Y. Coban, and E. Morkoc. 1998. On the production, elemental composition (C, N, P) and distribution of photosynthetic organic matter in the Southern Black Sea. Hydrobiologia, 363: 141-156.

Yunev, O., A. Vladimir, O. Basturk, A. Yilmaz, A.E. Kideys, S. Moncheva, and S.K. Konovalov. 2002. Long-term variation of surface Chlorophyll-a and primary production in the open Black Sea. Marine Ecology Progress Series, 230: 11-28.

MICROBIAL (PRIMARY AND BACTERIAL) PRODUCTION AND ORGANIC CARBON DISTRIBUTION IN THE SOUTHERN BLACK SEA

Nebil YÜCEL [1] and Süleyman TUĞRUL [2]

[1]Faculty of Marine Sciences and Technology, Iskenderun Technical University, İskenderun, Turkey
[2]Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
nebilyucel@gmail.com

1. Brief Introduction of physico-chemical parameters

The Black Sea, fed by large volumes of nitrate and silicate-laden river discharges and NO_x (nitrate+ammonia) rich wet precipitations, is one of the biggest semi-enclosed anoxic sea in the world (Sorokin 1983, Tuğrul *et al*. 2014). Therefore, its surface layer is occupied by brackish waters (salinity 16.5-18.5). The oxic upper layer is separated from the more saline, sulphide-bearing water layer by an oxic/anoxic transition layer situated in the permanent halocline below the upper winter mixing zone. These basic features are discussed elsewhere (Tuğrul *et al.* 2014). It is connected to Sea of Marmara through the narrow Bosphorus Strait allowing salty waters of Mediterranean to flow into intermediate depths of the Black Sea. Cyclonic current system carries NW shelf waters with the associated biochemical properties to the WS shelf and some fraction of the chemical loads is transported to the adjacent sea through the Bosphorus surface flow.

Major sources of nutrients for the Black Sea are the regional rivers (Danube, Dnieper and Dniester) flowing to NW shelf zone and Sakarya, Kızılırmak, Yeşilırmak feeding the southern coastal ecosystem (Oğuz *et al*. 2008). In winter, the open sea upper layer received nutrients from the nutricline depths of the cyclonic gyres formed in the west- and east-central basins. Therefore, primary production and thus algal biomass concentrations display apparent spatial and temporal variability over the Black Sea. Large amounts of POM export from the productive euphotic zone to halocline depths and deep waters have led to the formation of oxygen gradient (oxycline), oxygen deficient layer (SubOxic Layer, SOL) and sulfidic water layer over the deep basin. Recent studies have shown that the sulfidic anoxic water masses appear at depths of sigma-t: 16.15-16.20 in the deep basin (Tuğrul 1992, Tuğrul *et al.* 2014); the boundary partly deepens in the WS coastal zone due to intrusion of the partly oxygenated Bosphorus Plume (mixture of cold upper layer water of Black Sea and salty Marmara deep water (Konovalov and Murray 2001) into the suboxic/anoxic interface depths of Rim Currents on the SW shelf and slope (Tuğrul *et al*. 1992). Enhancement of nutrient inputs to the coastal ecosystem from land-based sources in these several decades increased rates of algal production in the coastal and open sea, POM abundance and export to greater depths below the euphotic zone leading to dramatic changes in the Black Sea ecosystem in the last fifty years (Oğuz *et al*.

2008). This report aims to evaluate recent studies performed on the microbial production, particularly in the southern Black Sea.

2. Primary and Bacterial Production

Autotrophs produce complex organic material from inorganic matter via photosynthesis or chemosynthesis; food chain starts with autotrophs called primary producers and chemoautotrophs in the aquatic environments. All marine life takes part in these processes to provide energy for their life (Kirchman 2008). In these processes, inorganic carbon and other major nutrients (N, P) are converted to organic forms (particulate and dissolved forms) and then finally oxidized to inorganic forms in different depths of water column and sediment layer with different rate of production and decomposition under oxygenated, suboxic and anoxic conditions. Primary producers need solar energy and nutrients to produce biodegradable organic matter (Kirchman 2008). Therefore, phytoplankton production takes place in the euphotic layer of the world oceans. Below the euphotic zone in the water column, chemoautotrophs take role of phytoplankters in the presence of anoxic waters. Similarly, marine bacteria show a vital role in the food web as acting efficiently in degradation of organic matter, cycling of elements and recycling of dissolved nutrients in marine ecosystem.

3. Primary Production

According to long-term data obtained in the Black Sea since 1960s, the rate of primary production (PP) peaks two times in a year; spring bloom is dominated by diatoms and autumn bloom mainly by dinoflagellates and coccolithophorids (Yılmaz *et al*. 2006). However, PP data from the coastal and offshore regions of southern Black Sea is limited (Yılmaz *et al*. 1998, 2006, Yayla *et al*. 2001, Yücel *et al*. 2011, 2013, Ağırbaş *et al*. 2014). Available results on PP rates are compiled in Table 1, showing that the rate varied between 112-1925 mg C m^{-2} d^{-1} in southern Black Sea. The highest PP rate was recorded in April 1996 in the southern Black Sea-Sinop off waters, the lowest rates were measured in the south-western Black Sea offshore waters (Yılmaz *et al*. 2006, Yücel *et al*. 2013).

Table 1. Rates of primary production measured in the southern coastal and offshore waters of the Black Sea

Referances	Primary Production (PP) mg C m^{-2} d^{-1}	Location	Period
Ağırbaş *et al.* 2014	285-565 Coastal 126-530 Offshore	Southeastern Black Sea	March-Dec. 2010
Yücel *et al*. 2013	259 Offshore	Southwestern Black Sea	July 2013
	374	Sakarya Canyon	
	1131 Coastal	Southwestern Black Sea	
Yücel *et al*. 2011	535	Southwestern Black Sea	Apr 2008
	330	Southeastern Black Sea	
	190	Southwestern Black Sea	Oct 2008
	386	Southeastern Black Sea	
Yılmaz *et al*. 2006		(Western Black Sea)	May 2001
	355	Bosphorus shelf break	
	319	Transit to gyre	
	145	Western central gyre	
	211	Turkish transect	
	119	Turkish shelf	
	237	Turkish shelf break	
Yayla *et al*. 2001	373	Deep (Western)	July 1997
	785	Nearshore (Western)	July 1997
	62	Nearshore (Western)	Mar 1998
	257	Nearshore (Eastern)	April 1998
	461	Deep (Eastern)	April 1998
	447	Nearshore (Eastern)	April 1998
	601	Nearshore (Western)	Sept. 1998
	487±184 (Average)	The Black Sea	Jul 1997-Sep 1998
Yılmaz *et al.* 1998	247-405-194	Bosphorus Region	Spring 1995-Autumn 1995-Summer 1996
	603	Sakarya Canyon region	
	1925	Sinop Offshore	Summer 1996 Apr 1996

Yılmaz *et al*. (1998) performed the measurements and PP and related parameters in different sub-regions of the southern Black Sea. According to their results, the PP rate varied between 247 and 1925 mg C m^{-2} d^{-1} in the spring and between 405 and 687 mg C m^{-2} d^{-1} in the summer-autumn period. They obtained the highest PP rate in frontal zone waters of the Rim Current near Off Sinop in April 1996. Then, Yayla *et al*. (2001) measured the PP rate in the Black Sea and, fluctuating between 62-785 mg C m^{-2} d^{-1} in

July 1997, March 1988 and September 1988. Average primary production rate of the three surveys was calculated as 487±184 mg C m^{-2} d^{-1} for the southern Black Sea (Table 1). The highest PP rate was recorded in Sakarya Canyon in July 1997. The lowest rate value was obtained in the Rim Current waters off the Bosphorus Strait in March 1998, apparently lower than that measured in April (Table 1). Yılmaz *et al.* (2006) measured primary production in western Black Sea at the six shelf and offshore stations in May 2001. Their PP rates ranged between 119 and 355 mg C m^{-2} d^{-1} and expectedly the highest value was obtained in the Bosphorus shelf break waters renewed by NW shelf waters via the cyclonic alongshore current system; the rate was lower in the Western central gyre in May 2001 (Table 1). More recently, Yücel *et al.* (2011) have measured PP at limited points of the southern Black Sea in 2008 (Figure 1); the rate varied from 190 m^{-2} d^{-1} in October 2008 and 535 mg C m^{-2} d^{-1} in April 2008 as depicted Figure 2. The SW coastal zone is naturally more productive in spring than late summer-autumn period when the near surface layer is seasonally stratified and terrestrial inputs decrease due to seasonally decreasing volume fluxes of the major rivers. In spring, bulk primary production was dominated by larger phytoplankton (>5 μm) (145-379 mg C m^{-2} d^{-1}) in the southern Black Sea (Figure 2).

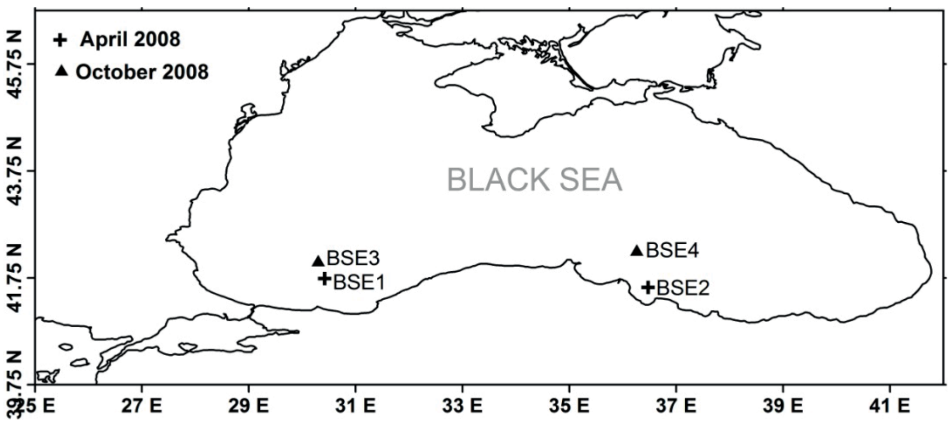

Figure 1. Location of stations for PP measurement in the southern Black Sea in 2008 (from Yücel *et al.* 2011)

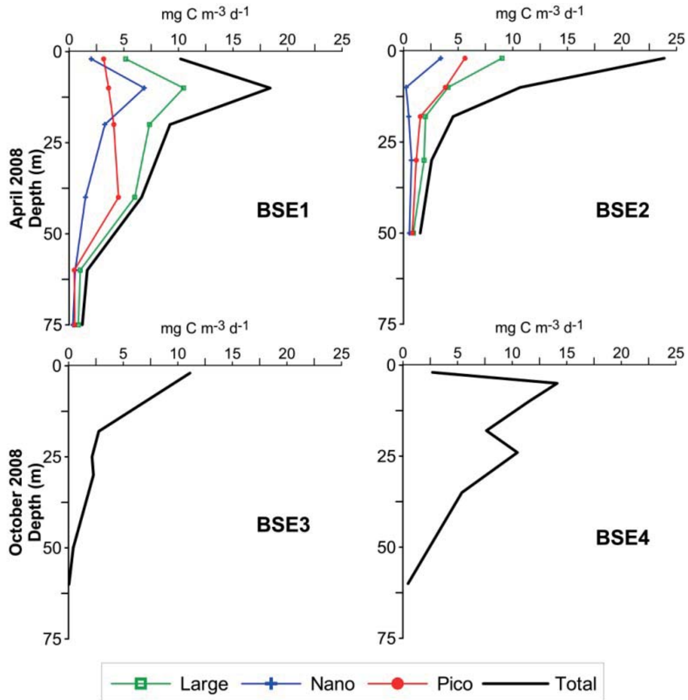

Figure 2. Vertical distributions of size fractionated and total primary production in the SW and SE Black Sea (Pico:Picoplankton (0.2-2.0 µM), Nano:Nanoplankton (2.0-5.0 µM), Large:Larger cells (5.0 µM <) (modified from Yücel *et al*. 2011)

More recent studies on primary production (PP) were performed in 2010 and 2013. Ağırbaş *et al*. (2014) studied seasonal variations of phytoplankton, chlorophyll *a*, primary production and their relation in the continental shelf waters of the SE Black Sea from March to December 2010. Depth integrated-daily primary production fluctuated between 285-565 mg C m^{-2} d^{-1} and 126-530 mg C m^{-2} d^{-1} in the coastal and offshore waters, respectively. Moreover, PP rates were measured 0.1-40 mg C m^{-3} d^{-1} in water column during the study period.

Yücel *et al*. (2013) studied three stations in the SW Black Sea coastal and open waters in July 2013 (Figure 3). As clearly shown in Figure 4, PP was almost limited to upper 10-15 m, indicating the existence of relatively thin euphotic zone in SW regions. However, relatively low rates of PP were determined in the cool water between 15-45 m depths, dominated by nano- and pico-plankton. Depth integrated PP rates measured at the visited regions were 259 mg C m^{-2} d^{-1} for the coastal (St. E4 in Figure 3), 347 mg C m^{-2} d^{-1} in the shelf waters off Bosphorus exit (E5) and 1131 mg C m^{-2} d^{-1} in the offshore waters on the Rim Current (St. E6). In the water column, PP rates ranged between 1.48

and 110 mg C m^{-3} d^{-1} in July 2013 (Figure 4). Higher rate values were consistently measured in the near-surface waters (Figure 4). Larger cells (>5 μm) were observed to dominate PP at the offshore station (top 10 meters) and coastal waters (top 15 meters). However, the contribution of pico-size plankton enhanced below surface at St. 5 defined as the Sakarya Canyon point in Figure 4. PP Rates and contribution of larger cells to the total PP decreased from west to east in July 2013.

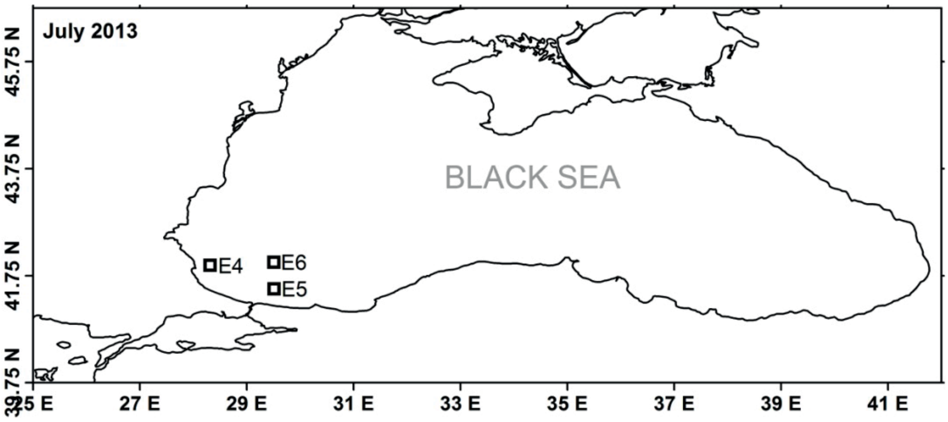

Figure 3. Location of sampling stations in Black Sea (from Yücel *et al*. 2013)

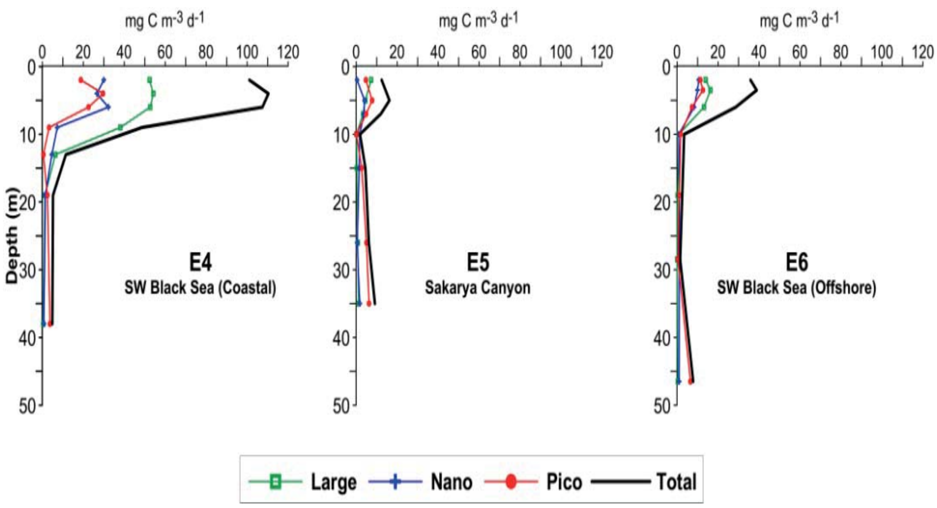

Figure 4. Vertical distribution of size fractionated and total primary production at SW Black Sea (Pico: Picoplankton (0.2-2.0 μM), Nano: Nanoplankton (2.0-5.0 μM), Large: Larger cells (5.0 μM <) (modified from Yücel *et al.* 2013)

4. Bacterial Production

There is no published study on the bacterial production in the southern Black Sea including Turkish Seas. Morgan *et al.* (2006) measured the bacterial abundance and production along the transect from NW Shelf waters to western Cyclonic Gyre of Black Sea in the period of May-June 2001. It is clear that NW shelf waters are highly productive and have different ecological properties compared to the SE coastal region. Water masses of NW shelf zone are carried by the Cyclonic Rim Current towards the SW coastal zone; its physical and biochemical properties are partly modified during their transport to the SW shelf. Therefore, bacterial production measured in the NW and western deep basin may also indicate ranges of bacterial production rates for the SW shelf and Rim Current. Surface bacterial production rate measured at a level of 0.15 mg C m^{-3} d^{-1} is greater than in suboxic and anoxic layers. Depth Integrated Bacterial Production varied slightly between 64-65 mg C m^{-2} d^{-1} in SW central Gyre in May-June.

In July 2013, Dr. Yücel (unpublished data) has measured bacterial production first time in the SW Black Sea at four stations (Figure 5). Bacterial Production rates varied between 0.025 - 0.658 mg C m^{-3} d^{-1} in the oxic and suboxic water column Expectedly, Bacterial Production values generally decreased with increasing depth except Sta. E6 where second peak (0.611 mg C m^{-3} d^{-1}) was observed at 105 meters (Figure 6). Depth Integrated Bacterial Production values varied between 9.70 and 85.57 mg C m^{-2} d^{-1} at four stations (Figure 6). Higher rates were measured in the Rim Current water column where the PP rate and algal biomass were relatively high (Figure 4). Bacterial activity (bacterial production) decrease with increasing depth below the euphotic zone down to lower boundary of oxycline, coinciding with the nitrate maximum depth. Then, it increases in suboxic layer where chemoautotrophic production is high (Figure 7) and then decreases in the upper depths of the anoxic waters where chemoautotrophic productions were determined at remarkable levels (Figure 7).

Table 2. Rates of bacterial production measured in the southern coastal and offshore waters of the Black Sea.

References	Bacterial Production (BP) mg C m^{-2} d^{-1}	Location	Period
Yücel *et al.* unpublished	 9.70 17.40 85.57 11.23	Southwestern Black Sea (Figure 5) (E4) (E5) (E6) (E7)	July 2013
Morgan *et al.* 2006	64 65	Western Gyre (Black Sea)	May-June 2001

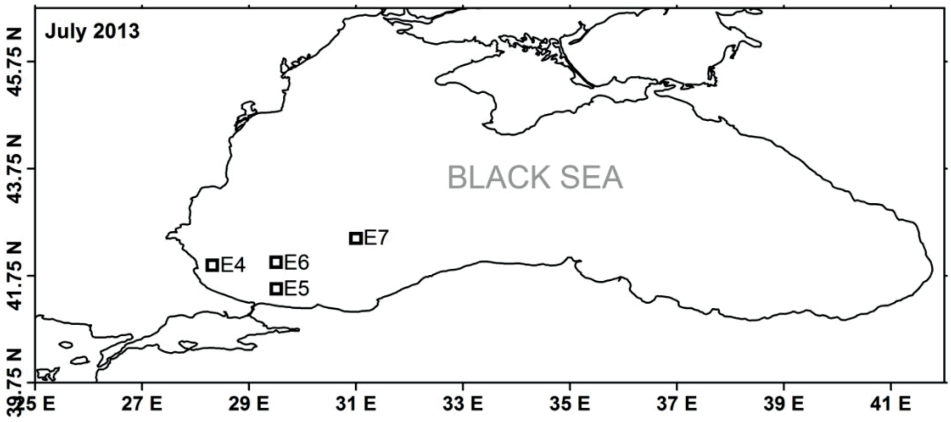

Figure 5. Location of sampling stations in Black Sea (from Yücel *et al.* unpublished data)

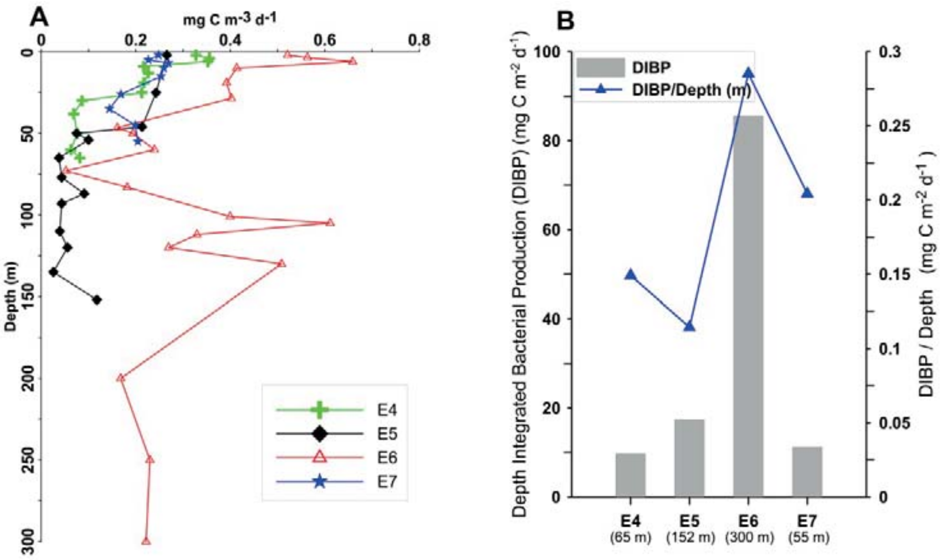

Figure 6. Vertical distributions of bacterial production (A) and distributions of Depth Integrated Bacterial Production (DIBP) and DIBP/Depth (B) at SW Black Sea (modified from Yücel *et al*. unpublished data)

5. Particulate Organic Matter (POM)

Not unexpectedly, coastal waters of the southwestern Black Sea are relatively rich in biogenic particulate organic matter (POM), because the fertile surface waters of the NW shelf region reach as far as SW coastal regions by strong along shore currents (Çoban 1997, Çoban-Yıldız *et al.* 2000, Polat and Tuğrul 1995). Accordingly, the western coastal surface waters of the Black Sea are always more productive and thus possess larger biomass and POM concentrations than in the cyclonically-dominated open sea having limited nutrient input from external and internal sources especially during the spring-autumn period. Typical depth profiles of particulate organic carbon (POC) and nitrogen (PON) in the Black Sea (Figure 7) are very similar to those in the oceans with the exception of an apparent maximum in the phosphate minimum zone and anoxic interface due to bio-mediated redox-dependent processes, fine particle formations and chemoautotrophic, bacterial productions (Tuğrul 1993, Çoban 1997, Çoban-Yıldız *et al.* 2006). Layer-averaged concentrations of POC and PON were calculated from limited data from the euphotic zone of the open and coastal-southwest Black Sea in between 1990 - 2013 (Table 3). The Layer-averaged POM values indicate remarkable seasonal variations. The open sea POM concentrations varied between 5.5-16 µM for POC and 0.65-1.55 for PON; the layer–averaged C/N ratio varied seasonally between 8 and 14. The coastal POC concentrations varied seasonally from 9 in late autumn to 94 µM in the productive season; expectedly, the PON concentrations were similar temporal patterns, in the range of 0.65 and 8.7 µM. In spring, the layer averaged POC concentrations generally varied between 40-94 and 40 µM in the euphotic zone having 0.2-0.5 µM of nitrate and very low phosphate (0.02-0.06 µM) concentrations (Table 4). However, the POM were observed to reach peak values of 80-95 µM during the spring bloom period when the river-fed NW shelf waters (salinity:16.5-17.5) having excess concentrations of nutrients reached as far as the southwestern Black Sea coastal regions via the cyclonic alongshore Rim Currents. Then, POM production and thus concentrations of bulk POM (slowly sinking particulate matter) in the coastal surface waters decrease to their natural levels in the late summer-autumn period when the nutrient inputs by the Danube inflow are almost consumed in the NW shelf. The C/N ratio in bulk POM, calculated from POC/PON measurements, varied between 7.7 and 14 in the euphotic zone (Table 3), with an average values of 10.4 for 1990-1996 period, which is greater than the conventional Redfield Ratio of about 6.7 estimated for the ocean POM, due presumably to selective decay of nitrogenous organic compounds in bulk POM and contribution of biochemically resistant terrestrial POM (with higher C/N ratio) input to the POM pool in the coastal near-surface waters of Black Sea. Consistently higher C/N ratios of the southern Black Sea POM indicate the existence of carbohydrate and cellulose-enriched POM in the southern Black Sea surface waters. High POC / Chll-*a* ratios of bulk POM indicate significant contribution of non-living, biogenically refractory particulates to the POM pool in the near-surface waters of Black Sea (Çoban *et al.* 2000, Çoban-Yıldız *et al.* 2006).

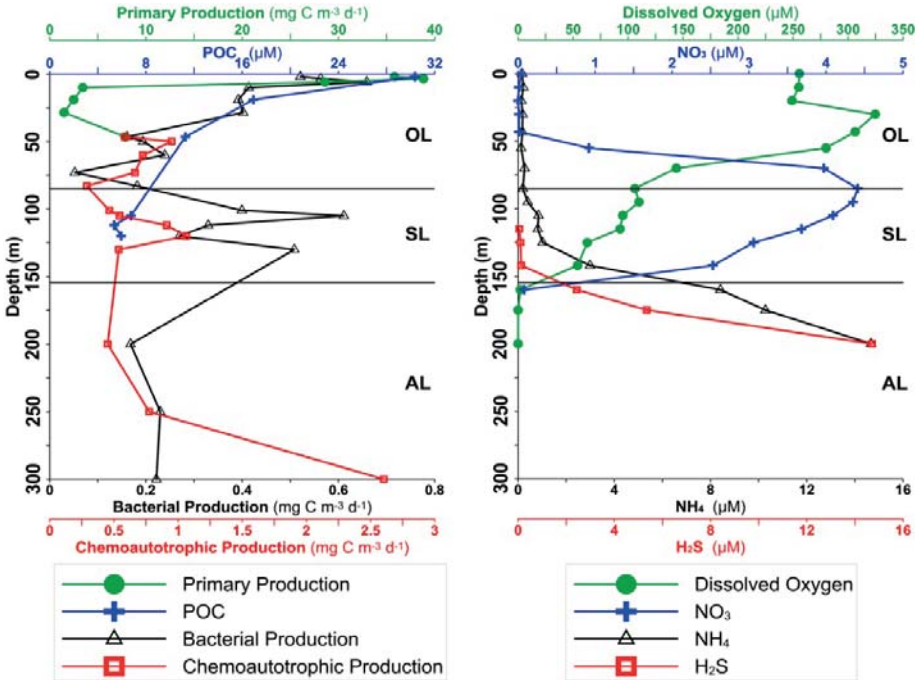

Figure 7. General biochemical characteristics of the Southern Black Sea in July 2013 (OL:Oxic Layer, SL:Suboxic Layer, AL:Anoxic Layer) modified from Yücel *et al*. 2013 and Yücel *et al*. unpublished)

Table 3. Layer-averaged concentrations of POC and PON are in the euphotic zone of the coastal-southwestern Black Sea for 1990-1996 and in July 2013

SEASON	POC	PON	C/N
September 1990	19.88	1.96	10.2
September 1991	14.68	1.26	11.6
December 1991	11.32	1.00	11.2
July 1992	21.48	1.45	14.7
April 1993	94.45	8.70	11.7
August 1993	10.90	0.98	11.1
December 1993	9.29	0.98	9.6
May 1994	11.69	1.50	7.7
Mar-Apr 1995	39.13	4.01	11.2
Sep-Oct 1995	10.53	0.85	14.0
June-July 1996	9.95	0.95	10.5
1990-1996 Averages	**15.6**	**1.5**	**10.4**
July 2013	**25.7**	**2.75**	**8.9**

Table 4. Layer averages of nutrients and Chl-*a* concentrations in the euphotic zone of SW Black Sea for the 1986-2013 period.

Parameter	Number of data	Mean	Min.	Max.
PO_4 (µM)	1206	0.05	0.02	0.18
NO_3+NO_2 (µM)	1279	0.21	0.03	1.53
Chl-a (µg/L)	493	0.52	0.05	3.12

6. Total Dissolved Organic Carbon (DOC)

General biochemical characteristic of the southern Black Sea is shown in Figure 7. Rate of the primary production is high in the near surface layer (surface-15m), then decrease with depth. DOC and POM distributions are very similar to biomass (Chl-*a*) and PP profiles decreasing from the productive surface layer to the bottom of the euphotic zone. The upper layer (surface-30 m) DOC concentrations, measured by Tuğrul (1993) using both the persulphate-UV oxidation (WET) and the high temperature dry oxidation (HTO), are relatively high in the southwest coastal (shelf and Rim Current) regions of the Black Sea. The coastal DOC concentrations ranged between 165 and 250 µM in the early 1990's (Tuğrul 1993). The DOC, POC and nutrient- enriched NW shelf waters are transported to the SW coastal areas via alongshore currents during the year. (Sorokin 1983, Polat and Tuğrul 1995, Çoban *et al*. 2000). The near-surface DOC concentrations were observed to decrease to levels of 155-190 µM in the central region of southwest Black Sea (Tuğrul 1993, Çoban 1997), consistent with spatial variability in bulk POM concentrations. Below the euphotic zone, the DOC concentration decreases steadily with depth in the oxycline and suboxic waters and reaches the background values in the suboxic/anoxic interface and then remains almost constant in the deep anoxic waters, slightly deceasing from 130 µM in the suboxic waters to about 105 µM in the anoxic layer (Tuğrul 1993, Çoban 1997).

References

Agirbaş, E., A.M. Feyzioğlu, and Ü. Kopuz. 2014. Seasonal changes of phytoplankton chlorophyll *a*, primary production and their relation in the continental shelf area of the south eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 713-726.

Çoban, Y. 1997. The Abundance and Elemental Composition of Suspended Organic Matter in the Turkish Seas (Black Sea, Marmara and Eastern Mediterranean). Ma. Sc.Thesis, METU, Institute of Marine Sciences, Erdemli, Mersin, Turkey, 187 pp.

Çoban-Yıldız, Y., S. Tuğrul, D. Ediger, A. Yılmaz, and S.C. Polat. 2000. A comparative study on the abundance and elemental composition of POM in three interconnected basins: the Black, the Marmara and the Mediterranean Seas. Mediterranean Marine Science, 1(1): 51-63.

Çoban Yildiz, Y., M.A. Altabet, A. Yilmaz, and S. Tugrul. 2006. Carbon and nitrogen isotopic ratios of suspended particulate organic matter (SPOM) in the Black Sea water column. Deep-Sea Research II, 53:1856-1874.

Kirchman, D.L. 2008. Microbial Ecology of the Oceans, pp.593. Second Edition, Wiley-Blackwell, A John Wiley & Sons.

Konovalov, S.K. and J.W. Murray. 2001. Variation in the chemistry of the Black Sea on a scale of decades (1960-1995). Journal of Marine System, 31: 217-243.

Morgan, J.A., H.L. Quinby, and H.W. Ducklow. 2006. Bacterial abundance and production in the Western Black Sea. DeepSea Research II, 53: 1945-1960.

Oğuz, T., V. Velenikova, A. Cociasu, and A. Korchenko. 2008. The state of eutrophication, pp. 83-109. In T. Oğuz [ed.], State of the Environment of the Black Sea. Commission on the Protection of the Black Sea, Istanbul, Turkey.

Polat, S.C. and S. Tuğrul. 1995. Nutrient and organic carbon exchanges between the Black and Marmara Seas through the Bosphorus Strait. Continental Shelf Research, 15(9): 1115-1132.

Polat-Beken, Ç., H. Atabay, M. Mantıkçı, İ. Tan, D. Ediger, and S. Tuğrul. 2017. Nutrients, chlorophyll *a* and dissolved oxygen. Black Sea Marine Environment: The Turkish Shelf. Turkish Marine Research Foundation (TUDAV).

Sorokin, Y.I. 1983. The Black Sea, pp. 253-291. In P.H. Ketchum [ed.], Ecosystems of the World, Vol 26: Estuaries and Enclosed Seas, Elsevier, Amsterdam.

Tuğrul, S., O. Başturk, C. Saydam, and A. Yilmaz. 1992. Changes in the hydrochemistry of Black Sea inferred from water density profiles, Nature. 359: 137-139.

Tuğrul, S. 1993. Comparison of TOC concentrations by persulphate-UV and HTCO techniques in the Marmara and Black Seas. Marine Chemistry, 41: 265-270.

Tugrul, S., J.W. Murray, G.E. Friederich, and I. Salihoğlu. 2014. Spatial and temporal variability in the chemical properties of the oxic and suboxic layers of the Black Sea. Journal of Marine System, 135: 29-43.

Yayla, M., A. Yılmaz, and E. Morkoç. 2001. The dynamics of nutrient enrichment and primary production related to recent changes in the ecosystem of the Black Sea. Aquatic Ecosystem Health and Management, 4: 33-49.

Yılmaz, A., S. Tuğrul, C. Polat, D. Ediger, Y. Çoban, and E. Morkoç. 1998. On the production, elemental composition (C, N, P) and distribution of photosynthetic organic matter in the Southern Black Sea. Hydrobiologia, 363: 141-156.

Yılmaz, A., Y. Çoban-Yıldız, F. Telli-Karakoç, and A. Bologa. 2006. Surface and mid-water sources of organic carbon by photoautotrophic and chemoautotrophic production in the Black Sea. Deep Sea Research Part II: Topical Studies in Oceanography, 53(17-19): 1988-2004.

Yücel, N., Z. Uysal, S. Tuğrul, G. Assimakopoulou, E. Ozsoy, and E. Erdogan. 2011. Primary production and phytoplankton composition in the southern Black Sea. SESAME Final Scientific Conference, Athens, Greece, 4-8 April 2011.

Yücel, N., S. Tuğrul, Z. Uysal, and B. Salihoğlu. 2013. Photoautotrophic and Chemoautotrophic Production in Marmara and Black Seas. 7. International Symposium on Ecology and Environmental Problems, 18-21 December 2013, Antalya, Turkey.

LONG-TERM IMPACTS OF ANTHROPOGENIC NUTRIENT INPUTS ON THE BLACK SEA UPPER (OXIC-SUBOXIC) LAYER CHEMISTRY

Süleyman TUĞRUL

Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
tugrul@ims.metu.edu.tr

1. Introduction

The Black Sea, a typical enclosed ecosystem fed by the major rivers (mainly by the Danube), has been subject to anthropogenic pressures since the 1960's (Cociascu *et al.* 1996, Sorokin 2002, Oğuz *et al.* 2008). The increased nutrient (N, P) loads of these rivers with modified N/P/Si molar (increased N/Si) ratios have drastically influenced bio-chemical properties of the whole Black Sea after the mid 1970's (Cociasu *et al.* 1996; Oğuz *et al.* 2008). Expectedly, these changes occurred first in the wide northwestern (NW) shelf ecosystem receiving the increased inputs of nutrients and organic pollutants by mainly the Danube (Cociasu *et al.* 1996, Oğuz *et al.* 2008). Enhanced eutrophication in the NW shelf surface waters in the early 1980's (Cociasu *et al.* 1996) then led to influence the whole ecosystem until mid 1990's, via major cyclonic circulations (Mee 1992, Konovalov and Murray 2001, Oğuz *et al.* 2002, 2003). Enhanced algal production (eutrophication) drastically altered species composition and bloom time and frequency, leading to marked decreases in water transparency and development of hypoxia and anoxia in the bottom waters of NW shelf (Cociasu *et al.* 1996, Oğuz *et al.* 2008). Then, impacts of the human-induced eutrophication were observed over the entire basin. Large amounts of particulate organic matter (POM) produced in the surface layer were exported below the euphotic zone in the coastal regions and open sea. Consequently, excess POM production has altered natural upper layer chemical and bio-optical properties of the whole Black Sea, leading to long-term (decadal) changes in the biological and distinct chemical properties of the oxic waters, the soboxic layer down to the suboxic/sulphidic transition zone after the 1970's (Murray *et al.* 1995, Konovalov and Murray 2001, Tuğrul *et al.* 1992, 2014). In order to better understand and assess long-term impacts of human-induced eutrophication on the Black Sea sub-basins, we should first examine the basic hydrographic and bio-chemical properties of the Black Sea in the "pristine" period of 1950-1960. On the other hand, oceanographic studies in the Black Sea by the 1970's show that the open Black Sea had oligotrophic properties with low nutrient and biomass concentrations, high water transparency and healthy ecosystem developed in the wide NW shelf occupied with oxygenated bottom water and benthic habitat (Oğuz *et al.* 2008). In this period, total annual loads of nutrients supplied to the sea from natural and anthropogenic sources and molar (N/P/Si) ratios of nutrients in the major rivers before the mid 1960' remained at acceptable levels for the marine ecosystem. In this study, we first evaluated basic chemical properties of the Black Sea based on limited data obtained before the 1970's and long-term data collected since the late 1980s. Then, the results reached from the comparison of limited data before the 1970's and the present chemical features developed after the late 1980's under the enhanced nutrient inputs are used to assess levels of long-term impacts of enhanced eutrophication on the oxic and suboxic water biochemical properties of the Western Black Sea.

2. Basic Chemical Properties of Black Sea System

The Black Sea, a land-locked deep basin with sulfide bearing waters below 125-200m, is strongly stratified with a surface layer of low salinity (S~17-18) due to large riverine input of fresh water (Sorokin 2002). In the oxygenated upper layers, there is a temperature minimum zone (so-called the Cold Intermediate Water Layer, 6-8 °C; Figure 1), formed in winter principally on the northwest shelf (Tolmazin 1985) and in the central gyres under severe winter conditions (Gregg and Yakushev 2005, Oğuz *et al.* 2003, 2006). Below the oxygenated productive upper mixed layer, an oxygen gradient and oxygen deficient zone is formed in the permanent halocline (approximately 100-150 m thick); the steep oxycline developed in the upper halocline, is followed by the SubOxic Layer (SOL) where the decreasing rate of oxygen is very low (Figure 1).The depth and thickness of the main oxycline and SOL is dominated by the regionally variable depth of permanent halocline (salinity increasing zone), deepening in the coastal rim current and anticyclonic eddies and decreasing towards the central gyres (Oğuz 2002). The deep basin below the SOL is occupied by totally anoxic, hydrogen sulfide-bearing water masses.

The permanent halocline is a natural barrier for nutrient supply from the deeper layers to the euphotic zone (EZ) and oxygen transport from the upper layer to the anoxic subhalocline waters (Konovalov and Murray 2001, Oğuz 2002, Gregg and Yakushev 2005). In summer, the formation of a seasonal thermocline becomes another natural factor limiting nutrient supply from the nutricline depths to the EZ (Baştürk *et al.* 1998, Oğuz 2002, Tuğrul *et al.* 2014). Terrestrial inputs dominate the coastal water ecosystem; however, the open sea ecosystem is dominated by cyclonic rim currents and upwelling processes supplying nutrients from the upper halocline in winter (Oğuz 2002, Gregg and Yakushev 2005). When the upper layer is thermally stratified during the spring-autumn period, new production in the euphotic zone is dominated by external sources.

Typical depth profiles of nutrients display distinct chemical features in the suboxic and anoxic waters of the deep basin (Figure 1). Nitrate and phosphate concentrations are very low in the coastal and offshore euphotic zone, and then increase apparently in the upper halocline and then reach maximum levels just below the main oxycline. In the oxygen deficient zone (SOL) where O_2<20 μM), as clearly shown in Figure 1, the nitrate declines steeply to nearly undetectable levels (<0.1 μM) within the suboxic/anoxic interface (O_2 < 3.0 μM). The ammonium concentration is consistently very low in the upper oxic-suboxic layer waters in the coastal and open sea and then increases steadily in the sulfidic deep waters due to anaerobic decay of organic matter sinking from the surface layer. The phosphate profile (Figure 1) exhibits a broad maximum within the suboxic layer water of the shelf and deep basin and then increased sharply to form the deep maximum at the sulfidic water boundary (H_2S~1 µM). The silicate (Si) depth profiles in the shelf and open sea are very similar to that of salinity (Figure 1), increasing steadily within the permanent halocline to 75-80 levels µM at the anoxic boundary (Figure 1) and reaching the maximum concentrations of about 300-320 µM in the deep basin waters below 1500 m (Codispoti *et al.* 1991, Tuğrul *et al.* 2014).

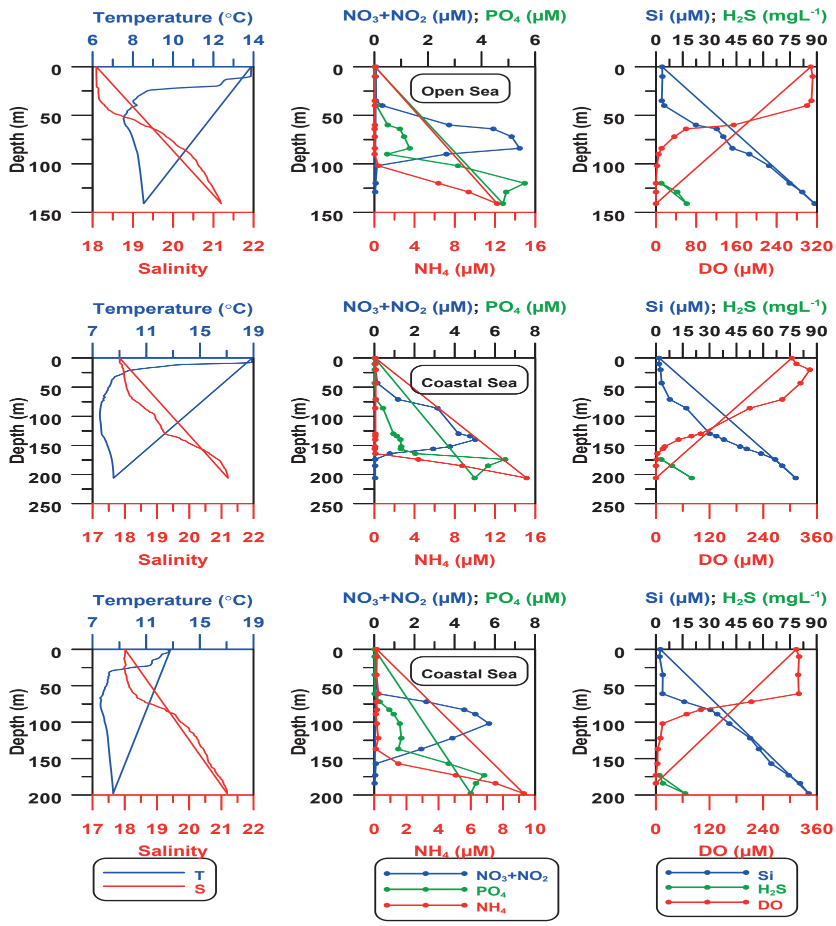

Figure 1. Typical depth profiles of salinity, temperature, nutrients, dissolved oxygen and sulfide in the western open sea and SW coastal regions (depth >200 m) in May 2007

Salty Mediterranean waters are enriched in nutrients but depleted in oxygen. Before flowing into the SW Black Sea intermediate waters, it mixes with the overlying cold oxygenated brackish waters of the SW shelf (Özsoy *et al.* 1993; Murray *et al.* 1991) and sink into the pycnocline and down to sulfidic water layer; these limited intrusions supply oxygen and nutrients to depths, and partly modify vertical distributions in the upper oxic waters of the SW shelf and Rim Current regions as discussed in the previous studies (Codispoti *et al.* 1991, Konovalov *et al.* 2001, 2003, Tuğrul *et al.* 2014).

3. Impacts of Human-Induced Pressures on Nutrient Contents of the Rivers

Limited historical data from the " pristine" (pre-anthropogenic and pre-damming of the rivers) period of 1950-1960 indicate that unpolluted major rivers feeding the NW shelf ecosystem had high concentrations of silicate and nitrate but low phosphate values (Ludwig *et al.* 2010). Therefore, the major rivers reached the coastal regions with very high N/P but lower N/Si (<1) ratios until the construction of dams on mainly the Danube was completed in mid 1970's (Cociasu *et al.* 1996, Oğuz *et al.* 2008). After damming the major river waters in the NW Black Sea Region in the 1960's, reactive silicate concentrations of the major river waters reaching the NW shelf decreased markedly whilst nutrients inputs from agricultural, industrial and domestic sources to the rivers enhanced drastically in the 1980's, leading to at least 2-3 fold increases in the annual loads of DIN (nitrate +ammonia) and phosphorus (P) inputs by the major river to especially NW shelf zone in this period (Cociasu *et al.* 1996, Oğuz *et al.* 2008). The enhanced DIN contents of the major rivers expectedly led to a critical change in the DIN/Si ratio (increasing over 1.0) as compared to the "pristine" conditions (N/Si <1.0) in the 1950's-1960's (Tuğrul *et al.* 2014). After the mid 1990's, human-induced nutrient (DIN, P) input to the Danube has decreased gradually, due to decreases in fertilizer production and N, P loads of domestic and industrial wastewater discharges (Cociasu e*t al.* 1996, Oğuz *et al.* 2008). However, the DIN/Si ratio in the Danube inflow to the Black Sea has still remained over one (>1), due to high rates of sedimentation of inorganic particulate matter leading to apparent decreases in Si content of the dammed river waters.

4. Impacts of anthropogenic nutrient inputs on Black Sea Ecosystem

The Black Sea is a typical river-fed enclosed ecosystem occupied with sulfide-bearing waters below 150-200 m in the deep basin. Therefore, bio-chemical properties of its upper layer is sensitive to human-induced pressures as experienced drastically since the late 1970's (Cociascu *et al.* 1996, Oğuz *et al.* 2008). The increased nutrient (N, P) inputs mainly by the Danube with increased N/Si ratios, have drastically altered the major bio-chemical properties of the NW shelf waters (Mee 1992, Cociasu *et al.* 1996, Oğuz *et al.* 2008) and then influenced the entire Black Sea after the mid 1970's (Konovalov and Murray 2001, Kıdeyş 2002, Yunev *et al.* 2002) via major cyclonic circulations and rim currents (Sorokin 2002). Enhanced eutrophication and thus increased particulate organic matter (POM) production in the euphotic zone (EZ) have led to excess export of POM to the depths below the EZ over the basin. Bio-chemical oxidation of excess POM within the oxycline and suboxic layer waters has altered natural chemical and bio-optical properties of the NW shelf waters and entire Black Sea. Briefly, enhanced algal production altered drastically species composition and bloom time and frequency, leading to marked decreases in the EZ thickness by at least 10-15 m regionally to 4-8 m range in the coastal and 8-14 m open sea and also development of hypoxic and anoxic conditions in the bottom waters of NW shelf (Cociasu *et al.* 1996). Consequently, decadal changes have occurred in the upper layer (oxic-suboxic water) chemistry down to the sulfidic water boundary in the entire deep basin after the late 1970's (Tuğrul *et al.* 1992, 2014; Murray *et al.* 1995, Konovalov and Murray 2001).

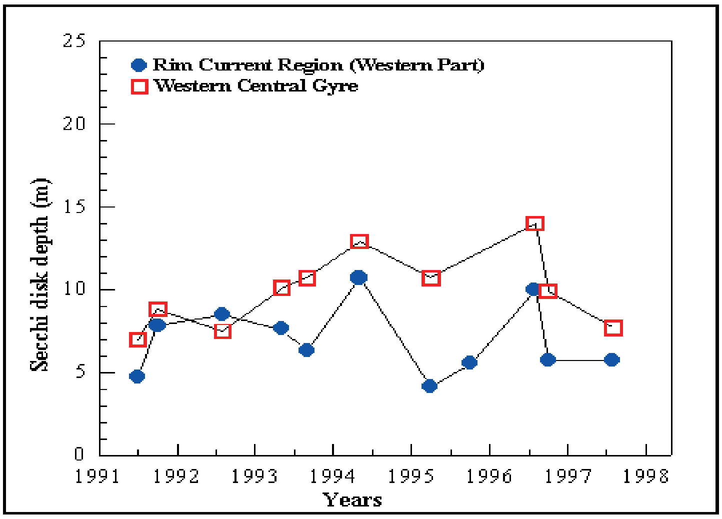

Figure 2. Annual variability in the Secchi disk depth in the SW Rim Current and offshore regions the Black Sea for the 1991-1997 period (reproduced from Baştürk *et al.* 1998)

4.1. Impacts of the Increased Nutrient Inputs on the Surface Layer Chemical Properties

In the pre-anthropogenic period before the mid 1960's, the silicate concentrations of surface waters ranged between 30-70 µM (Sorokin 1983, Tuğrul *et al.* 1992, 2014). However, the surface nitrate was as low as < 0.1-0.2 µM in the open sea surface waters having low phosphate values (0.1-0.3 µM). The Si/N ratio in the surface layer was very high (> 100) for the pristine period, before the 1970's. In this period, the major rivers and wet deposition fed the coastal and open system with high N/P ratios (>50) and but natural Si/N (>1) in the rivers but very low ratios in NO_x (nitrate+nitrite)-rich but silicate-low rain water. High Si/N ratio in the coastal and open Black Sea (Figure 3) indicate that terrestrial NO_x (nitrate+nitrite) inputs from natural sources were not sufficient to consume excess Si stock in the Black Sea photic zone before the 1970's. Very low N/P ratios (<5) in the past strongly suggest the nitrate-limited primary production over the basin, except the estuarine waters (salinity<17.0) in the NW shelf zone fed by the nitrate, Si-laden Danube discharges (with N/P ratio>25). Internal P-inputs from the nutricline depths and faster recycling in the EZ was sufficient to compensate P-uptake by photosynthesis during the pre-anthorpogenic period (see Figure 3; Tuğrul *et al.* 2014).

Then, in the 1970's, dam constructions on the major rivers markedly reduced the annual inputs of reactive silicate to brackish waters of the wide NW shelf and other coastal regions. At this time, increased agricultural and industrial activities and urbanization enhanced nitrate, ammonia, total and reactive phosphorus inputs to the major rivers feeding the Black Sea ecosystem. These human-induced pollution sources enhanced DIN and P inputs by the major rivers to the Black Sea by at least 2-3 fold. Excess POM produced in the near-surface waters consumed excess silicate in the surface layer and planktonic species composition and decreased the EZ thickness markedly after the mid 1970's (Oğuz *et al.* 2008 and references therein). Excess POM sinking below the EZ led to the development of hypoxia and anoxia in the NW shelf bottom waters and damaged all the demersal and benthic habitats in the 1980's (Oğuz *et al.* 2008). Excess algal production almost drastically consumed excess Si and limited PO_4 inventories of the near-surface waters of the entire basin. Thus, the surface Si concentrations decreased apparently and reduced the Si/NO_3 ratio by at least 100-fold in the coastal and open EZ waters in the 1980's (Figure 3; Tuğrul *et al.* 1992, 2014). In the coastal regions and Rim Current, the surface Si concentrations increased gradually in the period of 1995-2005, and then displayed a decreasing trend to 1-2 µM levels in the spring-summer period of more recent years (Figure 3). The limited phosphate stock in the surface waters, available at levels of 0.1-0.3 µM in the 1950-1960's (Figure 3), have been consumed and the concentration values declined to <0.02-0.05 µM levels in the 1980's (Tuğrul *et al.* 1992, 2014). Since rivers discharges carried excess NO_x to the coastal sea, after the mid 1970's, the surface nitrate concentrations in the NW shelf were as high as 4-7 µM in winter, decreasing to 0.4-0.6 µM levels in the coastal and open waters of SW basin (Tuğrul *et al.* 2014). The N/P ratio (<10) has remained low in the coastal and open surface waters (salinity>17.5) during spring-autumn period (Figure 3), suggesting nitrate-limited algal production (Yayla *et al.* 2001).

Expectedly, the enhanced POM production and export below the euphotic zone in the 1980's increased the nitrate inventory of the upper layer (pynocline) in the coastal and open sea (see Figure 3; Tuğrul *et al.* 2014). At this time, the excess Si in the euphotic zone was consumed markedly in diatom production, leading to a net decrease in the Si inventory of the upper layer down to the sulphidic water boundary at 150-200 m (Tuğrul *et al.* 2014). Long-term decreases in the silicate inventory of the upper layer has led to decreases dramatically to very low levels (even <1.0) in the in the 1980's (Figure 3). Annual averages of long-term silicate data from the 1887-2013 period (mostly obtained in spring-autumn seasons) in the western Black Sea Rim coastal waters and rim current display an apparent decreasing trend between 1986-1990 period and then increased gradually after mid 1990's (Figure 3). The surface Si concentrations in the open sea (salinity>18.0) gradually increased to 5-7 μM in the early 1990's (Tuğrul *et al.* 2014) and have remained higher than those in the river-fed coastal water. In this period, however, human-induced nutrient (DIN, P**)** discharges to the major rivers were reduced (Oğuz *et al.* 2008) and Si supply from the halocline depths became sufficient for consumption in diatom production. Average Si/N ratios for the surface mixed layer (0-10m) have remained high (>10) after the early 1990's (Figure 3).

Salinity-dependent surface layer distribution of nutrient and oxygen data obtained in June 2013 are illustrated in Figure 4 to see levels of nutrients remained excess after utilization in photosynthesis. It appears that less saline waters had higher NO_x values in less saline coastal zone with lower silicate levels. The silicate was higher in the N, P-depleted offshore waters, indicating increasing trend of Si/NO_x ratio from coastal to the open sea.

4.2. Long-Term Changes in the Chemical Features of the Oxic-Suboxic Layers

Typical depth and density-dependent vertical distributions of the major chemical features in the oxygen gradient zone (oxycline) and SubOxic Layer (SOL) of the deep basin and Rim Current are illustrated in Figures 1, 5, 6 are produced from the data obtained in 1994, 1969, and between 1995-2013. The chemical profiles are principally similar over the deep basin (depth > 200m). However, the cold intermediate layer, the main oxycline and the increasing nutricline (Figure 1) are situated at greater depths in the SW coastal basin and Rim Current (depth > 200 m). These regional differences result from various physical and bio-chemical processes which include the circulation patterns, the POM export and ventilation processes of the oxic/suboxic halocline waters in the SW Rim Current and open sea (Özsoy *et al.* 1993, Oğuz *et al.* 2002, Konovalov *et al.* 2003).

In order to examine and then assess long-term impacts of human-induced eutrophication on the chemical features formed permanently in the permanent halocline of the Black Sea, density-dependent profiles should be compared, rather than depth profiles, even at the same location (Tuğrul *et al.* 1992, 2014, Konovalov and Murray 2001). The increased export of POM after the 1970's have altered the depths of the nutricline and main oxycline boundaries, as illustrated in Figure 5 (Tuğrul *et al.* 1992, 2014 Murray *et al.* 1995). The nitrate concentrations (thus inventory) of the oxic upper layer down to nitrate maximum depth have increased by 2-4 folds from the mid-1960's to the late 1980's due to enhanced POM inputs to the nutricline depths (Tuğrul *et al.* 1992, Konovalov and Murray 2001). However, in the deep basin, the nitrate content (stock) of the nutricline waters could be eroded by denitrification in summer period (Figure 5), when the POM input much exceeded the rate of oxygen diffusion from the upper oxycline depths. The oxycline shifted upward in recent decades by 10-30 m and thus led to the enlargement of SOL (O_2 decreasing gradient very small) in the deep Black Sea basin (Figure 5, 6). Old and recent oxygen profiles in Figure 5 and 6 clearly show that the oxycline (O_2 > 30 µM) extended down to sigma-t: 15.75 density surface in the 1960's; then, its boundary has shifted upward by about 0.3-0.4 density units in the 1980's. Winter ventilation of the upper layer enhanced oxygen diffusion into the upper subhalocline leading to seasonal enlargement of the main oxycline boundary downwards only by a few 5 m's (Figures 5, 6).

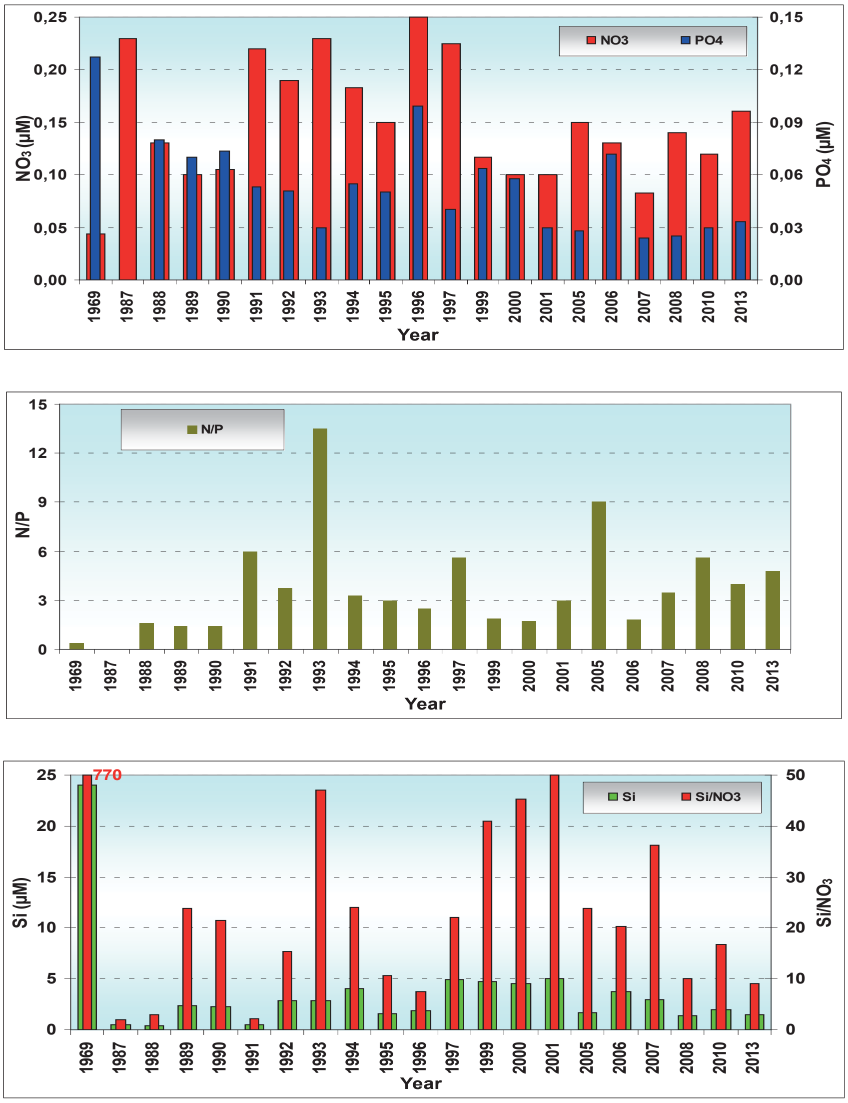

Figure 3. Long-term variations of nutrients and their molar ratios in the surface waters (0-10 m averages) of SW Rim Current (modified from the Figure in Tuğrul *et al.* 2014)

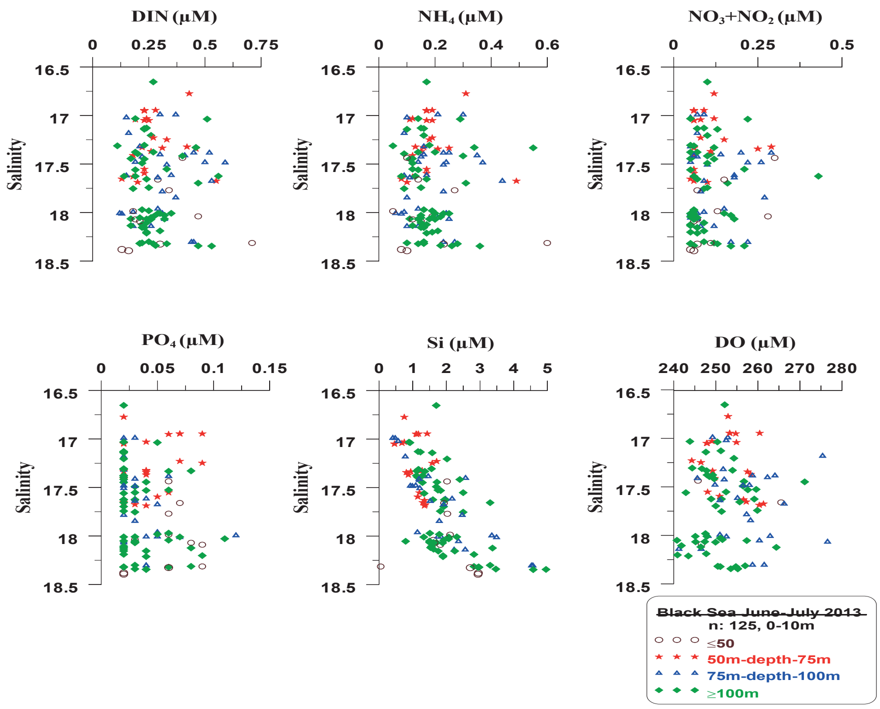

Figure 4. Salinity versus nutrients and dissolved oxygen in the SW coastal (depth < 100 m) and Rim Current (depth >100 m) regions of SW Black Sea in June 2013

In conclusion, before the 1960's when human-induced nutrient inputs to the major rivers remained at minimal levels, the less contaminated major rivers in the Black Sea region were rich in nitrate and reactive silicate, but depleted in reactive phosphate (Figure 3), leading to N/P ratio > 25 but low N/Si (<1) as wet deposition were rich in DIN, but depleted in reactive Si and phosphorus. At this time, the western Black Sea surface waters had high silicate (30-70 μM) (Figure 3) but low concentrations of phosphate (0.1-0.3 μM) and nitrate (< 0.1 μM), leading to very high Si/DIN ratios (>100) but low N/P (<10), indicating N-limited primary productivity in the coastal and open sea (salinity >17.5). It can be stated that before the 1970's, the terrestrial inputs of nitrate were not sufficient to consume all the excess Si stock in the nitrate depleted euphotic zone. Construction of dams on the major rivers in the period of 1960-1970's reduced drastically the silicate loads of the river waters reaching the sea whilst the DIN and TP inputs from domestic, industrial and agricultural sources to the major river increased drastically, leading to apparent changes in the Si/NO_3 ratio (decreased from >1 to ~ 0.5 level) of the rivers.

The current ecological conditions in the Black Sea and expected future trends in nutrient inputs from the external sources strongly suggest that the "reference conditions" of pre-anthropogenic and pre-damming period in the Black Sea before the 1960's are unlikely to be reached in the future. Accordingly, present and future trends in external inputs of nutrients would lead to development of new ecological conditions in the coastal and open Black Sea. Therefore, the ultimate target for the sustainable management of the Black Sea ecosystem should be to estimate the minimum range of the total (river + precipitation) annual NO_x inputs from the external sources to the entire Black Sea basin. Then the systematic observations are essential to monitor short and annual variability in POM production and export below the euphotic zone (EZ), the EZ thickness, oxygen supply into oxygen gradient zone situated below the winter mixing zone. Understanding the results of these interacting process permits us to understand long-term variability in the main oxycline and thus anoxic boundary (O_2 at undetectable level, < 1.0 μM) in the deep basin.

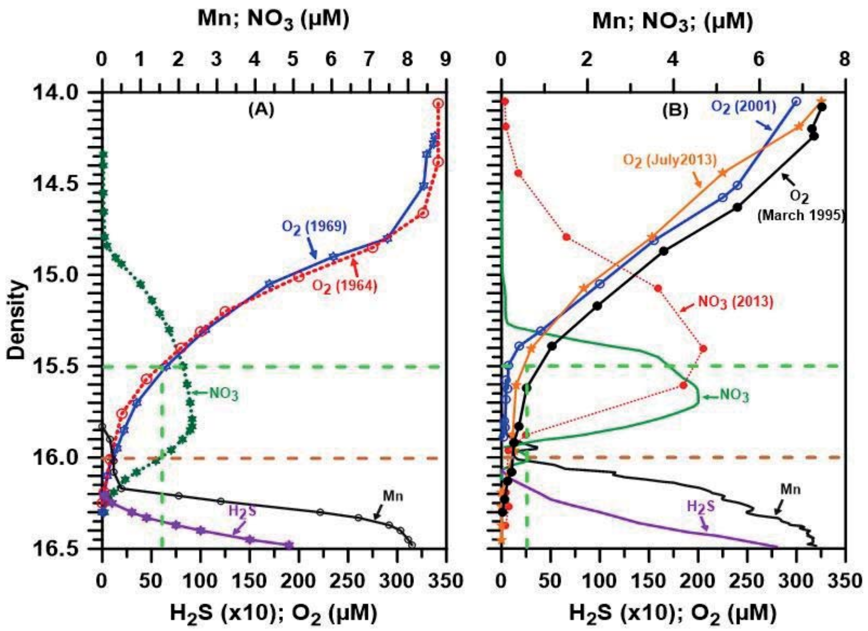

Figure 5. Typical density-dependent vertical distributions of nutrients, oxygen (O_2) and hydrogen sulfide (H_2S) down to depths of sigma-t: 16.5 density surfaces in the west central Black Sea in March 1970, 1964 and between 1995-2013; green dashed lines represent the value of oxygen at 15.5 density surface in the past and after late 1980's (modified from Tuğrul *et al.* 2014)

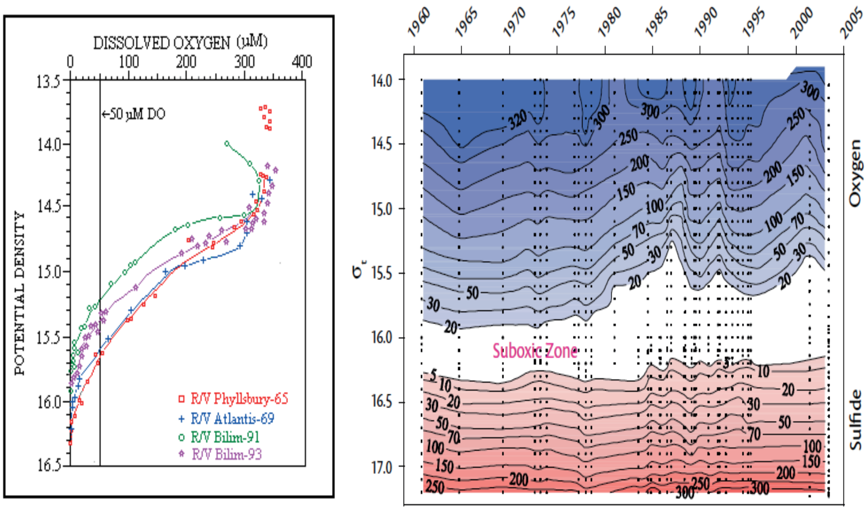

Figure 6. Long-term variability in the density-dependent oxygen profiles (left panel, reproduced from Baştürk *et al.* 1998) and density-dependent transects (right panel) of oxygen (blue) and sulphide (red) concentrations measured in the upper layer of the deep basin (left panel) between 1960-2005 (reproduced from Konovalov and Murray 2001)

Acknowledgement

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References

Baştürk, Ö., S. Tuğrul, S. Konovalov, and İ. Salihoğlu. 1998. Effects of circulation on the saptial distributions of principle chemical properties and unexpected short- and long-term changes in the Black Sea, p. 39-54. In L.I. Ivanov, and T. Oğuz [eds.], Ecosystem modeling as a management tool for the Black Sea. NATO Science Series, Vol. 47, Kluwer Academic publishers, Netherlands.

Cociasu, A., L. Dorogan, C. Humborg, and L. Popa. 1996. Long-term ecological changes in Romanian coastal waters of the Black Sea. Marine Pollution Bull. 32: 32-38.

Codispoti, L.A., G.E. Friederich, J.W. Murray, and C.M. Samatamota. 1991. Chemical variability in the Black Sea: implications of data obtained with a continuous vertical profiling system that penetrated the oxic/anoxic interface. Deep-Sea Research, 38(2): 691-710.

Gregg, M.C. and E. Yakushev. 2005. Surface ventilation of the Black Sea's cold intermediate layer in the middle of the western gyre. Geophys. Rec. Lett., 32 (3): 1-4.

Kıdeyş, A.E. 2002. Decline and recovery of a large marine ecosystem, the Black Sea. Science, 297: 1482-1484.

Konovalov, S.K. and J.W. Murray. 2001. Variations in the chemistry of the Black Sea on a time scale of decades (1960-1995). J. Mar. Syst., 31: 217-243.

Konovalov, S.K., L.I. Ivanov, and A.S. Samodurov. 2001. Fluxes and budget of sulphide and ammonia in the Black Sea anoxic layer. Journal of Marine Systems, 31(1): 203-216.

Konovalov, S.K., G.W. Luther, G.E. Friedrich, D.B. Nuzzio, B.M. Tebo, J.W. Murray, T. Oğuz, B. Glazer, R.E. Trouwborst, B. Clement, K.J. Murray, and A.S. Romanov 2003. Lateral injection of oxygen with the Bosphorus plume-fingers of oxidizing potential in the Black Sea. Limnol. and Oceanogr., 48(6): 2369-2376.

Ludwig, W., A.F. Bouwman, Dumont, E. and F. Lespinas. 2010. Water and nutrient fluxes from major Mediterranean and Black Sea rivers: Past and future trends and their implications for the basin-scale budgets. Global Biogeochem. Cycles, 24(4): 1-14.

Mee, L.D. 1992. The Black Sea in crisis: The need for concerted international action. Ambio, 21(4): 278-286.

Murray, J.W., Z. Top, and E. Özsoy. 1991. Hydrographic properties and ventilation of the Black Sea. Deep-Sea Res., 38(2): 663-689.

Murray, J.M., L.A. Codispoti, and G.E. Freiderich. 1995. Oxidation-reduction environments: the suboxic zone in the Black Sea, 244: 157-176. In C.P. Huang, C.R. O'Melia and J.J. Morgan [eds.], Aquatic Chemistry, ACS Advances in Chemistry Series.

Oğuz, T. 2002. Role of physical processes controlling oxycline and suboxic layer structures in the Black Sea. Global Biogeochemical Cycles, 16: 1-10.

Oğuz, T., T. Cokacar, P. Malanotte-Rizzoli, and H.W. Ducklow. 2003. Climatic warming and accompanying changes in the ecological regime of the Black Sea during 1990s. Global Biogeochemical Cycles, 17(3): 1088.

Oğuz, T., J.W. Dippner, and Z. Kaymaz. 2006. Climatic regulation of the Black Sea hydro-meteorological and ecological properties at interannual to decadal time scales. J. Mar. Syst., 60: 235-254.

Oğuz, T., V. Velikova, A. Cociasu, and A. Korchenko. 2008. The state of eutrophication, 448 pp. In T. Oguz [ed.], State of the Environment of the Black Sea (2001-2006/7). Publications of the Commission on the Protection of the Black Sea against Pollution (BSC) 2008-3, Istanbul, Turkey.

Özsoy, E., Ü. Ünlüata, and Z. Top. 1993. The evolution of Mediterranean water in the Black Sea; interior mixing and material transport by double diffusive intrusions. Progress in Oceanography, 31(3): 275-320.

Sorokin, Y.I. 1983. The Black Sea, p. 253-292. In B.H. Ketchum [ed.], Estuaries and Enclosed Seas Ecosystems of the World. Elsevier, New York.

Sorokin, Y.I. 2002. The Black Sea- Ecology and Oceanography, 875 pp. Backhuys Publishers, UNESCO Venice Office, Leiden.

Tolmazin, D. 1985. Changing coastal oceanography of the Black Sea. I. Northwestern shelf. Prog. Oceanogr. 15: 217-276.

Tuğrul, S., Ö. Baştürk, C. Saydam, and A. Yılmaz. 1992. Changes in the hydrochemistry of the Black Sea inferred from water density profiles. Nature, 359: 137-139.

Tuğrul, S., J.W. Murray, G.E. Friederich, and İ. Salihoğlu. 2014. Spatial and temporal variability in the chemical properties of the oxic and suboxic layers of the Black Sea. Journal of Marine Systems, 135: 29-43.

Yayla, M.K., A. Yılmaz, and E. Morkoç. 2001. The dynamics of nutrient enrichment and primary production related to the recent changes in the ecosystem of the Black Sea. Aquatic Ecosystem Health and Management, 4(1): 31-49.

Yunev, O.A., V.I. Vedernikov, O. Başturk., A. Yılmaz, A. Kıdeyş, S. Moncheva, and S. Konovalov. 2002. Long-term variations of surface chlorophyl-*a* and primary production levels in the open Black Sea. Marine Ecological Progress Series, 230: 11-28.

CATCHMENT-SEA INTERACTIONS IN THE BLACK SEA

Korhan ÖZKAN, Koray ÖZHAN and Mustafa YÜCEL

Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
okorhan@metu.edu.tr

1. The Black Sea and its catchment

The Black Sea is a geologically younger sea. During the early Holocene, it was a large freshwater lake located lower than the water level of the Mediterranean Sea. The current Black Sea ecosystem was formed approximately seven or eight thousand years ago, when the Mediterranean waters broke through the Bosporus valley (Ryan *et al.* 1997). This gradually formed a sea with maximum depth of *c.* 2 km and a strong density gradient (known as a pycnocline), where the salty water from the Mediterranean Sea sank to the bottom and fills the Black Sea from below. Overall, the water balance of Black Sea is positive and this extra mesohaline water is delivered to the Mediterranean Sea through the Dardanelles straight (Oğuz *et al.* 1990). The limited oxygen advection as well as respiration of organic matter fluxes has resulted in permanent anoxic conditions below 150–200 m depth.

Currently, the Black Sea covers 423,000 km^2, while its catchment is 5.21 times larger the surface area (Jaoshvili 2002) with an average elevation of 398 m (Ludvig *et al.* 2009). This catchment area drains approximately one-third of continental Europe, where is inhabited by more than 160 million people. Rivers as well as other surface and underground flows across this large and highly populated catchment delivers vast amount of water, solutes and particles into the Black Sea. These fluxes as well as the inland nature and long retention time of the Black Sea make the land-derived chemical pollutants and nutrients very important determinants of the Black Sea ecosystem.

The largest ten rivers (with respect to water flux) of the Black Sea catchment are the Danube (203 km^3 year^{-1}), Dnieper (54 km^3 year^{-1}), Don (28 km^3 year^{-1}), Rioni (12,9 km^3 year^{-1}), Kuban (13 km^3 year^{-1}), Dniester (10,2 km^3 year^{-1}), Çoruh, Kızılırmak, Sakarya, and Yeşilırmak rivers, carrying about 85% of the riverine freshwater to the Sea (Jaoshvili 2002, Algan 2006). While the total annual water influx to the Black Sea is estimated to be 350–400 km^3 (Ludvig *et al.* 2009), the Danube constitutes approximately half of the total water input alone. An analysis of the water discharges of a set of rivers in the Black Sea catchment (not including Turkish coast or side) detected no trend during the two-decades study period (Ludvig *et al.* 2009). This is in contrast with the trends observed in the Mediterranean catchment, where a widespread decrease in river discharges driven by anthropogenic water use and climate change was observed (Ludvig *et al.* 2009). However, these estimates have been performed based on available monitoring of the main rivers and modelling studies (Ludvig *et al.* 2009), which rely on limited data due to the lack of widespread, intensive monitoring. Therefore, the current estimates should be taken with caution and more detailed integrated observations are needed to better estimate water and mass fluxes between the catchment and the Black Sea.

The Black Sea has a total coastal length of 4340 km and one-third (*c.* 1400 km) of this coastline is covered by Turkish catchments along the entire southern border of the Black Sea (Figure 1). The southern part of the Black Sea is mostly characterized by a steeply declining shelf in the sea and High Mountains parallel to the sea on the land. However, these mountains have clefts in several places by deep valleys formed by large rivers connecting northern Anatolia to the Black Sea (Jaoshvili 2002). Four of these catchments are formed by large rivers: Kızılırmak (1335 km), Sakarya (720 km), Yeşilırmak (519 km) and Çoruh (400 km) catchments (Table 1). Çoruh River is a trans-boundary catchment, where the majority of the catchment is in Turkish territories, however the river drains in Black Sea in Georgia. The remaining three catchments consist of several small rivers and streams that are delineated together as a catchment: East Black Sea, West Black Sea and Marmara catchments. Marmara catchment and Black Sea interaction is complex as a large portion of this catchment draining into the Marmara Sea; however, still indirectly affecting Black Sea through water exchange between the Marmara and Black Seas. In total, 271,790 km^2 –approximately one third of Turkey drains into the Black Sea (Figure 1, Table 1).

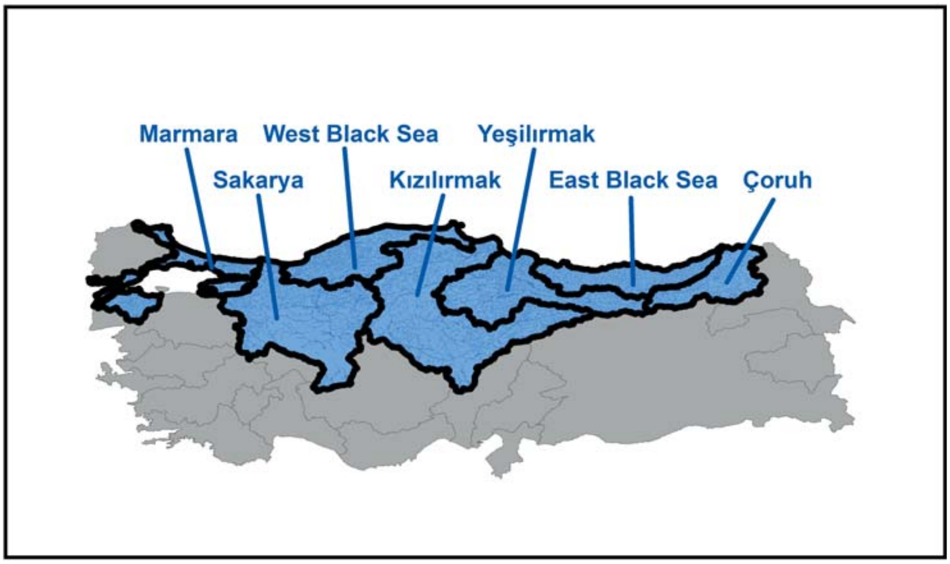


Figure 1. Seven catchments along the Turkish coasts of the Black Sea. Notice that some of the catchments are aggregated catchments including several small adjacent streams

Table 1. Main characteristics of Turkish catchments draining into the Black Sea. The data is compiled mostly from the reports of Ministry of Forestry and Water Affairs. The values reflect assessments conducted between 2007 and 2016.

Catchment	Area (km^2)	River length (km)	Total Population (Million)	Average surface runoff (m^3 s^{-1})	Agricultural area (% cover)
Kızılırmak	78646	1355	3,1	206	55
Sakarya	58160	720	7,6	203	52
Yeşilırmak	38733	519	1,9	184	42
Çoruh	19768	400	1	200	19
East Black Sea	22844	-	2,3	473	13
West Black Sea	28922	-	1,9	315	21
Marmara	23385	-	15,2	264	37

As the Black Sea shelf is very steep on the Turkish coastline, the majority of these catchments – especially in the eastern shelf – directly drains into the deep-sea environment. Few of the large rivers are capable of sustaining large deltas formed by the deposition of transported sediments, such as Yeşilırmak and Kızılırmak rivers. Remaining river and streams can only sustain smaller coastal wetlands. Two of these wetlands - İğneada and Kızılırmak - includes regionally rare coastal swamp forest ecosystems. All of these coastal wetlands host an important amount of biodiversity and thus provides important services for the Black Sea ecosystem; such as providing breeding grounds for seabirds, like Great Cormorants (Kirwan *et al.* 2010).

2. Rivers and eutrophication

Rivers constitute a network that carries terrestrial matter and energy from the catchment into the sea. As a consequence, rivers have also been transporting excess nutrients (nitrogen and phosphorus) from the catchments produced by urban and agricultural activities (*e.g.,* wastewater effluent, agricultural fertilizer use, point and nonpoint sources) to the Black Sea. This resulted in a dramatic increase in dissolved ion concentrations and suspended materials in rivers and consequently eutrophication in coastal seas. Eutrophication has led to alterations in plankton abundance and composition (Butcher 1947) as well as an increase in noxious phytoplankton blooms, oxygen depletion and loss of healthy benthic communities in many parts of the seas (Rosenberg 1985, Justic *et al.* 1995).

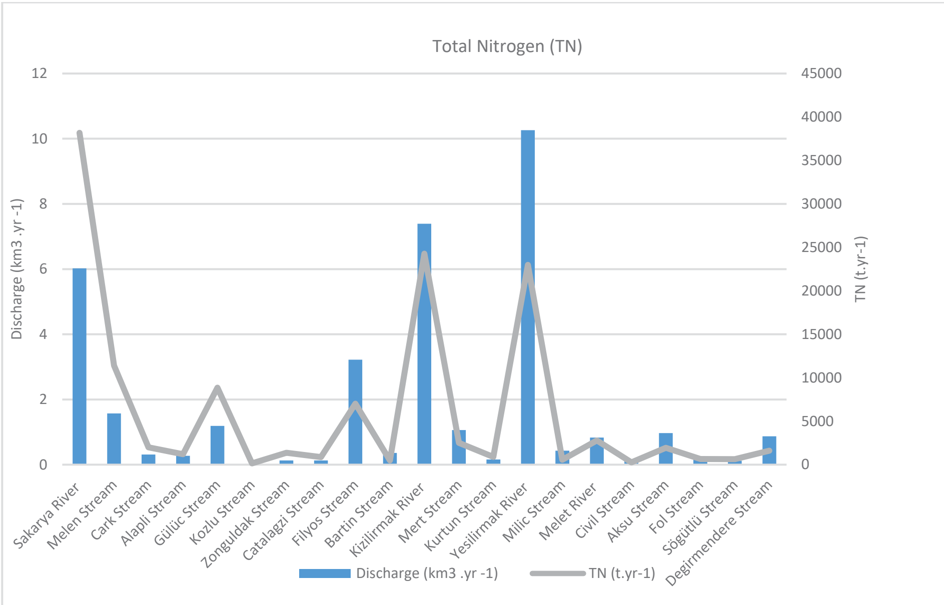
The Black Sea is regarded as a regional sea that has been most severely damaged as the result of human activity. Based upon comprehensive studies, in 1996, Ministers of the Environment from Black Sea countries recognized the eutrophication of the Black Sea as an international problem (SoKolnikov 1999). Due to the coastal eutrophication resulting from the excess nutrients carried by rivers, high-frequency algal blooms have become characteristic of the north-western part of the Black Sea, and the area covered by the blooms increased 10±30-fold in comparison with 1950-1960 period (Zaitsev and Mamaev, 1997). Eutrophication have also led to permanent or ephemeral hypoxia (low oxygen levels) in north-western continental shelf of the Black Sea in the mid-1970s (Mee 2006). These hypoxic conditions extended across 40,000 km^2 by the 1990s causing devastating effects on benthic life (such as the loss of *Cystoseria* and *Zostera* habitats) as well as fish populations through destruction of spawning and nursery habitats (Dumont 1999, Keskin 2010, Gücü *et al.* 2016, Mee 2006). As a result of the dramatic destruction of the Black Sea ecosystem, six Black Sea countries – Bulgaria, Georgia, Romania, the Russian Federation, Ukraine, and Turkey – have regionally teamed up to protect the Black Sea at the beginning of 1994 and initiated the Bucharest Convention on the protection of the Black Sea against pollution.

An assessment on the dissolved nitrogen (N) and phosphorus (P) inputs to the Black Sea in 1998 (Topping *et al.* 1999) suggested that percent contribution of the neighbouring countries to the total nitrogen (TN) load were: Romania-27%, Bulgaria-14%, Ukraine-12%, Russian Federation-10%, Turkey-6%, Georgia->1%, and non-coastal countries- *c* 30.%. Whereas, the percent contribution of the neighbouring countries to the total phosphorus (TP) load were: Romania-23%, Ukraine-20%, Russian Federation -13%, Turkey-12%, Bulgaria-5%, Georgia-1% and non-coastal countries-26%. However, another assessment by Tuncel *et al.* (1998) suggested that the contribution of Turkish rivers was 13% of all N discharges to the Black Sea, which might account up to 74% off all non-Danube sources. They also estimated that the P influx from Turkish rivers accounts for 8% of the annual P discharge to the Black Sea, which might account up to 46% off all non-Danube sources (Tuncel *et al.* 1998).

Bakan and Büyükgüngör (2000) reported nutrient concentrations in major rivers and streams in the Black Sea coast of Turkey sampled in early 1990's. Overall, Sakarya, Filyos, Kızılırmak, Yeşilırmak and Mert rivers account for 78% of the total water and 60% of the total nutrient discharge of the rivers assessed in the study. The main nutrient influx is concentrated on the central part of the Black sea coastline (Figure 2). However, few of the streams and rivers were surprisingly enriched by certain nutrients. For example, Değirmendere Stream carried 2.4% of the total water discharge but accounted for 13% of *o*-P and 24% of the total TP discharge from Turkish catchments into the Black Sea. Similarly, Kozlu Stream was enriched with NH_3, and Zonguldak Stream was enriched with TN (Table 2 and Figure 2). This probably reflects the effect of neighbouring large cities. When river and streams nutrient loads compared to annual load of nutrients from sewerage systems of 6 major cities, Sinop, Samsun, Ordu, Giresun, Trabzon, and Rize, on the coast of the Black Sea (Bakan and Büyükgüngör 2000, Table 3), total water discharge from the sewage was negligible (36 $km^3.yr^{-1}$ vs. 0.05 $km^3.yr^{-1}$) but, *o*-P and TP input from the sewage was substantially high, as expected.

In another study by Tuncel *et al.* (1998), many of these rivers were resampled for nutrient concentrations in the same period - May, August and October 1993. A very high variability was observed in the nutrient fluxes as some measured variables had up to 10-fold differences in comparison to previous measurements (Table 2). This reflects the significant variability in nutrient fluxes due to sampling extent, timing, frequency, duration and seasonality.

There are also more recent studies on the nutrient concentrations in the rivers along the Black Sea catchment (Boran and Sivri 2001, Verep *et al.* 2005, Gültekin *et al.* 2012, Alkan *et al.* 2013). Furthermore, recent seasonal standardized monitoring programs have been commenced on the Turkish coasts by the governmental organisations. However, the data are not publicly accessible and therefore comparative analyses are not possible. Moreover, many of these studies have different spatial extents, different methodologies and varying temporal frequencies, which makes comparisons and synthesis difficult. Furthermore, it should be noted that these studies are not complete inventories of the nutrient load from Turkish catchments. For example, the Çoruh River is not included in these assessments as it discharges to the Black Sea from the Georgian territory although it has a significant discharge and it predominantly carries water and material from the Turkish catchments. Therefore, it is currently difficult to make strong inferences on the total nutrient flux from the Turkish catchments.



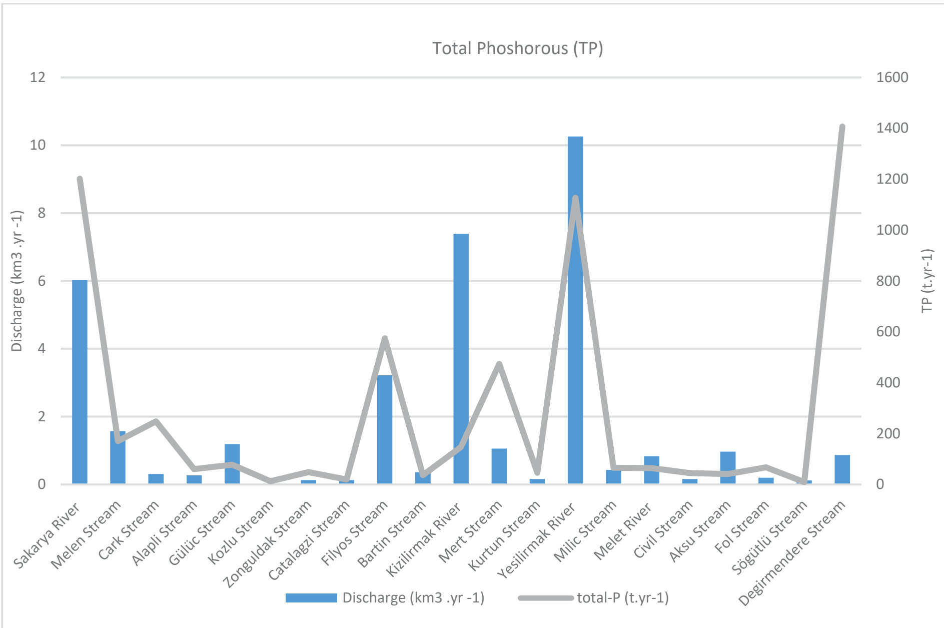


Figure 2. Annual loads of total nitrogen (TN, above) and total phosphorous (TP, below) from a set of rivers and streams along Turkish Black Sea coastline from west to east (Bakan and Büyükgüngör 2000)

Table 2. Annual loads of nutrients from rivers and streams along the Turkish Black Sea coast (Bakan and Büyükgüngör 2000 and Tuncel *et al.* 1998 (*))

Rivers and Streams	Discharge ($km^3.yr^{-1}$)	Discharge* ($km^3.yr^{-1}$)	o-PO4 ($t.yr^{-1}$)	TP ($t.yr^{-1}$)	TP* ($t.yr^{-1}$)	NH_3 ($t.yr^{-1}$)	NO_3 ($t.yr^{-1}$)	NO_3* ($t.yr^{-1}$)	TN (t.yr-1)
Sakarya River	6.02	3.57	1214.4	1201.5	140.2	3449	11354	4087	38178
Melen Stream	1.57	0.63	149.6	170.7	98	565	2006	723	11400
Çark Stream	0.31		174.3	247.8		329	690		1989
Alaplı Stream	0.27		44.4	60.7		67	550		1201.8
Gülüç Stream	1.19		43.6	77.5		1459	5530		8850
Kozlu Stream	0.02	0.02	10.9	12.4	2.4	96	71	11	148.7
Zonguldak Stream	0.13		47.9	48.4		214	452		1366.9
Çatalağzı Stream	0.13		4.8	19.9		298	315		874.6
Filyos Stream	3.22	3.12	566.9	574.6	390	554	2152	3139	7022
Bartın Stream	0.36	0.2	28.7	36.5	36	102	81	25	483.9
Kızılırmak River	7.39	7.63	78.8	147.2	88	6139	7765	1694	24274
Mert Stream	1.06	0.16	371.7	473.7	29	1178	1694	94	2519
Kurtun Stream	0.16	0.07	157.8	45.8	2.1	55	231	19	895
Yeşilırmak River	10.26	7.17	3277.7	1126.7	1000	2894	5813	5781	22983
Miliç Stream	0.43	0.01	153.9	65.6	0.9	6.3	57	3.6	561.3
Melet River	0.83		97.2	64.6		196	1774		2784
Civil Stream	0.16	0.01	27.9	44.6	21	9.4	22	21	274.1
Aksu Stream	0.97	1.18	84.3	41.2	903	98	1282	903	1934
Fol Stream	0.2		67.8	67.4		100	483		649.1
Sögütlü Stream	0.12		28.7	9.4		98	480		640.8
Değirmendere Stream	0.87	0.99	989.3	1406.7	384	279	459	384	1609.8
Total	36		7621	5943		18186	43261		130639

Table 3. Annual load of nutrients from sewerage system of a set of cities along the Turkish Black Sea coast

City	**discharge ($km^3.yr^{-1}$)**	***o*-PO_4 ($t.yr^{-1}$)**	**TP ($t.yr^{-1}$)**	**NH_3 ($t.yr^{-1}$)**	**NO_3 ($t.yr^{-1}$)**	**TN ($t.yr^{-1}$)**
Sinop	0.004	32.7	37.3	85.9	7.3	122.0
Samsun	0.008	46.9	62.4	25.6	12.3	145.3
Ordu	0.01	54.9	68.1	19.3	17.1	62.0
Giresun	0.004	27.9	50.8	16.5	9.5	138.1
Trabzon	0.01	69.3	49.8	9.6	30.2	238.8
Rize	0.009	32.7	43.9	41.8	14.2	299.9

3. Rivers and contaminants

The extent of marine pollution is relatively less documented in contrast to the general oceanography of the Black Sea. The pollution in the Black Sea is mostly driven by influx from land-based pressures, which is similar to other enclosed seas. These land-based pollutants (heavy metals, poly aromatic hydrocarbons (PAHs), pesticides, polychlorinated biphenyls (PCBs), etc.) are predominantly transported by the rivers. The shallow, mixed surface waters of the Black Sea receive river discharges that are heavily loaded with nutrients and contaminated with industrial and mining wastes. Accordingly, the Black Sea suffers from serious environmental problems. Turkish catchments contribute relatively low to the total influx of contaminants into the Black Sea in comparison to the discharges from the larger rivers, like Danube. Main sources of contamination in Turkish catchments are transported via Kızılırmak, Sakarya, and Yeşilırmak Rivers, which carry mostly untreated domestic wastewater, domestic and industrial pollutants into the Black Sea (Bakan *et al.* 1996).

The first comprehensive data set on the annual pollutant fluxes from land-based sources along the Turkish coast was reported by Tuncer *et al.* in 1998. The study covered up six industrial discharge channels, 12 sewage outlets, and 24 rivers and streams along the coast. The three sampling surveys were carried out in May, August and October 1993. The highest metal concentrations were measured in industrial discharges (Tuncer *et al.* 1998). Concentrations of all measured metals were by far the highest in the direct discharges of the copper smelter located in the city of Samsun. Concentrations of metals were fairly low in rivers and streams in general compared to industrial discharges. This probably indicated the lower intensity of industrial activities in these river catchments (Tuncer *et al.* 1998). However, the total influx from the direct industrial and domestic discharges constitute only a minute fraction of annual pollutant fluxes to the Black Sea due to the low water discharge from these sources. The rivers, on the other hand, constitute a large fraction of the total pollutant discharge to Black Sea due to the larger total discharge volume, although the local pollutant concentrations were low. Overall, the total discharges and fluxes for a variety of pollutants from Turkish catchments were much lower than that of Danube catchment (Table 4). However, the contribution from Turkish catchments are still a significant pressure on Black Sea ecosystem. Generally, annual loads of pollutants from the Turkish coast are the second highest after Ukraine (Tuncer *et al.* 1998).

Table 4. Annual fluxes of total nitrogen (TN), total phosphorous (TP), Cu, Pb, and Zn into the Black Sea from Turkish coast and comparison the river discharges to Danube (Tuncer *et al*. 1998).

	Fluxes from Turkish coast		
	Domestic and industrial sources (t year^{-1})	Rivers (t year^{-1})	Flux from Danube (t year^{-1})
discharge	0.019	27.3	203
TN	3400	36300	229181
TP	147	3534	34938
Cu	34	303	900
Pb	18	42	4500
Zn	220	988	6000

Organic contaminants resulting from discharges of untreated domestic waste appears to be the most important contamination problem along the Black Sea coast. A study quantified 11 pesticides and PCBs found that 316 tons of o,p'DDE, 176 tons of endrin and 115 tons of DDD were being discharged from the Turkish coast into the Black Sea on annual basis in 1993 (Tuncer *et al.* 1998). The highest concentrations of all parameters were measured in October and the lowest concentrations were measured in May following the trend in precipitation and water discharge of these rivers (Tuncer *et al.* 1998). Although the use of organic compounds, such as DDT, is not allowed for several decades, approximately 100 tons of DDT have been discharged via rivers suggesting continued unlawful usage of this hazardous pesticide in agriculture (Bakan and Ariman 2004). Sakarya River and its catchment, which lies to the western part of the Black Sea, include fertile plains and are by far the most important source for almost all of the pesticides (Tuncer *et al.* 1998) and it was followed by the Kızılırmak and Yeşilırmak rivers. Moreover, high concentrations of total DDTs (7-71 ng/g) and HCHs (36-37 ng/g) discharge from the coast of Turkey into the Black Sea were detected in smaller riverine sources, such as Mert and Kurtun Stream (Bakan and Ariman 2004). No PCBs were detected in the central Black Sea coast indicating the effect of the lack of large scale industry in the region (Bakan and Ariman 2004). Concentrations of total petroleum hydrocarbons in the southern Black Sea shelf sediments were comparable to relatively unpolluted areas in other seas of the world (Balkıs *et al.* 2012). Overall, high concentrations of petroleum hydrocarbons in shelf sediments were associated with the discharges from the Samsun, Trabzon and Sinop Harbors as well as the inputs from the Sakarya, Yenice, Kızılırmak and Yeşilırmak Rivers (Balkıs *et al.* 2012).

As mentioned before, industrial discharges account for a substantial fraction of metal discharges into the Black Sea on annual basis, although they do not make significant contributions to the fluxes of conventional pollutants. This phenomenon was particularly obvious for Cd since approximately 90% of the annual Cd flux had come from industries (Tuncer *et al.* 1998). Kızılırmak, Yeşilırmak, Sakarya, Filyos and Gülüç Rivers are also important riverine sources along Turkish coasts for Cd, Cu, Pb and Zn as they account for approximately 7%, 78%, 50% and 60% of the Cd, Cu, Pb and Zn, respectively (% contribution in total load along Turkish coasts).

A more recent study (Altas and Büyükgüngör 2007) focused on the central Black Sea region measured heavy metal concentrations seasonally in 21 rivers during May 2000-October 2001. It was reported that Cd and Cu levels generally and Pb and Zn levels sometimes exceeded the thresholds set by the Marine General Quality Criteria given in Turkish environmental regulations. Whereas, Ni concentrations were at the desired levels. The transportation of heavy metals from Yeşilırmak, Kızılırmak and Sakarya Rivers into the Black Sea was quite high (Altas and Büyükgüngör 2007). Furthermore, smaller rivers like Melet River and Filyos Stream had high contributions to the Black Sea heavy metal pollution although their annual water discharges were at low levels (Altas and Büyükgüngör 2007). The comparison of between the Altas and Büyükgüngör (2007) and Tuncer *et al.* (1998) study indicates a gradually increase in heavy metal pollution between 1993 and 1996.

A big data gap regarding pollutants from rivers, particularly last couple of decades, prevent us to draw robust conclusions about recent status of the effect of Turkish rivers and catchments on the Black Sea pollution. An extensive monitoring program is needed in most of the rivers and streams flowing along the Black Sea. Monitoring of pollutant trends in the rivers and streams, particularly in the major rivers that are not heavily polluted, is required since they can show the initial signs of pollution. Studies on rivers and streams should be given with their estimated annual flux for a better assessment on their overall impact on the Black Sea Ecosystem. Furthermore, more frequent measurements and inclusion of continuous data profiles from some critical rivers is required to better assess annual flux of pollutants along the coast of the Black Sea. Apparently, there are some ongoing or recently completed monitoring studies led by Turkish governmental organizations, however, their data sets not publicly available. In all likelihood, disclosure of those data sets will help us better understand recent trends of pollutants in the Black Sea rivers.

4. Catchment-Black Sea interactions in a wider oceanographic context

River inputs constitute the major source of nutrients to the coastal Black Sea – however the availability of these nutrients for basin-wide primary production is controlled by a complex web of biogeochemical interactions. If the nutrients are not supplied via lateral mixing from coast to offshore via eddies or far-reaching river plumes, they have to be supplied via vertical mixing. The origin of deep-water nutrients in the Black Sea is eventually river or atmospheric inputs, accumulating in deep waters after a number of regeneration cycles. Their transport to euphotic zone in the Black Sea may be limited due to a special feature of the Black Sea: the suboxic zone. Located underneath the nutricline and the sharp pycnocline, the suboxic zone is a nearly 50-m thick zone in the Black Sea characterized by trace (<2 μM) O_2 and H_2S levels. This zone is an intense area of denitrification, nitrate-depleting respiration pathway that yields N_2 as a product, therefore causing net nitrogen removal.

The primary production in the Black Sea is typically higher near the coastal areas along the rim current area (Hay *et al.* 1990, Yılmaz *et al.* 1998a, b). In the open sea, primary production rates range from 50-200 g C m^{-2} y^{-1}, while in the coastal zone the rates easily exceed 400 g C m^{-2} y^{-1} (Bologa *et al.* 1999). The classical spring and fall phytoplankton blooms in the Black Sea now seem to emerge year-round, especially near the southern coast of the Black Sea (Salihoğlu B., personal comm.). The productivity gradients are also reflected in the resource concentrations. In the open Black Sea surface waters nitrate+nitrite levels are within 0.07 to 0.3 μM while in the coastal sea the levels may increase to 1 μM. In the immediate vicinity of the river mouths/deltas, the concentrations may reach as high as 8 μM. Since N/P ratio in the river input has increased to 22-33 in the 1990s as compared to 12 in 1960s, the growth of phytoplankton in the Black Sea open waters have typically been considered as P-limited (Cociasu *et al.* 1996). However, in the deep waters of the open Black Sea, the N/P ratio decreases down to 8, due to the intense denitrification rates as discussed above. In the very open part of the Black Sea, in the middle of the great eastern and western cyclonic gyres, the N/P ratio further decreases to 5, implying the N limitation in the open part. This means that, despite proximity (150-200 km), the river input is not as important in the central basins, making vertical diapycnal transport, atmospheric N input and N-fixation important processes to consider.

Despite gaps, our knowledge on the biogeochemical fate of river-derived macronutrient N and P in the Black Sea is still relatively developed. However, the known biogeochemistry of inorganic micronutrients, such as iron, zinc and copper, is not sufficient to assess the fate of river-derived metal species. Few studies, such as by Duman *et al.* 2006, emphasizes the particle-reactive nature of metals: heavy metal distribution were found to be grain size dependent in the southern shelf of Amasra. There is no study in the Turkish Black Sea coast conducted on metal micronutrient cycling across river mouths to open sea in high spatial resolution. Similar studies performed in front of

Danube indicated a complex web of redox-driven cycling of iron and manganese and their differential mobilization (Wijsman *et al.* 2002). Particle transport mechanisms could be important here: the extent of river freshwater plumes may determine the metal transport across the shelf. The shelf area width is another parameter, since the southern Black Sea shelf is not as wide as western, we can anticipate a less efficient entrainment of metal-laden particles in the shelf. Hypoxia, too, may act to mobilize pre-deposited metals on the shelf, but as we do not have any information on the extent of hypoxia in the southern Black Sea shelf, we cannot determine the relative importance of this process. Plus, we have practically no data on the nature of metal species entering from Anatolian rivers and their differential mobilization across the catchment-ocean interface in the Black Sea. The added complexity stems from massive mobilization of particles due to turbidity currents may transport large amounts of freshly deposited particles from shelf to deep sea, as evidenced by iron-oxide rich sediment layers in the deepest part of the Black Sea (Yücel *et al.* 2010a) and the associated non-steady state biogeochemical signatures in the surface sediments and deep bottom waters (Yücel *et al.* 2010b).

Overall, in order to estimate the net effect of the river derived materials in the Black Sea ecosystems in the near future three major phenomena should be taken into account. First, the depositional and transport regimes across the narrow southern should be assessed: lateral transport via mesoscale eddies, or seafloor turbidity currents and the seasonal extent of river plumes should be determined. Second, the size fractionation of the incoming material is important as this will determine the immediate or far-field deposition of the material on the shelf or continental slope. In that case, local redox conditions of the shelf/slope will influence the differential mobilization of different elements such as N, P, and Fe. In that regard, redox-sensitive and conservative elements should be studied with specifically tailored methods and approaches. Third, in addition to total concentration measurement, chemical speciation datasets need to be generated to mitigate limitations in the assessment of the influence of river inputs.

5. Research gaps and future perspectives

The spatial and temporal discontinuity, insufficient temporal intensity, lack and lag of data sharing as well as different and inadequate sampling methods significantly hampers the current level of understanding of the catchment-sea interactions in the Black Sea. The mechanisms for the transport of the catchment effect to the open sea habitats of the Black Sea should be better elucidated. Especially, the formation and functioning of mesoscale eddies, seafloor turbidity currents and the river plumes requires addressing. Therefore, integrative and smart sampling monitoring programmes, from open sea to full extent of the catchment, supported by autonomous and real time monitoring platforms are urgently needed to better understand the current state of the catchment-sea interactions and to better predict future changes. Specifically, for some rivers, which carry critical level of pollutants such as Yeşilırmak, Kızılırmak and Sakarya rivers, should also be integrated in those monitoring programmes and monitored at least once every season with their water flux rate. Overall, it will provide better implementation of Marine Strategy and Water Framework Directives in harmony.

There is accumulating knowledge on the importance of extreme events for the functioning of the ecosystems and climate change predictions indicate an increase in the intensity of these extreme events. The catchment Black Sea interaction is largely driven by the water discharge, which is very sensitive to extreme events in precipitation. Therefore, more studies on the intensity and the effect of extreme events on the catchment sea interactions are needed. Moreover, biological responses of these discharges need to be addressed for ecotoxicology and ecosystem functioning studies. The response at autotrophic organism fairly well studied comparing to heterotrophic communities. Therefore, studies focusing on the cascading effects of pollutants on heterotrophic communities are needed.

Lastly, the catchment and sea interactions are complex interplay of the surface and underground flows. The majority of the current studies are focusing on the surface flow in the rivers and streams. There is a need for the better understanding on the fluxes and dynamics of underground and remaining surface flows (surface runoff, ephemeral flows, leakages, etc.). Especially, the knowledge gap on small streams draining from high mountains / high relief eastern Black Sea coast requires attention. Although they are small in volume, they might still carry significant fluxes. Furthermore, Turkey has engaged in a large-scale hydro power plant (HPP) investment plan along the Black Sea catchment with expected dramatic impacts on the sediment and nutrient transport to the sea (Hay 1994). Therefore, the potential impact of HPP on the Si flux and overall ecosystem change should be addressed immediately for the Black Sea.

References

Alkan, A., S. Serdar, D. Fidan, U. Akbaş, B. Zengin, and M. Baran. 2013. Physico-chemical characteristics and nutrient levels of the eastern Black Sea rivers. Turkish Journal of Fisheries and Aquatic Sciences, 13: 847-859.

Altas, L. and H. Büyükgüngör. 2007. Heavy metal pollution in the Black Sea shore and offshore of Turkey. Environmental Geology, 52: 469-476.

Bakan, G. and H. Büyükgüngör. 2000. The Black Sea. Marine Pollution Bulletin, 41: 24-43.

Bakan, G. and S. Ariman. 2004. Persistent organochlorine residues in sediments along the coast of mid-Black Sea region of Turkey. Marine Pollution Bulletin, 48: 1031-1039.

Balkıs, N., A. Aksu, and M.S. Erşan. 2012. Petroleum hydrocarbon contamination of the Southern Black Sea Shelf, Turkey. Environmental Science and Pollution Research, 19: 592-599.

Boran, M. and N. Sivri. 2001. Determination the Nutrient and Suspended Solid Mater Loads of Solaklı and Sürmene River (Trabzon, Türkiye), (in Turkish). E.U. Journal of Fisheries & Aquatic Sciences, 18(3-4): 343-348.

Butcher, R.W. 1947. Studies in the ecology of rivers: VII. The algae of organically enriched waters. Journal of Ecology, 35: 186-191.

Cociasu, A., L. Dorogan, C. Humborg, and L. Popa. 1996. Long-term ecological changes in Romanian coastal waters of the Black Sea. Marine Pollution Bulletin, 32: 32-38.

Duman M, Ş. Duman, T.W. Lyons, M. Avcı, M. İzdar, and E. Demirkurt. 2006. Geochemistry and sedimentology of shelf and upper slope sediments of the south-central Black Sea. Marine Geology, 227(1): 51-65.

Dumont, H.J. 1999. Black Sea Red Data Book. UNOPS. 413 pp.

Gücü, A.C., Ö.E. İnanmaz, M. Ok, and S. Sakinan. 2016. Recent changes in the spawning grounds of Black Sea anchovy, *Engraulis encrasicolus*. Fish Oceanogr., 25(1): 67-84.

Gültekin, F., A.F. Ersoy, E. Hatipoğlu, and S. Celep. 2012. Determination of water quality parameters in wet season of surface water in Trabzon. Ekoloji, 21(82): 77-88.

Hay, B.J., S. Honjo, S. Kempe, V.A. Itekkot, E.T. Degens, T. Konuk, and E. İzdar. 1990. Interannual variability in particle flux in the southwestern Black Sea. Deep-Sea Research, 37: 911-928.

Hay, B.J. 1994. Sediment and water discharge rates of Turkish Black Sea rivers before and after hydropower dam construction. Environmental Geology, 23(4): 276-283.

Jaoshvili, S. 2002. The rivers of the Black Sea. Copenhagen: European Environment Agency.

Justić, D., N.N. Rabalais, and R.E. Turner. 1995. Stoichiometric nutrient balance and origin of coastal eutrophication. Marine Pollution Bulletin, 30(1): 41-46.

Keskin, Ç. 2010. Distribution of demersal fish species in the Black Sea, Sea of Marmara and north Aegean Sea. Rapp. Comm. Int. Mer Médit., 39: 558-560.

Kirwan, G., B. Demirci, H. Welch, K. Boyla, M. Özen, P. Castell, and T. Marlow. 2010. The Birds of Turkey. Bloomsbury Publishing.

Ludwig, W., E. Dumont, M. Meybeck, and S. Heussner. 2009. River discharges of water and nutrients to the Mediterranean and Black Sea: major drivers for ecosystem changes during past and future decades? Progress in Oceanography, 80(3): 199-217.

Mee, L.D. 2006. Reviving Dead Zones. Sci. Am., 295: 78-85.

Oğuz, T., E. Özsoy, M.A. Latif, H.I. Sur, and Ü. Ünlüata. 1990. Modeling of hydraulically controlled exchange flow in the Bosphorus Strait. Journal of Physical Oceanography, 20(7): 945-965.

Readman, J.W., G. Fillmann, I. Tolosa, J. Bartocci, J.P. Villeneuve, C. Catinni, and L.D. Mee. 2002. Petroleum and PAH contamination of the Black Sea. Marine Pollution Bulletin, 44(1): 48-62.

Rosenberg, R. 1985. Eutrophication-the future marine coastal nuisance? Marine Pollution Bulletin, 16: 227-231.

Ryan, W.B., W.C. Pitman, C.O. Major, K. Shimkus, V. Moskalenko, G.A. Jones, P. Dimitrov, N. Gorür, M. Sakinç, and H. Yüce. 1997. An abrupt drowning of the Black Sea shelf. Marine Geology, 138(1-2): 119-126.

SoKolnikov, M. 1999. Causes and effects of eutrophication in the Black Sea. Danube Pollution Reduction Programme. Summary report, pp.13-17. Programme Coordination Unit UNDP/GEF Assistance. Vienna.

Topping, G., H. Sarikaya and L.D. Mee. 1999. Sources of pollution to the Black Sea, pp. 280. In L.D. Mee and G. Topping [eds.], Black Sea Pollution Assessment (Vol. 10). New York, NY, USA: United Nations Publications.

Tuncer, G., T. Karakas, T.I. Balkas, C.F. Gökçay, S. Aygun, C. Yurteri, and G. Tuncel. 1998. Land-based sources of pollution along the Black Sea coast of Turkey: concentrations and annual loads to the Black Sea. Marine Pollution Bulletin, 36(6): 409-423.

Verep, B., O. Serdar, D. Turan, and C. Şahin. 2005. Determination of water quality in terms of Physico-Chemical Structure of the River Iyidere (Trabzon). Ekoloji, 14(57): 26-35.

Watson, V. 1989. Control of attached algae by nitrogen and phosphorus in the Clark Fork River, pp. 287-297. Proceedings of the Symposium on Headwaters Hydrology. American Water Resources Association, Bethesda Maryland.

Wijsman, J.W.M., P.M.J. Herman, J.J. Middelburg, and K. Soetaert. 2002. A model for early diagenetic processes in sediments of the continental shelf of the Black Sea. Estuarine, Coastal and Shelf Science, 54: 403-421.

Yılmaz, A., S. Tuğrul, C. Polat, D. Ediger, Y. Çoban, and E. Morkoç. 1998a. On the production, elemental composition (C,N,P) and distribution of photosynthetic organic matter in the southern Black Sea. Hydrobiologia, 363: 141-156.

Yılmaz, A., O.A. Yünev, V.I. Vedernikov, S. Moncheva, and A.S. Bologa. 1998b. Typical and extreme phenomena of spatial distribution of chlorophyll-a in various seasons of 1990-1995 period, 1:105-120. In L.I. Ivanov and T. Oğuz [eds.], Ecosystem modeling as a management tool for the Black Sea. Kluwer Academic Publishers, Netherlands.

Yücel M, G.W. Luther, and W.S. Moore. 2010. Earthquake-induced turbidite deposition as a previously unrecognized sink for hydrogen sulfide in the Black Sea sediments. Marine Chemistry, 121: 176-186.

Yücel, M., S.K. Konovalov, T.S. Moore, C. Janzen, and G.W. Luther. 2010. Sulfur speciation in the upper Black Sea sediments. Chemical Geology, 269: 364-375.

Zaitsev, Y. and V. Mamaev. 1997. Marine Biological Diversity in the Black Sea. A Study of Change and Decline, pp. 208. United Nations Publications, New York.

RIP CURRENTS ACROSS THE SHORES OF THE BLACK SEA

Serdar BEJİ [1] and Barış BARLAS [2]

[1]Istanbul Technical University, Department of Ocean Engineering, Istanbul, Turkey
[2]Istanbul Technical University, Department of Naval Architecture, Istanbul, Turkey
sbeji@itu.edu.tr

1. Introduction

Offshore directed currents formed in the surf zone due to breaking waves are called “rip currents” and essentially typical to the oceans. Being a nearly closed basin, the Black Sea is probably the only exception with frequent rip currents on its beaches. As the name implies, the rip currents run counter to the incoming waves and establish itself as a strong stream channel with somewhat different colour. The prominent characteristic of running against the waves is a rather puzzling aspect of rip currents therefore their occurrence and generation mechanism require careful examination. Particularly in countries with shores facing the oceans such as Australia and United States, numerous studies and articles are available regarding rip currents, their formation, and related drowning incidents. Coasts of the Black Sea, while harbouring many rip currents, have not received much attention in this aspect. Apparently, no study on rip currents seems to be undertaken in Turkey until relatively recently (Beji and Barlas 2007).

Formation and physical aspects of rip currents are important to understand the mechanism working behind. Covering these aspects, Dalrymple *et al.* (2011) gave a detailed review on field measurements, instrumentation, laboratory techniques, and numerical modelling. Kumar *et al.* (2011) used a 3D numerical ocean model for surf zone applications using examples of rip current formation in longshore bar. Orzech *et al.* (2011) investigated the formation of mega cusps on rip channel bathymetry. The relationship between alongshore rip channel migration and sediment transport was investigated using time-averaged video images to identify the positions of rip channels by Orzech *et al.* (2010). Thiebot *et al.* (2012) analysed the influence of wave direction on the morphological response of a double sandbar system, and interactions between the patterns in the two shore-parallel bars.

Potential hazards of rip currents to human lives are among the most important issues for studying rip currents. Brighton *et al.* (2013) studied rip current related drowning incidents in Australia while Gensini and Ashley (2010) analysed fatalities caused by rip currents in the United States for the period of 1994-2007. Sherker *et al.* (2010) assessed the beliefs and behaviours of Australian beachgoers in relation to beach flags and rip currents. Miloshis and Stephenson (2011) suggested rip current escape strategies as "do nothing" and "swim parallel to the beach". Drowning risk factors at surf beaches in Australia were analysed by Morgan *et al.* (2009). Chandramohan *et al.* (1997) identified rip current zones on the Goa beaches in India while Sabet and Barani (2011) did the same for the southern coast of Caspian Sea. Studies on rip current related drownings on the Black Sea beaches of Istanbul were given in Barlas *et al.* (2012) and Beji and Barlas (2013).

The Black Sea beaches of Istanbul are among the most dangerous regions of the world in terms of rip current fatalities. According to the records, each year on the average 33 people fall victim to rip currents on these beaches. This fatality rate for a city of approximately 15 million population is remarkably greater than those observed in Australia and in U. S. Such a high fatality rate raises a number of questions ranging from educational aspects to cultural attitudes. Therefore, extensive campaigning concerning the dangers of rip currents and the relevant rescue techniques as well as other educational recommendations related to social attitudes is needed.

2. General Characteristics of Rip Currents

A rip current is a powerful and separate seaward current that can flow over 2 m/s running usually perpendicular to the beach, out into the sea. In general the speeds of rip currents are between 0.3 to 1.5 m/s (Dalrymple *et al.* 2011). Compared to the 800 m freestyle World record in swimming, which is nearly 1.8 m/s, the speeds of the rip currents are quite high. The rip currents may extend 50 to 300 meter in length, and 6 to 30 meter in width (Short and Hogan, 1994). The formation of rip currents depends on definite aspects, which may be enumerated under the following items (Bowen 1969, Lyons 1991).

- Nearshore bathymetry,
- Wind direction and speed; wave height and period,
- Sand properties of the beach,
- Shape of the shoreline,
- Structures at the beach.

The nearshore bathymetry is probably the most important factor in the formation of rip currents. A bar-trough-bar type bottom configuration is a trademark of a rip current as seen in Figure 1 (Hansen and Svendsen 1986).

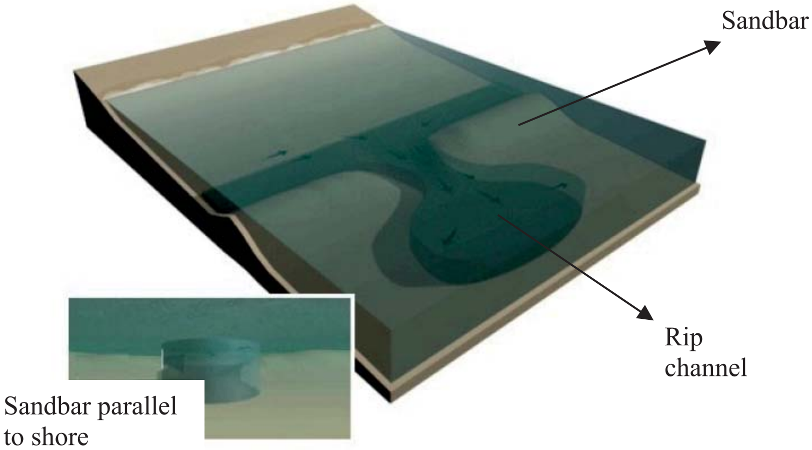


Figure 1. A typical bathymetry allowing rip current formation (COMET 2017)

The offshore directed rip currents interact with the incident waves to produce a negative feedback on the wave forcing, hence to reduce the strength and offshore extent of the currents. The two physical processes arising from refraction by currents; namely, bending of wave rays and changes of wave energy, are both found to be important. The incident wave height has some effects on the strength and offshore extent of rip currents, but these are rather weak compared to the effects of rip channel spacing and depth (Yu and Slinn 2003). Once the waves are high enough to break over the top of the bar, the question of how high they can become is relatively unimportant. Since wave breaking over a bar is primarily dictated by water depth, it is sufficient condition for breaking to get wave heights comparable or greater than the water depth over the bar. If the bar is shallow enough the required wave height for breaking is smaller (Haller and Dalyrymple 1999). The process is determined by the ratio of water depth to wave height, which is a relative quantity. On the other hand, the depth of the trough across which the rip flows offshore is a quite important parameter in determining the strength of the rip current. In principle the deeper the channel the stronger the current is. Rip currents are usually observed in the aftermath of a storm or windy weather conditions if the wind blows from a favorable direction to generate sufficiently high waves advancing perpendicular to the beach. Atmospheric conditions are therefore another crucial factor in the formation of rip currents. Average bottom slope in the nearshore region is also observed to influence the current strength by dictating the rate of change of shoaling. Gradual shoaling over long distances or a mild-slope type bathymetry gives rise to stronger currents (Arthur 1962). Finally, fine sand beaches increase the probability of rip current formations, while coarse sand or pebble beaches decrease the probability (Pfaff 2003).

3. Rip Currents on Black Sea Shores

Rip currents are rather common features of beaches facing oceans but rather unusual for relatively small enclosed bodies of water. In this respect, the Black Sea is remarkably different in that rip currents are encountered frequently along the southern shores of it. Reasons for rip current occurrences are related to favourable aspects of the beaches of the Black Sea, as the existence of rip currents depends on the beach bathymetry, wind direction and speed, wave height and wave period, the form of the beach, physical structures at the beach, and the sand characteristics. Especially with cusp-like shore forms, many beaches on the southern coasts of the Black Sea have rather fine sand, bar-trough-bar type underwater formations, and are open to high northerly winds with severe waves as high as 5 meters or even higher. Co-existence of all these factors make the beaches of the Black Sea quite predisposed to rip currents and the overall result is that year after year lives are lost at the beaches due to rip currents. If the bottom topography has gentle slopes and shoals over long distances, rip currents are usually stronger and effective over large regions. For other type bathymetries strength and extend of rip currents are somewhat limited. Depending on the formation type, some rip currents may be permanent; that is to say, they may exist on yearly basis throughout the favourable conditions. However, there are also temporary rip currents which exist only for a few or several hours. In the aftermath of severe storms it is much more likely to observe rip currents. With increasing wave period and wave height, the speed and extend of rip currents increase. Gently sloping and fine sand beach types are especially favourable for rip current formation. Figure 2 shows the rip current formation on the shores of Şile-Kurfallı.

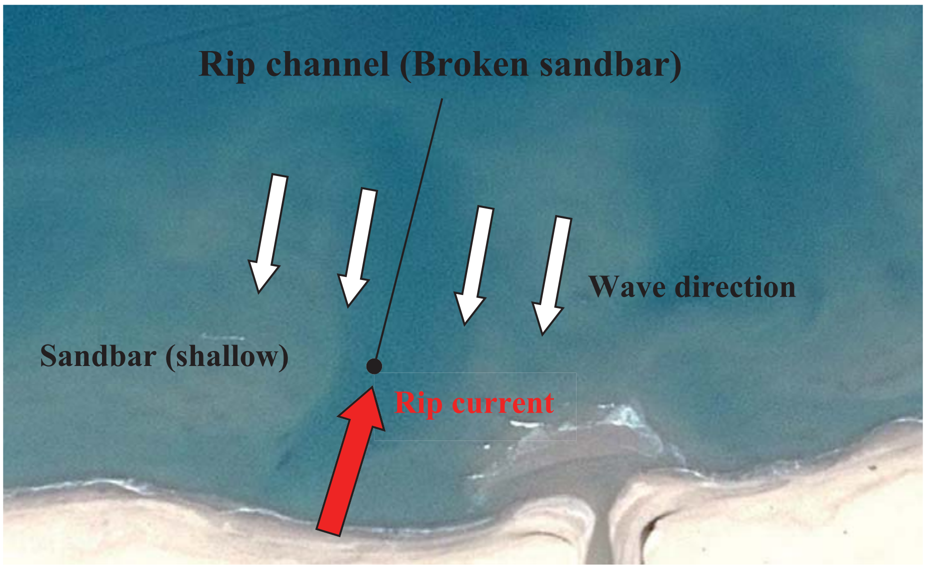


Figure 2. Schematic description of rip current formation on Şile-Kurfallı shores

Sand properties of a beach is another important factor that determine the character of rips and decide whether rip currents form or not. Actually, sand properties affect rip currents not directly but indirectly by shaping the bottom topography or bathymetry. With the action of waves and currents, fine sand spreads more homogenously and evenly over the area and creates gently sloping regions. Such a bathymetry is more favourable for the formation of rips. On the other hand, coarse sand reduces probability of rip formation by creating a bottom topography with somewhat steeper slope. A pebble beach has the least probability of generating rip currents (Pfaff 2003). Figure 3 shows relatively fine sand structure of Ağaçlı (Eyüp) and Kilyos (Sarıyer) beaches. Fine sand beaches, as indicated, have gently sloping depths hence provide favourable conditions for the formation of strong rip currents. Coarse sand beaches however have relatively steeper slopes hence generate weaker rip currents or no rip currents at all.

Figure 3. Fine sand structure of Ağaçlı (Eyüp) ve Kilyos (Sarıyer) shores (photo by B. Barlas).

Reports from actual rescue operations reveal that the observed rip currents on the shores of the Black Sea are quite severe. Wind speeds basically determine wave heights and in turn wave heights directly affect the strength of rip currents. Therefore, weather condition is the primary factor for rip currents. For the shores of Black Sea, a wind of Beaufort 3-4 may initiate rip currents because the wave heights near the shore may approach 2-3 m. As the weather gets severer, for Beaufort 4-5 the wave heights increase to 4-5 m and for Beaufort 7-8 wave heights exceed 5 m. The latter is a very severe weather condition and normally people would avoid getting into sea but there may be some exceptional cases as for instance one reported by the Underwater Search and Rescue Team of Istanbul Gendarmerie Command. On the eve of a storm on 30 June 2013 a person was reported lost off the Kurna Beach in Sile, Istanbul. But the weather was getting much worse and no other information about the person was obtained therefore no search could be initiated for two days. On 02 July 2013, in presence of a storm with Beaufort 7.9 and nearshore wave heights exceeding 5.5 m the body of the victim was reportedly seen adrift in the sea. Despite the extreme wind and sea conditions, the Underwater Search and Rescue Team arrived at the indicated location and began attempts to recover the body from the water. The Team observed virtually a mega rip channel of 200-300 m long into the sea and a current speed of 4-5 m/s. The body was trapped in a vicious circle: the rip was carrying the body 200-300 m offshore and wherever the rip was weakening, the body, being free of the current, was overtaken and carried back towards the shore by the very high waves moving onshore. Then, approximately 50 m to the shore the body was again caught up by the rip current and quickly drifted offshore. The Rescue Team was trying to get hold of the body whenever it was closest to the shore but that was a very difficult and dangerous task even for the divers. Despite the heavy diver's equipment they were also being caught up in the current and carried away for hundreds of meters. Most of the times they were trying to save their own lives. Eventually, after more than an hour's efforts the body was recovered from the sea. This single incidence shows clearly that the Black Sea may be even more dangerous than the Oceans when it comes to rip currents and may produce rip channels of 300 m long and 4-5 m/s current speeds, which are extremely rare (Beji 2015).

4. Rip Current Casualties on the Black Sea Shores of Istanbul

When a swimmer is caught up in a rip, he/she is pulled offshore. If the swimmer is inexperienced, he/she attempts to swim back to the shore against the rip current and consequently becomes tired of struggling, suffers exhaustion, fears, and eventually panics. In the end, as a result of wasted efforts, the swimmer drowns.

Literature regarding the casualties due to rip currents is quite diverse about the incident rates. Lushine (1991) reported on the average 150 annual deaths due to rip currents in the United States while his figures were criticized by Gensini and Ashley (2010) who gave 35 annual deaths for the period of 1994-2007. On the other hand, in Australia Sherker *et al.* (2010) indicated an average of 82 annual drownings, many of these attributable to rip currents while Brighton *et al.* (2013) gave 21 annual deaths on the average. Outside the U. S. and Australia, studies are relatively fewer. Chandramohan *et al.* (1997) identified rip current zones on the Goa beaches in India and Sabet and Barani (2011) did the same for the southern coast of Caspian Sea. Arozarena *et al.* (2015) presented an analysis of data from the Judicial Investigation Organization of Costa Rica which indicated 1391 drownings between 2001 and 2012; approximately 590 of those drownings, 42%, were reported as due to rip currents.

Istanbul is the largest city in Turkey with a population over 15 million and has nine known beaches, four in the European and five in the Asian part of the Black Sea coasts as sketched in Figure 4. The total length of the coastline is approximately 153 km (92 km in European side and 61 km in Asian side); the coastline length of popular beaches is approximately 57 km (30 km in European side and 27 km in Asian side).

Figure 4. Beaches (red lines) under the responsibility of Istanbul Gendarmerie Command

Examination of the Istanbul Gendarmerie Command's hazard event data gives a total number of 341 incidents during the period of 2007-2013, and among all the reported drownings, the fatalities associated with rip currents are 227 or nearly 67%. This percentage is higher than the international average range of 49-58% reported by Brighton *et al.* (2013). However, variations do occur depending probably on the beach characteristics; Brewester (2010) for instance, puts the figure to 80% for rip current drownings in California, U.S.A. though this is likely to be an overestimate.

While the figure of 67% for the Black Sea beaches is above the international range, it cannot be attributed solely to uncertainty involved in the identification of the exact cause of drownings. The logs kept according to the reports of the well-trained rescuers and/or the Underwater Search and Rescue Team of the Gendarmerie are quite detailed and the examination of these records shows that every care is taken to ascertain the exact nature of the drownings. The team usually arrives within less than an hour of drowning, question the eyewitnesses and frequently observe the rip current itself if it still exists. Therefore, considering all these points, approximately 67% rate of rip-related events obtained from the records is considered an accurate enough figure. Thus, in an average year approximately 33 people drown due to rip-related drowning incidents on the Black Sea beaches of Istanbul. Considering the range between minimum rate 53% in 2011 and maximum rate 82% in 2009, the lowest and highest number of rip drownings would respectively be 27 and 44 people, depending on wind and wave conditions occurring on that particular summer (Table 1).

Table 1. Reported rip-related drowning fatalities during the period of 2007-2013

Year	Drowning fatalities	Rip current fatalities	Percentage of rip current fatalities (%)
2007	51	36	71
2008	34	27	79
2009	54	44	82
2010	47	30	64
2011	51	27	53
2012	53	31	59
2013	51	32	63
Total	341	227	Avg. 67

A breakdown of fatalities, where deaths by beaches and the percentage of fatalities per kilometre, is given in Table 2. Fatality percentage per kilometre is presented as an indicator of the "danger level" of a particular beach. Since the number of swimmers would be approximately proportional to the beach length; the mere number of deaths or their percentage for a definite beach would not correctly reflect its danger level. Therefore, it should be more meaningful to give the fatality percentage per kilometre of beach. Accordingly, Riva and Karaburun respectively are the most dangerous beaches in terms of rip current fatalities. These two beaches account for 6.9% and 5.1% of total deaths per km. Many of these fatalities occur on weekends, especially on Sundays when daily beach-going tourist population is highest. There is a relatively large difference in fatalities between Saturday and Sunday due to the fact that in Turkey most people in private sector work half a day on Saturdays; therefore, considerably more people go to the beaches on Sundays compared to Saturdays. As expected, weekends with 56% of total fatalities, have more fatalities than all the weekdays combined.

The fatality reports also reveal a difference in gender vulnerability. Males are over seven times more likely to drown in rip currents than females. The percentage of male fatalities due to rip currents stands as 77.2% while female fatalities are 11.9% out of 89.1% fatalities of total incidents. This trend is also reported in international statistics (Brighton *et al.* 2013), but the difference is accentuated in Turkey due to the fact that socially men go to beaches more frequently, while women prefer to stay at home or if they go they refrain from swimming because of religious and cultural attitudes; *i.e.*, not wanting to show her body. In addition, many men are reported to be drown while trying to save their family members or friends from the rip currents. Socially another persistent problem is the over-confident attitude of young adults to warnings. These young people refuse to heed any safety advice and even in some cases go so far as to harass lifeguards or gendarmeries who warn them on the beach.

Table 2. Total number of reported rip current fatalities by beach during the period of 2007-2013

Beach	Rip Drownings	Percentage (%)	Beach length (km)	Percentage of rip drownings per km* (%)
Binkılıç	9	4.6	2	2.3
Karaburun	30	15.4	3	5.1
Ağaçlı	10	5.1	2.5	2.0
Kilyos	9	4.6	4.5	1.0
Riva	20	10.3	1.5	6.9
Sahilköy	7	3.6	2.2	1.6
Alacalı	8	4.1	2	2.0
Sofular	10	5.1	2	2.6
Ağva	9	4.6	3	1.5
Other beaches	83	42.6		

*Percentage of rip drownings per km was calculated by dividing each percentage by beach length in km.

Children aged younger than 18 account for 22% of all rip current fatalities. 54% of fatalities are between the ages 18-35. This group are risk takers and over-represented in drowning statistics. Lifeguards indicate that most beach-going tourists, those other than local inhabitants, lack knowledge and experience about rip currents and most are not good swimmers. When fatalities are considered by month, July stands out as the most dangerous. Half of the total fatalities occur in July, followed by 28% in August. Normally, being a summer vacation time, August would be expected to be nearly as dangerous as July but for the effect of Ramadan. Ramadan, the religious fasting month for Muslims, is very prominent during the period of the data set examined. The beginning and ending of Ramadan are determined by the lunar Islamic calendar. Since the lunar year is 10 to 12 days shorter than the solar year, Ramadan migrates throughout the seasons and each year Ramadan begins about 10 to 12 days earlier than the previous year. The month of Ramadan is spent by Muslims for fasting during the daylight hours from dawn to sunset. Fasting practices are primarily an act of willing abstinence from all food, drink, sexual intercourse and some other activities. Thus, among other refrainments, people do not go to beaches, or if they go, they do not swim to avoid unintentional water intake. The month of Ramadan therefore has a very significant effect on reducing drowning fatalities. For example, fatalities during August were considerably lower than July because the month of Ramadan befall in the month of August from 2009 to 2012.

Although absence of lifeguards in some beaches is a problem, a more dangerous practice is that some families or groups especially prefer desolate beach parts for quite different reasons. In such remote beach areas without lifeguards, when one is in danger, the others from the family or friends try to help him/her, resulting usually in more fatalities. For example, on July 7th, 2012 four sisters aged 10, 14, 16 and 17 drowned together. According to the drowning report, the two youngest siblings were in danger and the elder ones attempted to rescue them, but they were all caught by the rip current and all four drowned. On July 24th, 2010 two friends aged 30 and 32 drowned together. According to the drowning report, at first, one of the friends was in danger and the other one was trying to rescue him, eventually both were caught by the rip current, and both drowned. There were 18 families or groups involved in the rip current fatality reports, and out of these 38 people died.

5. Winds versus Rip Currents for the Black Sea Shores of Istanbul

The presence of rip currents along a coastline may be related to the presence of onshore wind and associated wind-driven wave breaking activity. While several studies have related the wind speed to the presence and hazard level of rip currents (see for instance Brewster, 2010), here we simply relate wind speed to the occurrence of drowning fatalities in rip currents.

The data set relevant to the analysis presented below was obtained from Turkish State Meteorological Service. The wind data obtained from two different meteorological stations located in close proximity of the beaches, Kumkoy in European side and Sile in Asian side were used here. This database includes atmospheric events, such as wind directions, and magnitudes. The fatality reports and meteorological data were considered together to get an insight into fatalities by first ascertaining whether the casualties were related to the rip currents or not, and then checking if a correlation could be established between the casualties and the atmospheric events. Fatality locations were mapped to depict the spatial distribution of fatal rip currents. On the day that a rip current fatality occurred, the atmospheric condition in relation to the beach was also indicated.

Table 3. Wind speed versus reported rip current fatalities for the period of 2008-2012

Wind speed (m/s)	Rip current fatalities	%
<1.0	0	0.0
1.0-1.5	22	17.2
1.5-2.0	41	32.0
2.0-2.5	21	16.4
2.5-3.0	21	16.4
3.0-3.5	20	15.6
3.5-4.0	3	2.3
4+	0	0.0

Thus, considering the wind speeds versus rip current fatalities, about one third of the fatalities occurs when the wind speed is between 1.5-2.0 m/s as shown in Table 3. When the wind speed is below 0.8 m/s, there are no rip current fatalities, simply because there are no rip currents. When the wind speed is greater than 4 m/s, the people do not go to the beaches because of very severe weather conditions. However, for the wind speeds of 1.0-1.5 m/s, the rip current magnitude is not too intense, so people consider themselves capable enough to swim, but for poor swimmers this is the most dangerous case. Nearly 60% of the fatalities in this wind speed interval is found to be children. By using regression analysis, the wind speed versus fatality risk is shown in Figure 5.

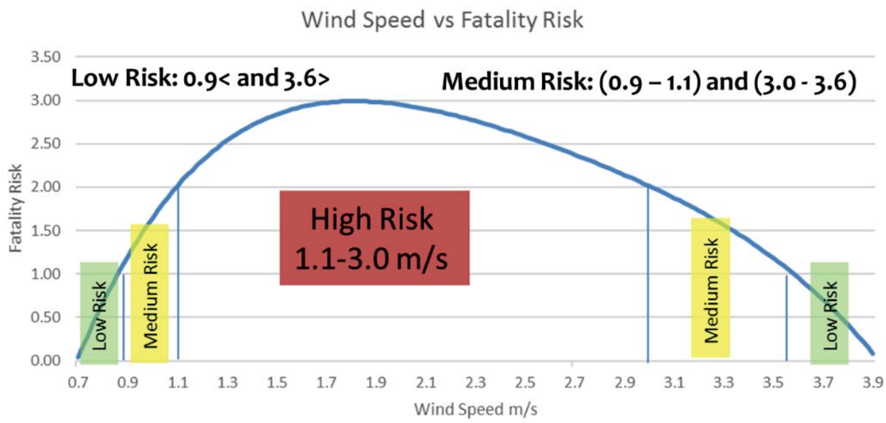


Figure 5. Wind speed versus fatality risk due to rip currents for the Black Sea shores of Istanbul

6. Surviving Rip Currents

Ballantyne *et al.* (2005) studied the behaviour of international and domestic students and their knowledge of beach safety practices while drowning risk factors at surf beaches are analysed by Morgan *et al.* (2009). Dangers of rip currents and prevention methods were reported by Hatfield *et al.* (2012) on a campaign to improve beachgoer recognition of calm-looking rip currents, which are known to contribute to surf drownings. Drozdzewski *et al.* (2012) surveyed people who had been caught in a rip current and survived. Williamson *et al.* (2012) compared attitudes and knowledge of beachgoers from rural inland residents and international tourists in Australia concerning beach safety. An important outcome of this study was that the odds of international tourists making a safe swimming choice in the vicinity of a rip current were three times lower than usual beachgoers and rural inland residents. Quite similar views concerning daily tourists were reported by natives and lifeguards of towns on the coasts of the Black Sea in Turkey during in person interviews. Caldwell *et al.* (2013) studied the ability of beach users' knowledge of rip currents at Pensacola Beach, Florida and found that most beach users, and particularly local participants, are overconfident in their ability to identify rip channels and currents. In the same vein, Brannstrom *et al.* (2014) surveyed the ability of beach users on three heavily used public beaches in Texas to identify a rip current. Only 13% of respondents correctly selected the photograph showing the most hazardous conditions and correctly identified the precise location of the rip current. In a similar vein, Drozdzewski *et al.* (2015) reported the experiences of weak and non-swimmers caught in rip currents at Australian beaches. While it may not be always easy to recognize a rip current the following points are helpful for deciding.

- A mixture of water masses irregularly moving away from the shore as if in a channel,
- Notable change of the colour of water in a limited region,
- A foamy region moving into the sea,
- Irregular and turbulent appearance in waves approaching the shore.

Figure 6. Photograph of a clearly identifiable rip current

Existence of one or more of the above items usually indicate the presence of a rip current. An observer on the beach may see these signs easier with the aid of an UV filter sunglass. Figure 6 shows the photograph of a rip current taken above the sea. Note that the current sets the bottom sediments in motion and creates a murky and brownish water region.

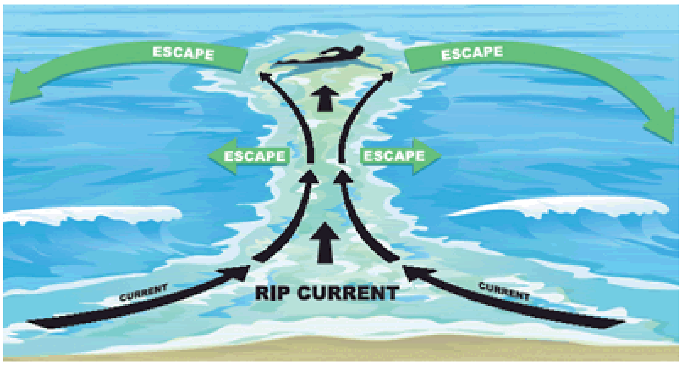


Figure 7. Strategy to escape from a rip current (NOAA 2017)

The foremost escape technique from rip currents advices victim to swim parallel to the beach wherever the rip current weakens in strength as sketched in Figure 7. Likewise, Miloshis and Stephenson (2011) suggest rip current escape strategies as "do nothing" and "swim parallel to the beach". In particular, they indicate that, of the two methods, "do nothing" or "allow the rip current to take a swimmer" is the most effective strategy. However, recent studies have shown dominant rip current re-circulation within the surf zone and have endorsed "just floating" as an appropriate escape strategy (McCarroll *et al.* 2014).

The following items are essential for surviving rip currents:

- Improve your swimming skills,
- Do not swim alone,
- Always be alert about potential dangers,
- If caught up in a rip current, remain calm and do not waste your energy in vain,
- Do not fight against the current. Swim parallel to the shore wherever the current weakens enough to allow you to do so and then swim back to the shore from a different path,
- If too tired to swim, just calmly try to remain afloat and let the current take you till it weakens in strength. Then, swim parallel to the shore outside the rip and return back.
- If too tired to swim back after getting out of the grip of the current, ask for help from the shore by holding your arm.

To help someone caught up in a rip current:

- Ask for help from a lifeguard if within the reach,
- If no lifeguard present throw something floatable (life jacket, buoy ring, beach ball, any kind of personal floatation devices –PFDs) to the person in danger.
- Very loudly tell the person what he/she should do to survive.
- Do not forget that many people who try to rescue a person from a rip current get drowned so unless you are a really expert swimmer do not get into water.

7. Concluding Remarks

Rip currents are mostly encountered across the shores facing the oceans. Therefore, countries like U.S. and Australia have accumulated a considerable literature concerning various aspects of rip currents. The Black Sea, being an almost completely isolated basin, stands out as an unusual case in terms of rip current occurrences. Across the southern shores of the Black Sea, rip currents are considerably frequent and rather dangerous owing to exceptionally high waves at times of northerly winds. Studies on the rip currents of the Black Sea beaches are rather few and have started only recently for the beaches of Istanbul facing the Black Sea (Beji and Barlas 2007). The main reason for this late attention is probably the late identification of the rip currents themselves on the Black Sea shores of Turkey. Nevertheless, in recent years more studies on incident rates, prevention techniques and mechanisms of rip currents on the Black Sea beaches of Turkey have been reported and campaigns for public awareness have been initiated (Barlas *et al.* 2012, Beji and Barlas 2013, Barlas and Beji 2013, 2016).

Records of Istanbul Gendarmerie Command reveal that on the average 33 people are drown each year in rip currents on the Black Sea beaches of Istanbul. Such high drowning rate calls for a questioning of the role of educational aspects and cultural attitudes in this problem. Besides the usual precautions such as warning signs concerning the dangers of rip currents and the relevant rescue techniques of remaining afloat and avoiding to swim against the current, other educational recommendations related to social and cultural aspects are needed. Pamphlets explaining the rip currents and their dangers, one-page brochures advising on correct attitude, educational programs for children, preachers addressing the problem and recommending obedience to authorities in mosques, magazine and TV spots may be considered as educational activities.

The absence of lifeguards on some beaches contributes to fatalities. However, an equally important problem stems from the social attitudes of beach-goers. For different reasons, some young couples and families prefer isolated parts of beaches where no guards are on duty. In such circumstances, when one is in danger, in the absence of lifeguards, family or friends try to help the victim, often resulting in more fatalities.

Precautions appropriate to the cultural attitudes of the people are suggested to reduce downing incidents and related fatalities. The success of educational or informational activities in this region therefore requires much effort, especially when young adults are in question. Children are relatively easier to reach and they are more willing to listen to the warnings and obey the instructions. Therefore, it is expected that the brochures and billboards prepared in this context will be effective over the medium term by first educating children and youngsters.

References

Arozarena, I., C. Houser, A. Gutierrez Echeverria, and C. Brannstrom. 2015. The rip current hazard in Costa Rica. Natural Hazards, 77(2): 753-768.

Arthur, R.S. 1962.A note on the dynamics of rip currents. Journal of Geophysical Research, 67(7): 2778-2779.

Ballantyne, R., N. Carr, and K. Hughes. 2005. Between the flags: an assessment of domestic and international university students' knowledge of beach safety in Australia. Tourism Management, 26 (4): 617-622.

Barlas, B. and S. Beji. 2013. Drownings associated with rip currents in the gendarmerie region of Istanbul, (in Turkish), p. 1-12. In Proceedings of Rip Currents and Drownings Workshop, Istanbul.

Barlas, B., S. Beji, Ö.E. Taşçı, and M. Işık. 2012. Investigation of rip currents in Istanbul’s coastline (in Turkish), p. 299-308. In Proceedings of Technical Congress of Naval Architecture and Ocean Engineering, Istanbul.

Barlas, B. and S. Beji. 2016. Rip current fatalities on the Black Sea beaches of Istanbul and effects of cultural aspects in shaping the incidents. Natural Hazards, 80(2): 811-821.

Beji, S. and B. Barlas. 2007. The investigation of rip currents that cause drownings off the coast of Şile/Istanbul (in Turkish). Research Report, Chamber of Turkish Naval Architects and Marine Engineers, Istanbul.

Beji S. and B. Barlas. 2013. Mechanism of rip currents (in Turkish), p. 13-22. In Proceedings of Rip Currents and Drownings Workshop, Istanbul.

Beji, S. 2015. Observations on severe rip currents on the shores of the Black Sea (in Turkish), p. 7-9. In Rip Currents and Drownings, AFAD, Istanbul.

Bowen, A.J. 1969. Rip currents 1: Theoretical investigations. Journal of Geophysical Research, 74: 5468-5478.

Brannstrom, C., S. Trimble, A. Santos, H.L. Brown, and C. Houser. 2014. Perception of the rip current hazard on Galveston Island and North Padre Island, Texas, USA. Nat. Haz., 72: 1123-1138.

Brewster, B.C. 2010. Rip current misunderstandings. Nat. Haz., 55: 161-162.

Brighton, B., S. Sherker, R. Brander, and A. Bradstreet. 2013. Rip current related drowning deaths and rescues in Australia 2004-2011. Nat. Hazards Earth Syst. Sci., 13: 1069-1075.

Caldwell, N., C. Houser, and K. Meyer-Arendt. 2013. Ability of beach users to identify rip currents at Pensacola Beach, Florida. Nat. Haz., 68:1041-1056.

Chandramohan, P., V.S. Kumar, and B.K. Jena. 1997. Rip current zones along beaches in Goa, West Coast of India. Journal of Waterway Port Coastal and Ocean Engineering, 123(6): 322-328.

COMET, 2017. Rip Currents: Nearshore Fundamentals, http://www.meted.ucar.edu/marine/ripcurrents/NSF/print.htm.

Dalrymple, R.A., J.H. MacMahan, J.H.M. Reniers, and V. Nelko. 2011. Rip currents. Annu. Rev. Fluid Mech., 43: 551-581.

Drozdzewski, D, W. Shaw, D. Dominey-Howes, R.W. Brander e*t al*. 2012. Surveying rip current survivors: preliminary insights into the experiences of being caught in rip currents. Nat. Haz. & Earth Syst. Sci., 12: 1201-1211.

Drozdzewski, D., A. Roberts, D. Dominey-Howes, and R.W. Brander. 2015. The experiences of weak and non-swimmers caught in rip currents at Australian beaches. Aust. Geog. 46(1):15-32.

Gensini, V.A. and W.S. Ashley. 2010. An examination of rip current fatalities in the United States. Nat. Hazards, 54: 159-175.

Haller, M.C. and R.A. Dalrymple. 1999. Rip current dynamics and nearshore circulation. Research Report CACR-99-05, Center for Applied Coastal Research, University of Delaware.

Hansen, J.B. and I.A. Svendsen. 1986. Experimental investigation of the wave and current motion over a longshore bar. Proceedings 20th International Conference Coastal Engineering, American Society Civil Engineers.

Hatfield, J., A. Williamson, S. Sherker, R.W. Brander, *et al*. 2012. Development and evaluation of an intervention to reduce rip current related beach drowning. Acc. Anal. & Prev., 46: 45-51.

Kumar, N., G. Voulgaris, and J.C. Warner. 2011. Implementation and modification of a three-dimensional radiation stress formulation for surf zone and rip-current applications. Coastal Engineering, 58: 1097-1117.

Lushine, J.B. 1991. A study of rip current drownings and related weather factors. National Weather Digest, 16: 13-19.

Lyons, S. 1991. Rip Currents: Description, Observations and Theories. Cooperative Institute for Applied Meteorological Studies, Department of Atmospheric Sciences, Texas A&M University, 3150 TAMU, College Station, TX 77843-3150.

McCarroll, R.J., R.W. Brander, J. MacMahan, *et al*. 2014. Evaluation of swimmer-based rip current escape strategies. Nat Haz., 71(3):1821-1846.

Miloshis, M. and W.J. Stephenson. 2011. Rip current escape strategies: lessons for swimmers and coastal rescue authorities. Nat. Hazards, 59: 823-832.

Morgan, D., J. Ozanne-Smith, and T. Triggs. 2009. Self-reported water and drowning risk exposure at surf beaches. Aust N Z J Public Health, 33: 180-188.

NOAA, 2017. Rip currents: break the grip of the rip, http://www.ripcurrents.noaa.gov/signs_brochures.shtml.

Orzech, M.D., E.B. Thornton, J.H. MacMahan, W.C. O'Reilly, and T.P. Stanton. 2010. Alongshore rip channel migration and sediment transport. Marine Geology, 271: 278-291.

Orzech, M.D., J.H.M. Reniers, E.B. Thornton, and J.H. MacMahan. 2011. Megacusps on rip channel bathymetry: Observations and modelling. Coastal Engineering, 58: 890-907.

Pfaff, S. 2003. Rip Current Forecasting, WFO MHX Coastal and Marine Conference, Morehead City, NC, USA.

Sabet, B.S. and G.A. Barani. 2011. Field investigation of rip currents along the southern coast of the Caspian Sea. Scientia Iranica, 18(4): 878-884.

Sherker, S., A. Williamson, J. Hatfield, R. Brander, and A. Hayen. 2010. Beachgoers' beliefs and behaviours in relation to beach flags and rip currents. Accident Analysis and Prevention, 42: 1785-1804.

Short, A.D. and C.L. Hogan. 1994. Rip currents and beach hazards: Their impact on public safety and implications for coastal management. Journal Coastal Research, 12: 197-209.

Thiebot, J., D. Idier, R. Garnier, A. Falques, and B.G. Ruessink. 2012. The influence of wave direction on the morphological response of a double sandbar system. Continental Shelf Research, 32: 71-85.

Williamson, A., J. Hatfield, S. Sherker, R.W. Brander, and A. Hayen. 2012. A comparison of attitudes and knowledge of beach safety for Australian beachgoers, rural residents and international tourists. Aust. & NZ J. Pub. Health, 36(4): 385-391.

Yu, J. and D.N. Slinn, 2003. Effects of wave-current interaction on rip currents. Journal of Geophysical Research, 108(C3): 1-19.

CARBON FLOW WITHIN PLANKTONIC FOOD WEB

Ülgen AYTAN

Faculty of Fisheries, Recep Tayyip Erdogan University, Rize, Turkey
ulgen.kopuz@erdogan.edu.tr

1. Introduction

In aquatic environment, there are two main pathways by which carbon flows from autotrophic to heterotrophic organisms: the classical herbivorous food web and the microbial food web (Azam *et al.* 1983, Sherr *et al.* 1986, Legendre and Rassaulzadegan 1995). In the classical herbivorous food web, the carbon flows directly from large autotrophs to metazoans (Pomeroy 1974). In the microbial food web, the carbon flows from bacteria and small phytoplankton (< 20µm) to nano- microzooplankton and then to higher trophic levels (Azam *et al.* 1983, Calbet and Landry 2004). The importance of the nano- and micrograzers was first described in oligotrophic ecosystems, where autotrophs are dominated by smaller cells. However, since then, it has been recognized that these grazers (heterotrophic nanoflagellates and microzooplankton < 200 µm) also control lower level production and dynamics in productive coastal regions (Calbet and Landry 2004). They are also favourite prey for mesozooplankton in a range of aquatic environments, from the poles to upwelling regions (Stoecker and Capuzzo 1990; Atkinson 1996; Calbet and Saiz 2005). By this way they play significant roles in structuring plankton communities and in nutrient regeneration (Calbet and Saiz 2005, Calbet 2008). Making a distinction between the two historical perspectives, in the herbivorous food web the predators are metazoans, while in the microbial food web the predators are protozoans. An intermediate situation is called the multivorous food web, where both metazoan and protozoan consume both large and small cells (Legendre and Rassoulzadegan 1995). As a result of these studies, the traditional view of a short and efficient herbivorous food web, has been gradually replaced in last decades by a perspective where the year-round workhorses are actually the smaller cells, while larger cells have a more sporadic and seasonal importance.

Drastic changes in biogeochemical properties occurred in the Black Sea ecosystem during the last half century due to pollution, eutrophication, over-fishing, climatic cooling/warming and introduction of non-native species (Besiktepe *et al.* 1999, Kideys 2002, Daskalov 2002, Oguz and Gilbert 2007, Oguz *et al.* 2012). Decreases of nutrient levels during the 1990's were regarded as an improvement of the state of the ecosystem. However, the ecosystem seems not to have return to the classical herbivorous food web of the pre-eutrophication period and is now dominated by dinoflagellates and other nano-size phytoplankton species with respect to diatoms, and relatively low levels of phytoplankton (Oguz and Velikova 2010). In addition, the Black Sea is still under serious environmental threats in result of being a semi-enclosed basin, with high river discharge of several industrialized countries and uncontrolled coastal pollution. The domination of dinoflagellates and nanoflagellates, reduced frequency and magnitude of phytoplankton blooms, and declines in phytoplankton biomass may have also been related to climatic variability (Kideys 2002, Daskalo 2002, Oguz and Gilbert 2007, Nesterova *et al.* 2008, Oguz *et al.* 2012). For example, in-situ phytoplankton biomass in the interior basin followed closely temperature decadal variations, with higher (lower) biomass occurred during cold (warm) years (Oguz *et al.* 2006, Nesterova *et al.* 2008). Predicted warming over the next decades (Collins *et al.* 2013) might significantly increase carbon flow through the microbial food web (Caron and Hutchins 2012). Monitoring of the status of the marine food web has been considered essential for the implementation of the "food web" descriptive of the Marine Strategy Framework Directive (EU 2008), which aims to achieve a healthy functioning of marine ecosystems and a sustainable use of marine resources.

In this chapter the carbon flow within planktonic food web were reviewed from the available literature in the Black Sea. First the importance of nano-micrograzers as grazers on lower levels is discussed, and then their role as a prey for higher trophic levels is considered.

2. Carbon flow within the microbial food web in the Black Sea

The number of available studies on microbial communities (< 200 um) in the Black Sea are strongly biased toward classical herbivorous food web contributors such as diatoms, dinoflagellates and their mesozooplankton predators, in particular copepods (BSC 2008). A few studies on microbial food web components (heterotrophic bacteria, pico autotrophs, small flagellates, and microzooplankton) are accessible (Bird and Karl 1991, Sorokin *et al.* 1995, Bouvier *et al.* 1998, Uysal 2001, Feyzioglu *et al.* 2004, Morgan *et al.* 2006, Kopuz 2010, Kopuz *et al.* 2012), but for the most part they only contemplate abundances and distribution of specific compartments and do not examine trophic interactions. As a result, little is known about the dynamics of the microbial food web in the Black Sea, in particular the role of nano-and microzooplankton grazing on controlling lower level production. The only available information on the growth and grazing dynamics within microbial food web comes from studies in NW Black Sea (Bouvier *et al.* 1998), in the Western and Northern Black Sea (Stelmakh *et al.* 2009, Stelmakh 2013, Stelmakh and Georgieva 2014) and in the SE Black Sea (Aytan *et al.* 2017). The importance of nano- and micrograzers on heterotrophic bacteria and phytoplankton in the Black Sea will be reviewed in the following subsections.

2.1. Nano- and Microzooplankton grazing on Heterotrophic Bacteria

Heterotrophic bacteria are a crucial component of marine food webs (Pomeroy 1974, Azam *et al.* 1983) and play key role in carbon and nutrient cycling in the ocean

(Azam *et al.* 1994). The flow of carbon from heterotrophic bacteria to upper trophic levels is still a poorly understood aspect of microbial food web dynamics. Abundance and distribution of heterotrophic bacteria were subject to several studies in the Black Sea, but only a few studies are available on bacterial growth and mortality due to nano- and microzooplankton.

Bouvier *et al.* (1999) measured feeding activity of nano- and micrograzers on heterotrophic bacteria during summer 1995 in the NW Black Sea based on the uptake of fluorescently labelled-prey. Predation on heterotrophic bacteria by both nano- and micro-grazer was found, but notably nano-sized mixotrophic ciliates only fed on bacteria. This study proved an active microbial food web. However as noted by the authors the feeding activity might have been underestimated because of the employed methodology. In a recent study (Aytan *et al.* 2017), all compartments of microbial communities (Figure 1) during 2011 in SE Black Sea coastal waters were investigated. They also examined nano- and microzooplankton bacterivory from size-fractionated dilution experiments in February, June and December 2011. Growth and grazing rates of heterotrophic bacteria were calculated based on cell count. Production and grazing losses were computed based on the estimated growth and grazing rates, and initial carbon biomass. In this study, heterotrophic bacteria were the most substantial component of the Hetero-C biomass, with contributions ranging between 19% and 70% (Figure 1b).

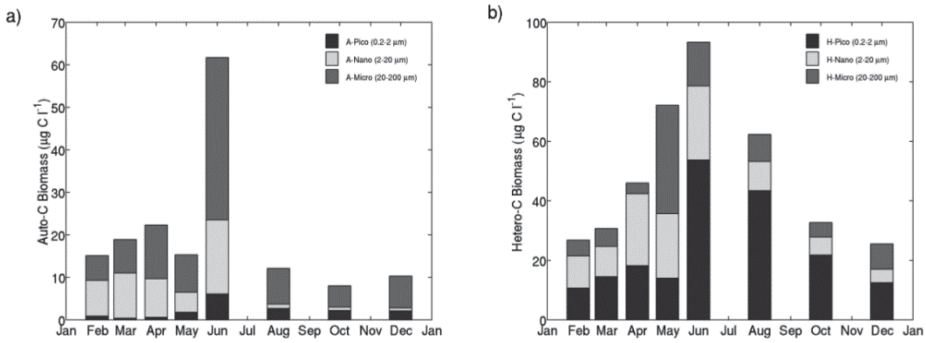


Figure 1. Contribution of size classes to autotrophic (a) and heterotrophic (b) carbon biomass from February to December 2011 at the sampling station (Aytan *et al.* 2017)

In agreement with Bouvier *et al.* (1999), Aytan *et al.* (2017) also found evident grazing of nano- and micrograzers on heterotrophic bacteria. The grazing rates of grazers were always higher than growth rates of heterotrophic bacteria, except on one occasion (< 20 µm size fraction) in December. This clear pattern showed that nano- and microzooplankton heavily grazed on heterotrophic bacteria and removed > 100% of daily bacterial production (Table 1). The highest daily bacterial production was found in the June experiment together with the highest bacterial biomass.

Table 1. Mean growth and grazing mortality rates of heterotrophic bacteria calculated from the size-fractioned dilution experiments. μ = growth rate, g = grazing mortality rate; r^2 = the correlation coefficient of the linear regression of apparent growth rate against the fraction of unfiltered seawater; BP= bacterial production, G= grazing losses; *ns* = not significant; * $p < 0.05$; ** $p < 0.01$ (modified from Aytan *et al.* 2017)

Date	Size Fraction	μ (d^{-1})	g (d^{-1})	g: μ	r^2	BP (μg C $l^{-1}d^{-1}$)	G (μg C $l^{-1}d^{-1}$)
February 2011	< 200 μm	0.34	0.40	1.17	*ns*	*3.7*	*4.3*
	< 20 μm	0.15	0.38	2.53	0.62^*	1.2	3.1
June 2011	< 200 μm	0.80	1.20	1.50	0.90^{**}	37.6	56.5
	< 20 μm	0.77	1.22	1.58	0.95^{**}	35.5	56.4
December 2011	< 200 μm	0.63	0.76	1.20	0.96^{**}	11.1	13.4
	< 20 μm	0.79	0.49	0.62	*ns*	*18.6*	*11.6*

Despite heavy predation on bacterial production, relatively high standing stocks of heterotrophic bacteria were reported in the region throughout the year (Figure 1b). The high heterotrophic bacteria standing stock was suggested to may have been supported by the high dissolved organic carbon concentrations in the Black Sea (~2 times higher than the ocean; Ducklow *et al.* 2007) and other sources than local phytoplankton production such as river-transported materials, terrestrial runoff, anthropogenic discharges, benthic fluxes, cycles of sediment resuspension and seasonal reemergence of subsurface CDOM accumulations (Lee *et al.* 2001). The author concluded that heterotrophic bacteria are an important carbon source for nano- and micrograzers in the region, especially in the period of low primary production.

2.2. Nano- and Microzooplankton grazing on phytoplankton

Phytoplankton growth and microzooplankton grazing are crucial processes to understand energy flow in the pelagic food web. Phytoplankton are primary producers, and microzooplankton (<20-200μm) are the main consumer of the daily primary production in the sea (Calbet 2008). However, little attention has been given to phytoplankton growth and microzooplankton grazing in the Black Sea.

Seasonal dynamics of microzooplankton grazing were assessed by dilution experiment in Southern Crimea coastal waters during 2006-2007 and 2010 (Stelmahk 2013). Large diatoms were found as favourite prey of microzooplankton and annual removal of primary production in the surface waters was reported as ca. 65%. In May 2013, as a part of Black Sea expedition of the “R/V "Professor Vodyanitsky", removal of primary production by microzooplankton reported between 4-204% in Western Black Sea coastal waters, 18-72% in Western Black Sea open waters and 12-30% in Eastern Black Sea coastal waters (Table 2) (Stelmak and Georgieva 2014). In the same study, they found that phytoplankton bloom occurred when daily grazing on primary production (g/μ) was less than 75%. Author conclude that microzooplankton play an important trophic function by removing major part of the phytoplankton primary production.

Table 2. Chlorophyll-*a*, microzooplankton grazing rate (g), net phytoplankton growth rate (μ-g), the ratio g/μ (%) over the Black Sea in May 2013 (modified from Stelmak and Georgiva 2014)

Chl *a* (mg/m^3)	g (day^{-1})	μ - g (day^{-1})	g/μ (%)
Western Black Sea, near-shore area			
0.11	0.55	0.65	52
0.12	0.53	0.64	55
1.10	0.53	-0.27	204
0.33	0.13	0.84	13
0.09	0.34	1.00	25
0.11	0.04	0.94	4
0.11	0.32	0.73	30
Western Black Sea, open-sea area			
0.13	0.19	0.84	18
0.13	0.99	0.45	69
0.10	0.50	0.44	53
0.11	0.50	0.63	44
0.10	0.61	0.46	72
Eastern Black Sea, near-shore area			
0.18	0.15	1.12	12
0.14	0.17	1.18	13
0.10	0.20	0.90	18
0.11	0.24	0.56	30
0.10	0.24	0.89	21

In the previously described study of Aytan *et al.* (2017), concomitantly with the bacterivory, nano- and microzooplankton herbivory was also estimated from the size-fractionated dilution experiments (Landry and Hassett 1982) of February, June and December 2011. Growth and grazing rates of phytoplankton were calculated based on the net changes in chlorophyll-*a*. Considering the whole autotrophic community (< 200 μm fraction experiment) the percentage of primary production consumed by nano- and microzooplankton was reported to be as 46%, 21% and 30% in February, June and

December, respectively (Table 3). The relatively low grazing in June was found to be associated with *E. huxleyi* bloom which might deter grazing. This situation was also reported in the Northern Black Sea (Stelmakh 2013, Stelmakh and Georgieva 2014) and other regions (*e.g.* Fileman *et al.* 2002, Strom *et al.* 2003, Fredrickson and Strom 2009). The low grazing in December was suggested to might have been related to nutritional quality of phytoplankton given the low growth rates measured.

Table 3. Mean growth and grazing mortality rates of phytoplankton calculated from the size-fractioned dilution experiments. μ = growth rate, g = grazing mortality rate; r^2 = the correlation coefficient of the linear regression of apparent growth rate against to fraction of unfiltered seawater; P= primary production, G= grazing losses; *ns* = not significant; * $p < 0.05$; ** $p < 0.01$ (modified from Aytan *et al*. 2017)

Date	Size Fraction	Initial Chl-*a*	μ (d^{-1})	g (d^{-1})	g: μ	r^2	P (μg C $l^{-1}d^{-1}$)	G (μg C $l^{-1}d^{-1}$)
February 2011	< 200 μm	0.47	1.67	0.77	0.46	0.67*	43.1	20.0
	< 20 μm	0.36	1.14	0.47	0.41	0.82**	19.9	8.2
June 2011	< 200 μm	1.52	2.43	0.53	0.21	0.79*a	289.7	63.2
	< 20 μm	0.48	1.68	0.11	0.07	*ns*	*50.0*	*3.3*
December 2011	< 200 μm	0.74	0.23	0.07	0.30	*ns*	*3.0*	*0.9*
	< 20 μm	0.29	0.28	0.39	1.44	*ns*[a]	*1.2*	*1.7*

In the same study, in addition to chlorophyll-*a* growth and mortality, the growth and mortality of *Synechococcus* spp. was also estimated based on cell count during February and December 2011. 194 and 44% of daily *Synechococcus* spp. production was removed by nano- and micrograzers in February and December (Table 4). *Synechococcus* spp. can be an important contributor to Auto-C (e.g. Kopuz *et al.* 2012) in the Black Sea. However, carbon flow to grazers was lower during the reported study, because of the low biomass and growth rates of *Synechococcus* spp. Authors stated that the importance of *Synechococcus* spp. to grazers might increase deeper in the water column since maximal biomass has been reported around euphotic depth (~30 m) in the Black Sea especially during thermal stratification (*e.g.* Uysal 2001, Kopuz *et al.* 2012).

Table 4. Mean growth and grazing mortality rates of *Synechococcus* spp. calculated from the size-fractioned dilution experiments. μ = growth rate, g = grazing mortality rate; r^2 = the correlation coefficient of the linear regression of apparent growth rate against to fraction of unfiltered seawater; P= production, G= grazing losses; *ns* = not significant; * $p < 0.05$; ** $p < 0.01$ (modified from Aytan *et al.* 2017).

Date	Size Fraction	μ (d^{-1})	g (d^{-1})	g: μ	r^2	P (μg C $l^{-1}d^{-1}$)	G (μg C $l^{-1}d^{-1}$)
February 2011	< 200 μm	0.35	0.68	1.94	0.90^{**}	0.4	0.8
	< 20 μm	0.11	0.72	6.54	0.89^{**}	0.1	0.8
December 2011	< 200 μm	0.46	0.19	0.41	*ns*	*1.1*	*0.4*
	< 20 μm	1.27	0.51	0.40	0.56^{*}	3.7	1.5

By analysing the full spectrum of prey and predator <200 um, total carbon consumption (bacterivory+herbivory) revealed high-energy flux through the nano- and microzooplankton in the SE Black Sea (Aytan *et al.* 2017). Trophic interactions obtained from the study revealed that in February, an active microbial web with a pronounced importance of autotrophic preys (66%) as a carbon source compared to heterotrophic preys (heterotrophic bacteria and heterotrophic nanoflagellates) (Figure 2). In contrast to February, there was a change in the contribution of different prey to total carbon consumed with an increased importance of heterotrophic prey (53%) compared to autotrophs (47%) in Juna. In December, dilution experiments showed relative importance of HB as a carbon source for nano- and microzooplankton compared to autotrophs (Figure 2).

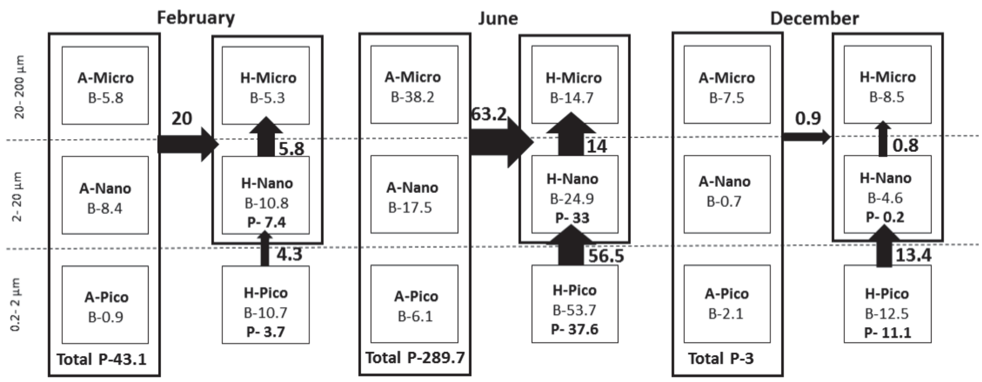


Figure 2. Schematic representation of carbon flow within microbial food web in the SE Black Sea during 2011. Arrows show daily grazing losses (μg C l^{-1} d^{-1}) according to estimation of < 200 μm experiments. A-Pico=Synechococcus, A-Nano=autotrophic nanoflagellates, A-Micro=diatom and autotrophic dinoflagellates, H-Pico=heterotrophic

bacteria, H-Nano=heterotrophic nanoflagellates, H-Micro=Ciliates and heterotrophic dinoflagellates.B= Biomass (µg C l^{-1}), P= Daily production (µg C l^{-1} d^{-1}) (Aytan *et al.* 2017).

Recently, as a part of TUBITAK ÇAYDAG 114Y232 project (entitled "The role of microzooplankton within the planktonic food web of the SE Black Sea"), the dynamics of classical herbivorous food web and microbial food web were assessed in the SE Black Sea between May 2015 and April 2016 in river mouth, and the coastal and open waters of Southeastern Black Sea. Seasonal dilution experiments (Landry and Hassett 1982) were conducted to determine grazing pressure of microzooplankton on phytoplankton size groups. Growth rates and daily primary productions of pico-, nano-and microphytoplankton with mortality rates and daily grazing losses due to microzooplankton grazing were calculated.

For the first time, detailed community assessment of microzoplankton was done. It was found that microzooplankton was represented by a total of 108 species belonging to Protozoa and Metazoa. Microzooplankton abundance ranged from 63 to 2733 cell.l^{-1} dominated by heterotrophic dinoflagellates. Microzooplankton biomass ranged from 0.7 to 28.9 µgC.l^{-1} and dominated by micrometazoans. Abundance and biomass values tended to decrease from river mouth to open waters. Total microplankton abundance was dominated by microphytoplankton, whereas microzooplankton was an important contributor of total microplankton biomass (41-50%). Estimated primary production and grazing losses ranged from 0.2 to 42 µg C l $^{-1}$ d $^{-1}$ and 0.54 to 59.5 µg C l $^{-1}$ d $^{-1}$, respectively. Microzooplankton were main grazers of phytoplankton and responsible for greater than 100 % of daily primary production losses. Microzooplankton mostly consumed micro-size phytoplankton. Primary production and grazing losses due to grazing decreased from the river mouth to the open waters. A significant positive correlation (R^2 = 0.36, $p<0.001$) between the phytoplankton growth and the microzooplankton grazing rate was found in the study (Figure 3b) and the results strongly agree with the global assessment in the coastal and open ocean regions (Figure 3a) made by Calbet and Landry (2004). The results of TUBITAK ÇAYDAG project 114Y232 suggest that microzooplankton is an important component of plankton and a main grazer of phytoplankton in the Southeastern Black Sea.

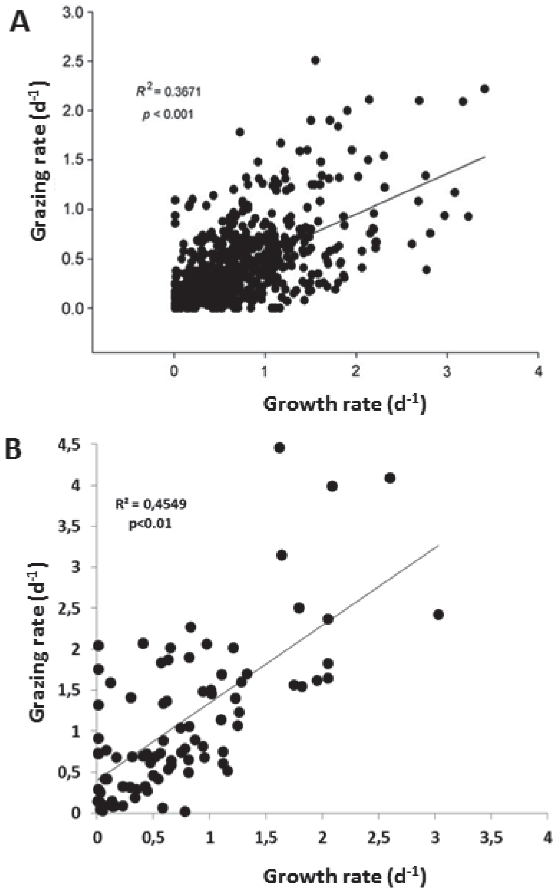


Figure 3. Relation between phytoplankton growth and microzooplankton grazing (A-Global data, Calbet and Landry 2004, B- SE Black Sea, TUBITAK CAYDAG 114Y232

3. Carbon flow from microphytoplankton and microzooplankton to copepods

The transfer of carbon via the microbial food web to higher trophic levels challenges much of the traditional views on marine food webs. As shown above, nano- and microzooplankton can consume more than half of phytoplankton biomass per day and most of the primary production could be circulated by microzooplankton to higher trophic levels instead of sedimentation or advection.

Traditionally, phytoplankton are known to be the main food source for mesozooplankton, in particular copepods (Calbet and Alcaraz 2008). Among mesozooplankton, copepods play a key role in pelagic food web transferring energy from primary producers to planktivorous fish. Copepods, in particular calanoids and cyclopoids are considered as selective feeders (Lampert 1987). Although copepods comprise an important part of total mesozooplankton biomass in the Black Sea, their feeding behaviour is still poorly understood. In the Black Sea, Petipa (1964) reported that dinoflagellates and diatoms were found as dominant food item in the gut content of *Calanus*; Crustacean exoskeletons and small dinoflagellates in the gut of *Calanus* were reported by Arashkevich *et al.* (1997). Besiktepe *et al.* (2005) reported herbivory of female *C. euxinus* ranged from 6% to 11% of their body carbon weight in April and from 15% to 35% in September 1995 by gut pigment content analysis. They indicate that the herbivorous daily ration was sufficient to meet the routine metabolic requirements of female *C. euxinus* in April and September 1995 in the Black Sea. Recently, contrary to traditional view, microzooplankton (< 200µm, protozoa and metazoa) have been recognised as a favourite prey for mesozooplankton (200-2000 µm), in particular copepods in a range of aquatic environments, from upwelling regions to oligotrophic ocean gyres to polars (Calbet 2008). They can consume more than half of phytoplankton biomass per day and most of the primary production is circulated by microzooplankton to higher trophic levels instead of sedimentation or advection (Calbet and Alcaraz 2008).

As a part of previously described TUBITAK CAYDAG 114Y232 project, a total of 51 copepod feeding experiments were conducted between May 2015-April 2016 in the Southeastern Black Sea to assess the contribution of microphytoplankton (diatom and autotrophic dinoflagellates) and microzooplankton (heterotrophic dinoflagellates, ciliates and micrometazoa) to *Calanus euxinus* and *Acartia clausi* diet. Filtration and ingestion rates for each copepod species were calculated. To understand feeding selectivity the "Relative Preference Index" was also calculated. In open waters of the SE Black Sea, filtration rates of *Acartia clausi* ranged between 8-535 (mean 92±181) ml.copepod^{-1}.d^{-1} and 0-485 (mean 148±151) ml.copepod^{-1}.d^{-1} for microphytoplankton and microzooplankton, respectively (Figure 4a). The highest filtration rates of *Acartia clausi* was estimated for heterotrophic dinoflagellates (mean 291±607 ml. copepod^{-1}. d^{-1}). Filtration rates of *Calanus euxinus* ranged between 0-237 (mean 94±88) ml.copepod^{-1}.d^{-1} and 0-247(mean 137±109) ml.copepod^{-1}.d^{-1} for microphytoplankton and microzooplankton, respectively (Figure 4b). The highest filtration rates of *Calanus euxinus* was estimated for micrometazoa (235±171 ml. copepod^{-1}. d^{-1}).

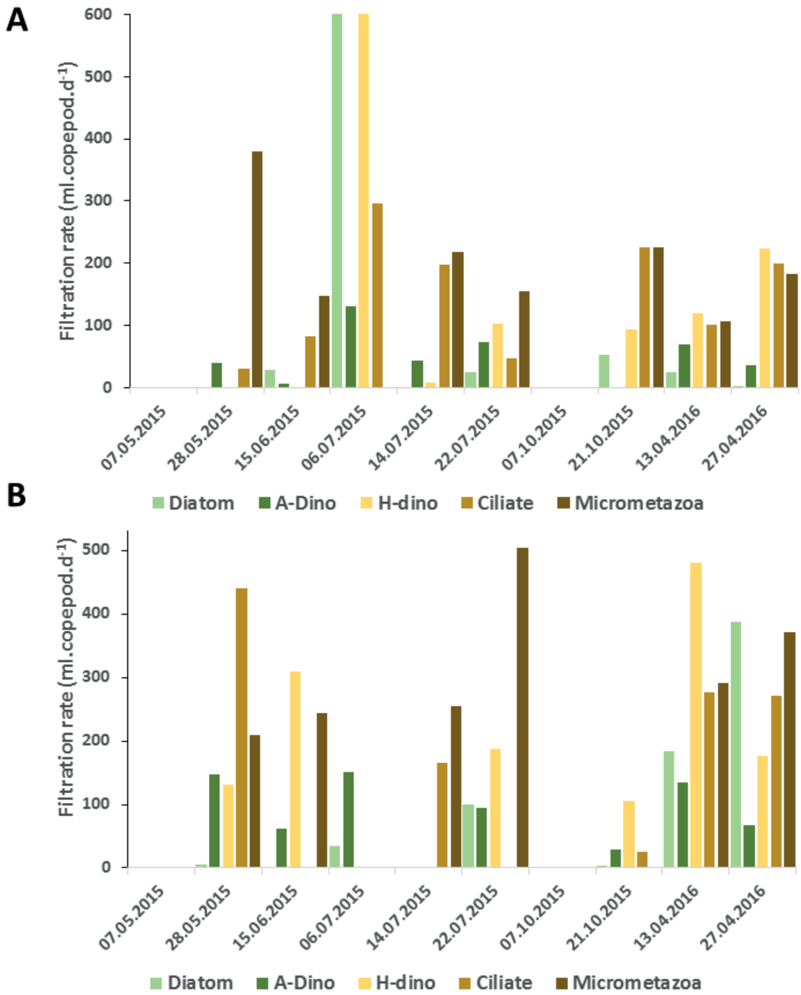


Figure 4. Filtration rates of *Acartia clausi* (A) and *Calanus euxinus* (B) on different prey groups in open waters (20 nm) of SE Black Sea

Results obtained from the study showed that, in open waters, ingestion rate of *Acartia clausi* for microphytoplankton and microzooplankton ranged between 0.003-0.104 (0.06±0.08) µgC. copepod. d^{-1}, and 0-0.301 (0.08±0.1) µg C.copepod.d^{-1} , respectively. Among preys, the highest ingestion rate was estimated for heterotrophic dinoflagellates (0.05±0.12 µg C.copepod.d^{-1}). Overall, averaged contribution of microphytoplankton and microzooplankton to *Acartia clausi* diet was 46% (10-82%) and 54% (18-90%), respectively (Figure56a). Ingestion rate of *Calanus euxinus* for microphytoplankton and microzooplankton ranged between 0-0.312 (0.081±0.101) µgC. copepod. d^{-1}, and 0-0.224 (0.091±0.087) µg C.copepod.d^{-1}, respectively. Among preys, the highest ingestion rate was estimated for autotrophic dinoflagellates (0.047±0.04 µgC.copepod.d^{-1}) and micrometazoans (0.046±0.04 µgC.copepod.d^{-1}). Overall, averaged contribution of microphytoplankton and microzooplankton to *Calanus euxinus* diet was 42% (0-100%) and 58% (0-100%), respectively (Figure 5b). These results indicate that both calanoid copepods exhibited selective feeding behaviour on microzooplankton. Copepods mostly fed on microphytoplankton during the short-term bloom period. However, microzooplankton was an important carbon source for copepods during critical periods of low food concentration.

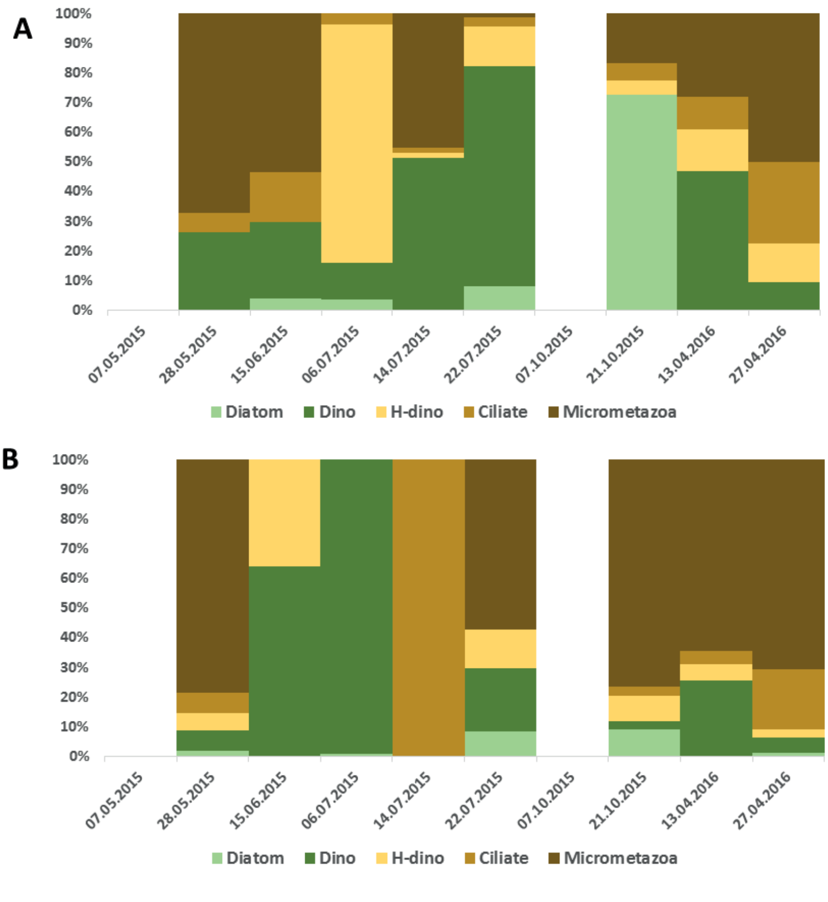


Figure 5. Contribution of different prey group to *Acartia clausi* (A) and *Calanus euxinus* (B) diet in open waters (20 nm) of SE Black Sea

4. Conclusion

Reviewed studies in this chapter show the strong grazing impact of nano- and microzooplankton on bacterial and primary production in the Black Sea. It is also shown that microzooplankton is a key group in the energy flow between the primary production and copepods. This suggests an active microbial food web. These results add up to increased evidence indicating that microzooplankton is an important participant of plankton and main grazer of phytoplankton in temperate coastal systems. Nevertheless, the classical food web seems also an important pathway of carbon to higher trophic levels during the phytoplankton seasonal blooms. Therefore, the system seems better described as a multivorous food web since both the microbial and herbivorous food webs appear to play significant roles in carbon flow within pelagic food web. Monitoring studies are necessary to understand the transient nature between these two extreme trophic modes and for realistic approaches in modelling studies these should be considered.

Acknowledgements

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References

Araschkevich, E., L. Svetlichny, E. Gubareva, S. Besiktepe, A.C. Gucu, and A.E. Kideys. 1997. Physiological and ecological studies of *Calanus euxinus* (Hulsemann) in the Black Sea including its life cycle, p. 327-349. In L.I., Ivanov, T. Oguz [eds.], Ecosystem Modeling as a Management Tool for the Black Sea. NATO ASI Series, Vol. 47 (1). Kluwer Academic Publishers, Dordrecht.

Atkinson, A. 1996. Subantarctic copepods in an oceanic, low chlorophyll environment: ciliate predation, food selectivity and impact on prey populations. Mar Ecol Prog Ser., 130: 85-96.

Aytan, U., A.M. Feyzioglu, A. Valente, E. Agirbas, and E. Fileman. 2017. Microbial plankton communities in the coastal southeastern Black Sea: biomass, composition and trophic interactions. Oceanologia, 138: 1-14.

Azam, F., T. Fenchel, J.G. Field, J.S. Gray, L.A. Meyer-Reil, and F. Thingstad. 1983. The ecological role of water column microbes in the sea. Marine Ecological Progress Series, 10: 257-263.

Azam, F., D.C. Smith, G.F. Steward, and Å. Hagström. 1994. Bacteria organic matter coupling and its significance for oceanic carbon cycling. Microb. Ecol., 28: 167-179.

Besiktepe, S., L. Svetlichny, T. Yuneva, Z. Romanova, and G. Shulman. 2005. Diurnal gut pigment rhythm and metabolic rate of *Calanus euxinus* in the Black Sea. Mar. Biol., 146: 1189-1198.

Bird, D.F. and D.M. Karl. 1991. Microbial biomass and population diversity in the upper water column of the Black Sea. Deep- Sea Research, 38: 1069-1082.

Bouvier, T., S. Becquevort, and C. Lancelot. 1998. Biomass and feeding activity of phagotrophic mixotrophs in the northwestern Black Sea during the summer 1995. Hydrobiologia, 363: 289-301.

BSC 2008. State of the Environment of the Black Sea (2001 - 2006/7), pp. 448. In T. Oguz [Chief Ed], Publications of the Commission on the Protection of the Black Sea Against Pollution (BSC) 2008-3, Istanbul, Turkey.

Calbet, A. and M.R. Landry. 2004. Phytoplankton growth, microzooplankton grazing, and carbon cycling in marine systems. Limnology and Oceanography, 49: 51-57.

Calbet, A. and E. Saiz. 2005. The ciliate-copepod link in marine food ecosystems. Aq. Microb. Ecol., 38: 157-167.

Calbet, A. 2008. The trophic role of microzooplankton in marine systems. ICES Journal of Marine Science, 65: 325-331.

Calbet, A. and A. Alcaraz. 2008. Microzooplankton, key organisms in the pelagic food web, 5: 227-241. In P. Safran [Ed.], Fisheries and Aquaculture. EOLSS Publications.

Caron, D.A. and D.A. Hutchins. 2012. The effects of changing climate on microzooplankton grazing and community structure: drivers, predictions and knowledge gaps. J. Plankton Res., 35(2): 235-252.

Collins, M., R. Knutti, J. Arblaster, J.L. Dufresne, T. Fichefet, P. Friedlingstein, X. Gao, W.J. Gutowski, T. Johns, G. Krinner, M. Shongwe, C. Tebaldi, A.J. Weaver, and M. Wehner. 2013. Long-term climate change: Projections, commitments and irreversibility, p. 1029-1136. In T.F. Stocker, D. Qin, G.K. Plattner, M. Tignor, S.K. Allen, J. Doschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley [Eds.], Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

Daskalov, G. M. 2002. Overfishing drives a trophic cascade in the Black Sea. Mar. Ecol. Prog. Ser., 225: 53-63.

Ducklow, H. W., D.A. Hansell, and J.A. Morgan. 2007. Dissolved organic carbon and nitrogen in the Western Black Sea. Marine Chemistry, 105: 140-150.

Feyzioglu, A.M., I. Kurt, M. Boran, and N. Sivri. 2004. Abundance and distribution of cyanobacteria *Synechococcus* spp. in the South-eastern Black Sea during 2001 summer, Indian Journal of Marine Sciences, 33 (4): 365-368.

Kideys, A.E. 2002. Fall and rise of the Black Sea ecosystem, Science, 297: 1482-1484.

Kopuz, U. 2012. Dynamics of picoplankton in microbial loop and their importance at pelagic food web in the southeastern Black Sea. PhD Thesis (in Turkish). Karadeniz Technical University, 170 p.

Kopuz, U., A.M. Feyzioglu, and E. Agirbas. 2012. Picoplankton dynamics during late spring 2010 in the south-eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 12: 397-405.

Lampert, W. 1987. Laboratory studies on zooplankton-cyanobacteria interactions. New Zealand Journal of Marine and Freshwater Research, 21: 483-490.

Landry M.R. and R.P. Hassett. 1982. Estimating the grazing impact of marine micro-zooplankton. Marine Biology, 67: 283-288.

Lee, C.H. I. Kudo, M. Yanada, and Y. Maita. 2001. Bacterial abundance and production and heterotrophic nanoflagellate abundance in subartic coastal waters (Western North Pacific Ocean). Aquat. Microb. Ecol., 23: 263-271.

Legendre, L. and F. Rassaulzadegan. 1995. Plankton and nutrient dynamics in marine water. Ophelia, 42: 153-172.

Morgan, J.A., H.L. Quinby, and H.W. Ducklow. 2006. Bacterial abundance and production in the western Black Sea. Deep-Sea Research II, 53: 1945-1960.

Nesterova, D., S. Moncheva, A. Mikaelyan, A. Vershinin, V. Akatov, L. Boicenco, Y. Aktan, F. Sahin, and T. Gvarishvili. 2008. The state of phytoplankton, p. 112-147. In T. Oguz [Chief Ed.], State of the Environment of the Black Sea (2001– 2006/7). The Commission on the Protection of the Black Sea against Pollution Publication.

Oguz, T. and D. Gilbert. 2007. Abrupt transitions of the top-down controlled Black Sea pelagic ecosystem during 1960-2000: Evidence for regime-shifts under strong fishery exploitation and nutrient enrichment modulated by climate-induced variations. Deep Sea Res. I, 54 (2): 220-242.

Oguz, T. and V. Velikova. 2010. Abrupt transition of the northwestern Black Sea shelf ecosystem from a eutrophic to an alternative pristine state. Mar. Ecol. Prog. Ser., 405: 231-242.

Oguz, T., B. Salihoglu, S. Moncheva, and V. Abaza. 2012. Regional peculiarities of community-wide trophic cascades in strongly degraded Black Sea food web. J. Plankton Res., 34: 338-343.

Petipa, T.S. 1964. Diurnal rhythm of food and diurnal diet of *Calanus helgolandicus* in the Black Sea (in Russian). Works of Sevastopol Biological Station. Academy of Sciences, USSR 15:69-93.

Pomeroy, L.R. 1974. The ocean's food web, a changing paradigm. Bio. Sci., 24: 499-504.

Sherr, B.F., E.B. Sherr, T.L. Andrew, R.D. Fallon, and S.Y. Newell. 1986. Trophic interactions between heterotrophic protozoa and bacterioplankton in estuarine water analyzed with selective metabolic inhibitors. Marine Ecological Progress Series, 32: 169-179.

Sorokin, Y.I., P.Y. Sorokin, V.A. Avdeev, D.Y. Sorokin, and S.V. Ilchenko. 1995. Biomass, production and activity of bacteria in the Black Sea, with special reference to chemosynthesis and the sulfur cycle. Hydrobiologia, 308: 61-76.

Stelmakh L.V., I.I. Babich, S. Tugrul, S. Moncheva, and K. Stefanova. 2009. Phytoplankton growth rate and zooplankton grazing in the western part of the Black Sea in the autumn period. Oceanology, 49: 83-92.

Stelmakh, L. 2013. Microzooplankton grazing impact on phytoplankton blooms in the coastal seawater of the Southern Crimea (Black Sea). International Journal of Marine Science, 3(15): 121-127.

Stelmakh, L. and E. Georgieva. 2014. Microzooplankton: the trophic role and involvement in the phytoplankton loss and bloom-formation in the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 955-964.

Stoecker, D.K. and J.M. Capuzzo. 1990. Predation on Protozoa: its importance to zooplankton. Journal of Plankton Research, 12(5): 891-908.

Uysal, Z. 2001. Chroococcoid cyanobacteria *Synechococcus* spp. in the Black Sea: pigments, size, distribution, growth and diurnal variability. Journal of Plankton Research, 23(2): 175-189.

PHYTOPLANKTON IN THE BLACK SEA

Ali Muzaffer FEYZİOĞLU and Fatih ŞAHİN

Faculty of Marine Sciences, Karadeniz Technical University, 61530 Camburnu, Turkey
Faculty of Fisheries, Sinop University, 5700 Sinop, Turkey
muzaffer@ktu.edu.tr

1. Introduction

Enclosed or semi-enclosed sea means a gulf, basin or sea surrounded by two or more States and connected to another sea or the ocean by a narrow outlet or consisting entirely or primarily of the territorial seas. The European continent has tree large semi enclosed seas. The Black Sea is one of the enclosed sea basin in European continent. Beside these properties, it is the largest anoxic basin in the world (Mee 1992 and Turgut *et al*. 1992). The Black Sea is virtually isolated, connected with the Mediterranean by small and narrow channel, Bosphorus and characterized by two large cyclonic gyres in eastern and western parts (Oguz *et al*. 1993). This two cyclonic gyre system separates the Black Sea as east and west Black Sea Region in the south along the Anatolian coast. Because of the enclosed basin characteristics, the pelagic ecosystem of the Black Sea is continuously changing at surprising rates (Soydemir *et al*. 2002).

Enclosed basin can be divided in two main categories according to water exchange processes. First category includes the seas having a negative water balance, where the evaporation exceeds the total input of fresh water. Mediterranean Sea provides a classical example of negative water balance. Second category includes seas having positive water balance, where the inflow of fresh water from precipitation and from surrounding drainage area exceeds the evaporation. Black Sea is example of the sea which have positive water balance. This can lead, as in the case of the Black Sea, to a permanent stratification between low saline surface layers and more saline deep water (Barale and Murray 1995). This two layer stratified system is accompanied by a distinct biochemical structure characterized by complete anoxia of sub-pycnocline waters and their separation from the oxygenated surface waters though a transition zone called the Suboxic Layer. The oxygenated surface layer comprises the euphotic zone of about 40-50 m (Oguz *et al*. 1999).

Euphotic zone can be described as upper layers of water body which have sufficient light for photosynthesis. Pigment contain plants by making use of light energy are able to combine simple substance to synthesize complex organic molecules by means of photosynthesis. Plankton which contains chlorophyll and carotenoids as pigment material calls phytoplankton, is an important component of pelagic system. By far the greater part of primary production in the sea is performed by the phytoplankton (Tait and

Dipper 2001). Structure and functional characteristics of the phytoplankton are closely related to the ecological stage of environment and can be used as indices for determining the ecological stage costal ecosystem in the Black Sea (Yunev *et al*. 2002).

Phytoplankton are tiny drifting plants which are vital components of the marine and freshwater aquatic food chains. These organisms include drifting or floating bacteria, archaea, algae. Out of the systematic description the most common classification of the planktonic organisms is the size. The various size categories of plankton which cover phytoplankton are as follows: **Picoplankton (0.2–2 µm)** are mostly bacteria (called bacterioplankton). **Nanoplankton (2–20 µm**) include small phytoplankton (mostly single-celled diatom), flagellates (both photosynthetic and heterotrophic), small ciliates, radiolarians and coccolithophorids. **Microplankton (20–200 µm)** include large phytoplankton (large single-celled or chain-forming diatoms, dinoflagellates), foraminiferans, ciliates, nauplii (early stages of crustaceans such as copepods and barnacles). **Mesoplankton** (0.2–20 mm,) are very common and visible to the naked eye. They are diverse and include mostly multi cellular zooplankton and larger unicellular phytoplankton. Lager than 20 mm organisms include completely zooplankton (Suthers and Rissik 2009).

Existing environmental changes and their impact on phytoplankton composition is of great important (Uysal 1996). There isn't enough background data on phytoplankton composition and unique species distribution for South Eastern Black sea coast. A few studies have been reported by limited researchers (Benli 1987, Tuncer and Feyzioglu 1989, Karacam and Duzgunes 1990, Feyzioglu and Tuncer 1994, Uysal and Sur 1995, Feyzioglu and Duzgunes 1996, Uysal *et al.* 1998, Ekere *et al*. 1999, Feyzioglu and Sivri 2003, Eker and Velicova 2009, Bat *et al*. 2007, Sahin *et al.* 2003, Sahin *et al*. 2007, Sahin *et al*. 2008, Baytut and Gonulol 2010, Baytut *et al*. 2005, Kopuz *et al*. 2012, Kopuz *et al.* 2014, Agırbas *et al*. 2014, Agırbas *et al*. 2015, Feyzioglu *et al*. 2015, Ediger *et al*. 2015, Feyzioglu and Guneroglu 2011, Feyzioglu and Ogut 2006, Feyzioglu *et al*. 2004 and Uysal 2002).

The aim of the present is to give the brief and condense information about the Black Sea phytoplankton. During preparation of the chapter we tried to give qualitative and quantitative specification of the Black Sea phytoplankton in size class. The data present here mostly belong to the Southern part of the Black Sea and cover the studies after 1989 to present.

2. Piko and Nanoplankton

Pico and nanoplankton are cosmopolitan in distribution in the surface waters of both freshwater lakes and the sea (Fogg 1995). The first members of the picoplankton to be discovered in the oceans were phycoerythrin-containing unicellular cyanobacteria *Synechococcus* (Waterbury *et al*. 1979, Johnson and Sieburth 1979). Majority of oceanic species comprises small picoplanktonic algae which are particularly small phytoplankton with size between 0.2 and 2 µm and include mainly chroococcoid cyanobacteria, *Synechococcus* spp. (Suthers and Rissik 2009, Uysal 2006). They are major contributors to the total primary production in marine environment. Iturriaga and Mitchell (1986) indicate that they comprise 64% of the total photosynthesis in the North Pacific Ocean. Limited studies were done on picoplanktonic groups in the Black sea (Uysal 2000, Uysal 2001, Kurt 2002, Uysal 2006, Feyzioglu *et al.* 2004, Kopuz *et al*. 2012, Kopuz 2012, Feyzioglu *et al*. 2015).

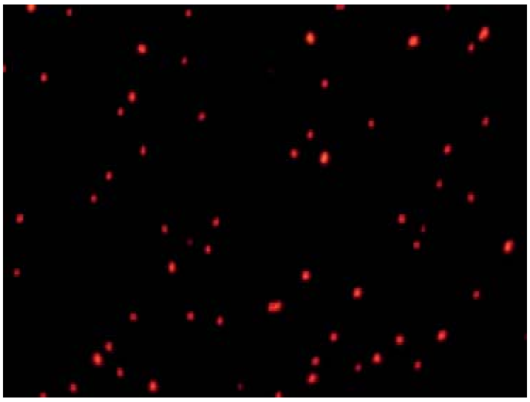


Figure 1. Fluorescence image of *Synechococcus* spp. (x100) (Photo: by A.M.Feyzioglu)

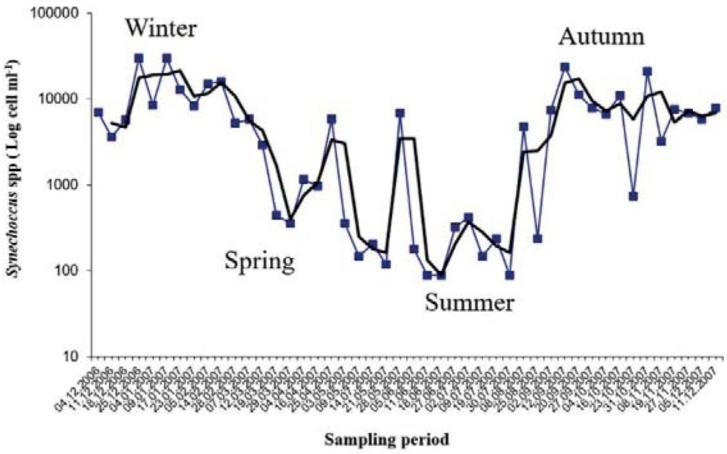
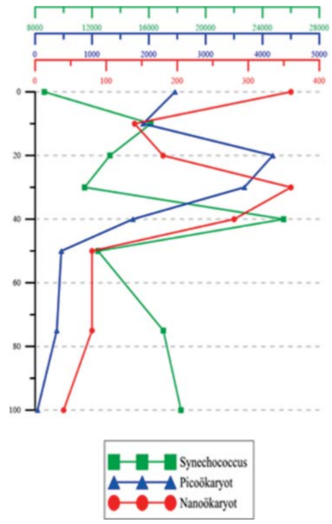
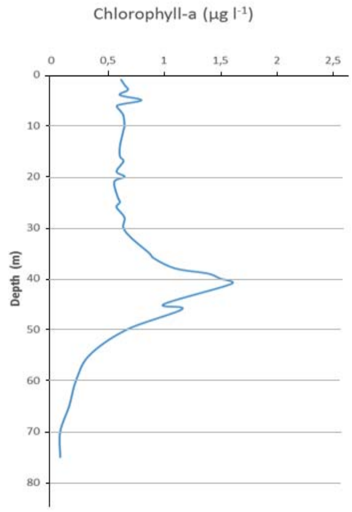


Figure 2. Changes of *Synechococcus* spp. cells number in biweekly period in Black Sea Anatolian coast

The most important picoplanktonic group is *Synechococcus* spp. (Figure 1) in the Black Sea Pelagic zone. Their biomass can reach to 10^5 cells ml^{-1} during the autumn and winter. In contrary, their abundance can fall to 10^2 ml^{-1} during the summer and spring period (Figure 2). As a general trend in vertical distribution, these groups reach a maximum abundance between 20m-40m depth. Their pigment composition help them to use blue and green light wave length efficiently. So contribution of *Synechococcus* spp. to chlorophyll-a biomass near the photic depth is the highest (Figure 3A and B).



A



B

Figure 3. Vertical profile of pico ve nanoplantonic (cells ml^{-1}) (A) and Chlorophyll-a (µg l^{-1}) (B)

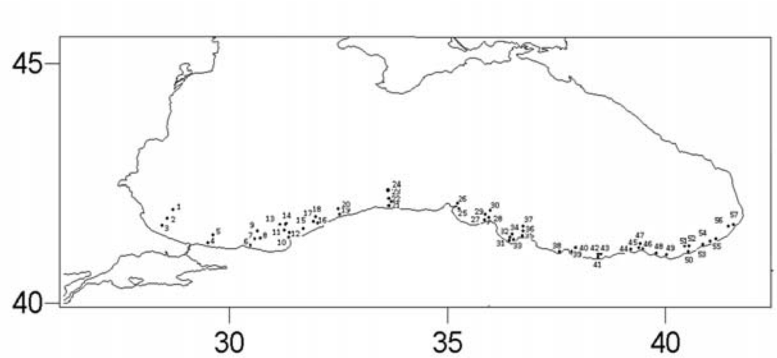


Figure 4. Sampling locations (Feyzioglu *et al*. 2015)

Previous studies showed that picoplankton community structure had spatial differences along the southern Black Sea coast line (Uysal 2006, Feyzioglu *et al*. 2015). According to Feyzioglu *et al*. (2015) *Synechococcus* spp. community structure can be divided into 20 regional groups along the Black Sea Anatolian coast (Figure 4). Those groups include Istanbul– Karacakoy, Şile, Sakarya-Karasu, Eregli, Zonguldak, Bartın, İnebolu, Sinop, Kızılırmak River, Samsun, Yesilırmak River, Fatsa, Ordu, Giresun, Trabzon, Araklı, Rize, Cayeli-Pazar and Hopa (Figure 5). Similar trend of the cluster analysis result were shown in the same region by the researcher (Uysal 2006).

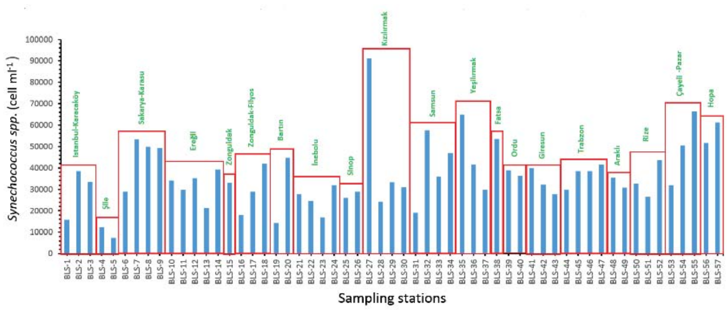


Figure 5. Regional distribution of *Synechococcus* spp. according to community structure.

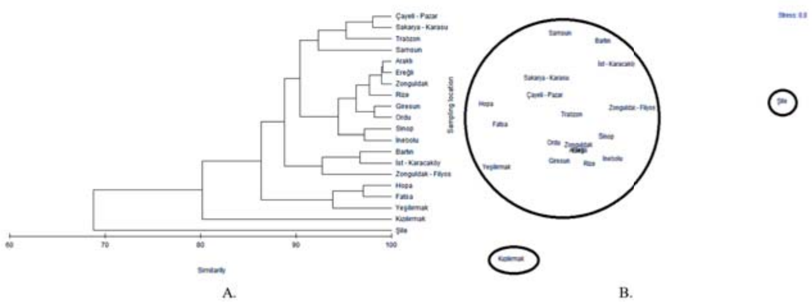


Figure 6. A) Regional Hierarchical Similarity Cluster Analyses and **B)** MDS analyses results for *Synechococcus* spp.

Hierarchical Cluster Analyses and MDS analyses are useful tools to compare the region community. According to result of the analysis, the similarity of the regions were higher than 85% (Figure 5). Along south eastern Black Sea coast, Kızılırmak River and

Şile were shown to have a different picoplankton structure (Figure 6). Şile off was the most specific site along the Anatolian coast. Because *Synechococcus* spp. biomass was the lowest in Şile off. Therefore Şile showed high differences along Anatolian coast. This may be the combination effect of Istanbul Strait and western cyclonic gyro. Kızılırmak River plume is also an important area for picoplanktonic organism along the Anatolian coast of the Black Sea. Although some region have high cell concentration in western part of the Anatolian coast, in general *Synechococcus* spp. cell consecrations were higher at eastern part than western part of the Anatolian coast. The largest cell size of *Synechococcus* spp. were found at late autumn (Feyzioglu *et al.* 2015). The vertical profiles of the cell numbers show that maximum cell numbers were between 20-50 m depth along the water column (Figure 6) (Kopuz 2012, Kopuz *et al*. 2012 and Feyzioglu *et al*. 2011). This group is responsible from the deep sea chlorophyll maximum. It can be said that cell size and the carbon biomass were high and picoplanktonic organisms have high production rate in that depth. So they cause elongation of the food chain. This group should be monitored for the understanding of the process of ecosystem.

Figure 7. SEM image of *Emiliania huxleyi* (x10000) (Photo: by A.M. Feyzioglu).

Nanoplankton include the free living organisms which have a size range between 2-20 µm and the well-known representative of this group in the Black Sea is *Emiliania huxleii.* Contribution of eukaryotic picoplankton like *Emiliamia huxleyi* to the total phytoplankton biomass, as a rule, was not significant, except in special cases mainly in warm months and in deep layers. The growth of *E. huxleyi* population is limited to approximately upper 20 m layer because of their strong light requirement, but recently *E. huxleyi* became one of the main contributors to the abundance and biomass of phytoplankton in surface water of Black sea (Mikaelyan *et al*. 2011). This species was recorded in waters both over the shelf and in the open sea. The first bloom of this species in the Black Sea was observed in 1951. Previously, *Emiliania huxleyi* blooms were rare (Mikaelyan *et al.* 2005 and Mikaelyan *et al*. 2011). In recent years, the regular population outbreaks of coccolythophorids in the early summer season were started to be observed in the Black Sea and cell number reaches over a million. In some years coccolithophore bloom has occupied the sea interior and has spread on shelf areas. Most frequently, blooms occurred in the coastal waters and were absent in the deep basin (Mikaelyan *et al*. 2015).

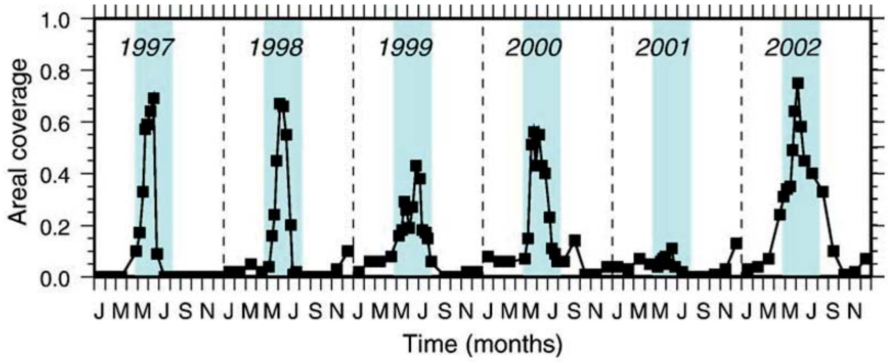


Figure 8. Time series of areal coccolith coverage as a percentage of the total area of the Black Sea basin. (Oguz and Merico 2006)

The bloom season and the percentage coverage of Black Sea surface area during the bloom period are shown Figure 8. Coloured area shows that the May–July period in which *E.huxleyi* blooms occur in the Black Sea according to satellite image analysis is early summer and covers 45 -75 % of the surface area of Black sea in that period (Oguz and Merico 2006).

3. Microphytoplankton

Microphytoplankton include the free living organisms which have a size range between 20-200µm in dimension. These groups constituted a major part of the phytoplankton biomass. Microphytoplankton cover mostly diatom and dinoflagellate species. Numerous researches conducted in the XX th century showed that generally two main taxonomic groups determined the structure of planktonic microalgae communities in the Black Sea: diatoms and dinoflagellates (Mikaelyan *et al*. 2015). Their contribution to the phytoplankton biomass is significant in photic zone especially upper 25 meter depth because of their chlorophyll-*a* content.

The number of free living phytoplankton species in the world oceans are approximately 4000 species. About 1400–1800 of them are diatoms, 1,555 are dinoflagellates and approx. 700 species belong to other groups (Sournia 1991 and Gómez 2005). The Black Sea comprises about 15% of the world species. So, Black Sea phytoplankton includes approx. 600 species (Anonymous 2005). Among these species, 58 Diatom, 53 Dinoflagellate, 4 Silicoflagellate and 3 Euglena species are the most abundant ones and frequently observed along the Black Sea Anatolian coast (Table 1) (Figure 7).

Table 1. The most frequently observed Microphytoplankton species all around the year in the Black Sea Anatolian coast

Diatom
Achnanthes longipes C.Agardh
Amphora arenicola Grunow
Amphora sp.
Amphora ovalis (Kützing) Kützing
Asterionellopsis glacialis (Castracane) Round
Bacteriastrum delicatulum Cleve
Bacteriastrum furcatum Shadbolt
Cerataulina pelagica (Cleve) Hendey
Ceratoneis closterium Ehrenberg
Chaetoceros affinis Lauder
Chaetoceros brevis F.Schütt
Chaetoceros compressus Lauder
Chaetoceros crinitus F.Schütt
Chaetoceros curvisetus Cleve
Chaetoceros danicus Cleve
Chaetoceros decipiens Cleve
Chaetoceros lauderi Ralfs ex Lauder
Chaetoceros vixvisibilis Schiller
Chaetoceros wighamii Brightwell
Coscinodiscus granii L.F.Gough
Coscinodiscus nodulifer A.W.F.Schmidt
Coscinodiscus radiatus Ehrenberg
Cyclotella choctawhatcheeana Prasad
Cymatopleura sp.
Cymbella sp.
Dactyliosolen fragilissimus (Bergon) Hasle
Didymosphenia geminata (Lyngbye) Mart.Schmidt
Ditylum brightwellii (T.West) Grunow
Epithmia sp.
Grammatophora marina (Lyngbye) Kützing
Hannaea arcus (Ehrenberg) R.M.Patrick
Hemiaulus hauckii Grunow ex Van Heurck
Hemiaulus sinensis Greville
Leptocylindrus danicus Cleve
Licmophora ehrenbergii (Kützing) Grunow
Lyrella lyra (Ehrenberg) Karajeva
Melosira moniliformis (O.F.Müller) C.Agardh
Melosira nummuloides C.Agardh
Melosira varians C.Agardh
Nitzschia longissima (Brébisson) Ralfs
Odontidium hyemale (Roth) Kützing
Pleurosigma normanii Ralfs
Proboscia alata (Brightwell) Sundström

Pseudo-nitzschia australis Frenguelli
Pseudo-nitzschia delicatissima (Cleve) Heiden
Pseudo-nitzschia pungens (Grunow ex Cleve) Hasle
Pseudosolenia calcar-avis (Schultze) B.G.Sundström
Rhizosolenia setigera Brightwell
Skeletonema costatum (Greville) Cleve
Striatella delicatula (Kützing) Grunow ex Van Heurck
Surirella sp.
Thalassionema nitzschioides (Grunow) Mereschkowsky
Thalassiosira angustelineata (A.Schmidt) G.Fryxell & Hasle
Thalassiosira decipiens (Grunow ex Van Heurck) E.G.Jørgensen
Thalassiosira gravida Cleve
Thalassiosira nordenskioeldii Cleve
Tryblionella angustata W.Smith
Ulnaria ulna (Nitzsch) Compère

Dinoflagellates

Achradina pulchra Lohmann
Akashiwo sanguinea (K.Hirasaka) G.Hansen & Ø.Moestrup
Alexandrium minutum Halim
Dinophysis acuminata Claparède & Lachmann
Dinophysis acuta Ehrenberg
Dinophysis caudata Saville-Kent
Dinophysis fortii Pavillard
Dinophysis hastata Stein
Dinophysis norvegica Claparède & Lachmann
Dinophysis saccula Stein
Diplopsalis lenticula Bergh
Gonyaulax africana Schiller
Gonyaulax digitalis (Pouchet) Kofoid
Gonyaulax spinifera (Claparède & Lachmann) Diesing
Gyrodinium spirale (Bergh) Kofoid & Swezy
Heterocapsa triquetra (Ehrenberg) Stein
Lingulodinium polyedra (F.Stein) J.D.Dodge
Oxitoxum sp.
Phalacroma rotundatum (Claparéde & Lachmann) Kofoid & Michener
Pronoctiluca pelagica Fabre-Domergue
Prorocentrum compressum (J.W.Bailey) Abé ex Dodge
Prorocentrum micans Ehrenberg
Prorocentrum aporum (Schiller) Dodge
Prorocentrum cordatum (Ostenfeld) J.D.Dodge
Protoceratium reticulatum (Claparède & Lachmann) Bütschli
Protoperidinium bipes (Paulsen) Balech
Protoperidinium brevipes (Paulsen) Balech
Protoperidinium claudicans (Paulsen) Balech
Protoperidinium conicum (Gran) Balech
Protoperidinium crassipes (Kofoid) Balech
Protoperidinium curtipes (Jørgensen) Balech
Protoperidinium depressum (Bailey) Balech

Protoperidinium divergens (Ehrenberg) Balech
Protoperidinium excentricum (Paulsen) Balech
Protoperidinium granii (Ostenfeld) Balech
Protoperidinium leonis (Pavillard) Balech
Protoperidinium oblongum (Aurivillius) Parke & Dodge
Protoperidinium pallidum (Ostenfeld) Balech
Protoperidinium paulsenii (Pavillard) Balech
Protoperidinium pellucidum Bergh ex Loeblich Jr.& Loeblich III
Protoperidinium steinii (Jörgensen) Balech
Protoperidinium subinerme (Paulsen) A.R.Loeblich III
Scrippsiella trochoidea (Stein) Balech ex Loeblich III
Torodinium robustum Kofoid & Swezy
Tripos furca (Ehrenberg) F.Gómez
Tripos fusus (Ehrenberg) F.Gómez
Tripos muelleri Bory
Dictyochophyceae
Dictyocha fibula Ehrenberg
Octactis octonaria (Ehrenberg) Hovasse
Octactis speculum (Ehrenberg) F.H.Chang, J.M.Grieve & J.E.Sutherland
Euglenophyceae
Euglena acusformis J.Schiller
Euglena viridis (O.F.Müller) Ehrenberg
Eutreptia lanowii Steuer
Noctilucophyceae
Noctiluca scintillans (Macartney) Kofoid & Swezy
Scaphodinium mirabile Margalef

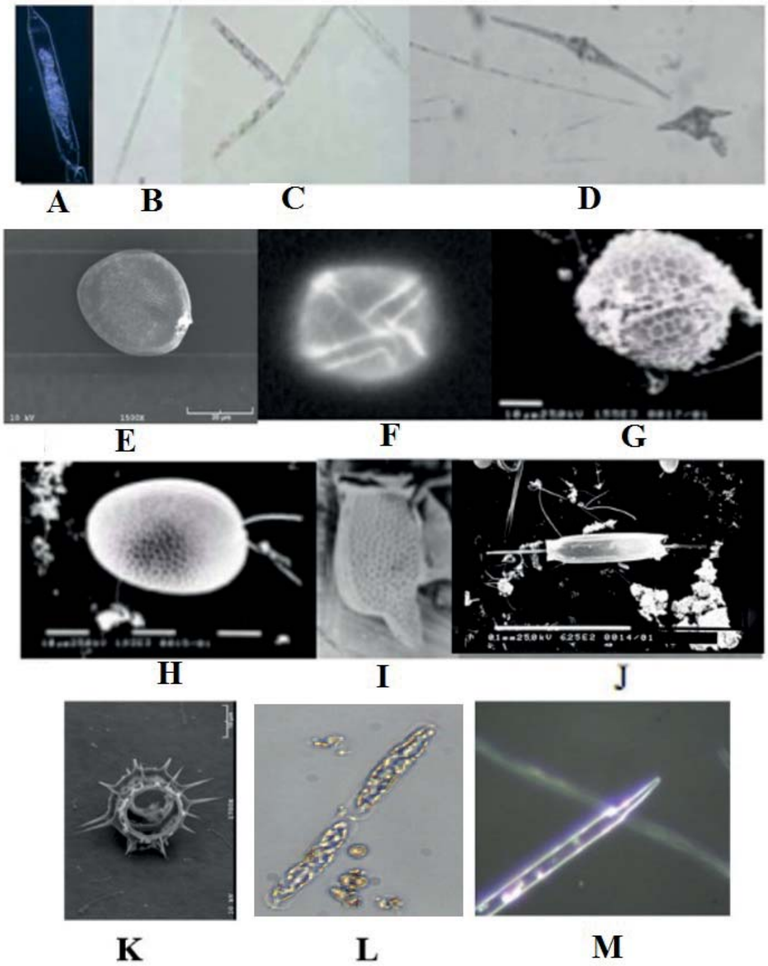


Figure 7. Images of the most common microphytoplanktonic species of the Black Sea phytoplankton (A-*Rhizosolenia calcar-avis,* B-*Pseudo-nitzshia delicatissima,* C-*Thalassionema nitzschioides*, D-*Ceratium fusus,* E-*Prorocentrum micans,* F-*Alexandrium minutum,* G-*Protoceratium retikulatum*, H-*Prorocentrum compressum,* I-*Dinophysis caudata,* J -*Ditylum brightwelli,* K-*Octactis octonaria,* L-*Rhizosolenia fragilisima,* M-*Proboscia alata*) (Photo: by A.M. Feyzioglu)

The Black Sea is ecologically in a dramatic change. This is because of the climate change, changes in hydrological and meteorological conditions, pollution, changes in water quality in coastal area because of the Hydroelectric Power Plant (HPP) construction on river run-off, increase in light transmittance due to reduction of particulate matter. This reduction causes to increase Secchi disc depth and deeper light penetration. It means low phytoplankton production and a deeper PAR depth. After 2000, Secchi disc depth was two times deeper in June, November December and March than before 2000 (Figure 8). These changes in environmental conditions can easily be seen before the late 1990s and after 2000 and the effects on the phytoplankton populations.

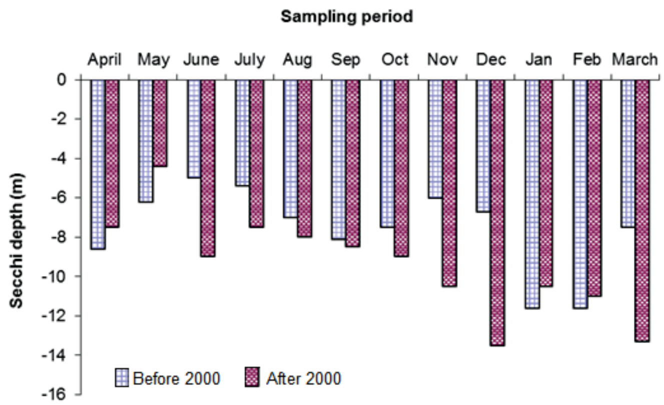


Figure 8. Mean Secchi disc depth before and after millennium

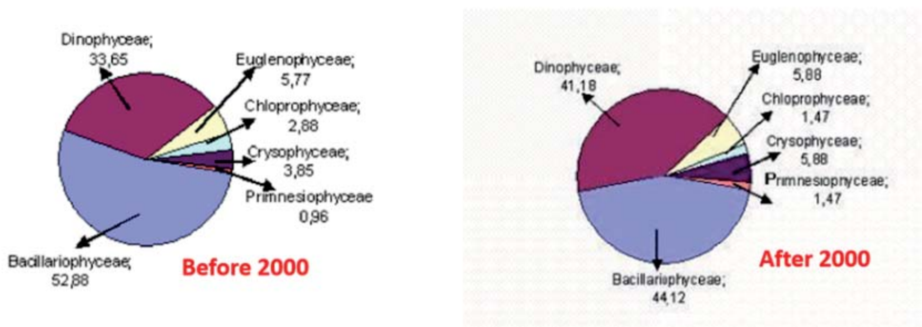


Figure 9. Ratio of main phytoplankton classes living in the Black Sea Anatolian coast

In the western part of the Black Sea, the species composition was shifted from diatoms to coccolithophores and dinoflagellates possibly owing to the decrease in the dissolved silicate (Moncheva and Krastev 1997). Pennate diatom species were more copious before 2000 when compared to the species composition after 2000. Diatom and dinoflagellate ratio changed and dinoflagellate ratio increased. Diatom and dinoflagellate ratio was 52,88% and 33,65 % respectively before millennium. But after millennium, this ratio was observed as 44,12% and 44,18% for diatom and dinoflagellate, respectively (Figure 9). The reason for the increase in dinoflagellate ratio after 2000 may be due to the difference in the use of nitrogen and phosphorus ratio by diatom and dinoflagellates.

Because low nitrogen to phosphorus (N:P) ratio (below the Read field ratio) was favourable for coccolithophore growth whereas the high N:P ratio and increased above the Redfield ratio stimulated the development of diatoms (Silkin *et al.* 2014).

Observations shown that species composition tend to change not only over the years but also geographically. When the spatial distribution of microphytoplankton is compared, it is observed that there are 4 regions in the comparisons made basically using phytoplankton similarity indices. When a similarity level of 50% is used, which is most useful to distinguish, 3 different groups were able to be distinguished. These groups are at the west part, eastern part and center part of the Black Sea where the east and west anticyclonic gyro meet. Although the Kızılırmak River and Yesilırmak River are located at the eastern Black Sea continental shelf area, their plume areas show different characteristics from those at the other part of the eastern Black Sea continental shelf area in microphytoplankton species diversity (Figure 10).

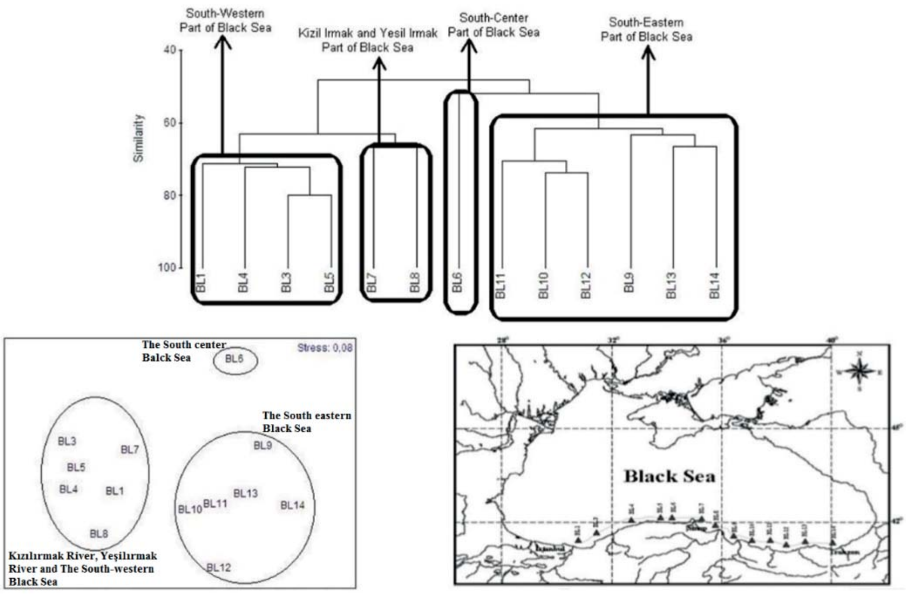
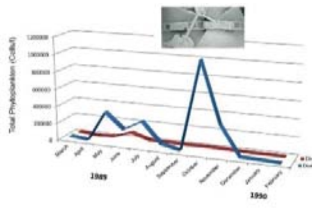
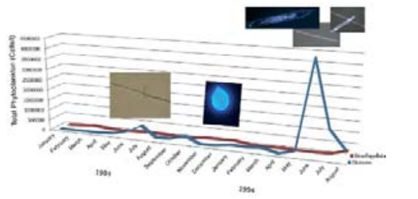


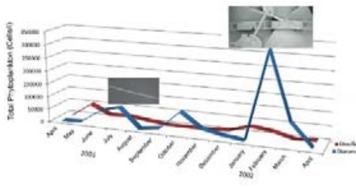
Figure 10. A similarity index of phytoplankton in the Black Sea coast (Feyzioglu and Guneroglu 2010)



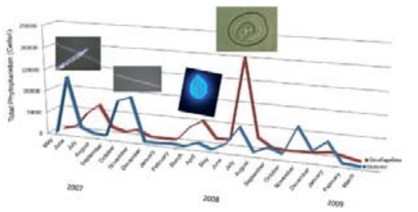
A



B



C



D

Figure 11. Cell concentrations in litre and bloom species of microphytoplankton during the bloom season along the 20 year times period

Time series data show that not only microphytoplanktonic species composition but also cell number of the present species varied along the last two decades in the region. In the beginning of the 90s phytoplankton bloom consisted of diatom population in spring and late fall. In this period, *Skelotonema costatum* was the key species of the bloom and the species reached to 1,2x 10^6 cells l^{-1} (Figure 11-A). The following year the blooms were observed in July and the responsible species for the event was *Pseudo-nitzschia* spp. and reached to 1,1x10^6 cells l^{-1}. Second year in mid-90s microphytoplankton population reached to maximum biomass so far and reached 4,5x10^6 cells l^{-1} in June. *Proboscia alata, Pseudosolenia calcar-avis* and *Pseudo-nitzshia pungens* were the dominant diatom species in this bloom period (Figure 11-B). Although, dominant species were *Pseudo-nitzshia* spp. and *Skeletonema costatum* in the early 2000s, their concentrations per litre didn't exceed 3,5x 10^5 cell l^{-1} (Figure 11-C). After this period, the cell concentrations of diatom were not observed higher than 3.5 x105 cells l^{-1} even in the bloom period. But Dinoflagellate blooms occasionally suppressed diatoms. Dominant dinoflagellate species were *Scrippsiella trochoidea* and *Prorocentrum cordatum* and their concentration exceeded 2x10^5 cells l^{-1} (Figure 11-D). Beside the dinoflagellate species like *Protoperidinium* spp., *Gymnodium* spp., *Gyrodinium* spp. started to dominate in the Black Sea pelagic ecosystem, some species like *Achradina pulchra, Lessardia elongata* and *Opisthoaulax vorticella* also began to be monitored despite their low number recently. *Noctiluca scintillans* which is one of the important species because of their large size, begins to grow noticeably in coastal area and cause the red tide events along the shore line in the period of April and May. This species also started to play important role as key species due to its feeding preference (Zhang *et al.* 2016).

Recent studies indicate that when microphytoplankton biomass decrease, pico- and nanoplankton biomass increase. In the food web of the Black sea ecosystem, energy transfers to the upper level mostly through flow on microbial loop. Decrease of the microplankton biomass and increase of the microbial process cause loss of energy along the food web in the Black Sea continental shelf area. This increase in energy loose is thought to be effective on the efficiency of fisheries in the upper energy level.

References

Agirbas, E., A.M. Feyzioglu, and U. Kopuz. 2014. Seasonal changes of phytoplankton chlorophyll a, primary production and their relation in the continental shelf area of the south eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 713-726.

Agirbas, E., A.M. Feyzioglu, U. Kopuz, and C. Llewellyn. 2015. Phytoplankton community composition in the south-eastern Black Sea determined with pigments measured by HPLC-CHEMTAX analyses and microscopy cell counts. Journal of the Marine Biological Association of the United Kingdom, 95(1): 35-52.

Anonymous, 2005. Black Sea, Phytoplankton in the Black Sea. http://blacksea-education.ru/phytoplankton.shtml

Barale, A. and C. Murray. 1995. The surface color field of enclosed marine basins: pigment patterns of the Black Sea. Remote Sensing Reviews 12: 61-82.

Bat, L., F. Sahin, F. Ustun, A.E. Kideys, and H.H. Satilmis. 2007. The qualitative and quantitative distribution in phytoplankton and zooplankton of southern Black Sea of Cape Sinop, Turkey in 1999-2000. OCEANS'07 IEEE Aberdeen Conference and Exhibition, Aberdeen Exhibition and Conference Centre, Aberdeen, Scotland 18-21 June, 2007, 1-3, 186-191.

Baytut, O., Gonulol A. and T. Koray. 2005. New records for marine phytoplankton of Turkish seas from southern Black Sea coasts, E.U. Journal of Fisheries And Aquatic Sciences, 22(1-2): 229-231.

Baytut, O. and A. Gonulol. 2010. Temporal variations of phytoplankton in relation to eutrophication in Samsun Bay, Southern Black Sea, Turkish Journal of Fisheries and Aquatic Sciences, 10(3): 363-372.

Benli, H.A. 1987. Investigation of plankton distribution in the South Black Sea and its effects on particle flux, SCOPE/UNEP Sonderband Heft 62, Hamburg, Juli, pp. 77-87.

Ediger D., C. Beken, A.M. Feyzioglu, F. Sahin, and I. Tan. 2015. Establishing boundary classes for the quality classification of southeastern Black Sea using phytoplankton biomass. Turkish Journal of Fisheries and Aquatic Sciences, 15(3): 723-731.

Eker, E., L. Georgieva, L. Senichkina, and A. E. Kideys. 1999. Phytoplankton distribution in the western and eastern Black Sea in spring and autumn 1995. ICES Journal of Marine Science, 56: 15-22.

Eker-Develi, E. and V. Velikova. 2009. New record of a Dinoflagellate species, *Lessardia elongata* in the Black Sea. Journal of the Marine Biological Association-2 JMBA2-Biodiversity Records, 6545: 1-3.

Feyzioglu, A.M. and S. Tuncer. 1994. Seasonal changes in net phytoplankton along Trabzon coastline in eastern Black Sea (in Turkish). Tr. J.Biol. 18:161171.

Feyzioglu, M. and E. Duzgunes. 1996. Seasonal dynamic of Ceratium (Dinophyceae) in Eastern Black Sea (in Turkish). XIII. Ulusal Biyoloji Kongresi Tebligleri, 416-424.

Feyzioglu, A.M. and N. Sivri. 2003. Spatial and temporal changes of *N. scintillans* Kofoid&Swezy along Trabzon coastal in eastern Black Sea (in Turkish). E.U. Su Ürünleri Dergisi, 20: 75-79.

Feyzioglu, A.M., I. Kurt, M. Boran, and N. Sivri. 2004. Abundance and Distribution of *Synechococcus* spp in the south-eastern Black Sea during 2001 summer. IJMS, 33(4): 365-368.

Feyzioglu, A.M. and H. Ogut. 2006. Red tide observations along the eastern Black Sea coast of Turkey. Turk J Bot., 30: 375-379.

Feyzioglu, A.M. and A. Guneroglu. 2011. Community structure of phytoplankton and some physical parameters of continental shelf waters of Anatolian coast of the Black Sea. Fresenius Environmental Bulletin, 20(3a): 694-703.

Feyzioglu, A. M., I. Yıldız, and U. Kopuz. 2011. Picophytoplankton (*Synechococcus* spp) dynamic at Eastern Black Sea coastal ecosystem in 2007 (in Turkish). FABA Fisheries and Aquatic Sciences (FABA), Samsun, Turkey, 7-9 September, p 9.

Feyzioglu, A.M, C. Eruz, and I. Yıldız. 2015. Geographic variation of Picocyanobacteria *Synechococcus* spp. along the Anatolian Coast of the Black Sea during the late autumn of 2013. Turkish Journal of Fisheries and Aquatic Sciences, 15: 465-469.

Fogg, G.E. 1995. Some comments on Picoplankton and its importance in the pelagic ecosystem. Aquatic Microbial Ecology, 9: 33-39.

Gómez, F. 2005. A list of free-living Dinoflagellate species in the World's Oceans. Acta Botanica Croatica, 64(1): 129-212.

Iturriaga, R. and B.G. Mitchell. 1986. Chroococcoid Cyanobacteria: A significant component in the food web dynamics of the open ocean. Marine Ecology Progress Series, 28: 291-297.

Johnson, P.W. and J.Mc.N. Sieburth. 1979. Chroococcoid Cyanobacteria in thesSea: a ubiquitous and diverse phototrophic biomass. Limnology and Oceanography, 24: 928-935.

Karacam, H. and E. Duzgunes. 1990. A study on phytoplankton in Trabzon coast (in Turkish). İ.U. Su Ürunleri Dergisi 4: 95-102.

Kopuz, U. 2012. Picoplankton dynamics in microbial loop and their importance at pelagic food web in the south-eastern Black Sea. PhD Thesis, Karadeniz Technical University, 170 pp.

Kopuz, U., A.M. Feyzioglu, and E. Agirbas. 2012. Picoplankton dynamics during late spring 2010 in the south eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 12: 397-405.

Kopuz, U., A.M. Feyzioglu, and A. Valente. 2014. An unusual red-tide event of *Noctiluca Scintillans* (Macartney) in the south-eastern Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 261-268.

Kurt, I. 2002. Seasonal and spatial distribution of cyanobacterium Synechococcus which influences to primary production in Black Sea, Master thesis, Karadeniz Technical University, 69 pp.

Mee. L. 1992. The Black Sea in crisis: a need for concerted international action. Ambio, 21(4): 286.

Mikaelyan, A.S., L.A. Pautova, S.I. Pogosyan, and I.N. Sukhanova. 2005. Summer bloom of Coccolithophorids in the northeastern Black Sea. Oceanology, 45(Suppl. 1): 127-138.

Mikaelyan, A.S., V.A. Silkin, and L.A. Pautova. 2011. Coccolithophorids in the Black Sea: their interannual and longterm changes. Oceanology, 51(1): 39-48.

Mikaelyan, A.S., L.A. Pautova, V.K. Chasovnikov, S.A. Mosharov, and V.A. Silkin. 2015. Alternation of diatoms and Coccolithophores in the northeastern Black Sea: a response to nutrient changes. Hydrobiologia, 755: 89-105.

Moncheva, S. and A. Krastev 1997. Phytoplankton long term alterations off Bulgarian Black Sea shelf, p. 79-93. In E. Ozsoy, and A.S. Mikaelyan [eds.], Sensitivity to Change: Black Sea, Baltic Sea and North Sea. Kluwer Academic Publishers, Dordrecht.

Oguz, T., V.S. Latun, M.A. Latif, V.V. Vladimirov, H.I. Sur, A.A. Markov, E. Ozsoy, V.V. Kotovshchikov, V.V. Eremeev, and U. Unluata. 1993. Circulation in the surface and intermediate layer of the Black Sea. Deep-Sea Research, 40:1597-1612.

Oguz. T., H.W. Ducklow, P. Malanotte-Rizzoli, J.W. Murray, E.A. Shushkina, V.I. Vedernicov, and U. Unluata. 1999. A physical-biochemical model of phytoplankton productivity and nitrogen cycling in the Black Sea. Deep-sea Research I, 46: 597-636.

Oguz, T. and A. Merico. 2006. Factors controlling the summer *Emiliania huxleyi* bloom in the Black Sea: A modelling study. J. Mar. Syst., 59: 173-188.

Sahin, F., L. Bat, H.H. Satilmis, F. Ustun, Z. Birinci, A.E. Kideys, and E. Develi. 2003. Seasonal changes in net phytoplankton of the central Black Sea off cape Sinop, Turkey. Scientific and Policy Challenges Towards an Effective Management of the Marine Environment, 12-18 October, Albena, Bulgaria, Abstract Book, 90p.

Sahin F., L. Bat, F. Ustun, Z. Birinci-Ozdemir, H. H., Satilmis, A.E. Kideys, and E.E. Develi. 2007. The dinoflagellate-diatom ratio in the southern Black Sea off Sinop in the years 1999-2000. 38th CIESM Congress - Istanbul, Turkey, 9-13 April.

Sahin, F., L. Bat, F. Ustun, Z. Birinci-Ozdemir, and H.H. Satilmis. 2008. Changes in composition and distribution of phytoplankton in the southern Black Sea during the last decade, 65 p. 2nd Biannual and Black Sea EC Project Joint Conference. Climate Change in the Black Sea- Hypothesis, Observations, Trends Scenarios and Mitigation Strategy for the Ecosystem. 6-9 October 2008 Sofia, Bulgaria. Conference Abstracts Book.

Silkin, V.A., L.A. Pautova, S.V. Pakhomova, A.V. Lifanchuk, E.V. Yakushev and V.K. Chasovnikov. 2014. Environmental Control on Phytoplankton Community Structure in the Neblack Sea. Journal of Experimental Marine Biology and Ecology 461: 267-274.

Sournia, A., Chrtiennot-Dinet, M.J. and M. Ricard. 1991. Marine Phytoplankton: How many species in the world? Journal of Plankton Research 13:1093-1099.

Soydemir, N., A.E. Kıdeys, and G. Eringen. 2002. Phytoplankton composition of the western Black Sea during the R/V Knorr cruise in May-June 2001. Oceanography of the Eastern Mediterranean and Black Sea, 1418 October, pp. 624-627.

Suthers, I.M. and D.D. Rissik. 2009. Plankton A Guide to Their Ecology and Monitoring for Water Quality. CSIRO Publishing, 272 p.

Tait, R.V. and F.A. Dipper. 2001. Elements of Marine Ecology. Butterworth-Heinemann Pub., Forth Edition, Great Britain, 462 p.

Tuncer, S. and A.M. Feyzioglu. 1989. Distribution of phytoplankton population of eastern Black Sea, 49 p. Sec. Int. Colloque of Med. Coast and Env. Protection, İzmir.

Turgut, S., O. Basturk, C. Saydam, and A. Yilmaz. 1992. Changes in the hydrochemistry of Black Sea inferred from water density profiles. Nature, 359: 137-139.

Uysal, Z. and H.I. Sur. 1995. Net plankton discriminating patches along the southern Black Sea coast in winter 1990. Oceanologica Acta, 18: 639-647.

Uysal, Z. 1996. A net plankton study in the Bosphorus junction of the Sea of Marmara. Tr. J. Botany, 20: 321-327.

Uysal, Z., A.E. Kıdeys, L. Senichkina, L. Georgıeva, D. Altukhov, L. Kuzmenko, L. Manjos, E. Mutlu, and E. Eker. 1998. Phytoplankton patches formed along the southern Black Sea coast in spring and summer 1996, Vol. 1: 151-162. In L.I. Ivanov and T. Oguz [eds.], Ecosystem Modeling as a Management Tool for the Black Sea. Kluver Academic Publishers. Printed in Netherlands.

Uysal, Z. 2000. Pigments, size and distribution of *Synechococcus* spp. in the Black Sea. Journal of Marine Systems, 24 (3-4): 313-326.

Uysal, Z. 2001. Chroococcoid Cyanobacteria *Synechococcus* spp. in the Black Sea: pigments, size, distribution, growth and diurnal variability. Journal of Plankton Research 23(2): 175-189.

Uysal, Z. 2002. On the formation of net phytoplankton patches in the southern Black Sea during the Spring. Hydrobiologia, 485: 173-182.

Uysal, Z. 2006. Vertical distribution of marine Cyanobacteria *Synechococcus* spp. in the Black, Marmara, Aegean, and Eastern Mediterranean Seas. Deep-Sea Research II, 53: 1976-1987.

Waterbury, J.B., S.W. Watson, R.R.L. Guillard, and L.E. Brand. 1979. Widespread occurrence of a unicellular, marine, planktonic cyanobacterium. Nature, 277: 293-294.

Yunev, O.A., V.I. Vedernikov, O. Basturk, A. Yilmaz, A.E. Kideys, S. Moncheva, and S.K. Konovalov. 2002. Long-term variation of surface chlorophyll a and primary production in the open Black Sea. Marine Ecology Progress Series, 230: 11-28.

Zhang, S., H. Liu, C. Guo, and P.J. Harrison. 2016. Differential feeding and growth of *Noctiluca scintillans* on monospecific and mixed diets. Mar. Ecol. Prog. Ser., 549: 27-40.

MACROALGAE AND PHANEROGAMS OF THE BLACK SEA

Ali KARAÇUHA [1] and Emine Şükran OKUDAN [2]

[1]Faculty of Fisheries, Dept. of Hydrobiology, Sinop University, Sinop, Turkey
[2]Faculty of Fisheries, Dept. of Hydrobiology, Akdeniz University, Antalya, Turkey
ali_karacuha@hotmail.com

Last studies conducted in the Black Sea show that 297 macroalgal taxa (Aysel *et al.* 2004) has been distributed however, only 4 years later 285 algal taxa have been declared from the Black Sea coast of Turkey by Taşkın *et al.* (2008). The differences in the number of taxa are due to the synonyms of the species over time. Therefore, Bat *et al.* (2011) have reported that it is essential to prepare an actual checklist based on "htpp://www.algaebase.org" due to the some omitted, undetermined and synonym species. The current list of macroalgae species distributed in the Black Sea region of Turkey according to the database "htpp://www.algaebase.org" is given in Table 1.

The numbers of taxa periodically increases from west to east until Sinop (Table 2). Aysel *et al.* (2005b) reported that the number then decreases in Samsun, but increases again in Giresun, which is the following station. R/C and R/O rates along the Black Sea coast of Turkey are higher than Aegean and Mediterranean coasts. In terms of O / CY and C / CY rates (Table 3) because of the high taxon number of blue-green bacteria has been reported by the same researchers. The reason for this was reported by Aysel *et al.* (2005b). According to the authors, the Black Sea has its own unique current system and that a strong current moving from the west to the east in the Turkish waters has been shown to be the cause of the changes in macroalgae numbers.

Table 1. The current list of macroalgae species distributed in the Black Sea region of Turkey (*Listed in IUCN Red Data Book)

RHODOPHYTA (168)	**Reference no**
Acrochaetium humile (Rosenvinge) Børgesen, 1915	2,3,7,11,12,13
Acrochaetium kylinii G.Hamel, 1927	2,11
Acrochaetium leptonema (Rosenvinge) Børgesen, 1915	2,3,7,12,13
Acrochaetium mahumetanum G.Hamel, 1927	2,4,7
Acrochaetium mediterraneum (Levring) Athanasiadis, 2003	4, 13
Acrochaetium microscopicum (Nägeli ex Kützing) Nägeli in Nägeli & Cramer, 1858	2,3,4,5,7,11,12,13
Acrochaetium moniliforme (Rosenvinge) Børgesen, 1915	2,3,11,13
Acrochaetium parvulum (Kylin) Hoyt, 1920	2,3,4,5,6,7,11,12,13

Acrochaetium secundatum (Lyngbye) Nägeli in Nägeli & Cramer 1858	2,3,4,11,12,13
Acrochaetium subpinnatum Bornet ex G.Hamel, 1927	2
Aglaothamnion tenuissimum (Bonnemaison) Feldmann-Mazoyer, 1941	4,5,7,11,12
Alsidium corallinum C.Agardh, 1827	2,3,4,6,7,11,13
Amphiroa rigida J.V.Lamouroux, 1816	2,3,4,5,7,11,12,13
Antithamnion cruciatum (C.Agardh) Nägeli, 1847	2,3,4,5,6,7,11,12,13
Antithamnion heterocladum Funk, 1955	3,4,11,13
Antithamnion tenuissimum (Hauck) Schiffner, 1915	2,3,4,7,11,12,13
Apoglossum ruscifolium (Turner) J.Agardh, 1898	2,3,4,5,6,7,11,12,13
Asterfilopsis furcellata (C.Agardh) M.S.Calderon & S.M.Boo 2016	7
Bangia atropurpurea (Mertens ex Roth) C.Agardh, 1824	2,3,4,5,7,8,9,10
Bonnemaisonia asparagoides (Woodward) C.Agardh, 1822	2, 10
Bornetia secundiflora (J.Agardh) Thuret, 1855	10
Callithamnion corymbosum (Smith) Lyngbye, 1819	2,3,4,5,6,7,11,12,13
Callithamnion granulatum (Ducluzeau) C.Agardh, 1828	2,3,4,5,6,7,11,12,13
Ceramium arborescens J.Agardh, 1894	2,3,7
Ceramium ciliatum (J.Ellis) Ducluzeau, 1806	2,3,4,5,6,7,11,12,13
Ceramium ciliatum var. *robustum* (J.Agardh) Mazoyer	2,3,4,5,6,7,11,12,13
Ceramium diaphanum (Lightfoot) Roth, 1806	2, 11,12,13
Ceramium circinatum (Kützing) J.Agardh, 1851	2,3,4,5,6,11,12,13
Ceramium codii (H.Richards) Mazoyer, 1938	1,2,3,11,13
Ceramium deslongchampsii Chauvin ex Duby, 1830	2,3,4,5,6,7,11,12,13
Ceramium diaphanum var. *zostericola* f. *acrocarpum* (Kützing) Feldmann-Mazoyer, 1941	13
Ceramium gaditanum (Clemente) Cremades, 1990	2,3,4,5,7,11,12,13
Ceramium rubrum var. *barbatum* Feldmann-Mazoyer, 1941	2,12
Ceramium secundatum Lyngbye, 1819	2,3,4,5,6,11,12,13
Ceramium siliquosum (Kützing) Maggs & Hommersand, 1993	2,3,4,5,6,7,12,13
Ceramium siliquosum f. *minusculum* (G.Mazoyer) Garreta *et al.* 2001	2,3,4,5,6,11,13
Ceramium siliquosum var. *elegans* (Roth) G.Furnari in G.Furnari, Cormaci & Serio 1999	2,3,4,5,6,7,11,13
Ceramium siliquosum var. *lophophorum* (Feldman-Mazoyer) Serio, 1994	2,3, 11,12,13
Ceramium siliquosum var. *zostericola* (Feldmann-Mazoyer) G.Furnari in G.Furnari, Cormaci & Serio, 1999	2,3,4,5,6,7,11,12,13
Ceramium tenerrimum (G.Martens) Okamura 1921	2,3,4,5,7,11,12,13
Ceramium tenerrimum var. *brevizonatum* (H.E.Petersen) Feldmann-Mazoyer	2,3,4,5,7,13
Ceramium tenuicorne (Kützing) Waern, 1952	6
Ceramium virgatum Roth, 1797	2,3,4,5,6,7,12,13
Ceramium virgatum var. *implexo-contortum* (Solier) G.Furnari in G.Furnari *et al.* 2003	3,4,5,6,7,11,12,13

Chondracanthus acicularis (Roth) Fredericq in Hommersand, Guiry, Fredericq & Leister 1993	13
Chondria boryana Bornet, 1892	2,12,13
Chondria capillaris (Hudson) M.J.Wynne, 1991	2,3,4,5,7,11,12,13
Chondria dasyphylla (Woodward) C.Agardh, 1817	2,3,4,5,6,7,11,12,13
Choreonema thuretii (Bornet) F.Schmitz, 1889	2,11,12,13
Chroodactylon ornatum (C.Agardh) Basson, 1979	2,3,4,5,6,7,11,12,13
Chrysymenia ventricosa (J.V.Lamouroux) J.Agardh, 1842	2,3
Chylocladia verticillata (Lightfoot) Bliding, 1928	2,3
Coccotylus truncatus (Pallas) M.J.Wynne & J.N.Heine, 1992	2,3,4,5,6,7,11,12,13
Colaconema codicola (Børgesen) H.Stegenga, J.J.Bolton, & R.J.Anderson, 1997	2,3,12,13
Colaconema daviesii (Dillwyn) Stegenga, 1985	2,3,4,5,7,10,12,13
Colaconema hallandicum (Kylin) Afonso-Carillo, Sanson, Sangil & Diaz-Villa, 2007	2,3,4,7,11,12,13
Colaconema savianum (Meneghini) R.Nielsen 1994	2,3,12,13
Compsothamnion thuioides (Smith) Nägeli 1862	2,3,4,6,7,11,12,13
Corallina officinalis Linnaeus, 1758	2,3,4,5,6,12,13
Corallina panizzoi R.Schnetter & U.Richter, 1979	7,11
Dasya baillouviana (S.G.Gmelin) Montagne in Barker-Webb & Berthelot 1841	2,3,4,5,6,7,11,12,13
Dasya corymbifera J.Agardh, 1841	2,3
Dasya hutchinsiae Harvey, 1833	2,3,4,5,7,11,12,13
Dasya ocellata (Grateloup) Harvey in Hooker 1833	2,3,7,13
Dermocorynus dichotomus (J.Agardh) Gargiulo, M.Morabito & Manghisi, 2013	2,3,4,5,7,11,12,13
Dipterosiphonia rigens (C.Agardh) Falkenberg, 1901	2,3,4,5,7,11,12
Ellisolandia elongata (J.Ellis & Solander) K.R.Hind & G.W.Saunders 2013	2,3,4,5,7,11,12,13
Erythrotrichia carnea (Dillwyn) J.Agardh, 1883	2,3,4,5,6,7,11,12,13
Erythrotrichia investiens (Zanardini) Bornet, 1892	4
Erythrotrichia vexillaris (Montagne) Hamel 1929	4
Eupogodon planus (C.Agardh) Kützing, 1845	2,3,4,5,7,11,12,13
Gayliella flaccida (Harvey ex Kützing) T.O.Cho & L.J.McIvor in Cho *et al.* 2008	13
Gelidiella nigrescens (Feldmann) Feldmann & Hamel, 1934	3,11,13
Gelidiocolax christianae Feldmann & G.Feldmann, 1963	2
Gelidium crinale (Hare ex Turner) Gaillon, 1828	2, 11,12,13
Gelidium crinale var. *corymbosum* (Kützing) Feldmann & G.Hamel, 1936	2, 11,12,13
Gelidium pulchellum (Turner) Kützing, 1868	2,11
Gelidium pusillum (Stackhouse) Le Jolis, 1863	7
Gelidium serra (S.G.Gmelin) E.Taskin & M.J.Wynne, 2013	2
Gelidium spathulatum (Kützing) Bornet, 1892	2, 11,12,13
Gelidium spinosum (S.G.Gmelin) P.C.Silva in Silva, Basson & Moe 1996	2,3,4,6,11,12

Gelidium spinosum var. hystrix (J.Agardh) G.Furnari in Cormaci *et al.* 1997	1,2,3,4,6,11,12,13
Gracilaria armata (C.Agardh) Greville, 1830	2,7,13
Gracilaria dura (C.Agardh) J.Agardh, 1842	2,3,4,5,7,13
Gracilaria gracilis (Stackhouse) M.Steentoft, L.M.Irvine & W.F.Farnham, 1995	2,3,4,5,6,7,11,12,13
Gracilariopsis longissima (S.G.Gmelin) Steentoft, L.M.Irvine & Farnham 1995	2,12,13
Gymnogongrus griffithsiae (Turner) C.Martius 1833	2,3,4,7, 11,12,13
Herposiphonia secunda (C.Agardh) Ambronn, 1880	2,3,4,5,7,11,12,13
Herposiphonia secunda f. *tenella* (C.Agardh) M.J.Wynne, 1985	2,3,4,5,7,11,12,13
Heterosiphonia crispella (C.Agardh) M.J.Wynne, 1985	13
Heterosiphonia plumosa (J.Ellis) Batters, 1902	2,3, 11,12,13
Huismaniella ramellosa (Kützing) G.H.Boo & S.M.Boo in G.H.Boo *et al.* 2016	2,3,4,5,6,11,12,13
Hydrolithon farinosum (J.V.Lamouroux) Penrose & Y.M.Chamberlain, 1993	2,3,4,7,11,12,13
Hypnea musciformis (Wulfen) J.V.Lamouroux, 1813	2,3,4,5,7,11,12,13
Hypoglossum hypoglossoides (Stackhouse) Collins & Hervey 1917	2,4,5,6,7,11,12,13
Jania longifurca Zanardini, 1844	7, 11,13
Jania rosea (Lamarck) Decaisne, 1842	13
Jania rubens (Linnaeus) J.V.Lamouroux, 1816	2,3,4,5,7,11,12
Jania rubens var. *corniculata* (Linnaeus) Yendo, 1905	2,3,4,5,6,7,11,12,13
Jania virgata (Zanardini) Montagne, 1846	2,3,4,5,6,7,11,12,13
Kylinia rosulata Rosenvinge 1909	2,3,4,7, 11,12,13
Laurencia glandulifera (Kützing) Kützing, 1849	13
Laurencia microcladia Kützing, 1865	13
Laurencia obtusa (Hudson) J.V.Lamouroux, 1813	2,3,4,5,6,7,11,12,13
Laurencia obtusa var. *gracilis* (C.Agardh) Zanardini, 1847	2,3,4,5,7,11,12,13
Liagora viscida (Forsskål) C.Agardh, 1822	2,3,4,6,7,11,12,13
Lithophyllum corallinae (P.Crouan & H.Crouan) Heydrich, 1897	2,3, 11,12,13
Lithophyllum cystosirae (Hauck) Heydrich 1897	2,3,4,5,7,11,12,13
Lithophyllum orbiculatum (Foslie) Foslie, 1900	2,3,12,13
Lomentaria articulata (Hudson) Lyngbye, 1819	2,3,4,5,7,11,12,13
Lomentaria articulata var. *linearis* Zanardini, 1841	7
Lomentaria clavellosa (Lightfoot ex Turner) Gaillon, 1828	2,3,4,5,6,7,11,12,13
Lomentaria uncinata Meneghini in Zanardini 1840	13
Lophosiphonia cristata Falkenberg, 1901	2,11
Lophosiphonia obscura (C.Agardh) Falkenberg in F.Schmitz & Falkenberg, 1897	2,3,4,5,6,7,11,12,13
Melobesia membranacea (Esper) J.V.Lamouroux, 1812	2,3, 11,12,13
Nemalion helminthoides (Velley) Batters, 1902	1,2,3,4,6,11,12,13
Nitophyllum punctatum (Stackhouse) Greville, 1830	2,3,4,5,7,11,12,13
Osmundea pinnatifida (Hudson) Stackhouse, 1809	1,2,3,4,5,6,11,12,13
Palisada perforata (Bory) K.W.Nam 2007	2,3,4,5,6,7,11,12,13

Palisada thuyoides (Kützing) Cassano, Sentíes, Gil-Rodríguez & M.T.Fujii in Cassano *et al.* 2009	2,3,4,5,7,11,12
Parviphycus antipai (Celan) B.Santelices, 2004	2,3,4,5,7,11,12,13
Parviphycus pannosus (Feldmann) G.Furnari in Furnari *et al.* 2010	2
Peyssonnelia dubyi P.Crouan & H.Crouan 1844	2, 13
Peyssonnelia rosa-marina Boudouresque & Denizot, 1973	3,4,7,11,13
Peyssonnelia rubra (Greville) J.Agardh, 1851	2,3,4,5,7,11,12,13
*Peyssonnelia squamaria (*S.G.Gmelin) Decaisne ex J.Agardh 1842	2,3,4,5,6,7,11,12,13
Phyllophora crispa (Hudson) P.S.Dixon, 1964	2,3,4,5,6,7,11,12,13
Phyllophora pseudoceranoïdes (S.G.Gmelin) Newroth & A.R.A.Taylor ex P.S.Dixon & L.M.Irinve 1977	2,3,4,5,7,11,12,13
Phymatolithon lenormandii (Areschoug) W.H.Adey, 1966	2,3,6,12,13
Pneophyllum confervicola (Kützing) Y.M.Chamberlain, 1983	2,3,11
Polysiphonia breviarticulata (C.Agardh) Zanardini, 1840	2,3, 11,12,13
Polysiphonia brodiei (Dillwyn) Sprengel, 1827	2,3,4,5,6,7,11,12,13
Polysiphonia denudata (Dillwyn) Greville ex Harvey in Hooker 1833	2,3,4,5,7,11,12,13
Polysiphonia deusta (Roth) Sprengel, 1827	2,3,13
Polysiphonia elongata (Hudson) Sprengel, 1827	2,3,4,5,6,7,11,12,13
Polysiphonia elongella Harvey in W.J.Hooker, 1833	4, 13
Polysiphonia fibrillosa (Dillwyn) Sprengel, 1827	2,5,6,7,11,13
Polysiphonia opaca (C.Agardh) Moris & De Notaris, 1839	2,3,4,5,6,7,11,12,13
Polysiphonia paniculata Montagne, 1842	2,3,7,12,13
Polysiphonia pulvinata (Roth) Sprengel, 1827	2,11,12
Polysiphonia scopulorum Harvey, 1855	4
Polysiphonia sertularioides (Grateloup) J.Agardh, 1863	2,3,4,5,6,7,11,12,13
Polysiphonia stricta (Dillwyn) Greville, 1824	2,6,7,12,13
Polysiphonia tenerrima Kützing, 1843	2,3,4,5,7,11,12,13
Porphyra atropurpurea (Olivi) De Toni, 1897	13
Porphyra laciniata (Lightfoot) C.Agardh, 1824	5
Porphyra minor Zanardini, 1847	2,3,6,7,11
Porphyra umbilicalis Kützing, 1843	2,3,4,5,7,11,12,13
Pterocladiella capillacea (S.G.Gmelin) Santelices & Hommersand, 1997	2,3,4,5,6,7,11,12,13
Pterocladiella melanoidea (Schousboe ex Bornet) Santelices & Hommersand, 1997	2,3,11
Pterocladiella melanoidea var. *filamentosa* (Schousboe ex Bornet) M.J.Wynne, 1998	2,3,7, 11,12,13
Pterothamnion plumula (J.Ellis) Nägeli in Nägeli & Cramer 1855	2,3,4,5,7,11,12,13
Pyropia leucosticta (Thuret) Neefus & J.Brodie in Sutherland *et al.* 2011	2,3,4,5,6,7,11,12,13
Rubrointrusa membranacea (Magnus) S.L.Clayden & G.W.Saunders, 2010	2,3,4,5,7,12,13
Sahlingia subintegra (Rosenvinge) Kornmann, 1989	2,3,4,5,7,11,12,13
Seirospora giraudyi (Kützing) De Toni, 1903	2,3
Solieria dura (Zanardini) F.Schmitz, 1895	13

Spermothamnion flabellatum Bornet in Bornet & Thuret 1876	2,3,5,7, 11,12,13
Spermothamnion repens (Dillwyn) Magnus, 1873	3
Spermothamnion repens var. flagelliferum (De Notaris) Feldmann-Mazoyer 1941	4
Stylonema alsidii (Zanardini) K.M.Drew, 1956	2,3,4,5,7,11,12,13
Stylonema cornu-cervi Reinsch, 1875	2,3,4,5,7,11,13
Titanoderma pustulatum (J.V.Lamouroux) Nägeli in Nägeli & Cramer, 1858	2,3,4, 11,12,13
Vertebrata fucoides (Hudson) Kuntze, 1891	2,3,4,5,6,7,11,12,13
Vertebrata subulifera (C.Agardh) Kuntze, 1891	2, 11,13
Vertebrata tripinnata (Harvey) Kuntze, 1891	2,3,6, 11,12,13
Xiphosiphonia pennata (C.Agardh) Savoie & G.W.Saunders, 2016	2,3, 11,12,13
OCHROPHYTA (68)	**References no**
Acinetospora crinita (Carmichael) Sauvageau, 1899	2,3,4,7,13
Asperococcus bullosus J.V.Lamouroux, 1813	2,3,6,12,13
Asperococcus ensiformis (Delle Chiaje) M.J.Wynne, 2003	2,3,12,13
Asperococcus fistulosus (Hudson) W.J.Hooker, 1833	2,3,6,12,13
Cladostephus spongiosum f. *verticillatum* (Lightfoot) Prud'homme van Reine, 1972	2,3,4,5,6,11,12,13
Colpomenia sinuosa (Mertens ex Roth) Derbès & Solier in Castagne 1851	13
Corynophlaea umbellata (C.Agardh) Kützing, 1843	1,2,3,4,5,6,12,13
Cutleria multifida (Turner) Greville, 1830	13
**Cystoseira barbata* (Stackhouse) C.Agardh, 1820	2,3,4,5,6,11,12,13
**Cystoseira barbata f. aurantia* (Kützing) Giaccone in Amico *et al.* 1985	2,3, 11,12,13
**Cystoseira bosphorica* Sauvageau, 1912	2,3,4,5,6,11,12,13
**Cystoseira compressa* (Esper) Gerloff & Nizamuddin, 1975	2,3,6,11,13
**Cystoseira corniculata* (Turner) Zanardini, 1841	2,3,7, 11,12,13
**Cystoseira crinita* Duby, 1830	2,3,4,5,6,7,11,12,13
**Cystoseira foeniculacea* (Linnaeus) Greville, 1830	3,7
**Cystoseira schiffneri* Hamel, 1939	2, 11,12,13
Dictyopteris polypodioides (A.P.De Candolle) J.V.Lamouroux, 1809	2,3,4,5,6,11,12,13
Dictyota dichotoma (Hudson) J.V.Lamouroux, 1809	2,12,13
Dictyota fasciola (Roth) J.V.Lamouroux, 1809	2,3,4,5,6,11,12,13
Dictyota fasciola var. *repens* (J.Agardh) Ardissone, 1883	2,3,12,13
Dictyota implexa (Desfontaines) J.V.Lamouroux, 1809	6, 11,13
Dictyota mediterranea (Schiffner) G.Furnari in Cormaci *et al.* 1997	13
Dictyota menstrualis (Hoyt) Schnetter, Hörning & Weber-Peukert, 1987	2,3,4,5,6,11,12,13
Dictyota spiralis Montagne, 1846	13
Ectocarpus fasciculatus Harvey, 1841	13
Ectocarpus penicillatus (C.Agardh) Kjellman, 1890	2,3,4,7, 11,12,13
Ectocarpus siliculosus (Dillwyn) Lyngbye, 1819	2,3,4,5,6,7,11,12,13
Ectocarpus siliculosus var. *arctus* (Kützing) Gallardo, 1992	3,4,5,7,11

Ectocarpus siliculosus var. *dasycarpus* (Kuckuck) Gallardo, 1992	2,3,4,5,6,7,11,12,13
Ectocarpus siliculosus var. hiemalis (P.Crouan & H.Crouan ex Kjellman) Gallardo 1992	2,3,4,5,6,7,11,12,13
Eudesme virescens (Carmichael ex Berkeley) J.Agardh, 1882	3,7,13
Feldmannia caespitula (J.Agardh) Knoepffler-Péguy, 1970	3,4,5,6,11
Feldmannia globifera (Kützing) Hamel 1939	2,11
Feldmannia irregularis (Kützing) G.Hamel, 1939	2,3,4,5,7,11,12,13
Feldmannia lebelii (Areschoug ex P.Crouan & H.Crouan) Hamel, 1939	2,3,4,5,7,11,12,13
Feldmannia padinae (Buffham) Hamel 1939	3,6,11,13
Giraudya sphacelarioides Derbès & Solier in Castagne, 1851	2,3
Halopteris filicina (Grateloup) Kützing, 1843	2,3, 11,12,13
Halopteris scoparia (Linnaeus) Sauvageau, 1904	2,3,4,5,6,11,12,13
Halothrix lumbricalis (Kützing) Reinke, 1888	2,3,4,7,11
Hecatonema streblonematoides (Setchell & N.L.Gardner) Loiseaux, 1970	2
Hincksia sandriana (Zanardini) P.C.Silva in Silva, Meñez & Moe 1987	2,3,7, 11,12,13
Kuetzingiella battersii (Bornet ex Sauvageau) Kornmann, 1956	2,3,7, 11,12,13
Litosiphon laminariae (Lyngbye) Harvey, 1849	2,3,7,12,13
Microcoryne ocellata Strömfelt, 1888	2
Mikrosyphar polysiphoniae Kuckuck, 1897	2,3,4,5,7,11,13
Myriactula arabica (Kützing) Feldmann, 1937	2,3,4,6,7,11,12,13
Myriactula rivulariae (Suhr ex Areschoug) Feldmann 1937	2,3,4,5,7,11,12,13
Myrionema orbiculare J.Agardh, 1848	2,3,7,12,13
Myrionema strangulans Greville, 1827	2,3,4,7, 11,12,13
Myriotrichia clavaeformis Harvey, 1834	2,3,4,5,6,7,11,12,13
Padina pavonica (Linnaeus) Thivy in W.R.Taylor 1960	2,3,6, 11,12,13
Petalonia zosterifolia (Reinke) Kuntze, 1898	2,3, 11,12,13
Protectocarpus speciosus (Børgesen) Kornmann in Kuckuck 1955	13
Punctaria plantaginea (Roth) Greville, 1830	2,3,4,5,6,11,12,13
Punctaria tenuissima (C.Agardh) Greville, 1830	2
Pylaiella littoralis (Linnaeus) Kjellman, 1872	13
**Sargassum acinarium* (Linnaeus) Setchell, 1933	2,3,6,7, 11,12,13
**Sargassum hornschuchii* C.Agardh, 1820	2,3,6, 11,12,13
**Sargassum vulgare* C.Agardh, 1820	2,3,6,7, 11,12,13
Scytosiphon lomentaria (Lyngbye) Link, 1833	2,3, 11,12,13
Spermatochnus paradoxus (Roth) Kützing, 1843	2,12,13
Sphacelaria cirrosa (Roth) C.Agardh, 1824	2,3,4,5,6,11,12,13
Stilophora nodulosa (C.Agardh) P.C.Silva in P.C.Silva, Basson & Moe, 1996	2,3,4,5,6,7,11,12,13
Stilophora tenella (Esper) P.C.Silva in P.C. Silva, Basson & Moe 1996	2,3,4,5,6,7,11,12,13
Streblonema fasciculatum Thuret in Le Jolis 1863	2,11
Striaria attenuata (Greville) Greville, 1828	2,3,4,5,6,12,13
Zanardinia typus (Nardo) P.C.Silva in Greuter 2000	2,3,4,5,6,11,12,13

CHLOROPHYTA (61)	**References no**
Acrocladus echinus (Biasoletto) Boedeker in Boedeker *et al*. 2016	12,13
Acrocladus pellucidus (Hudson) Boedeker in Boedeker *et al*. 2016	2,3,4,5,6,7,11,12,13
Aegagropila linnaei Kützing, 1843	2
Blidingia marginata (J.Agardh) P.J.L.Dangeard ex Bliding 1963	2,3,4,5,6,11,12,13
Blidingia minima (Nägeli ex Kützing) Kylin, 1947	2,3,4,5,6,7,11,12,13
Bolbocoleon piliferum N.Pringsheim, 1862	3, 13
Bryopsis corymbosa J.Agardh, 1842	2,3,12
Bryopsis cupressina J.V.Lamouroux, 1809	2,3,6, 11,12,13
Bryopsis duplex De Notaris, 1844	13
Bryopsis hypnoides J.V.Lamouroux, 1809	2,3,4,5,6,11,12
Bryopsis plumosa (Hudson) C.Agardh, 1823	2,3,4,5,6,7,11,12,13
Chaetomorpha aerea (Dillwyn) Kützing, 1849	3,4,5,6, 11,12,13
Chaetomorpha ligustica (Kützing) Kützing, 1849	2, 13
Chaetomorpha linum (O.F.Müller) Kützing, 1845	2,3,4,5,11,12,13
Cladophora albida (Nees) Kutzing, 1843	2,3,4,5,6,11,12,13
Cladophora coelothrix Kützing, 1843	2,12,13
Cladophora dalmatica Kützing, 1843	2,7, 11,12,13
Cladophora flexuosa (O.F.Müller) Kützing, 1843	3, 13
Cladophora fracta (O.F.Müller ex Vahl) Kützing, 1843	3,4,5,6,11,13
Cladophora glomerata (Linnaeus) Kützing, 1843	2,3,4,5,6,11,12,13
Cladophora hauckii Børgesen, 1946	13
Cladophora hutchinsiae (Dillwyn) Kützing, 1845	2,3,4,5,6,7,11,12,13
Cladophora laetevirens (Dillwyn) Kützing, 1843	2,3,4,5,6,11,12,13
Cladophora lehmanniana (Lindenberg) Kützing, 1843	2,3,6, 11,12,13
Cladophora prolifera (Roth) Kützing, 1843	2,3,6,7, 11,12,13
Cladophora sericea (Hudson) Kützing, 1843	2,3,4,5,6,11,12,13
Cladophora vagabunda (Linnaeus) Hoek, 1963	2,7,12
Codium tomentosum Stackhouse, 1797	2,3,12,13
Codium vermilara (Olivi) Delle Chiaje, 1829	13
Enteromorpha linza f. *minor* Schiffner in Schiffner & Vatova,1938	2,3,11,12
Entocladia cladophorae (Hornby) Starmach, 1972	2,7,13
Flabellia petiolata (Turra) Nizamuddin, 1987	11,13
Halimeda tuna (J.Ellis & Solander) J.V.Lamouroux, 1816	11,13
Neodangemannia microcystis M.J.Wynne, G.Furnari, Kryvenda & Friedl, 2014	3
Neostromatella monostromatica M.J.Wynne, G.Furnari & R.Nielsen, 2014	3
Phaeophila dendroides (P.L.Crouan & H.M.Crouan) Batters, 1902	2,3, 11,12,13
Rhizoclonium riparium (Roth) Harvey, 1849	2,3,4,7,11
Rhizoclonium tortuosum (Dillwyn) Kützing, 1845	2,3,4,5,6,11,12,13
Sphaeroplea annulina (Roth) C.Agardh 1824	13
Ulothrix flacca (Dillwyn) Thuret in Le Jolis, 1863	2,3,4,5,6,7,11,12,13
Ulothrix implexa (Kützing) Kützing, 1849	2, 11,12,13
Ulothrix tenerrima (Kützing) Kützing 1843	2,3,12
Ulothrix zonata (F.Weber & Mohr) Kützing 1833	2,3, 11,12,13

Ulva clathrata (Roth) C.Agardh, 1811	2,3,4,5,6,7,11,12,13
Ulva compressa Linnaeus, 1753	2,3,4,5,6,7,11,12,13
Ulva curvata (Kützing) De Toni, 1889	13
Ulva fasciata Delile, 1813	2,3,4,5,6,7,11,12,13
Ulva flexuosa Wulfen, 1803	2,3,4,5,6,7,11,12,13
Ulva intestinalis Linnaeus, 1753	2,3,4,5,6,11,12,13
Ulva kylinii (Bliding) H.S.Hayden, Blomster, Maggs, P.C.Silva, M.J.Stanhope & J.R.Waaland 2003	2,3,5,6,11,12,13
Ulva linza Linnaeus, 1753	2,3,4,5,6,7,11,12,13
Ulva prolifera O.F.Müller, 1778	2,3,5,6,7,11,12,13
Ulva pseudolinza (R.P.T.Koeman & Hoek) H.S.Hayden, Blomster, Maggs, P.C.Silva, M.J.Stanhope & J.R.Waaland, 2003	2,12
Ulva rigida C.Agardh, 1823	2,3,4,5,6,7,11,12,13
Ulva taeniata (Setchell) Setchell & N.L.Gardner, 1920	2
Ulvella lens P.Crouan & H.Crouan 1859	2,3,4,5,6,11,12,13
Ulvella leptochaete (Huber) R.Nielsen, C.J.O'Kelly & B.Wysor in Nielsen *et al.* 2013	2,7,11
Ulvella scutata (Reinke) R.Nielsen, C.J.O'Kelly & B.Wysor in Nielsen *et al.* 2013	2,3,6,11,13
Ulvella viridis (Reinke) R.Nielsen, C.J.O'Kelly & B.Wysor in Nielsen *et al.* 2013	2,3, 11,12,13
Valonia macrophysa Kützing, 1843	4
Valonia utricularis (Roth) C.Agardh, 1823	4

Table 2. Diversity of macrophytes from different areas in the Black Sea coast of Turkey (Aysel *et al.* 2005b)

Region	Seaweeds				Magnoliophyta	Total
	CY	R	O	C		
Rize, Artvin	3	43	15	27	3	91
Trabzon	1	23	8	23	3	58
Giresun	18	109	33	30	3	193
Ordu	14	93	27	26	4	164
Sinop	22	136	52	55	3	268
Samsun	20	106	27	22	3	178
Kastomomu	22	133	56	48	3	262
Bartın	12	116	43	39	3	213
Zonguldak	20	100	42	43	3	208
Kocaeli/Sakarya/Düzce	30	126	50	46	3	255
Kırklareli	23	71	24	30	3	151
Total	30	142	57	58	4	297

CY: Cyanophyta, R: Rhodophyta, O: Ochrophyta, C: Chlorophyta

Table 3. Dominancy in division level among the Black Sea coast of Turkey (Aysel *et al.* 2005b)

Region	Division					
	R/O	**R/C**	**R/CY**	**0/C**	**O/CY**	**C/CY**
Rize, Artvin	2.90	1.60	14.3	0.60	5.00	9.00
Trabzon	2.90	1.00	23.0	0.30	8.00	23.0
Giresun	3.30	3.63	6.05	1.10	1.83	1.66
Ordu	3.44	3.58	6.64	1.04	1.93	1.86
Samsun	3.92	4.81	4.30	1.22	1.35	1.10
Sinop	2.60	2.50	6.50	0.96	2.50	2.59
Kastamonu	2.37	2.77	6.04	1.16	2.54	2.18
Bartın	2.70	3.00	9.70	1.10	3.60	3.30
Zonguldak	2.40	2.30	5.00	1.00	2.10	2.20
Kocaeli, Sakarya, Düzce	2.52	2.73	4.20	1.08	1.66	1.53
Kırklareli	3.00	3.70	3.10	0.80	1.00	1.30

There are a total of 6 seagrass taxa (*Zostera marina*, *Zostera noltii*, *Ruppia cirrhosa*, *Potamogeton pectinatus, Potamogeton gramineus* and *Zannichelia palustris*) on the Black Sea coast of Turkey and the first four species mentioned above are distributed on the shores of Sinop (Aysel *et al.* 2000, 2004, Dural *et al.* 2006, 2011).

References

Numbers in [ ] referred to those in Table 1.

Aysel, V., A. Sukatar, B. Dural, and H. Erduğan. 2000. Black Flora of Turkey. Project no: TBAG-1325. 242 pp. [1]

Aysel, V., H. Erduğan, B. Dural-Tarakçı, E.Ş. Okudan, A. Şenkardeşler, and F. Aysel. 2004. Marine flora of Sinop (Black Sea, Turkey), Aegean University J. of Fisheries & Aquatic Sciences. 21(1-2): 59-68. [2]

Aysel, V., H. Erduğan, and B. Dural-Tarakçı. 2005a. Marine Flora of Kastamonu (Black Sea, Turkey). Journal of the Black Sea / Mediterranean Environment, 11: 179-194. [3]

Aysel, V., H. Erduğan, B. Dural-Tarakçı, and E.Ş. Okudan. 2005b. Marine algae and seagrasses of Giresun shores (Black Sea, Turkey). J. Black Sea/Mediterranean Environment, 11: 241-255. [4]

Aysel, V., H. Erduğan, B. Dural, and E.Ş. Okudan. 2006. Marine algae and seagrasses of Tekirdağ (Black Sea, Turkey). J. Black Sea/Mediterranean Environment, 12: 251-267. [5]

Aysel, V., H. Erduğan, B. Dural, and E.Ş. Okudan. 2008. A survey of Marine Algae and Seagrasses of Istanbul, (Turkey). J. Black Sea/Mediterranean Environment, 14: 129-144. [6]

Aysel V., B. Dural, A. Şenkardeşler, H. Erduğan, and F. Aysel. 2008. Marine algae and seagrasses of Samsun (Black Sea, Turkey). J. Black Sea/Mediterranean Environment, (14): 53-67. [7]

Bat, L., M. Sezgin, H.H. Satılmış, F. Şahin, F. Üstün, Z. Birinci-Özdemir, and O. Gökkurt-Baki. 2011. Biological diversity of the Turkish Black Sea coast. Turkish Journal of Fisheries and Aquatic Sciences, 11: 683-692. [8]

Dural, B., V. Aysel, N. Demir, I. Yazıcı, A. Karaçuha, E.Ş. Okudan, G. Atalay, and H. Keleş. 2006. The distribution, fenology and algal flora of seagrasses along western Black Sea coast (Turkey) and the flowering and mapping of Zosteracea in Sinop coast. Project no: TBAG-2332 (103T140), 156 pp. [9]

Dural, B., V. Aysel, N. Demir, H. Erdurağan, E.Ş. Okudan, A. Karaçuha, I. Yazıcı, and G. Atalay. 2011. Sinop port (Black Sea, Turkey), flowering plants and algae forming flora community. Samsun Symposium, 13-16 October, Samsun. [10]

Erduğan, H., V. Aysel, B. Dural-Tarakçı, E.Ş. Okudan, and F. Aysel. 2003. Marine flora and saegrasses of Düzce, Sakarya, Kocaeli (Black Sea, Turkey). Underwater Science and Technology Meeting, SBT 2003, Bursa Uludağ University: 20-29. [11]

Karacuha, A. and A. Gönülol. 2007. Algae flora in the upper infralittoral zone of Sinop and Ayancik coastline. Journal of FisheriesSciences.com,1(1): 1-12. [12]

Taskin, E., M. Öztürk, O. Kurt, and M. Öztürk. 2008. The check-list of the marine algae of Turkey. pp. [i-ii]-[1]-87. Manisa, Turkey [13]

ZOOPLANKTON OF THE SOUTHERN BLACK SEA

Melek İŞİNİBİLİR [1], İ. Noyan YILMAZ [2] and Funda ÜSTÜN [3]

[1]İstanbul University, Faculty of Aquatic Sciences, Istanbul, Turkey
[2]Istanbul University, Institute of Marine Sciences and Management, Istanbul, Turkey
[3]Sinop University, Faculty of Fisheries, Sinop, Turkey
melekis@istanbul.edu.tr

1. Introduction

Zooplankton, together with phytoplankton, constitutes the base of marine food web. 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 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 Black Sea constitutes a distinct area in the world oceans due to its geomorphology, its specific water balance and past geological events (Zaitsev *et al*. 2002). The Black Sea (420,000 km^2) is a deep basin located approximately between latitudes of 41° to 46° N and longitudes of 28° to 41.5° E. The major shelf area exists in the northwestern part, comprising 27 % of the total area of the Black Sea. The shelf areas, in the south eastern region are very narrow (Sorokin 1983). The upper layer of the Black Sea is predominantly cyclonic, strongly time-dependent and spatially structured basin-wide (Oguz *et al*. 2004). The cyclonically meandering rim current constitutes the unique basin-scale feature of the region. The interior of the rim current is formed by two separate cyclonic cells occupying the western (Western Gyre) and eastern halves (Eastern Gyre) of the basin. A permanent halocline exists in the depth of 100 - 150 m (Oguz *et al*. 2004). Below the halocline anoxic waters exist which contain hydrogen sulphide (Ovchinnikov and Titov 1990). The Black Sea is characterized by low salinity, varying between 17 and 18 psu in the surface layer and 22 - 24 psu in the intermediate layer (Zaitsev *et al*. 2002).

The water-mass exchange through the Turkish Straits System results in exchange of planktonic fauna between the Mediterranean Sea and the Black Sea (Beşiktepe *et al*. 1994, Kovalev *et al*. 1998). In the Black Sea, zooplankton studies first began about 150 years ago and continued with more detailed taxonomic studies (Kideys *et al*. 2000). Later efforts concentrated on feeding, growth, reproduction and other physiological parameters of zooplankton species (Beşiktepe *et al.* 1998, Svetlichny *et al.* 1998, 2006, 2009, Yuneva *et al.* 1999, Beşiktepe and Telli 2004, Svetlichny and Hubareva 2005, Isinibilir *et al.* 2009, 2011, 2014), besides their temporal and spatial distributions (Niermann *et al.* 1998, Kovalev *et al.* 1999, Gubanova *et al.* 2001) to understand the functioning of the ecosystem.

Despite the fact that the Black Sea zooplankton has been studied relatively well, information from Turkish coastal area is still considered as incomplete. Earliest studies on zooplankton started from Demir's work in 1954 in the Turkish coastal area of the Black Sea (Demir 1954). Afterwards, studies increased along the Turkish Black Sea coast (Beşiktepe and Unsal 2000, Ünal 2002, Mutlu 2005, 2009, Tarkan *et al.* 2005, Bat *et al.* 2007, Isinibilir *et al.* 2009, 2011, 2014, Üstün 2010, Üstün and Bat 2014, Üstün *et al.* 2014, Yıldız and Feyzioğlu 2014, Öztürk 2015). The studies generally targeted species composition and abundance trends in relation to environmental variability.

This chapter aims to present a brief evaluation of zooplankton studies in the Turkish coastal area of Black Sea.

2. Group/Species composition

Previous studies showed that many taxonomic groups inhabiting the Mediterranean Sea are absent or rarely present in the Black Sea, such as doliolids, salps, pterepods, siphonophors and euphausiids. Jellyfish species (Cnidaria and Ctenophora), Copepoda and some other groups that have a high species number in the Mediterranean Sea are also represented by single or few species in the Black Sea (Kovalev *et al.* 1999). About 150 zooplankton species are reported for the Black Sea, of which 70 are mainly Ponto Caspian brackish-water types and about 50 constitute meroplankton (Koval 1984). Since copepods have a prominent role in pelagic food web, majority of studies in the Black Sea were also focused on this group and Zenkevitch (1963) reported 77 copepod species in the Black Sea. During his pioneer work, Demir (1954) identified nine copepod species in Trabzon and afterwards a total of 53 copepod species were enlisted in the Turkish coastal waters (Table 1).

Güner (1994) identified five dominant copepod species in the southern Black Sea namely *Acartia clausi, Calanus euxinus, Centropages ponticus, Paracalanus parvus, Pseudocalanus elongatus* and Beşiktepe (1998) listed 5, replacing *Oithona similis* with *C. ponticus*. In addition to these species, *Acartia tonsa* and *Pontella mediterranea* were also found in Turkish coastal area of Black Sea (Ünal 2002, Üstün 2005, Üstün 2010, Öztürk, 2015). *Cymbasoma sinopense* was first recorded in Sinop, the Turkish Black Sea coast (Üstün *et al.* 2014) and *O. davisae* was first observed in the Southern Black Sea in 2009 (Üstün and Terbıyık 2016).

Oithona davisae was first recorded in Sevastopol Bay in December 2001 and was mistakenly identified as *Oithona brevicornis* (Zagorodnyaya 2002). The species has been routinely observed in samples as *O. brevicornis* since the mid-2000s (Altukhov and Gubanova 2006, Selifonova 2009) and the identification error has been recently corrected (Temnykh and Nishida 2012).

A species of *Calanus* in the Black Sea was first identified as *C. finmarchicus* by Karavaev in 1894. Later, Jashnov (1970) distinguished the Black Sea population as a subspecies *C. helgolandicus ponticus* due to its geographic distribution. However Hulsemann, (1991) identified it as *C. euxinus* based on the morphological differences of the integumental pores. Papadopoulos *et al.* (2005) and Unal *et al.* (2006) showed that *Calanus euxinus* and *Calanus helgolandicus* have no significant morphological and genetic differences. Therefore Isinibilir *et al*. (2009) suggested giving back the species name of *Calanus helgolandicus* to the Black Sea population adding var. *euxinus*.

Mediterranization is an important process for the enrichment of the Black Sea zooplankton. This processes was studied by Kovalev *et al*. (1998) and 60 copepod species originating from the Mediterranean Sea was listed, most of them found only off the Strait of Istanbul region. Strait of Istanbul plays a crucial role as a natural ecological barrier (Oğuz and Öztürk 2011). Zooplankton species transferred to the Black Sea by the lower water current of the Strait of Istanbul, initially settles to the Black Sea cold intermediate layer where the temperature is 6-8 °C. Most of the Mediterranean species die in this layer due to low temperature and salinity (Isinibilir *et al*. 2011). Isinibilir *et al*. (2011) reported 8 Mediterranean copepod species near the Strait of Istanbul, in addition to the typical Black Sea copepods. The euryhaline and thermophilic copepod species *Acartia tonsa* was reported for the first time from the north-western Black Sea in 1976 (Gubanova *et al*. 2000, 2001). The species has been accepted as an example for successful mediterranization (Kovalev *et al*. 1998, Oğuz and Öztürk 2011). However, Gubanova (2000) had demonstrated that *A. tonsa* occurred in the Black Sea earlier than in the Mediterranean Sea. Most probably *A. tonsa* was transferred to the Black Sea via ballast water from another oceanic region of the world and then spread to the Mediterranean basin (Gubanova *et al*. 2014).

Historical datasets showed that three copepod species (*Paracartia latisetosa, Acartia margalefi* and *Oithona nana*) disappeared from the Black sea (Gubanova *et al*. 2014). The changes in the copepod community of the Black Sea have been recorded since the 1970s when eutrophication and pollution in the coastal areas were observed (Gubanova *et al*. 2014). Gubanova *et al*. (2001, 2014) informed that *O. nana* disappeared completely from the Black Sea. However, Isinibilir *et al*. (2011) and Üstün (2010) observed this species in the Black Sea near the Strait of Istanbul and south-eastern coastal area.

Acoustic records revealed that the depth limit for the vertical distribution of zooplankton was confined to 100 m in the Black Sea, where anoxic conditions below 150 m delimit the further vertical distribution of zooplankters (Mutlu 2005). Three different groups were recognized in the vertical distribution. The first group, represented by *Acartia* spp., *Noctiluca scintillans*, cladocerans and Appendicularian *Oikopleura dioica*, preferred the surface layers throughout the day. In the second group, with species such as *Calanus euxinus* and *Oithona similis,* migrated to greater depths of the water column. The species in the third group, such as *Pseudocalanus elongatus*, dispersed in the upper layers at night and migrated to deeper layers in day time, but not as deep as *Calanus euxinus* and *Oithona similis* (Beşiktepe *et al*. 1998, Beşiktepe and Unsal 2000, Erkan *et al*. 2000).

Table 1. Registered zooplankton species of the southern Black Sea

Species	Reference
Copepoda	
Acanthodiaptomus denticornis (Wierzjhski 1857)	Deniz 2009
Acartia (Acartiura) clausi Giesbrecht, 1889	Demir 1954
Acartia (Acanthacartia) tonsa Dana, 1849	Kovalev *et al*. 1998
Acartia sp. Dana, 1846	Ünal 2002
Aetideus armatus Boeck, 1872	Kovalev *et al*. 1998
Aetideus sp. Brady, 1883	Isinibilir *et al*. 2011
Anomalocera petersonii Templeton, 1837	Demir 1954
Canthocamptus sp.	Deniz 2009
Calanipeda aqua dulcis Kriczagin, 1873	Deniz 2009
Calanus euxinus (helgolandicus) Hulsemann, 1991	Demir 1954
Calocalanus pavo Dana, 1849	Benli *et al*. 2001
Canuella perplexa T. & A., 1893	Deniz 2013
Centropages kroyeri Giesbrecht, 1893 (*Centropages kröyeri* Karaw, 1895)	Deniz 2009
Centropages ponticus Karavaev, 1894	Demir 1954
Centropages typicus Kröyer, 1849	Kovalev *et al*. 1998
Clausocalanus arcuicornis (Dana, 1849)	Benli *et al*. 2001
Clausocalanus pergens Farran, 1926	Kovalev *et al*. 1998
Corycaeus (*Urocorycaeus*) *furcifer* (Kroyer, 1849)	Benli *et al*. 2001
Corycaeus (*Agetus*) *typicus* (Kroyer, 1849)	Benli *et al*. 2001
Ctenocalanus vanus Giesbrecht, 1888	Isinibilir *et al*. 2011
Cymbasoma sinopense	Üstün *et al*. 2014

Enhydrosoma longifurcatum	Üstün 2010
Euchaeta marina (Prestandrea, 1833)	Kovalev *et al*. 1998
Euterpina acutifrons (Dana 1847)	Deniz 2009
Farranula rostrata (Claus, 1863)	Benli *et al*. 2001
Labidocera brunescens (Czarniavski, 1868)	Benli *et al*. 2001
Lucicutia flavicornis (Claus, 1863)	Terbıyık 2016
Mecynocera clausi, Thompson, 1888	Benli *et al*. 2001
Metridia lucens Boeck, 1865	Demir 1959
Metridia spp.	Terbıyık 2016
Microcalanus pusillus Sars 1903	Kovalev *et al*. 1998
Microsetella norvegica (Boeck, 1864)	Üstün 2010
Microsetella rosea (Dana, 1848)	Terbıyık 2016
Oithona davisae Ferrari F.D. & Orsi, 1984	Üstün *et al*. 2016
Oithona nana Giesbrecht, 1893	Demir 1954
Oithona similis (*helgolandica*) Claus, 1866	Demir 1954
Oncaea media Giesbrecht, 1891	Isinibilir *et al*. 2011
Oncaea mediterranea (Claus, 1863)	Terbıyık 2016
Oncaea minuta Giesbrecht, 1892	Isinibilir *et al*. 2011
Oncaea obscura Farran, 1908	Kovalev *et al*. 1998
Oncaea spp.	Terbıyık 2016
Oncaea subtilils Giesbrecht, 1892	Isinibilir *et al*. 2011
Paracalanus nanus G.O. sars, 1907	Benli *et al*. 2001
Paracalanus parvus (Claus, 1863)	Demir 1954
Paracartia letisetosa (Kriczagin, 1873)	Benli *et al*. 2001
Paramphiascella robinsoni (A. Scott, 1902)	Üstün 2010 ekledim
Pareucalanus attenuatus (Dana, 1849)	Benli *et al*. 2001
Pleuromamma abdominalis (Lubbock, 1856)	Terbıyık 2016
Pleuromamma gracilis (Claus, 1863)	Kovalev *et al*. 1998
Pontella mediterranea Claus, 1863	Demir 1954
Pseudocalanus elongatus (Boeck, 1865)	Demir 1954
Scolecithricella sp.	Isinibilir *et al*. 2011
Triconia minuta Giesbrecht, 1892	Terbıyık 2016
Cladocera	
Evadne nordmanni Loven, 1836	Demir 1954
Evadne spinifera Müller P.E., 1867	Demir 1954
Penilia avirostris Dana, 1849	Ünal 2002
Penilia schmackeri	*Demir 1954*
Pleopis (*Podon*) *polyphemoides* (Leuckart, 1859)	Demir 1954
Pseudevadne (Evadne) tergestina (Claus, 1877)	Demir 1954
Appendicularia	
Oikopleura dioica Fol, 1872	Demir 1954
Chaetognatha	

Parasagitta (Sin: *Sagitta*) *setosa* Müller, 1847	Ünal 2002
Sagitta bipunctata	Demir 1954
Sagitta spp.	Isinibilir *et al*. 2011
Siphonophora	
Lensia conoidea	Einarsson and Gürtürk 1959
Scyphozoa	
Aurelia aurita (Linné, 1758)	Demir 1954
Rhizostoma pulmo (Macri, 1778)	Özer and Çelikkale 1998
Chrysaora hysoscella (Linné, 1766)	Öztürk and Topaloğlu 2009
Ctenophora	
Beroe ovata Chamisso &Eysenhardt, 1821	Mutlu *et al*. 1994
Mnemiopsis leidyi (Agassiz, 1865)	Mutlu *et al*. 1994
Pleurobrachia pileus (Müller, 1776)	Mutlu *et al*. 1994
Bolinopsis vitrea (L. Agassiz, 1860)	Ozturk *et al*. 2011

3. Spatiotemporal patterns of zooplankton abundance

The coastal areas of the Black Sea have been greatly affected by anthropogenic influences during the last 40 years (Kovalev *et al*. 1998, Siokou-Frankou *et al.* 2004). The decline in the river outflow, increase in nutrient and pollutant input, intense shipping and introduction of non-native species have caused many ecological changes, resulting in intense eutrophication (Kideys 2002, Oguz and Velikova 2010). Consequently, mesozooplankton abundance and biomass have also increased and this was counterbalanced by the population growth of the medusa *Aurelia aurita*, an important predator of mesozooplankton, in the early 1980s (Konsulov and Kamburska 1998). Together with the changes in the pelagic realm, abundance of the heterotrophic dinoflagellate *Noctiluca scintillans* also increased and limited zooplankton through both top-down and bottom-up forcing. Furthermore, *Mnemiopsis leidyi* invasion in the early 1980’s has exacerbated the already perturbed coastal ecosystem (Vinogradov *et al*. 1989).

Limited samplings performed in the Turkish coastal waters of the Black Sea showed some spatial differences in community structure with abundance levels fluctuating through the years. The general Black Sea current regime which has two anti-cyclonic gyres located in eastern and western part of the Black Sea (Oguz *et al*. 2005) is one of the most important factors regulating the distribution of zooplankton community. The most obvious differences between eastern and western community was that the western region of the southern Black Sea displayed the highest abundance values of total zooplankton compared to the eastern Black Sea. In addition to abundance differences, pollution-tolerant species, such as *A. clausi, O. similis P. polyphemoides* and *N. scintillans*, had higher abundance and biomass in the western part, (Üstün 2010, Öztürk 2015). In general, the zooplankton of the southern Black Sea is dominated by *Oithona similis*, *Acartia clausi, Pseudocalanus elongates*, *Penilia avirostris* and *Noctiluca* *scintillans* (Erkan *et al*. 2000, Öztürk 2015). The cold water species, *Calanus euxinus*, *Pseudocalanus elongatus*, *Oithona similis* and *Pleopis polyphemoides* dominate winter-spring assemblages, while *Penilia avirostris, Acartia clausi*, *Paracalanus parvus* and *Centropages* spp. are the major summer species (Ünal 2002, Üstün 2005).

Ünal (2002), Üstün (2005) and Şen Özdemir (2013) studied the seasonal and inter-annual fluctuations of abundance values of major taxa of the southern coastal area of the Black Sea. The data, that is used as yearly averages to compare the annual differences, showed that total zooplankton abundance in 2012 (3780 ind. m^{-3}) was 2 times higher than that in 1999 (1785 ind. m^{-3}). Mesozooplankton abundance in 2012 also increased to almost 3 fold (2027 ind. m^{-3}) when compared to 1999. The reason for this increase can be largely attributed to the differences in abundance levels of particular groups, such as, *Noctiluca scintillans*, meroplankton and copepods. The former two groups in 2012 displayed much higher values than those since 1999.

The winter (December-February) and summer (July-September) average abundances of 2002-2009 from Sinop showed a slight increase due to higher contribution of copepods (Figure 1) (Üstün *et al.* 2014 and Üstün unpublished data). In winter, abundance levels were lower than the summer, as a result of the lower contribution of Cladocera. Winters of 2004-2006 had relatively lower zooplankton abundance when compared to other years. It is also worth to note that *N. scintillans* densities were higher in the winter and summer of 2004-2006.

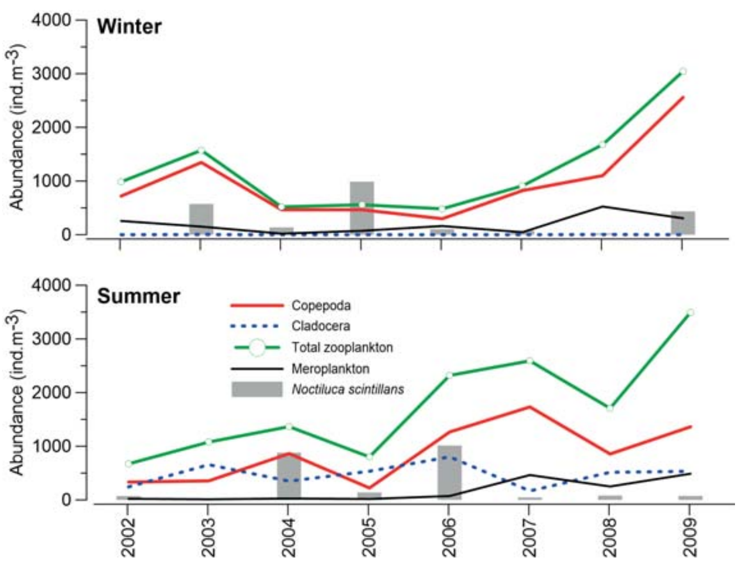


Figure 1. Winter (December-February) and summer (July-September) average abundances of total zooplankton (excluding *Noctiluca scintillans*), Cladocera, Copepoda, meroplankton and *Noctiluca scintillans* at Sinop Peninsula

Zooplankton studies carried out along the Black Sea coast of Turkey in 2008-2009 periods has been utilized to seek for spatial patterns in zooplankton abundance (Figure 2) (Yilmaz, unpublished data). The data collected from 1 mile and 3 miles distance from the shore showed comparable results, except October 2009, where near shore stations showed higher densities. The western to eastern differences were not consistent. Although total zooplankton abundance did not show any significant longitudinal difference, zooplankton community structure is known to display a weak east-west separation, İnceburun at Sinop acting as the critical point (Yilmaz, unpublished data).

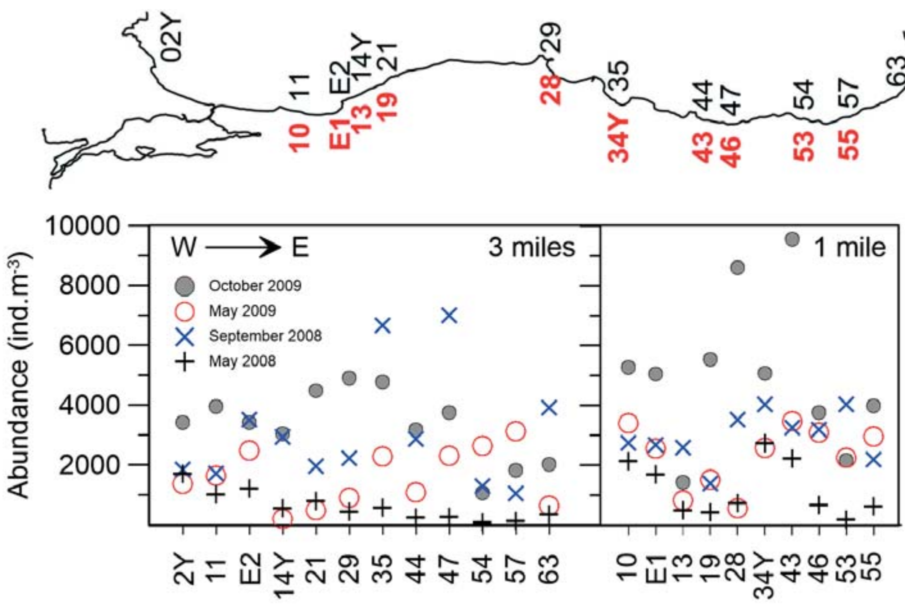


Figure 2. Spatial distribution of total zooplankton abundance along the Turkish Black Sea coast (Yilmaz, unpublished data)

4. **Jellyfish**

Black Sea is a prominent fisheries ground for Turkey, providing 70 % of fish catch of the nation. Five species of gelatinous zooplankton are common in the Black Sea: two scyphozoans, *Aurelia aurita* (Linnaeus, 1758) and *Rhizostoma pulmo* (Macri, 1778), and two alien ctenophores, *Beroe ovata* Bruguière, 1789 and *Mnemiopsis leidyi* A. Agassiz, 1865, and the resident ctenophore *Pleurobrachia pileus* (Müller, 1776). While all other species are distributed throughout the Black Sea, *R. pulmo* was the most frequently sighted species in coastal areas of the Black Sea (Mutlu 2009).

Aurelia is a very common genus in the Black Sea. The eutrophication and overfishing in this region affected increase in *Aurelia* biomass (Caddy and Griffiths 1990). Historical data showed that maximum biomass in the Turkish exclusive economic zone (EEZ) was recorded in spring of 1991 (~580 g m^{-2}). This abundance peak declined to 200 g m^{-2} in 1992-1993 and rised again to 400 g m^{-2} in 1994 (Mutlu *et al.* 1994, Kideys and Romanova 2001). Mutlu (2009) informed that biomass of *Aurelia* was ~400 g m^{-2} in 2006. (Figure 3).

Rhizostoma pulmo (Macri, 1778) is mainly confined to the coastal areas of the Black Sea (Mutlu *et al.* 1994). The population increase of *R. pulmo* in the late 1960s was followed by the decrease after 1974 (Zaitsev and Mamaev 1997). However coastal sampling along the south western part of the Black Sea provided much higher biomass values (i.e., 468 g.m^{-2} at offshore of Sakarya river, Isinibilir unpublished data). In the southern Black Sea, small medusa of *R. pulmo* start to appear at the surface waters by the end of July and disappear after early January (Ozer and Çelikkale 1998).

Pleurobrachia pileus (O. F. Müller, 1776) is found throughout the upper water column till the suboxic layer interface, mainly inhabiting below the pycnocline by day, and migrating towards the surface at night (Mutlu and Bingel, 1999). The first record of the genus in Turkish coastal waters of Black Sea was given off Trabzon by Demir (1954). The biomass and abundance of *P. pileus* increased from winter through spring to a peak in summer. The highest mean wet weight in 1991-1995 was reported as 250 g m^{-2}, while the maximum wet weight was 1429 g m^{-2} (Mutlu and Bingel 1999). The abundance of *Pleurobrachia* appeared to be stable in the southern Black Sea, with a slight increase in 1993 (Figure 3).

Mnemiopsis leidyi was accidentally introduced in the early 1980s, possibly with ballast water from the northwestern Atlantic coastal region (Vinogradov *et al.* 1989). *Mnemiopsis* was first discovered in the northwest (Sudak Bay) in November 1982 (Pereladov 1988). By summer / autumn 1988, the sepecies was dispersed to the whole basin, at an average biomass up to 1 kg WW m^{-2} and average abundances up to 310 ind.m^{-2} (Vinogradov *et al.* 1989). The invasion dynamics and ecological impacts of *M. leidyi* invasion on Black Sea ecosystem has been discussed extensively (*e.g.* Gücü 2002, Daskalov 2002, Costello 2012). The highest average abundance (500 g m^{-2}) was observed in 1991-1995 period and the patchy distribution along the Turkish coasts reached the highest biomass in winter (Figure 3). *M. leidyi* biomass decreased significantly in 2006-2007, with a maximum average biomass of 52.1 g m^{-2} (Mutlu 2009). *M. leidyi* population in the Black Sea was eventually balanced due to the decreased eutrophication, colder winter temperatures, depletion of zooplankton prey due to high predation rate and the introduction of its predator *Beroe ovata* (Kıdeys 2002, Mutlu 2009, Oğuz 2005).

In October 1997, the ctenophore, *Beroe ovata*, appeared at the shallow waters of the Black Sea (Zaitsev 1997). The average abundance and biomass of the species in the southern Black Sea in 2006-2007 were 1.4 ind.m^{-2} and 8.9 g m^{-2}, respectively (Mutlu 2009). Finenko (2003) provided strong evidence on the predation pressure of *B. ovata* on *M. leidyi* in the Northern Black Sea.

As recent changes in the jellyfish fauna, *Bolinopsis vitrea* (L. Agassiz, 1860) was recorded for the first time in the coastal waters of Kilyos and Riva (Istanbul) in November 2007 and in Bulgarian waters in September 2010 (Öztürk *et al*. 2011). This species also occurs in the Mediterranean Sea, including the Aegean Sea and the Adriatic Sea (Mills 1996, Shiganova *et al*. 2004, Shiganova and Malej 2009). In July 2009, a strongly stinging species, *Chrysaora hysoscella,* was observed at Riva, a very popular beach resort near Istanbul metropolis (Öztürk and Topaloğlu 2009).

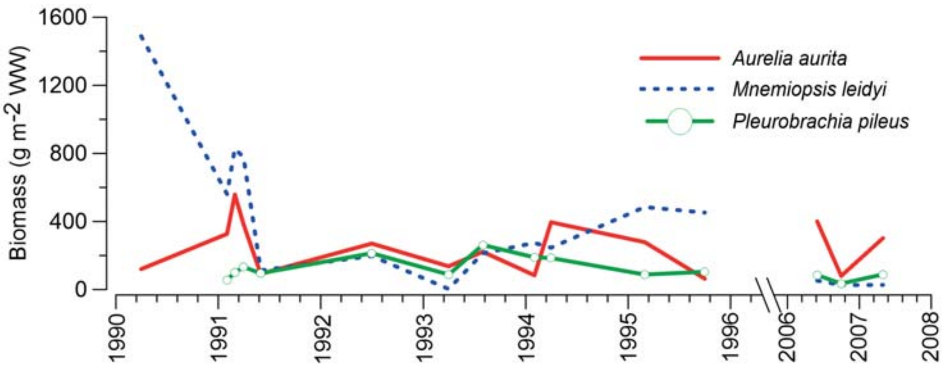


Figure 3. Temporal changes in the density of major gelatinous predators along the southern Black Sea (Data from Kideys & Romanova 2001 and Mutlu 2009).

The heterotrophic dinoflagellate *N. scintillans* is among the most important competitors of zooplankton; limiting stocks through both bottom-up and top-down forcing (Pavlova and Melnikova 2006, Gubanova *et al*. 2001). It often forms massive blooms with concentrations surpassing millions of cells per square meter, exceeding the total abundance of mesozooplankton metazoans (Konsulov and Kamburska 1998). The diet of the species includes phytoplankton, nauplii and eggs of zooplankton, organic detritus, and bacteria (Elbrachter and Qi 1998, Quevedo *et al*. 1999), and can successfully compete for food with other mesozooplankters, resulting in the reduction of their abundance (Yilmaz *et al.* 2005, Arashkevich *et al*. 2014). It has been suggested that *N. scintillans* blooms are related to eutrophication (Shiganova *et al*. 2008). However, the mass development of this species has been frequently observed not only in the eutrophicated regions but also in other parts of the basin (Erkan *et al*. 2000, Nikishina *et al*. 2011).

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References

Akoglu, E., B. Salihoglu, S. Libralato, T. Oguz, and C. Solidoro. 2014. An indicator-based evaluation of Black Sea food web dynamics during 1960-2000. J. Marine Syst., 134: 113-125.

Altukhov, D.A., A.D. Gubanova. 2006. *Oithona brevicornis* Giesbrecht in the Sevastopol Bay in October, 2005–March, 2006. Marine Ecology Journal (Morskyj Ecologichny Journal), 5(2): 32. (in Russian).

Arashkevich, E.G., K. Stefanova, V. Bandelj, I. Siokou, T.T. Kurt, Y.A. Orek, F. Timofte, A. Timonin, and C. Solidoro. 2014. Mesozooplankton in the open Black Sea: regional and seasonal characteristics. J. Marine Syst., 135: 81-96.

Bakır, A.K., T. Katağan, H.V. Aker, T. Özcan, M. Sezgin, A.S. Ateş, C. Koçak, and F. Kırkım. 2014. The marine arthropods of Turkey. Turk. J. Zool., 38: 765-831.

Bat, L., F. Şahin, F. Üstün, A.E. Kıdeyş, and H.H. Satılmış. 2007. The qualitative and quantitative distribution in phytoplankton and zooplankton of Southern Black Sea of Cape Sinop, Turkey in 1999-2000, p. 1-6. Aberdeen: Conference Publication of OCEANS 2007.

Benli, H.A., A.N. Tarkan, and T.M. Sever. 2001. Comparison of the mesozooplankton composition the southwestern Black Sea, Sea of Marmara and eastern Aegean Sea. Turk. J. Mar. Sci., 7: 163-179.

Besiktepe, S.T., H.I. Sur, E. Ozsoy, M.A. Latif, T. Oguz, and U. Unluata. 1994. The circulation and hydrography of the Marmara Sea. Prog. Oceanogr., 34: 285-334.

Beşiktepe, Ş. 1998. Studies on some ecological aspects of copepods and chaetognaths in the southern Black Sea, with particular reference to *Calanus euxinus*. Ph.D. Thesis, IMS-Middle East Technical University, Ankara, p. 201 pp.

Besiktepe, S., A. Kideys, and M. Unsal. 1998. In situ grazing pressure and diel vertical migration of female *Calanus euxinus* in the Black Sea. Hydrobiologia, 363: 323-332.

Besiktepe, S. and M. Unsal. 2000. Population structure, vertical distribution and diel migration of *Sagitta setosa* (Chaetognatha) in the south-western part of the Black Sea. J. Plankton Res., 22: 669.

Beşiktepe, Ş. and M. Telli. 2004. Egg production and growth rates of *Calanus euxinus* (Copepoda) in the Black Sea. J. Plankton Res., 26 (5): 571-578.

Caddy, J. and R. Griffiths. 1990. A perspective on recent fishery related events in the Black Sea; studies and review. General Fisheries Council for the Mediterranean, 63: 43-71.

Costello, J., K. Bayha, H. Mianzan, T. Shiganova, and J. Purcell. 2012. Transitions of *Mnemiopsis leidyi* (Ctenophora: Lobata) from a native to an exotic species: a review. Hydrobiologia, 1-26.

Daskalov, G.M. 2002. Overfishing drives a trophic cascade in the Black Sea. Marine Ecology Progress Series, 225: 53-63.

Demir, M. 1954. Report on the South Eastern coast of the Black Sea. İ.Ü.F.F. Hidrobiyoloji Araştırma Enstitüsü Yayınları Seri B, 1(4): 284-286.

Demir, M. 1959. Pelagic copepods (Copepoda) fauna of the Northeast Aegean, Marmara and South Black Sea, (in Turkish). Part II. Metridiidae. J Hydrobiology, Ser A, 5: 27-41.

Deniz, E. 2009. A qualitative and quantitative study on the copeppod fauna of littoral zone of Samsun. M.Sc. Thesis, On Dokuz Mayıs University, Samsun, p. 109. (in Turkish).

Deniz, E. 2013. The mesozooplankton fauna and its seasonal variation along Samsun coastal waters of the Black Sea. Ph. D. Thesis, On Dokuz Mayıs University, Samsun, p. 195. (in Turkish).

Einarsson, H. and N. Gurturk. 1959. On plankton communities in the Black Sea. Et ve Balık Kurumu Balıkcılık Arastırma Merkezi Raporları. Series Marine Research, 1(8): 1-28.

Elbrachter, M. and Y.Z. Qi. 1998. Aspects of *Noctiluca scintillans* population dynamics, p. 315-335. In D.M. Anderson, A.D. Cembella, and G.M. Hallegraeff [eds.], Physiological Ecology of Harmful Algal Blooms. NATO-ASI Series.

Erkan, F., A. Gucu, and J. Zagorodnyaya. 2000. The diel vertical distribution of zooplankton in the southeast Black Sea. Turk. J. Zool., 24: 417-428.

Finenko, G.A., Z.A. Romanova, G.I. Abolmasova, B.E. Anninsky, L.S. Svetlichny, E.S. Hubareva, L. Bat, A.E. Kideys. 2003. Population dynamics, ingestion, growth and reproduction rates of the invader *Beroe ovata* and its impact on plankton community in Sevastopol Bay, the Black Sea. Journal of Plankton Research, 25: 539-549.

Gubanova, A. 2000. Occurrence of *Acartia tonsa* Dana in the Black Sea. Was it introduced from the Mediterranean? Mediterranean Marine Science, 1: 105-110.

Gubanova, A., I.Y. Prusova, U. Niermann, N. Shadrin, and I. Polikarpov. 2001. Dramatic change in the copepod community in Sevastopol Bay (Black Sea) during two decades (1976-1996). Senckenbergiana Maritima, 31: 17-27.

Gubanova, A., D. Altukhov, K. Stefanova, E. Arashkevich, L. Kamburska, I. Prusova, L. Svetlichny, F. Timofte, and Z. Uysal. 2014. Species composition of Black Sea marine planktonic copepods. J. Marine Syst., 135: 44-52.

Gucu, A. 2002. Can Overfishing be Responsible for the Successful Establishment of *Mnemiopsis leidyi* in the Black Sea? Estuarine, Coastal and Shelf Science, 54: 439-451.

Gündüz, E. 1989. A new record of *Mesochra aestuarii* Gurney, 1921 (Copepoda, Harpacticoida) for Turkey. Doga Turk. J. Zool., 13: 228-232.

Güner E. 1994. Distribution of five Calanoid copepod species in the southern Black Sea. Master. Ph.D. Thesis, IMS-Middle East Technical University, Ankara, p. 117.

Hays, G.C., A.J. Richardson, and C. Robinson. 2005. Climate change and marine plankton. Trends in Ecology & Evolution, 20: 337-344.

Isinibilir, M., L. Svetlichny, E. Hubareva, F. Ustun, I.N. Yilmaz, A.E. Kideys, and L. Bat. 2009. Population dynamics and morphological variability of *Calanus euxinus* in the Black and Marmara Seas. Italian Journal of Zoology, 76: 403-414.

Isinibilir, M., L. Svetlichny, E. Hubareva, I. Yilmaz, F. Ustun, G. Belmonte, and B. Toklu-Alicli. 2011. Adaptability and vulnerability of zooplankton species in the adjacent regions of the Black and Marmara Seas. J. Marine Syst., 84: 18-27.

Isinibilir, M., E. Hubareva, and L. Svetlichny. 2014. Interpopulation dynamics between *Acartia clausi* (Copepoda) and *Noctiluca scintillans* (Dinoflagellata) in the Bosphorus area of the Black and the Marmara Seas. Italian Journal of Zoology, 81: 451-456.

Kideys, A.E., A.V. Kovalev, G. Shulman, A.D. Gordina, and F. Bingel. 2000. A review of zooplankton investigations of the Black Sea over the last decade. J. Mar. Sys., 24: 355-371.

Kideys, A. and Z. Romanova. 2001. Distribution of gelatinous macrozooplankton in the southern Black Sea during 1996-1999. Marine Biology, 139(3): 535-547.

Kideys, A.E. 2002. Fall and rise of the Black Sea ecosystem. Science, 297: 1482-1484.

Konsulov, A. and L. Kamburska. 1998. Black Sea zooplankton structural dynamic and variability off the Bulgarian Black Sea coast during 1991-1995, p. 281-293. In L. Ivanov and T. Oguz [eds.], Ecosystem Modeling as a Management Tool for the Black Sea. Kluwer Academic.

Koval, L.G. 1984. Zoo- and necro-zooplankton of the Black Sea. Kiev: Naukova dumka. p.127 (in Russian).

Kovalev, A.V., S. Besiktepe, J. Zagorodnyaya, and A.E. Kideys. 1998. Mediterraneanization of the Black Sea zooplankton is continuing, p. 199-207. In L.I. Ivanov and T. Oguz [eds.], Ecosystem Modeling as a Management Tool for the Black Sea. Kluwer Academic.

Kovalev, A., V. Skryabin, Y. Zagarodnyaya, A. Kıdeyş, U. Niermann, and Z. Uysal. 1999. The Black Sea zooplankton: Composition, spatial/temporal distribution and history of investigations. Turk. J. Zool. 23: 195-210.

McQuatters-Gollop A, L.D. Mee, D.E. Raitsos, and G.I. Shapiro. 2008. Non-linearities, regime shifts and recovery: The recent influence of climate on Black Sea chlorophyll. J. Mar. Syst. 74: 649-658.

Mills, E.C., R.P. Pugf, R.G. Harbison, and S.H.D. Haddock. 1996. Medusae, siphonophores and ctenophores of the Alboran Sea, south western Mediterranean. Scientia Marina, 60(1): 145-163.

Mutlu, E., F. Bingel, A. Gücü, V. Melnikov, U. Niermann, N. Ostr, and V. Zaika. 1994. Distribution of the new invader *Mnemiopsis* sp. and the resident *Aurelia aurita* and *Pleurobrachia pileus* populations in the Black Sea in the years 1991-1993. ICES J. Mar. Sci., 51: 407-421.

Mutlu, E. and Bingel, F., 1999. Distribution and abundance of ctenophores, and their zooplankton food in the Black Sea. I. Pleurobrachia pileus. Marine Biology, 135: 589-601.

Mutlu, E. 2005. A comparison of the contribution of zooplankton and nekton taxa to the near-surface acoustic structure of three Turkish seas. Mar. Ecol. Evol. Persp., 26: 17-32.

Mutlu, E. 2009. Recent distribution and size structure of gelatinous organisms in the southern Black Sea and their interactions with fish catches. Mar. Biol., 156: 935-957.

Niermann, U., F. Bingel, G. Erguen, and W. Greve. 1998. Fluctuation of dominant mesozooplankton species in the Black Sea. North Sea and the Baltic Sea: Is a general trend recognisable? Turk. J. Zool., 22: 63-82.

Niermann, U. 2004. *Mnemiopsis leidyi*: Distribution and effect on the Black Sea ecosystem during the first years of invasion in comparison with other gelatinous blooms, p. 3-31. In H. Dumont, T.A. Shiganova, and U. Niermann [eds.], Aquatic Invasions in the Black, Caspian and Mediterranean Seas, Kluwer Academic Publisher.

Nikishina, A.B., A.V. Drits, Y.V. Vasilyeva, A.G. Timonin, K.A. Solovyev, T.N. Ratkova, and V.M. Sergeeva. 2011. Role of the *Noctiluca scintillans* population in the trophic dynamics of the Black Sea plankton over the spring period. Oceanology, 51(6): 1090-1101.

Oguz, T. 2005. Black Sea ecosystem response to climatic teleconnections. Oceanography, 18(2): 122-133.

Oguz, T., S. Tugrul, A.E. Kıdeys, V. Ediger, and N. Kubilay. 2005. Physical and biochemical characteristics of the Black Sea, p. 1331-1369. In A.R. Robinson and K.H. Brink [eds.], The Global Coastal Ocean: Interdisciplinary Regional Studies and Syntheses, Volume 14, The Sea. Harvard University.

Oguz, T. and V. Velikova. 2010. Abrupt transition of the northwestern Black Sea shelf ecosystem from a eutrophic to an alternative pristine state. Mar. Ecol. Prog. Ser. 405: 231-242.

Oğuz, T. and B. Öztürk. 2011. Mechanisms impeding natural Mediterranization process of Black Sea fauna. J. Black Sea/Medit. Environ., 17: 234-253.

Oguz, T., E. Akoglu, and B. Salihoglu. 2012. Current state of overfishing and its regional differences in the Black Sea. Ocean Coast. Manag., 58: 47-56.

Ovchinnikov, I.M, and V.B. Titov 1990. Anticyclonic eddies of currents in the coastal area of the Black Sea. Dolk Akad Nauk SSSR., 314:739-746.

Ozer, N.P. and M.S. Celikkale. 1998. Seasonal occurrence of jellyfish *Rhizostoma pulmo* (Macri, 1778) in the Black Sea, p. 358-361. In M.S. Celikkale, E. Duzgunes, I. Okumus and C. Mutlu [eds.], Fisheco'98, The Proceedings of the First International Symposium on Fisheries and Ecology.

Öztürk, B. and B. Topaloğlu. 2009. Monitoring of *Chrysaora hysoscella* (Linnaeus, 1767) in İstanbul Strait and exit of the Black Sea. In: Abstracts of National Water Days Symposium, Turkish Marine Research Foundation, İstanbul, Turkey, 14 pp (in Turkish).

Öztürk, B., V. Mihneva, and T. Shiganova. 2011. First records of *Bolinopsis vitrea* (L. Agassiz, 1860) (Ctenophora: Lobata) in the Black Sea. Aquatic Invasions, 6: 455-460.

Öztürk, İ.D. 2015. Spatial distribution, composition and DNA barcoding of zooplankton in the southern Black Sea (July 2013). M.Sc. Thesis, IMS-Middle East Technical University, Ankara, p. 253.

Pavlova, E.V. and E.B. Melnikova. 2006. Annual fluctuations of zooplankton quantity indicators near Sevastopol (1998–2003). Marine Ecological Journal 5: 63-73 (in Russian).

Ruhl, H.A. and K.L. Smith. 2004. Shifts in deep-sea community structure linked to climate and food supply. Science, 305: 513-515.

Quevedo, M., R. Gonzales-Quiros, and R. Anadon. 1999. Evidence of heavy predation by *Noctiluca scintillans* on *Acartia clausi* (Copepoda) eggs of the central Cantabrian coast. Oceanol. Acta, 22: 127-131.

Selifonova, Z.P. 2009. Marine biological invasions in waters of the port of Novorossiysk in the Black Sea. Russ. J. Mar. Biol., 35: 242-249.

Shiganova, T.A., Y.V. Bulgakova, S.P. Volovik, Z.A. Mirzoyan, S.I. Dudkin. 2001. The new invader *Beroe ovata* Mayer 1912 and its effect on the ecosystem in the northeastern Black Sea. Hydrobiologia, 451: 187-197.

Shiganova, T.A., E.D. Christou, J.V. Bulgakova, I. Siokou-Frangou, S. Zervoudaki, and A. Siapatis. 2004. Study on the distribution and biology of the invader *M. leidyi* in the northern Aegean Sea, comparison with indigenous species *Bolinopsis vitrea,* p. 113-135. In H.T. Dumont, T.A. Shiganova, U. Niermann [eds.], The Ctenophore *Mnemiopsis leidyi* in the Black, Caspian and Mediterranean Seas and Other Aquatic Invasions. Kluwer Academic.

Shiganova, T., E. Musaeva, E. Arashkevich, L. Kamburska, K. Stefanova, V. Mihneva, L. Polishchuk, F. Timofte, F. Ustun, T. Oguz, M. Khalvashi, and A.N. Tarkan. 2008. State of zooplankton p. 201-242. In T. Oguz [ed.], State of the Environment of the Black Sea (2001– 2006/7). The Commission on the Protection of the Black Sea Against Pollution (BSC) Publications.

Shiganova, T.A. and A. Malej. 2009. Native and non-native ctenophores in the Gulf of Trieste, Northern Adriatic Sea. J. Plankton Res., 31: 61-71.

Siokou-Frangou, I., T. Shiganova, E.D. Christou, L. Kamburska, A. Gubanova, A. Konsulov, E. Musaeva, V. Skryabin, and V. Khoroshilov. 2004. Mesozooplankton communities in the Aegean and Black Seas: a comparative study. Mar. Biol., 144:1111-1126.

Sorokin, Y.I. 1983. The Black Sea, p. 253-291. In B.H. Ketchum [ed.], Ecosystems of the World: Estuaries and Enclosed Seas, Elsevier.

Svetlichny, L.S., E.S. Hubareva, and E.G. Arashkevich. 1998. Physiological and behavioural response to hypoxia in active and diapausing stage V copepodites of *Calanus euxinus*. Arch Hydrobiol Spec Issues Adv Limnol., 52: 507-519.

Svetlichny, L.S. and E.S. Hubareva. 2005. The energetics of *Calanus euxinus*: locomotion, filtration of food and specific dynamic action. J. Plankton Res., 27: 671-682.

Svetlichny, L.S., A.E. Kideys, E.S. Hubareva, S. Besiktepe, and M. Isinibilir. 2006. Development and lipid storage in *Calanus euxinus* from the Black and Marmara Seas: Variabilities due to habitat conditions. J. Marine Syst., 59: 52-62.

Svetlichny, L.S., T.V. Yuneva, E.S. Hubareva, A.M. Schepkina, S. Besiktepe, A.E. Kideys, L. Bat, and F. Sahin. 2009. Development of *Calanus euxinus* during spring cold homothermy in the Black Sea. Mar. Ecol-Prog. Ser., 374: 199-213.

Şen Özdemir, N. 2013. Zooplankton of Eastern Black Sea (Trabzon coastline) and seasonal changes in fatty acid composition of zooplankton. Ph. D. Thesis, Karadeniz Technical University, Trabzon, p. 198. (in Turkish).

Tarkan, A.N., M. Isinibilir, and A.S. Tarkan. 2005. Seasonal variations of the zooplankton composition and abundance in the Istanbul Strait. Pak. J. Biol. Sci., 8: 1327-1336.

Temnykh, A. and S. Nishida. 2012. New record of the planktonic copepod *Oithona davisae* Ferrari and Orsi in the Black Sea with notes on the identity of "*Oithona brevicornis*". Aquatic Invasions, 7: 425-431.

Terbıyık Kurt, T. 2016. Regional changes of the mesozooplankton assemblages in northeastern Mediterranean, Marmara Sea and Black Sea. Ph. D. Thesis, Çukurova University, Adana, p. 269. (in Turkish).

Ünal, E. 2002. Seasonality of zooplankton in the Southern Black Sea in 1999 and Genetics of *Calanus euxinus* (Copepoda). M.Sc. Thesis, IMS-Middle East Technical University, Ankara, p. 202.

Üstün, F. 2005. The composition and seasonal distribution of zooplankton in the region of Sinop Cape of the Black Sea, Turkey. M.Sc. Thesis, Ondokuz Mayıs Üniversitesi, Samsun, p. 149.

Üstün, F. 2010. General distribuiton of zooplankton in Turkish coast of the Black Sea and a study on egg production of *Acartia clausi* Gisbrecht, 1889 (Copepoda=Calanoida). Ph. D. Thesis, Sinop University, Sinop, p. 113. (in Turkish)

Üstün, F. and L. Bat, 2014. The egg production rate of *Acartia* (*Acartiura*) *clausi* Giesbrecht, 1889 (Copepoda) in Sinop Peninsula (Southern Black Sea). Turkish J. Fish. and Aquat. Sci., 14: 605-613.

Üstün, F., T. Terbıyık Kurt, and E. Suarez-Morales. 2014. A new species of Cymbasoma (Copepoda, Monstrilloida) from the northern coast of Turkey (Black Sea) with comments on the *C. longispinosum* species-group. Crustaceana, 87: 1393-1410.

Üstün F., L. Bat, F. Şahin, Z. Özdemir Birinci, and A.E. Kıdeyş 2016. Seasonality of mesozooplankton in the southern Black Sea (off Sinop) between 2002 and 2004. Journal of New Results in Science, 11:87-101.

Ustun, F. and T. Terbıyık Kurt. 2016. First report of the occurrence of *Oithona davisae* Ferrari F.D.& Orsi, 1984 (Copepoda: Oithonidae) in the Southern Black Sea, Turkey. Turkish J. Fish. and Aquat. Sci., 16: 413-420.

Vinogradov, M.E., E.A. Shushkina, E.I. Musaeva, and P.Yu.Sorokin. 1989. A newly species in the Black Sea: Ctenophore *Mnemiopsis leidyi* (A. Agassiz) (Ctenophora: Lobata). Oceanology, 29: 220-224.

Yıldız, İ. 2010. Composition and seasonal distribution mesozooplankton in South Black Sea. Ph. D. Thesis, Karadeniz Teknik University, Trabzon, p. 196. (in Turkish)

Yıldız, İ. and A.M. Feyzioğlu. 2014. Biological diversity and seasonal variation of mesozooplankton in the southeastern Black Sea coastal ecosystem. Turk. J. Zool., 38: 179-190.

Yilmaz, I.N., E. Okus, and A. Yuksek. 2005. Evidences for influence of a heterotrophic dinoflagellate (*Noctiluca scintillans*) on zooplankton community structure in a highly stratified basin. Estuarine, Coastal and Shelf Science, 64: 475-485.

Yuneva, T.V., L.S. Svetlichny, O.A. Yunev, Z.A. Romanova, A.E. Kideys, F. Bingel, Z. Uysal, A. Yilmaz, and G.E. Shulman. 1999. Nutritional condition of female *Calanus euxinus* from cyclonic and anticyclonic regions of the Black Sea. Mar. Ecol. Prog. Ser., 189: 195-204.

Zagorodnyaya, Y.A. 2002. *Oithona brevicornis* in Sevastopol Bay: Is it a single event of a new invader in the Black Sea fauna? Morskoy Ekologicheskiy Zhurnal (Marine Ecology Journal), 61: 43.

Zaitsev, Y.P., B.G. Aleksandrov, N.A. Berlinsky, and A. Zenetos. 2002. The Black Sea. Europe's Biodiversity–Biogeographical Regions and Seas. European Environment Agency, Copenhagen.

Zenkevich, L.A. 1963. Biology of Seas of the USSR. M. Acad. Nauk. USSR (in Russian).

MEIOBENTHIC RESEARCH ON THE BLACK SEA SHELF OF TURKEY: A REVIEW

Derya ÜRKMEZ [1], Murat SEZGİN [2] and Nelli G. SERGEEVA [3]

[1]Scientific and Technological Research and Application Center, Sinop University, Sinop, Turkey
[2] Faculty of Fisheries, Department of Hydrobiology, Sinop University, Sinop, Turkey
[3]Institute of Marine Biological Research of Russian Academy of Sciences, 2, Nakhimov ave., Sevastopol 299011, Russia
deryaurkmez@gmail.com

1. Introduction

The term "meiofauna" was first used by M. Mare (1942) to define a group of mobile invertebrates distinguished from macrofauna by their smaller size. Meiofauna is defined by size based on the standard mesh width of sieves with 500 – 1000 µm as upper and 20 – 63 µm as lower limit (Fenchel 1978, Higgins and Thiel 1988, Giere 2009). The term "meiobenthos" refers to a group of invertebrate organisms that are intermediate in size between macro– and microfauna and includes metazoan organisms and also ecologically relevant protozoans such as foraminiferans and ciliates inhabiting benthic environments with all sediment types in all climatic zones (Higgins and Thiel 1988, Giere 2009, Urban–Malinga *et al.* 2014, Sergeeva *et al*. 2017). These can be classified into two groups as permanent (species that remain in the meiobenthic size–range during their whole lifespan) and temporary (species that have larval stages in meiobenthos but grow into macrobenthos) meiobenthos. Nematodes and harpacticoid copepods often dominate permanent meiobenthic communities, although interesting animals such as tardigrades (also called "water bears"), kinorhynchs, ostracods, gastrotrichs and microturbellarians can be found in some habitats. Temporary meiobenthos may comprise polychaetes, oligochaetes and water mites. A great majority of known phyla have meiobenthic representatives. From these approximately more than 30 recognized phyla, only five comprise the permanent meiobenthos. Nematodes are typically the most abundant meiobenthic group and often constitute more than 90% of all sediment metazoans, followed by harpacticoid copepods, nauplii, and annelids (Grove *et al.* 2006, Giere 2009). Comprehensive knowledge on meiobenthos can be found in Higgins and Thiel (1988) and Giere (2009). Interstitial meiofauna live between grains of sand and typically are small and wormshaped. Many interstitial species have adhesive organs for attaching to sand grains. Burrowing meiofauna live in fine sediments and often have robust bodies for pushing aside mud and silt. Epibenthic meiofauna live on the streambed or on wood, leaves, or plants. These typically are the largest members of the meiofauna and often are good swimmers (Palmer *et al.* 2006). Referring to the first group, this initially subjective size–range of benthic invertebrates has since been shown to represent a discrete, ecologically defined group of organisms whose morphology, physiology and life–history characteristics have evolved to exploit the interstitial matrix of marine sediments. Meiobenthos play an important role in the sediment as they serve as food for higher trophic levels such as macrofauna (*e.g.* shrimp and demersal fishes) (Coull 1990, Feller and Coull 1995). They play a key role in the remineralization of detritus and recycling of nutrients (McIntyre 1969). It has been suggested that the production of meiobenthic organisms in shallow waters is much higher than that of microbenthic organisms (Platt and Warwick 1983). The past decade has witnessed a significant increase in interest in this fauna, which often dominates benthic animal communities in terms of numbers and species richness, and plays important roles in community and ecosystem processes (Robertson *et al.* 2000, Rundle *et al.* 2002). Moreover, several studies have demonstrated the usefulness of meiobenthos as bio–indicators of pollution, disturbance, and climate change (Balsamo *et al.* 2012, Coull and Chandler 1992, Pusceddu *et al.* 2014, Ürkmez *et al.* 2014, Zeppilli *et al.* 2015).

The Black Sea is the largest anoxic basin on Earth with a maximum depth of 2250 m. It has an oxygenated surface water layer overlying an anoxic deep–water layer. It is a unique marine water body where the dissolved oxygen disappears at a depth of about 200 m while hydrogen sulphide is present at all greater depths (Zaitsev 2008). It is connected to the Mediterranean and the world ocean system via the Sea of Marmara and the Straits of Bosphorus and Dardanelles.

In this work, we provide a summary of previous and recent meiobenthos studies conducted on the Black Sea coasts of Turkey trying to give some insights into the distribution of meiobenthos and several meiobenthic taxa at both shallow and the deep waters of the Turkish shelf of the Black Sea. We adopted the “operational” definition of meiobenthos, in which meiobenthic organisms are described as animals that pass through a sieve of 1 mm and retained on a sieve of 63 micron. Therefore, all organisms, including protozoans (ciliates, gromiids, soft– and hard–shelled foraminifers) and metazoans with two components – the permanent meiofauna (eumeiobenthos) and the temporary meiofauna (pseudomeiobenthos–juvenile stages of macrobenthos), are considered as meiobenthos.

2. Previous Data

The question of the lower boundary of macrofauna in the Black Sea was discussed in detail on the base of the findings obtained during the investigations carried out between 1925 and 1935 (Nikitin 1938, 1948, 1964, Yakubova 1948). It was shown that the depth of the boundary of macrobenthos ranged from 120 to 170 (200) m, with most of them located near the Bosphorus Strait. First studies on meiobenthic organisms inhabiting the Turkish shelf of the Black Sea were conducted by the Benthos Department of IBSS (Institute of the Biology of Southern Seas) in 1958 and1960 during the cruises of RV ‘*Academic Kovalevsky*’ at the Bosphorus area. A total of ten benthic stations (70–

113 m) were sampled and three ecological communities were distinguished. *Modiolula phaseolina*, located to the north–eastern part of the Bosporus exit area and *Sternaspis scutata* and *Amphiura stepanovi – Terebellides stroemi* communities located to the north–western of the Bosphorus. In general, meiobenthos of the area included the following taxa: Foraminifera (19 species), Nematoda, Kinorhyncha, Polychaeta, Ostracoda (14 species), Harpacticoida (2 species) and Acari. Free–living nematodes were the most numerous taxa as expected (Kiseleva 1969). The taxonomic analysis of sediment samples revealed 51 species of nematodes belonging to the 37 genera (Sergeeva 1974). In the 1970s, several free–living nematode species such as *Sabatieria praebosporica* Sergeeva 1973, *S. asperum* Sergeeva 1973, *Filoncholaimus ponticus* Sergeeva 1974, *Parironus ponticus* Sergeeva 1973, *Halichoanolaimus lukjanovae* Sergeeva 1973 and *Mesacanthion heterospiculum* Sergeeva 1974 were described as new species for science from the Bosphorus region and *Crenopharinx brevicaudata* (Sch.–Stekh. 1950), *Paramesacanthion truncus* Vitiello 1971, *Viscosia minudonta* Vitiello 1970 were also reported to be new records for the Black Sea (Sergeeva 1973a, b, 1974, 1977).

Meiobenthic organisms were also collected at the Bosphorus exit area of the Black Sea in 1959. Bặcesco and Mặrgineanu (1959) identified and described twenty species of meiobenthic organisms that were not only new for the Black Sea, but also new for science. Additionally, nineteen species of benthic foraminifera, three species of harpacticoids and three species of ostracods were documented (Bặcesco and Mặrgineanu 1959, Bặcescu 1960). Several ostracod species specific only to the Bosphorus exit area of the Black Sea were described in the late 1950s and early 1960s (Caraion 1959, Marinov 1962, Shornikov 1966). Another survey was carried out at the Bosphorus area (depth 80–100 m) with a focus on benthic Foraminifera in the 1960s and Didkowsky (1969) reported three main foraminiferan complexes. Subsequent studies yielded discovery of benthic foraminiferans belonging to 6 orders, 39 genera and 79 species, of which 27 were new species unique to the Bosphorus region of the Black Sea (Yanko and Vorobyova 1991). Several ostracod species were also described from the same area in the late 1950s and early 1960s (Caraion 1959, Marinov 1962, Shornikov 1966).

In 1996, several bottom sediment samples were collected at three harbours (Fatsa, Trabzon and Rize) of the south-eastern Black Sea (unpublished data). One grab sample was taken from a water depth of 6–7 m in each area. Sediments were composed of black pellitic silt and observed to be polluted by oil hydrocarbons. As a result of the analyses, meiobenthos was found to be composed of 9 main taxa. Eumeiobenthos included 6 groups (soft–shelled Foraminifera, Nematoda, Kinorhyncha, Harpacticoida, Ostracoda, Acarina) and pseudo-meiobenthos included 3 groups (Polychaeta, Oligochaeta, Bivalvia). Density of total meiobenthos ranged between 802 and 3948x10^3 ind.m^{-2}. As a remarkable finding, Rize harbour was mostly represented by monothalamous soft–shelled foraminifera (78% of total meiobenthos) and free–living nematodes were the second leading taxon. In Trabzon, the role of these two groups changed, and soft–shelled foraminifera were absent in the samples of Fatsa harbor. Free–living nematodes were dominant at three stations, and their density reached to $884x10^3$ ind.m^{-2}. Species composition of nematodes was specific at each area, ranging between 4 (Rize) and 24 species (Fatsa). *Terschellingia longicaudata* de Man, 1907 was the constant and dominant species in all samples and shared the first place with *Sabatieria pulchra* (Schneider, 1906) in the sample from Fatsa. As a result of this work, soft–shelled foraminifera (*Psammophaga simplora* Arnold 1982 and Allogromiinae gen. sp) were registered for the first time in the Turkish coastal waters under considerable technogenic stress.

In 1991, İnebolu region was investigated in terms of meiofauna and samples were obtained at several locations along a transect covering depths ranging from 50 to 190 m. A total number of 10 taxa were recorded and nematodes were dominant at all sampling depths (Luth 2004). Special interest was set to the taxonomic composition and distribution patterns of benthic communities inhabiting the layer where the oxic/anoxic interface meets the sea floor. Results showed a steep decline in number of taxonomic groups between depths of 130 m and 150 m, in the suboxic zone. Mobile forms with high oxygen demands such as crustaceans or fish were restricted to this zone.

Following chapters aim to provide a brief review of recent studies concerning meiobenthic communities inhabiting the shallow and deep benthic environments of the Black Sea shelf of Turkey.

3. Recent Data

3.1. Central Black Sea Coast of Turkey

The abundance, biomass and taxonomic composition of meiobenthos inhabiting shallow waters of southern and northern Black Sea coasts were analysed in the scope of a joint project between Sinop University, Faculty of Fisheries and IBSS (Sevastopol, Ukraine). A monthly sampling was carried out for twelve months between August 2009 and July 2010 at two depths (3 and 10 m) located on four transects (A, B, C, D) along Sinop coasts. As a result of the analyses, meiobenthic assemblages were found to be represented by 25 higher major taxa. The leading taxa in terms of abundance were Nematoda, Harpacticoida, Polychaeta and hard shelled Foraminifera in all samples. Several individuals of rare taxa such as Kinorhyncha and Tardigrada were encountered as well. In general, the mean meiobenthos abundance ranged from 18×10^3 ind. m^{-2} to 1320×10^3 ind. m^{-2} (St.D1–July 2010 and St.A1– December 2009) (Figure 1). Meiobenthos biomass values ranged between 294,9 to 20368,1 mg.m^{-2}. The highest biomass value was recorded at St. C2 in November 2009 and the lowest at St. D1 in July 2010. Mean biomass values for 3 and 10 m station groups ranged from 1972,6 mg.m^{-2} (April, 3m) to 11911,1 mg.m^{-2} (October, 10m) (Figure 2).

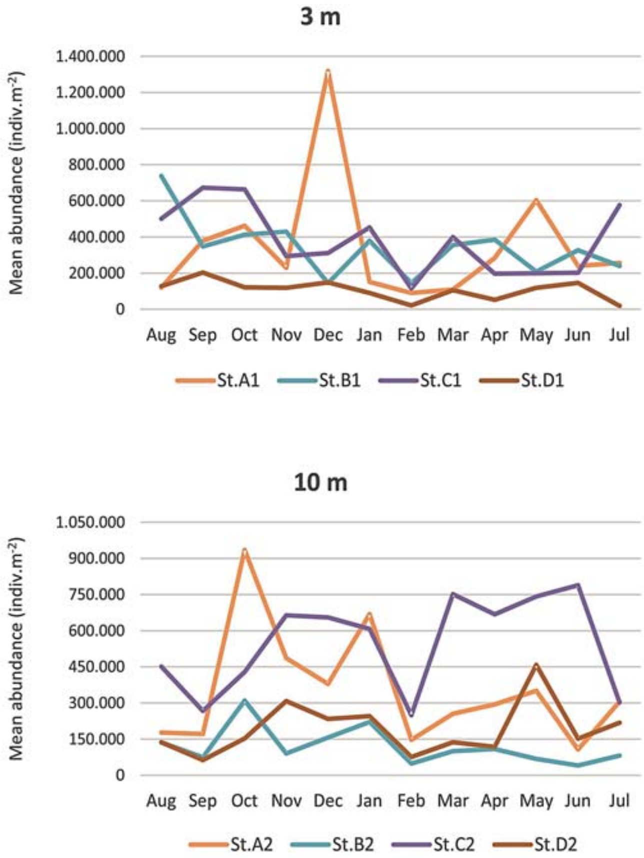

Figure 1. Monthly changes in meiobenthos abundance of Sinop Bay at 3 m (Stations A1, B1, C1, D1) and 10 m (Stations A2, B2, C2, D2) depths

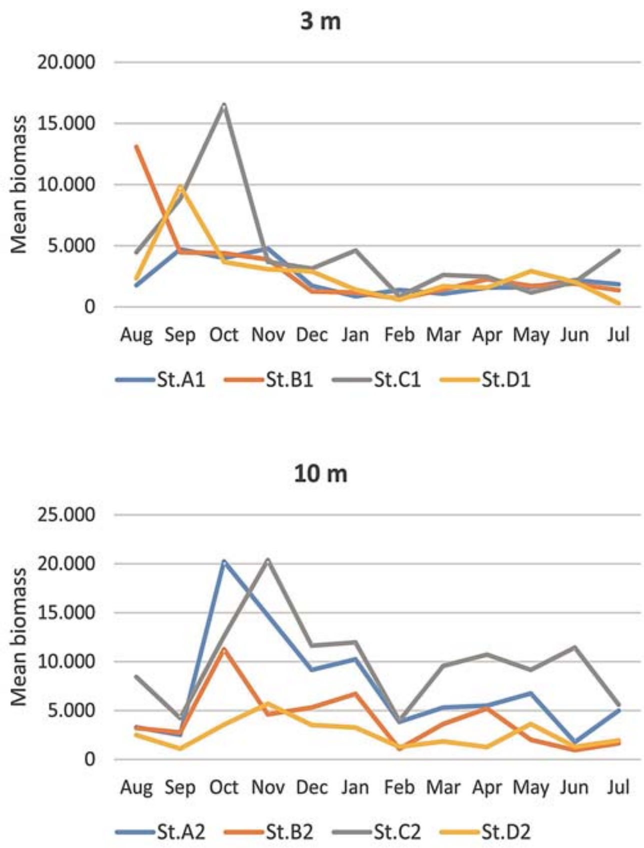

Figure 2. Monthly changes in meiobenthos biomass (mg.m^{-2}) of Sinop Bay at 3 m (Stations A1, B1, C1, D1) and 10 m (Stations A2, B2, C2, D2) depths

The percentage contributions were also calculated for each month at each station. Nematoda, Harpacticoida, hard shelled Foraminifera and Polychaeta were the main taxa making highest contributions to the mean meiobenthos abundance and their abundance showed seasonal fluctuations at the stations. The three major taxa (Nematoda, Harpacticoida and Polychaeta) occurred with low abundances at station D1, but the abundance of hard shelled Foraminifera was high, which was attributed to the fact that the granulometric structure of station D1 was different from the other stations, and the silt content made a suitable substrate for hard shelled Foraminifera (Mikhalevich 2013). The mean meiobenthos abundance at the stations displayed different patterns, mostly depending on the depth and the grain size structure of the sediment, and cluster analysis showed that the depth and granulometric structure were the main factors in the grouping of the stations (Figure 3).

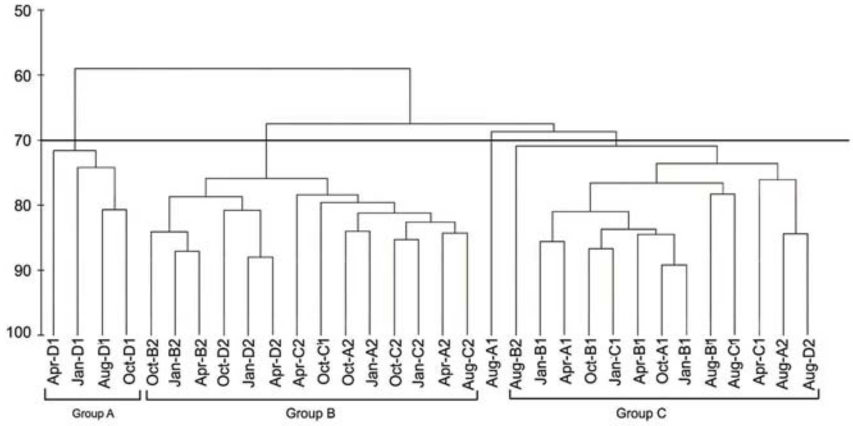

Figure 3. Dendrogram showing similarity of stations–months in terms of meiobenthos abundance (A, B, C, D are transects; 1 indicates stations at 3 m; 2 indicates stations at 10 m) (Ürkmez *et al.* 2016a)

The contribution of nematodes to the total abundance of four main groups was higher in spring and in autumn, a sign of reproduction periods. Correlation analysis showed that the most significant environmental factors which have impact on meiobenthic community structure of the research stations were the sediment parameters, namely the sediment particle size, sediment porosity, and the redox potential of the sediment. Additionally, several environmental factors related to sea water such as dissolved oxygen, temperature, pH, and nutrient content were also determined to have influence on meiobenthic community structure. This work provided comprehensive data about the meiobenthos of Turkish Black Sea giving a general overview on the dynamics of higher taxonomic groups. Meiobenthos abundance displayed changes depending on stations and months. The results demonstrated that depth is an important factor for the similarity of the taxonomic compositions at sites and their abundance and biomass fluctuated mainly under the influence of seasons, available food and granulometric size structure of the locations.

The highest number of individuals among all meiobenthic taxa was recorded for Nematoda. The abundance of nematodes ranged from 1×10^3 ind. m^{-2} (St. D1, February) to 456×10^3 ind. m^{-2} (St. A1, May) at 3 m (Fig. 4). Seasonal peaks were observed in October and May at station A1 and prominent variations were recorded at stations B1 and C1. The abundance of nematodes at 10 m were generally lower compared to 3 m depth and ranged from 1×10^3 ind. m^{-2} (St. D2, August) to 313×10^3 ind. m^{-2} (St. D2, May). Seasonal peaks were observed in March at station C2 and in May at station D2. See

Ürkmez *et al.* (2016a) for the distribution and spatio–temporal variation of other meiobenthic groups at Sinop Bay.

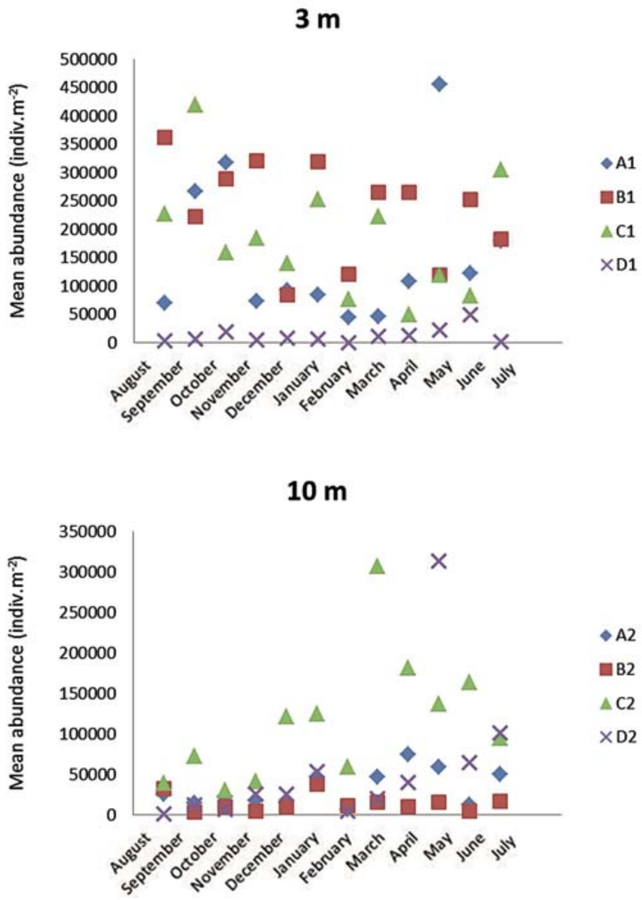

Figure 4. Spatio–temporal distribution of Nematoda in Sinop Bay at 3 m (Stations A1, B1, C1, D1) and 10 m (Stations A2, B2, C2, D2) depths (2009–2010)

Additionally, species composition of free–living nematodes, harpacticoid copepods and recent hard–shelled foraminifera of the sampling sites were investigated in detail within three dissertations. As a result of the identifications, 133 species of nematodes (Ürkmez 2015), 92 species (and 8 subspecies) of harpacticoids (Ersoy–Karaçuha 2013) and 36 species of recent hard–shelled foraminifera (Öksüz 2012) were recorded at the area. Besides the studies on the spatio–temporal distribution and taxonomic composition of meiobenthos at Sinop Bay, several more attempts were announced and published on the use of meiobenthos in the Black Sea for biomonitoring purposes (Ürkmez *et al.* 2011, Sezgin *et al.* 2013, Ürkmez *et al.* 2014, Öksüz *et al.* 2016, Ürkmez *et al.* 2017).

Moreover, a recent meiobenthos project conducted in the subtidal coastal waters of Sinop Bay revealed the first report of the kinorhynch *Echinoderes dujardinii* Claparede, 1863 (Kinorhyncha, Cyclorhagida) for the marine fauna of Turkey (Figure 5). Representatives of the phylum Kinorhyncha are among the less studied permanent metazoan meiofauna in the world. The occurrence of kinorhynchs in marine fauna of Turkey has first been reported by Bặcescu (1961) at the pre–Bosphoric area of the Black Sea. Other previous reports of *E. dujardinii* from the Black Sea were by Bặcescu *et al.* (1963), Marinov (1964) and Bặcescu (1968), however they were considered questionable (Higgins, 1983) due to the fact that details or descriptions were insufficient (Ürkmez *et al.* 2016b)

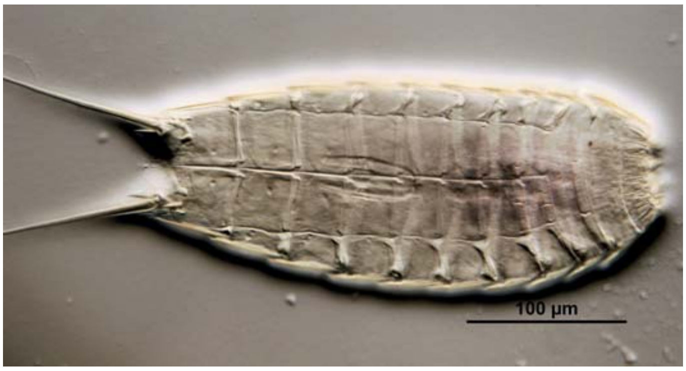

Figure 5. Light microscopy (with differential interference contrast (DIC) optics) of a female *Echinoderes dujardinii* (Kinorhyncha) obtained from the central Black Sea coast of Turkey (Photo: Derya Ürkmez)

As an important finding of this meiobenthos project, a species belonging to a rare genus of the phylum Tardigrada has recently been announced new for science and received the name *Megastygarctides sezginii* Ürkmez, Ostrowska, Roszkowska, Gawlak, Zawierucha, Kristensen and Kaczmarek, 2017 (Figure 6). The species is named after Professor Dr. Murat Sezgin, the coordinator of the project, who suddenly passed away during the course of the studies. Specimens of *Megastygarctides* have been previously found on the northern coast of the Black Sea (Crimean Peninsula, Ukraine/Russia) in addition to their type localities (Kharkevych 2013).

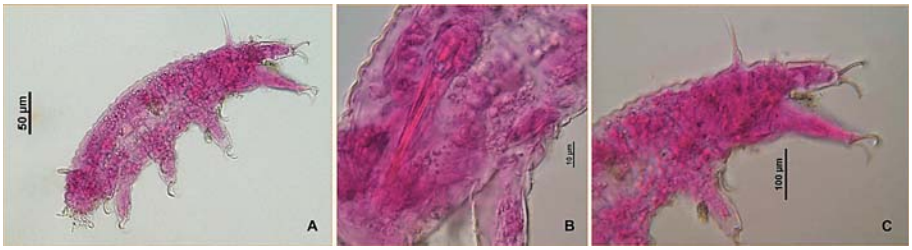

Figure 6. Light microscopy (with differential interference contrast [DIC] optics) of *Megastygarctides sezginii* from the Central Black Sea coast of Turkey A. Total body B. Stylet C. Posterior body showing legs and claws (Photos: Derya Ürkmez)

3.2. Southwestern Coast of the Black Sea

A preliminary quantitative survey of meiobenthos has been conducted for the first time at the southwestern coast of the Black Sea in November 2012. Sediment samples were collected at the coastline of İğneada by subsampling from Van Veen grab sediment samples collected at 8 stations located on 3 different depths (5, 10 and 20 m). It has been observed that meiobenthos was represented by 12 major taxonomic groups, namely Nematoda, Harpacticoida, hard–shelled and soft–shelled Foraminifera, Polychaeta, Bivalvia, Gastropoda, Ostracoda, Nemertea, Oligochaeta, Turbellaria and Acari. However, this number is lower compared to the number of meiobenthic taxa recorded at the shallow waters of Central Turkish Black Sea by Ürkmez *et al*. (2016c). Meiobenthic densities ranged between 67–757 ind. 10^3 m^{-2} in the area. The dominant group at the sampling area was Nematoda followed by Harpacticoida and hard–shelled Foraminifera. A similar observation has been reported for shallow waters (Ürkmez *et al.* 2016a) and deep waters (Ürkmez *et al.* 2015) of the central Turkish Black Sea. This pattern was recorded in many meiobenthos studies (Gheskiere *et al.* 2002, Sergeeva 2003, Armenteros *et al.* 2009, Semprucci *et al.* 2011, Semprucci *et al.* 2013). The other taxonomic groups displayed an irregular distribution at the sampling area. Several taxa such as Acari, soft–shelled Foraminifera and Nemertea were recorded at a few stations. Rare taxa such as Kinorhyncha, Tardigrada and Gastrotricha were not found in the samples.

Free–living nematodes comprised a significant portion of the meiobenthos and represented by 52 species belonging to 39 genera and 17 families. Dominant families in the present study were Desmodoridae, Xyalidae and Oncholaimidae which are generally found at muds or fine sands worldwide (Heip *et al.* 1985, Sandulli *et al.* 2014). *Desmodora pontica* (Filipjev, 1922) was the most abundant nematode species in the area (Figure 7). It was followed by *Viscosia* sp.1, *Neochromadora sabulicola* (Filipjev, 1918) and *Sabatieria* sp.1. Ürkmez *et al.* (2016a) reported *Bathylaimus australis* Cobb, 1894, *Bolbolaimus murinae* (Sergeeva, 1976) Jensen, 1978, *Neochromadora poecilosomoides* Filipjev, 1918, *Neochromadora sabulicola* (Filipjev, 1918), *Oncholaimellus mediterraneus* Schuurmans Stekhoven, 1942 and *Onyx perfectus* Cobb, 1891 for the first time from Turkey with this study, however they have been also known to occur at Sinop coasts (Ürkmez 2015, unpublished data). Nematodes were also examined in terms of their trophic composition. All trophic groups were found at the sampling area. Trophic group 2A (epistrate feeders) were the most abundant feeding group with a dominance of 47%. Second abundant feeding group was predator/omnivors (2B) with a dominance of 29%. These results are typical findings of habitats presenting with coarse sand /low organic matter (Wieser 1953).

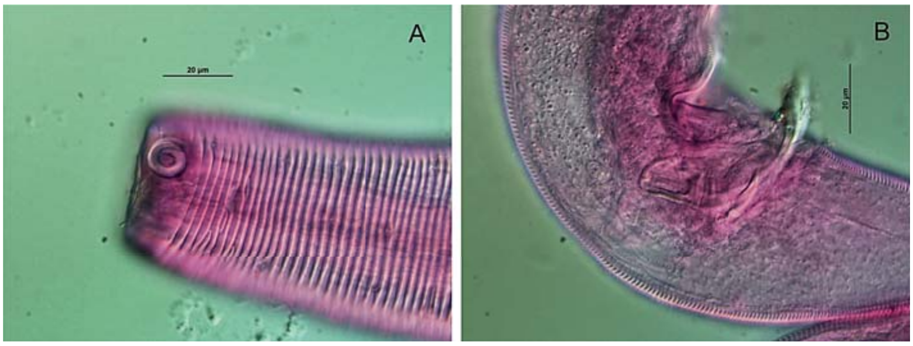

Figure 7. The most abundant nematode species in the area: *Desmodora pontica* A. Anterior region showing cuticle ornamentation and amphid B.Posterior region showing spicule and gubernaculum (Photo: Derya Ürkmez)

Harpacticoid copepods followed nematodes in terms of abundance in meiobenthos. 15 species belonging to 16 genera distributed within 10 families were identified. Among the families, Ectinosomatidae was the dominant group in terms of number of individuals accounting for 48% of the total, followed by Miraciidae (16%). Similarly, Ersoy–Karacuha and Sezgin (2013) reported that Miraciidae was dominant at the shallow waters of Sinop Bay. The most abundant species in the area were *Ectinosoma melaniceps* Boeck, 1865 (21% of total individuals), *Halectinosoma herdmani* (Scott T. & A., 1896) (19%), *Paramesochra* sp. (11%) and *Ameira parvula parvula* (Claus, 1866) (%9), all comprising 60% of total specimens. Interstitial vermiform and lanceolate Harpacticoida (which inhabit the space between sediment particles) were represented by the families Ectinosomatidae, Paramesochridae and Laophontidae, and made up 64% of the total number of individuals.

Recent benthic foraminifera was the third dominant group, however revealed a low diversity as a result of the evaluation of the samples. 12 species were found belonging to 3 families. Du Chatelet *et al.* (2009) also mentioned a low diversity in sediments including a high percentage of coarse sand. As it is expected in Black Sea, *Ammonia* and *Elphidium* species from the family Rotalidae were found to be dominant. Additionally benthic simbiont foraminifera of the genera *Adelosina* and *Spiroloculina* were recorded at the area.

It was observed that the meiobenthic assemblages in the area were quite diverse with a spatial variability. The major factor determining meiobenthos was considered to be the structure of the sediment composition and also currents that influence the food supply for meiobenthos. Spatial variability of the abundance of nematodes, and also to some extent some other groups, can be attributed to different granulometric characteristics of the sediment. This research provided first data on the meiobenthic assemblages of İğneada coasts providing species lists of three main groups (Nematoda, Harpacticoida, Hard–shelled Foraminifera), an area which has been proposed as a transboundary marine protected area (Ürkmez *et al.* 2016c).

3.3. Deep Waters of the Black Sea Exit of the Bosphorus

Below we discussed the general results of the benthic surveys performed at the Black Sea exit of the Bosphorus during the following two cruises, RV '*Arar*' (of Turkey) in November 2009 and RV '*Maria S. Merian*' (of Germany) in April 2010. A video–guided multicorer (9.5 cm diameter or 70.8 cm^2) and a gravity corer (7cm diameter or 38,5 cm^2) were used for sampling, which allowed collection of undisturbed samples. 25 benthic stations (9 in 2009 and 16 in 2010) were chosen along a transect (75–300m), covering an area ranging from oxic to the anoxic zone. Bottom–water oxygen concentrations along the interface zone at the Black Sea exit of the Bosphorus ranged from normoxic (175 µmol O_2L^{-1}) to hypoxic (less than < 63 µmol O_2 L^{-1}) or even to anoxic/sulfidic conditions within a distance of few kilometers (Holtappels *et al.* 2011, Sergeeva and Zaika 2013, Lichtschlag *et al.* 2015, Sergeeva *et al.* 2013, 2014, 2015, 2017).

Analyses of taxonomic structure and bathymetrical distribution of meiobenthic communities suggest that the oxic/anoxic transition zone supports a high abundance and rich protozoan and metazoan life (Sergeeva and Ürkmez 2017, Sergeeva *et al.* 2017). Altogether, these results confirm our early conclusion about a possible adaptation of some benthic forms to hypoxic/anoxic conditions and to the hydrogen sulfide environment (Sergeeva *et al.* 2012, Sergeeva and Zaika 2009). Received data suggest that some of the organisms (gromiids, allogromiids, ciliophores, hydrozoans, nematodes, and polychaetes) have indeed adapted to live under hypoxic/anoxic and sulfidic conditions in the Black Sea. This fauna is indigenous, rather than having been transported from adjacent oxygenated areas (Sergeeva and Mazlumyan 2011, 2013, Sergeeva *et al.* 2014). Characteristics of abundance and taxonomic diversity of meiobenthos in the study area (75–300 m) was uneven during November 2009 and April 2010. There was no clear negative effect of increasing depth and the emergence of extreme life conditions on meiobenthos characteristics. Despite the general tendency of a decrease in abundance and diversity towards maximum depths with oxygen deficiency or under the absence of oxygen and the appearance of hydrogen sulphide, several peaks of abundance and taxonomic richness were recorded at extreme areas.

In 2009, meiobenthic assemblage was dominated by Nematoda and composed of the following 21 taxa at the area: Ciliophora, Gromiidea, Foraminifera (soft–shelled and hard–shelled), Coelenterata, Nematoda, Kinorhyncha, Oligochaeta, Polychaeta, Turbellaria, Nemertea, Harpacticoida, Cumacea, Amphipoda, Tanaidacea, Ostracoda, Acari, Tardigrada, Bivalvia, Gastropoda, Ophiuroidea and Tunicata. Abundances decreased with increasing water depth from 75 to 300 m, but also several peaks were observed at depths of 75, 88, 103, 160, 250 m. The total abundance of meiobenthos ranged from 9 – 1.900x10^3 ind.m^{-2}. The abundance of temporary meiobenthos increased at 103 m water depth with high contributions of Turbellaria and Bivalvia at 250 m water depth, where Oligochaeta, Polychaeta and Turbellaria dominated.

Meiobenthos abundance significantly declined towards the depth of 300 m compared to the shallower stations, while the abundance of taxa such as Ciliophora and Nematoda showed a relative increase. The vertical distribution of the meiobenthos in the upper 9 cm of the sediment indicated that the maximum concentrations of meiofauna were usually found in the surface layer of the bottom sediment profiles with the 0–2 cm layer commonly containing 99% of the total meiobenthos abundance. More detailed information about the distribution of different taxa in the bottom sediments can be found in previously published papers (Sergeeva *et al.* 2013, Kharkevych and Sergeeva 2013, Sergeeva and Mazlumyan 2015).

In 2010, the taxonomic composition of meiobenthos included 26 groups of organisms. Rotifera, Gastrotricha, Pantopoda, Decapoda, and Cladocera were the additionally recorded taxa compared to the list of meiobenthos that was reported for November 2009. Moreover, 2–3 morphotypes of benthic fauna were recorded as *incertae sedis*, which require further study to identify their taxonomical level. The greater taxonomic diversity is evidently due to the large volume of collected bottom sediment samples in the spring period. Abundances of meiobenthos decreased with increasing water depth from 82 to 296 m, but a maximum peak was observed at 200 m depth, unlike in 2009. The total abundance of meiobenthos ranged from 8x10^3 – 1441 x10^3 ind. m^{-2}.

Nematodes formed an important part of meiobenthos at the investigated depths of the Bosphorus region. The contribution of different groups of organisms to the total number of meiobenthos varied. Nematodes dominated throughout the depth range, accounting for 39–99% of the total abundance. In the oxygenated zone (82–97 m), where the meiobenthos community showed the most diverse taxonomic diversity, the share of nematodes in the total population ranged from 60 to 81%. Under conditions of hypoxia and anoxia (159–252 m depth), the share of nematodes was 87–99.5%. At a depth of 296 m, the subdominant group was Ciliophora (35.75%) along with the dominance of Nematoda (53% of the community). According to preliminary data, the nematode fauna in 2009 included more than 110 species and morphospecies, and in 2010 this number reached to more than 145 (identification of species continues). The highest species richness (100–102 species) was recorded at depths of 123 and 103 m in autumn.

Harpacticoida was the second group, which played an important role in the deep–water communities of meiobenthos. A varied tolerance of Harpacticoida to the lack of oxygen was also observed in the deep, permanently hypoxic waters of the Bosphorus area. The number gradually reduced until a depth of 200 m, but it increased markedly at a depth of 250 m. This occurred at the boundary between the hypoxic and anoxic zones, where the largest numbers belonged to Nematoda, and the next most abundant group–Harpacticoida. The distribution of Harpacticoida along the water depths from 75 to 300 m in this area was compared between the two surveys (Kolesnikova *et al.* 2014). As a total, 40 species of Harpacticoida were found in this depth interval at the Bosporus area of the Black Sea. Their distribution with depth and the abundances differed between the two cruises (Figure 8). The data obtained onboard RV *'Arar'* showed that the abundance of Harpacticoida rapidly decreased from > 200x10^3 ind. m^{-2} at a depth of 75 m to 520 ind. m^{-2} at a depth of 190 m. In contrast, the data collected during the RV '*Maria S. Merian'* cruise revealed peaks of abundances at 150–160 m and 200 m depths, and abundance were low (7 to 9 x 10^3 ind. m^{-2}) at 80–117 m. However, the number of Harpacticoida was close to 1 x 10^3 ind. m^{-2} at 250 m depth in both datasets (Figure 8).

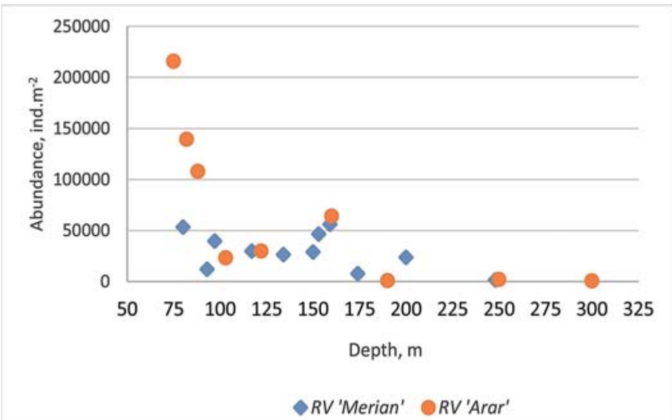

Figure 8. Vertical distribution of Harpacticoida (excluding naupliar stages) along the depth gradient in the Black Sea exit of Bosphorus based on the data collected during the RV '*Arar*' and the RV '*Maria S. Merian*' cruises (Kolesnikova *et al.* 2014)

In all, the number of harpacticoid species found per sample decreased with depth as follows: 4 to 27 (usually 7–10) species at 75–100 m, 6–12 species at 150–170 m, and 1–3 species at 200–300 m (Figure 9). The highest number of species (12) in one sample was detected at 152 m depth, whereas the maximum abundance (27 species) was recorded at 82 m during the R/V '*Arar*' cruise (Kolesnikova *et al*. 2014).

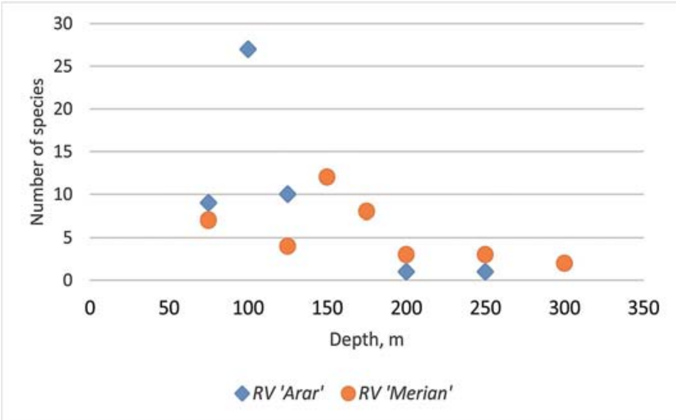

Figure 9. Vertical distribution of the total number of harpacticoid species at different depths (RV '*Arar*', November 2009 and RV '*Maria S. Merian*' May 2010) (Kolesnikova *et al.* 2014)

Three species, namely *Haloschizopera pontarchis* Por, 1959 (10.4x10^3 ind.m^{-2}), *Amphiascella subdebilis* (Willey, 1935) (5.3 x10^3 ind. m^{-2}) and *Enhydrosoma longifurcatum* (Sars, 1909) (4.9 x10^3 ind. m^{-2}) were dominant at 152 m. In comparison, different species (particularly *E. longifurcatum*, *B. imus* and *Mesochra* sp.) dominated at 200 m during the RV '*Maria S. Merian*' cruise with a total abundance of 34.4 x10^3 ind. m^{-2}. As an example, *Cletodes tenuipes* Scott, 1896 was found with no more than 1.6 – 1.7 x10^3 ind. m^{-2} during both cruises. This species was found at almost all stations in a broad range of depths from 80 m to 250 m. The abundance of *C. tenuipes* was highest at a depth of 152 m and then decreased in parallel to increasing depth. The deepest depth of occurrence was 250 m (240 ind. m^{-2}). During the RV '*Arar*' cruise, the abundance of Harpacticoida was 213.7x10^3 ind. m^{-2} at 75 m, with *E. melaniceps* (116.6x10^3 ind. m^{-2}) being the dominant species. At a depth of 100 m, 11 species were found, of which a relatively high number (4 to 18 x10^3 ind. m^{-2}) were *E. caeni*, *E. sarsi* and *E. mucronata*; the other species were less abundant than 500 ind. m^{-2}. Most of these species were also found at 75 m or 82 m. At 172 m, 8 species of Harpacticoida were found. Apart from the types discussed above, *H. herdmani*, *C. tenuipes*, *Typhlamphiascus confuses* (Scott T., 1902), *Laophonte brevifurca* Sars G.O., 1920 and *Amphiascus* sp. were recorded (Kolesnikova *et al.* 2014).

The abundance distribution of Polychaeta was very uneven in the depth range of 75–250 m. Marked peaks occurred at the depths of 88, 162 and 250 m. Maximum abundance value of Polychaeta reached up to 9.3 x10^3 ind. m^{-2} at the depth of 88 m, and the second largest peak (7.2x10^3 ind. m^{-2}) occurred at the depth of 250 m. The two species of deep–water polychaetes (*Vigtorniella zaikai* Kiseleva, 1992 and *Protodrilus* sp.) have different ecological requirements. The distribution of these species within the range of depths where oxygen–deficient bottom water impinges on the seafloor emphasizes the role of these species as indicators of hypoxia at the proximity of the hydrogen sulfide zone boundary. During the cruise of R/V *'Arar'* (November 2009), *V. zaikai* was found for the first time at 250 m depth, although it was absent at shallower sites (75–122, 160 and 190 m). It was penetrated into the sediment to a greater depth than it was in the northern half of the Black Sea; 25 % of specimens inhabited the first 1–2 cm layer and a few were even found in the 5–7 cm layer. Polychaetes were almost entirely represented by young individuals of the species *Vigtorniella zaikai* Kiseleva, 1992 and *Protodrilus* sp. at a depth of 162 m. These species usually inhabit suboxic layer and upper border of the hydrogen sulfide zone (Zaika *et al.* 1999, Zaika and Sergeeva 2008, Watson *et al.* 2016). *V. zaika* was the only polychaete species recorded at 250 m (Zaika and Sergeeva 2012). During the cruise of R/V *'Maria S. Merian'* in May 2010, both polychaete species were found at a wide range of depths (*V. zaikai* – at 134–250 m, *Protodrilus* sp. –at 116–159 m depths) in the region near the Bosphorus (Figure 10). The three notable features that can be inferred from the results from the 2010 samples are as follows: I – the wide range of water depths where *V. zaikai* occurred; II – confirmation of the existence of this species at 250 m depth; III – the "core habitat", with the maximum of abundance of each species, located at 150–159 m depth for *V. zaikai* and 134 m depth for *Protodrilus* sp.

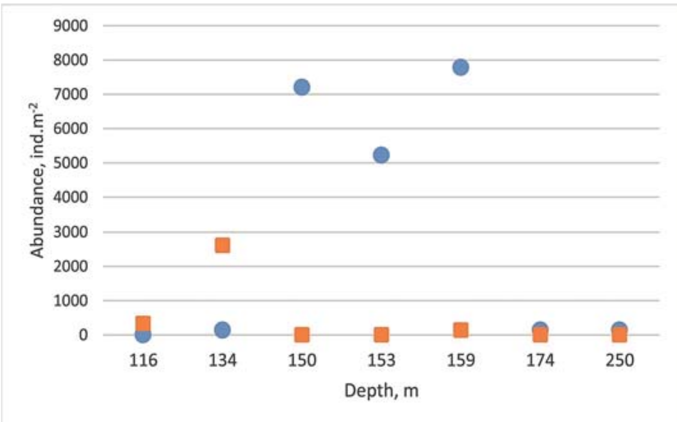

Figure 10. Abundance of the boundary zone polychaete species along the depth gradient in the region near the Bosphorus: *V. zaikai* (blue dots), *Protodrillus* sp. (orange dots) (May 2010) (Zaika and Sergeeva 2012)

The results of investigations concerning tardigrades (2009–2010) in the Bosphorus outlet area of the Black Sea were provided by Kharkevich and Sergeeva (2013). Specimens of Tardigrada were found at 3 stations out of 9 during the cruise of R/V *'Arar'* and only at 1 station out of 18 meiobenthos stations during the cruise of the R/V *'Maria S. Merian'*. In total, 53 specimens of tardigrades were recorded along a depth range of 88–250 m. Two species of tardigrades belonging to Halechiniscidae (Heterotardigrada), namely *Dipodarctus subterraneus* (Renaud–Debyser, 1959) and *Tanarctus ramazzottii* (Renaud–Mornant, 1975) were recorded for the first time in the Black Sea. Average abundance of tardigrades widely varied from 141 ind. m^{-2} to 11.4×10^3 ind. m^{-2}. Their vertical distribution in the sediments showed that most of the specimens (up to 98 %) were found in the top 0–1 cm sediment layer. Bottom–water oxygen concentrations in the study area ranged from 0.17 mmol L^{-1} at 103 m water depth to 0.12 mmol L^{-1} at 88 m water depth. The composition and structure of sediment samples differed in all stations. In the samples from 88 m (st.4) the sediment was represented by gray aleuritic mud with fragments of mollusk shells, at depths of 117 m (st.283) – black mud with mussel shells, at 122 m deep (st.6) – by black mud, and at 250 m (st.9) – flowing black mud with a strong smell of hydrogen sulfide.

The protozoans and fungi along the shelf and continental slope of the Black Sea with oxygen deficiency were previously reported by Sergeeva *et al.* (2014), Sergeeva and Kopytina (2014) and Sergeeva and Zaika (2008). *Cothurnia maritima* Ehrenberg, 1838 on oligochaete *Tubificoides* sp.; *Paracineta livadiana* (Mereschkowsky, 1881) and *Corynophrya lyngbyi* (Ehrenberg, 1834) on the harpacticoid copepod *A. subdebilis*, *H. pontarchis*, *C. tenuipes* and *E. longifurcatum* were recently found in the Bosphorus region of the Black Sea (at depths 200 and 248 m), under hypoxic/anoxic conditions (Sergeeva and Dovgal 2014). A suctorian ciliate *Loricophrya bosporica* sp. nov. was described from the body surface of the nematode specimens belonging to the genus *Desmoscolex* collected at the oxic/anoxic boundary of the Bosphorus outlet area of the Black Sea (Sergeeva and Dovgal 2016). Vertical distribution of the free–living benthic Ciliophora in the Bosphorus area at depths between 120–300 m revealed two peaks of abundance at 103 and 250 m water depths (Sergeeva *et al.* 2017, Sergeeva and Ürkmez 2017). Different forms were present, including moving and attached forms, with a total of more than 30 species (morphotypes). The highest number of benthic ciliate morphotypes was registered at 250 m, in the region with a lower peak of abundance (Sergeeva and Mazlumyan 2015).

Hard–shelled and monothalamous soft–shelled foraminifera showed several peaks of abundances in the area of the Bosphorus Strait. Data collected along a transect across the depth range of 75–300 m during the cruise of the RV *'Arar'* revealed density peaks for both groups of foraminiferans at depths greater than 80 m (Sergeeva and Mazlumyan 2013); hard–shelled forms showed a peak at a depth of 82 m (66.5×10^3 ind. m^{-2}), and monothalamids at 88 m (37×10^3ind. m^{-2}). With a further depth increase, the abundance of both groups decreased, however not uniformly. Monothalamids showed a second small peak (11.5 x10^3 ind. m^{-2}) at a depth of 122 m. Hard–shelled foraminifera revealed a second peak at a depth of 160 meters. These two foraminiferal groups continued to meet until a depth of 250 m. Actually we noted that the number of hard–shelled foraminifera was often higher than that of monothalamids at depths of up to 150 m. At depths of 190–250 m, the number of hard–shelled foraminifera was less than 1x10^3 ind. m^{-2}, whereas the density of monothalamids was 6x10^3 ind. m^{-2} at a depth of 250 m and 260 ind. m^{-2} at a depth of 300 m. The genus *Hyperammina*, which has a fragile arenaceous shell was largely responsible for the peak of foraminifera at a depth of 82 m. On the other hand, the largest representatives of *Hyperammina* can be included to macrobenthos. Additionally, numerous specimens of *Ammonia compacta* (Hofker, 1964) and *Eggerella scabra* (Williamson, 1858) were also responsible for this peak (Sergeeva and Mazlumyan 2013). The number of soft–shelled monothalamids was significantly higher than that of the hard–shelled forms at all studied depths in April 2010 (Figure 11).

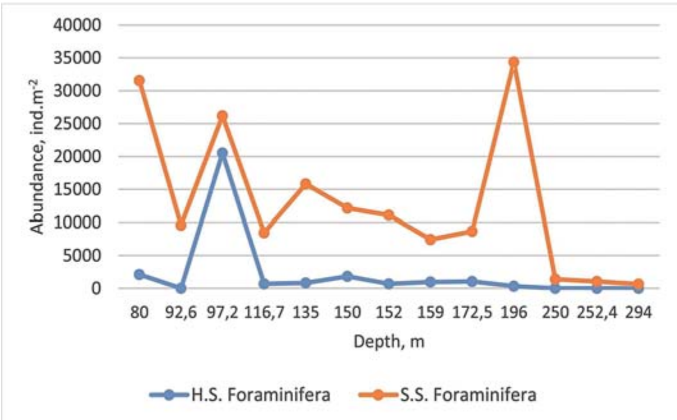

Figure 11. The distribution of soft–shelled (S.S.) and hard–shelled (H.S.) Foraminifera along the transect on the Bosphorus Area (RV '*Maria S. Merian*', May 2010) (Sergeeva *et al.* 2015)

The number and position of the peaks and the maximum depth at which soft–shelled foraminifera occurred showed variation from depth 80 m (31.5x10^3 ind. m^{-2}) to 250–296m (1.4x10^3 ind. m^{-2} at 250 m, and 700 ind. m^{-2} respectively). The density of hard–shelled foraminifera never exceeded 1–2 x 10^3 ind. m^{-2}, except for sharp peaks (20.5x10^3 ind. m^{-2}) at depths of 96 m and 200 m. Hard–shelled foraminifera in contrast to the soft–shelled were more numerous at lower depths (75–160 m). Soft–shelled forms were found at all studied depths but a prominent peak was observed at 88 m. They were also recorded at bottoms under conditions of acute hypoxia / anoxia (250–300 m). Most specimens were found in the top layer (0–2 cm) or in the overlying surface detritus. The identified soft–shelled representatives inhabiting these depths were *Goodayia rostellatum*

Sergeeva and Anikeeva, 2008 and *Tinogulmia* sp. (Gooday 1990, Sergeeva *et al*. 2005, Sergeeva and Anikeeva 2013) observed as the most tolerant ones to oxygen deficiency (Sergeeva and Mazlumyan 2013). This suggests that monothalamids are more resistant to hypoxia. Comparison of the distribution of monothalamous and multi–chambered foraminifera with soft and hard shells, respectively, in the depth of the sediment, supports the conclusion that the former have a greater tolerance to hypoxia.

3.4. Deep Waters off the Central Black Sea

Extreme habitats are the focus of several recent surveys in the world oceans and also in the Black Sea (Sergeeva *et al.* 2013). Oxygen–deprived zones are one of these areas gaining more importance due to climate changes. Black Sea is well known with its large anoxic basin with oxygen deficiency (Luth and Luth 1998, Oğuz *et al.* 2001). However, a permanent suboxic zone where O_2 and H_2S do not coexist was also reported (Murray *et al.* 1989, Duman *et al.* 2006). Nematoda is the most abundant taxon among meiobenthic organisms and have a potential to inhabit different environments on earth. They tend to better survive under low–oxygenated, even anoxic conditions compared to other meiobenthic taxa (Giere 2009). Similar areas in the world are called oxygen minimum zones (OMZ) with their concentrations falling below 0.5 mlL^{-1} (Levin *et al.* 1991, Gooday *et al.* 2010). In these areas with low oxygen distribution, the structure of meio–, macro– and megafaunal benthic communities show a prominently different abundance and diversity (Levin *et al.* 2000, Neira *et al.* 2001). A survey targeting to better understand the oxic/anoxic interface off Sinop coasts in terms of several aspects included the investigation of meiobenthic communities at this special area.

In order to provide the first comparative source of nematode data for local biodiversity of oxic/anoxic interface of the Turkish Black Sea, a quantitative study on meiobenthos and nematode fauna was carried out along a transect throughout oxic, suboxic and anoxic sediments at the western part off Sinop Peninsula, Southern Black Sea. The material was collected during the Black Sea Leg of the NA012 Expedition of E/V Nautilus (Ocean Exploration Trust) in August 2011. Identification of sampling stations and sediment core collection was conducted with remotely operated vehicles (ROVs, '*Hercules*' and '*Argus*') equipped with necessary sensors. Salinity, temperature and dissolved oxygen measurements were recorded via a Falmouth Scientific CTD attached on ROV '*Hercules*'. Three dives were performed at different depths and representative soft bottom locations were selected based on dissolved oxygen readings of the optode (Aanderaa) equipped on the ROV: (1) oxic zone, 69.61 µM; (2) suboxic zone, 1.44 µM; (3) anoxic zone, 0 µM (Table 1). Oxygen level became depleted between depths of 100 and 120 m.

Table 1. Information on the sampling sites at the oxic/anoxic interface of Sinop shores

Exped. No	Dive No.	Date	Latitude	Longitude	Depth (m)	O_2 (μM)	Sediment characteristic
NA012-003	H1152	09.08.2011	42°09.1628N	34°30.6970E	90	69,61	Silt+clay+empty mollusk shells
NA012-001	H1149	05.08.2011	42°11.1197N	34°26.9579E	120.5	1,44	Yellow gravel+empty mollusk shells
NA012-002	H1150	06.08.2011	42°11.6808N	34°28.6798E	203	0	Black clay

Meiobenthos was represented by a total of 13 meiobenthic higher taxa and Species diversity of meiobenthos decreased from oxic site towards the anoxic site. The total abundance ranged from $1.1x10^3$ ind. m^{-2} to $217x10^3$ ind. m^{-2} with the highest value recorded in the oxic sample. Free–living marine nematodes were quantitatively the dominant taxon at three sites. Data of this study provided discovery of a new nematode species (*Leptolaimus sergeevae* (Ürkmez and Brennan 2013)) for science and the first occurrence of a genus and a species (*Trefusia* aff. *longicauda* De Man, 1893) in the Black Sea. Detailed results of this study can be found elsewhere (Brennan *et al.* 2013, Ürkmez *et al.* 2015, Sergeeva and Ürkmez 2017).

As a consequence, analyses showed that the number of main meiobenthic taxa decreased at the anoxic site. Taxa number was low at this site indicating that oxygen deficiency may have an influence on the meiobenthos composition as observed in oxygen minimum zones (OMZ) worldwide (Neira *et al.* 2001). This study also provided us with the first insights into the nematode assemblage of the oxic/anoxic interface in the Southern Black Sea (Sinop) and showed the dominance of particular families (Comesomatidae, Linhomoeidae and Desmodoridae at the oxic site; Trefusiidae at the suboxic site). As an interesting finding, the suboxic site was represented with a large population of *Trefusia* aff. *longicauda* (42.5%). In accordance with this, Sergeeva and Gulin (2007) have mentioned that the hypoxic zone was characterized by particularly adapted benthic groups. Sergeeva and Zaika (2013) have reported 38 species and 6 genera as inhabitants of hypoxic zones in the north-western part of the Black Sea. Results of this research demonstrated that severe oxygen depletion affects the meiobenthos and nematode abundance; moreover, such conditions may actually support the abundance of several taxa. This may be attributed to a probable cause of their tolerance to suboxic conditions; along with the reduction of predation at these O_2 depleted zones.

4. Conclusion

Meiobenthic organisms are a significant part of the Black Sea, not only in terms of shallow bottoms but exclusively in terms of deep-sea benthos, and these organisms are of particular importance due to their ability to tolerate or exclusively live under extreme conditions. Reports were present on live and active organisms in sulfidic parts of the Black Sea (Zaika 2008, Zaika and Sergeeva 2009). In recent years, attention has focused on the meiobenthos living under the extreme conditions of the Black Sea and there have been several papers reporting meiobenthos from these environments (Sergeeva and Zaika 2013, Sergeeva *et al.* 2013, Sergeeva and Dovgal 2014, 2016, Sergeeva *et al.* 2014, Sergeeva and Mazlumyan 2015). It was also reported from the Black Sea coasts of Turkey that several species can be particularly abundant at extreme conditions (Ürkmez *et al.* 2015). Based on all these available data, it is possible to refuse the view accepted for many years about the azoic part of the Black Sea both as a result of samplings and by direct observations of active protozoans and metazoans, living in the deep-water hydrogen sulfide and anoxic zones (Korovchinsky and Sergeeva 2008; Sergeeva *et al.* 2014, Ürkmez *et al.* 2015, Sergeeva and Ürkmez 2017). Future studies at these extreme zones of the Black Sea coasts of Turkey will yield more information about the taxonomic composition of meiobenthos and may give insights to the knowledge of which species are characteristic and indicative of hypoxic/anoxic areas.

In Turkey, field of meiobenthos was an ignored part of benthic studies by national scientists for many years because of the fact that it was a true scientific challenge due to lack of senior meiobenthologists in Turkey, also due to the difficulties encountered in identifications without keys and the requirement of time–consuming works with microscopes. After several surveys of foreign scientists in the Black Sea, recent projects started in 2009 at the Turkish Black Sea coasts with research focusing mainly on the taxonomic diversity and ecology of meiobenthos. Despite important taxonomic works carried out up to date, many species are still new to science, which means that much more effort is needed to discover the true biodiversity of meiobenthic organisms in the Black Sea. There is an urgent need to carry out large scale quantitative studies both at shallow and deep waters and this will require more number of expert scientists well-trained in meiobenthology and specific equipment to be used in the field, particularly for deep sea sampling. Moreover, in the future, we should also strictly adopt the idea to embed meiobenthos in routine coastal monitoring investigations to have the real picture of benthos and to better understand the ecosystems under great pressure such as the case in the Black Sea.

Acknowledgments

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References

Armenteros, M., A. Ruiz–Abierno, R. Fernández–Garcés, J.A. Pérez–García, L. Díaz–Asencio, M. Vincx, and W. Decraemer. 2009. Biodiversity patterns of free–living marine nematodes in a tropical bay: Cienfuegos, Caribbean Sea. Estuarine, Coastal and Shelf Science, 85(2): 179-189.

Bặcesco, M. and C. Mặrgineanu. 1959. Elements mediterranees nouveaux pour la faune de la mer Noire, trouves dans les eaux de Roumelie (Nord–Ouest–Bosphore). Archivio di Oceanografia e Limnologia, 2: 63-73.

Bặcescu, M. 1960. Citeva animale necunoscite incă in Marea Neagrά si Dewscrierea unor malacostracei noi provenind din apele pontice prebosforice. Biologie Animalặ, 12: 107-124.

Băcescu, M. 1961. Le role des iles dans la dispersion récente des espèces indo–pacifiques en Méditerranée occidentale et quelques observations sur la faune marine de L'ile des serpents, en comparaison avec celle peuplants les parages prébosphoriques de la Mer Noire. In V. Le peuplement des iles Méditerraneennes et la problème de l'insularité, Banyulssur–Mer. Paris, France: Centre National de la Recherche Scientifique, pp. 241-253 (in French).

Băcescu, M., E. Dumitrescu, A. Marcus, G. Paladian, and R. Mayer. 1963. Donnees quantitatives sur la faune petricole de la mer noire a Agigea (Secteur Roumain), dans les conditions speciales de l'annee 1961. Travaux du Museum d'Histoire Naturelle "Grigore Antipa," 4: 131-155.

Băcescu, M. 1968. Class Kinorhyncha: Determination of Fauna of the Black and Azov Seas. (in Russian). Naukova Dumka, 1: 237-250.

Balsamo, M., F. Semprucci, F. Frontalini, and R. Coccioni. 2012. Meiofauna as a tool for marine ecosystem biomonitoring, pp.77-104. In A. Cruzado (ed.), Marine Ecosystems.

Brennan, M.L., D. Davis, C. Roman, I. Buynevich, A. Catsambis, M. Kofahl, D. Ürkmez, J.I. Vaughn, M. Merrigan, and M. Duman. 2013. Ocean dynamics and anthropogenic impacts along the southern Black Sea shelf examined through the preservation of premodern shipwrecks. Continental Shelf Research, 53: 89-101.

Caraion, F.E. 1959. Ostracode noi in Marea Neagră (apele bosforice). Comunicările Academia Republicii Populare Romine, 9: 265-273.

Coull, B.C. 1990. Are members of the meiofauna food for higher trophic levels? Transactions of the American Microscopical Society, 109: 233-246.

Coull, B.C. and G.T. Chandler. 1992. Pollution and meiofauna: Field, laboratory and mesocosm studies. Oceanography and Marine Biology: Annual Review, 30:191-271.

Didkowsky, V.Y. 1969. Foraminifera of the near Bosporus area of the Black Sea, pp.70-72, (in Russian). In K.A. Vinogradov, Z.A. Vinogradova, Yu. P. Zaitsev (eds.), Biological Problems of Oceanography of the Southern Seas, Kiev: Naukova Dumka.

Du Chatelet E.A., V. Bout–Roumazeilles, A. Riboulleau, and A. Trentesaux. 2009. Sediment (grain size and clay mineralogy) and organic matter quality control on living benthic foraminifera. Contrôle du sédiment (granulométrie et minéralogie des argiles) et de la qualité de la mati`ere organique sur les foraminif`eres benthiques vivants. Rev. Micropaléontol., 52(1): 75-84.

Duman, M., Duman S., Lyons T.W., Avci M., Izdar E., Demirkurt E. 2006. Geochemistry and sedimentology of shelf and upper slope sediments of the south-central Black Sea. Marine Geology, 227:51-65. DOI: 10.1016/j.margeo.2005.11.009.

Ersoy–Karaçuha, M. 2013. Qualitative and quantitative analysis of harpacticoid copepods (Crustacea: Harpacticoida) of Sinop Peninsula (Southern Black Sea). PhD Thesis, Samsun, pp. 249 (in Turkish).

Feller, R.J. and B.C. Coull. 1995. Non–selective ingestion of meiobenthos by juvenile spot (*Leiostomus xanthurus*). (Pisces) and their daily ration. Vie Milieu, 45(1): 48-59.

Fenchel, T.M. 1978. The ecology of micro and meiobenthos. Annual Review of Ecology and Systematics, 9: 99-121.

Gheskiere, T., E. Hoste, L. Kotwicki, S. Degraer, J. Vanaverbeke, and M. Vincx. 2002. The sandy beach meiofauna and free–living nematodes from De Panne (Belgium), pp. 43-49. In M. Peeters, and J.L. Van Goethem (eds.), Belgian Fauna and Alien Species, Bulletin van het Koninklijk Belgisch Instituut voor Natuurwetenschappen 72 (Suppl.), Brussel, 297 pp.

Giere, O. 2009. Meiobenthology: The Microscopic Motile Fauna of Aquatic Sediments, 528 pp. Springer–Verlag, New York.

Gooday, A.J. 1990. *Tinogullmia riemanni* sp. nov. (Allogromiina; Foraminiferida), a new species associated with organic detritus in the deep sea. Bulletin British Museum Natural History (Zoology), 56(2): 93-103.

Gooday, A.J., Bett B.J., Ecobar E., Ingole B. and Levin L.A. 2010. Habitat heterogeneity and its influence on benthic biodiversity in oxygen minimum zones. Marine Ecology An Evolutionary Perspective, Blackwell Verlag GmbH, 31:125-147. DOI: 10.1111/j.1439-0485.2009.00348.x.

Grove, S.L., P.K. Probert, K. Berkenbusch, and S.D. Nodder. 2006. Distribution of bathyal meiofauna in the region of the Subtropical Front, Chatham Rise, south–west Pacific. Journal of Experimental Marine Biology and Ecology, 330: 342-355.

Heip, C., M. Vincx, and G. Vranken. 1985. The ecology of marine nematodes. Oceanography and Marine Biology: An Annual Review, 23: 399-489.

Higgins, R.P. and H. Thiel. 1988. Introduction to the Study of Meiofauna, pp1-488. Smithsonian Institution Press: Washington D.C., London.

Holtappels M., A. Lichtschlag, Yu Ihsan., A. Boetius, N. Cagatay, L. Gaute, and M. Kuypers. 2011. Coupled denitrification – sulfide oxidation stimulated by the inflow of oxic Mediterranean waters into the anoxic layers of the Black Sea. Geophysical Res., Abstracts, 13, EGU2011-9125.

Kharkevych, K. 2013. Species composition and ecology of tardigrades of the Black Sea. Natura Montenegrina, 12(2): 357-368.

Kharkevych, Kh. O. and N.G. Sergeeva. 2013. Deep–Water Tardigrada of the Istanbul Strait's (Bosporus) outlet area of the Black Sea: Vestnik zoologii, 47(3): 17-27.

Kiseleva, M.I. 1969. Composition and distribution of benthos in the near–Bosporus Black Sea region, (in Russian), pp. 233–253. In V.A. Vodyanitsky, V.N. Greze, M.A. Dolgopolskaya and E.V. Pavlova (eds.), Water cycle through Bosporus and his influence on hydrology and biology of the Black Sea. Kiev, Naukova Dumka.

Kolesnikova, E.A., V.E. Zaika, N.G. Sergeeva, and A. Lichtschlag. 2014. Harpacticoida Copepoda under hypoxia conditions in the Black Sea, pp.51-76. In L. Seuront (ed.) Copepods Diversity, Habitat and Behavior, Nova Science Publ.

Korovchinsky, N.M., Sergeeva, N.G. 2008. A new family of the order Ctenopoda (Crustacea: Cladocera) from the depths of the Black Sea. Zootaxa, 1795: 57-66, DOI: 10.5281/zenodo.182646

Levin, L.A., C.L. Huggett, and K.F. Wishner. 1991. Control of deep–sea benthic community structure by oxygen and organic–matter gradients in the eastern Pacific Ocean. Journal of Marine Research, 49: 763-800.

Levin, L.A., J.D., Gage, C., Martin and P.A. Lamont 2000. Macrobenthic community structure within and beneath the oxygen minimum zone, NW Arabian Sea. Deep-Sea Research II, 47: 189-226. DOI: 10.1016/S0967-0645(99)00103-4.

Lichtschlag, A., D. Donis, F. Janssen, G.L. Jessen, M. Holtappels, F. Wenzhöfer, S. Mazlumyan, N. Sergeeva, C. Waldmann, and A. Boetius. 2015. Effects of fluctuating hypoxia on benthic oxygen consumption in the Black Sea (Crimean Shelf). Biogeosciences Discuss, 12: 6445-6488.

Luth, U. and Luth C. 1998. Benthic meiofauna and macrofauna of a methane seep area South-west of the Crimean Peninsula, Black Sea. In Luth U., Luth C. & Thiel H. (Eds.), MEGA-SEEPS- Methane Gas Seeps Exploration in the Black Sea (pp. 59-77). Berichte aus dem Zentrum fuer Meeres und Klimatoforsch, Hamburg.

Luth, U. 2004. The benthos of the oxic/anoxic interface in the western Black Sea: comparative macro– and meiofauna investigations on transects from the Ukrainian, Romanian and Turkish shelf, pp. 2-69. In B. Öztürk, V.O. Mokievsky and B. Topaloğlu (eds.), Proceedings of the International Workshop on Black Sea Benthos 19-23 April, Istanbul-Turkey.

Mare, M.F. 1942. A study of a marine benthic community with special reference to the marine meiobenthos: a review. Journal of the Marine Biological Association of the United Kingdom, 25: 517-554.

Marinov, T. 1962. The upper ostracodes fauna at the Black sea western coast, (in Bulgarian). Proceedings of the Institute of Fisheries, Varna, 2: 81-108.

Marinov, T. 1964. On the microzoobenthos fauna of the Black Sea (Kinorhyncha and Halacaridae), (in Bulgarian). Bulletin of the Institute of Fish Culture and Fisheries, Varna KH, 4:61-71.

McIntyre, A.D. 1969. Ecology of marine meiobenthos. Biological Reviews, 44: 245-288.

Mikhalevich, V.I. 2013. On the distribution of recent hard shelled foraminifera in the Black Sea. Proceedings of IGCP 610 First Plenary Conference and Field Trip, "From the Caspian to Mediterranean: Environmental Change and Human Response during the Quaternary", Tbilisi, Georgia, 96-98.

Neira, C., J. Sellanes, L.A. Levin, and W.E. Arntz. 2001. Meiofaunal distributions on the Peru margin: relationship to oxygen and organic matter availability. Deep Sea Res., 48(11): 2453-2472.

Nikitin, V.N. 1938. The lower boundary of benthic fauna and its distribution in the Black Sea, (in Russian). Rep. Ac. Sci. USSR. 21(7): 341-345.

Nikitin, V.N. 1948. Biocenotic groupings and quantitative distribution of bottom fauna in the eastern part of the southern coast of the Black Sea / Proc. Sevastopol Biological Station, 6: 256-273.

Nikitin, V.N. 1964. Quantitative distribution of bottom macrofauna in the Black Sea. Proceedings OAN USSR, 59: 286-329.

Oğuz, T., Murray J.W. and Callahan A.E. 2001. Modeling redox cycling across the suboxic–anoxic interface zone in the Black Sea. Deep Sea Research I, 48:761-787.

Öksüz, İ. 2012. Benthic foraminiferal assemblages of the surface sediments of Sinop Coasts. MSc Thesis, Sinop, pp.161 (in Turkish).

Öksüz, İ., M. Sezgin, and D. Ürkmez. 2016. The use of living benthic foraminifera as ecological indicators in Sinop Bay (Black Sea, Turkey). In Abstract Book of International Meiofauna Workshop, p. 48.

Palmer, M.A., D.L. Strayer, and S.D. Rundle. 2006. Meiofauna, pp.415-433. In F.R. Hauer and G.A. Lamberti (eds.), Methods in Stream Ecology, Elsevier: New York.

Platt, H.M. and R.M. Warwick. 1983. Free Living Marine Nematodes. Part I. British Enoplids. Cambridge University Press. Cambridge, 307 pp.

Pusceddu, A., C. Gambi, C. Corinaldesi, M. Scopa, and R. Danovaro, 2014. Relationships between meiofaunal biodiversity and prokaryotic heterotrophic production in different tropical habitats and oceanic regions. PLoS ONE, 9(3): e91056.

Robertson, A.L., S.D. Rundle, and J.M. Schmid–Araya. 2000. Putting the meio– into stream ecology: Current findings and future directions for lotic meiofaunal research. Freshwater Biology, 44: 177-183.

Rundle, S.D., A.L. Robertson, J.M. Schmid–Araya. 2002. Freshwater Meiofauna: Biology and Ecology. Leiden: Backhuys Publishers.

Sandulli, R., F. Semprucci, and M. Balsamo. 2014. Taxonomic and functional biodiversity variations of meiobenthic and nematode assemblages across an extreme environment: a study case in a Blue Hole cave. Ital. J. Zool., 81(4): 508-516.

Semprucci, F., P. Colantoni, C. Sbrocca, G. Baldelli, M. Rocchi, and M. Balsamo. 2011. Meiofauna in sandy back–reef platforms differently exposed to the monsoons in the Maldives (Indian Ocean). J. Mar. Syst., 87 (3-4): 208-215.

Semprucci, F., F. Frontalini, A. Covazzi–Harriague, R. Coccioni, and M. Balsamo. 2013. Meio– and macrofauna in the marine area of the Monte St. Bartolo Natural Park (Central Adriatic Sea, Italy). Scientia Marina, 77(1): 189-199.

Sergeeva, N.G. 1973a. New species of free–living Nematodes of the order Chromadorida in the Black Sea, (in Russian). Russian Journal of Zoology, 52(8): 1238-1241.

Sergeeva, N.G. 1973b. New species of free–living Nematodes of the order Enoplida from the Black Sea, (in Russian). Russian Journal of Zoology, 52(11): 1710-1714.

Sergeeva, N.G. 1974. New free–living Nematodes (Enoplida) from the Black Sea, (in Russian). Russian Journal of Zoology, 53(1): 120-125.

Sergeeva, N.G. 1977. New free–living Nematodes in the Black Sea, (in Russian). Vestnik Zoologii, 1: 36-44.

Sergeeva, N.G. 2003. Meiobenthos of the Crimean fluffy bottom bed, (in Russian), pp. 248-251. In V.N. Eremeev, and A.V. Gaevskaya (eds.), Modern condition of biological diversity in near-shore zone of the Crimea (the Black Sea sector). Ekosi-Gidrophizika, Sevastopol, 248-251.

Sergeeva, N.G., O.V. Anikeeva, and A.J. Gooday. 2005. The monothalamous foraminiferan *Tinogullmia* in the Black Sea. Journal of Micropalaeontology, 24: 191-192.

Sergeeva, N.G. and M.B. Gulin. 2007. Meiobenthos from an active methane seepage area in the NW Black Sea. Marine Ecology, 28: 152-159.

Sergeeva, N.G. and V.E. Zaika. 2008. Ciliophora in hydrogen sulfide zone of the Black Sea. Mar. Ecol. J., 7: 80-85.

Sergeeva, N.G. and S. Mazlumyan. 2011. Meiobenthos abundance in the bottom sediments of the Bosporus area. Institute of Biology of the Southern Seas, National Academy of Sciences of Ukraine, Sevastopol.

Sergeeva, N.G., A.J. Gooday, S.A. Mazlumyan, E.A. Kolesnikova, A. Lichtschlag, T.N. Kosheleva, and O.V. Anikeeva. 2012. Meiobenthos of oxic/anoxic interface of southwestern region of the Black Sea: Abundance and Taxonomic composition. In A.V.

Altenbach, J.M. Bernhard, and J. Seckbach (eds.), Anoxia: Paleontological Strategies and Evidence for Eukaryotes Survival, Springer, pp. 369-401.

Sergeeva, N.G. and O.V. Anikeeva. 2013. Soft–walled foraminifera under normoxia / hypoxia conditions in the shallow areas of the Black Sea. Chapter IX. In M. Dan Georgescu (ed.), Foraminifera. Aspects of Classification, Stratigraphy, Ecology and Evolution, 227-247.

Sergeeva, N.G. and S.A. Mazlumyan. 2013. Foraminifera under conditions of hypoxia/anoxia at the Istanbul Strait's (Bosphorus) outlet area to the Black Sea. In Proceedings of the IGCP– 610 First Plenary Meeting and Field Trip, Tbilisi, Georgia, pp. 122-125.

Sergeeva, N.G. and V.E. Zaika. 2013. The Black Sea meiobenthos in permanently hypoxic habitat. Acta Zoologica Bulgarica, 65(2): 139-150.

Sergeeva, N.G., S. Mazlumyan, N. Cağatay, and A. Lichtschlag. 2013. Hypoxic meiobenthic communities of the Istanbul Strait's (Bosporus) outlet area of the Black Sea. Turkish Journal of Fisheries Aquatic Sciences, 13: 33-41.

Sergeeva, N.G. and I.V. Dovgal. 2014. First finding of epibiont peritrich and suctorian ciliates (Ciliophora) on oligochaetes and harpacticoid copepods from the deep–water hypoxic/anoxic conditions of the Black Sea. Ecologica Montenegrina, 1(1): 49-54.

Sergeeva, N.G. and N.I. Kopytina. 2014. The first marine filamentous fungi discovered in the bottom sediments of the oxic/anoxic interface and in the bathyal zone of the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 497-505.

Sergeeva, N.G., S.A. Mazlumyan, A. Lichtschlag, and M. Holtappels. 2014. Benthic Protozoa and Metazoa living under anoxic and sulfide conditions in the Black Sea: direct observations of actively moving Ciliophora and Nematoda. International Journal of Marine Science, 4(42): 1-11. http://ijms.biopublisher.ca.

Sergeeva, N.G. and S.A. Mazlumyan. 2015. Deep–water hypoxic meiobenthic Protozoa and Metazoa taxa of the Istanbul Strait's (Bosporus) outlet area of the Black Sea. Ecologica Montenegrin., 2(3): 255-270.

Sergeeva, N.G,. V.E. Zaika, and O.V. Anikeeva. 2015. An overview on distribution and abundance of meiobenthic foraminifera in the Black Sea. Ecol. Mont., 2(1): 117-134.

Sergeeva, N.G. and I. Dovgal. 2016. *Loricophrya bosporica* n. sp. (Ciliophora, Suctorea) epibiont of *Desmoscolex* cf. *minutus* (Nematoda, Desmoscolecida) from oxic/anoxic boundary of the Black Sea Istanbul Strait's outlet area. Zootaxa, 4061(5): 596-600.

Sergeeva, N.G. and D. Ürkmez. 2017. Current views on the diversity and distribution of deep–water meiobenthos at the Turkish shelf (Black Sea). Ecologica Montenegrina, 14: 60-73.

Sergeeva, N.G., D. Ürkmez, I.V. Dovgal, and M. Sezgin. 2017. Protists (Ciliophora, Gromiida, Foraminifera) in the Black Sea meiobenthic communities. J. Black Sea/Mediterranean Environment, 23(2): 121-155.

Sezgin, M., D. Ürkmez, and M. Ersoy–Karaçuha. 2013. Application of Nematode/Copepod index in the Black Sea: Any indication for use in monitoring of organic pollution? 4th Black Sea Scientific Conference, BSGES–2013, "Challenges Towards Good Environmenal Status", Constanta–Romanya. p. 41.

Shornikov, E.I. 1966. Ostracoda belonging to the group of the fossil *Candona lobate* (Zalanyi, 1929) in the recent state in the Caspian Sea, (in Russian). Russian Journal of Zoology, 45: 1094-1096.

Urban–Malinga, B., A. Drgas, S. Gromisz, and N. Barnes. 2014. Species–specific effect of macrobenthic assemblages on meiobenthos and nematode community structure in shallow sandy sediments. Marine Biology, 161(1): 195-212.

Ürkmez, D., N.G. Sergeeva, and M. Sezgin. 2011. Seasonal changes of nematodes from Sinop coasts of the Black sea: Proceedings of the 6th International Conference "Environmental Micropaleontology, Microbiology and Meiobenthology". (Borissiak Paleontological Institute RAS, Russia, September 19-22). Moscow, 279-282.

Ürkmez, D. and M.L. Brennan. 2013. A new species of *Halaphanolaimus* (Nematoda: Leptolaimidae) from the southern Black Sea (Turkey) with a modified key for species identification. Zootaxa, 3691(2): 220-228.

Ürkmez, D., M. Sezgin, and L. Bat. 2014. Use of nematode maturity index for the determination of ecological quality status: a case study from the Black Sea. Journal of the Black Sea and Mediterranean Environment, 20(2): 96-107.

Ürkmez, D. 2015. Dynamics of the meiobenthic nematode fauna of Sinop Bay and the taxonomy and ecology of chromadoridae. PhD Thesis, Sinop, pp.369 (in Turkish).

Ürkmez, D., M.L. Brennan, M. Sezgin, and L. Bat. 2015. A brief look at the free–living Nematoda of the oxic/anoxic interface with a new genus record (*Trefusia*) for the Black Sea. Oceanological and Hydrobiological Studies, 44(4): 539-551.

Ürkmez, D., M. Sezgin, M. Ersoy Karaçuha, İ. Öksüz, T. Katağan, L. Bat, E. Dağlı, and F. Şahin. 2016a. Within–year spatio–temporal variation in meiofaunal abundance and community structure, Sinop Bay, the Southern Black Sea. Oceanological and

Hydrobiological Studies, 45(1): 55-65.

Ürkmez, D., F. Pardos, M. Sezgin, M. Ersoy–Karaçuha, and İ. Öksüz, 2016b. *Echinoderes dujardinii* Claparede, 1863 (Kinorhyncha, Cyclorhagida): A new record for the kinorhynch fauna of Turkey. Ecologica Montenegrina, 6: 1-8. http://www.biotaxa.org/em/article/view/20897/20204.

Ürkmez, D., M. Sezgin, M. Ersoy–Karaçuha, and İ. Öksüz. 2016c. Meiobenthic assemblages from the southwestern coast of the Black Sea, İgneada (Turkey). Biologia, 71/9: 1017-1026.

Ürkmez, D., M. Sezgin, L. Bat, and F. Şahin. 2017. Assessment of the ecological quality status (EQS) of a coastal area (Sinop, Black Sea) based on nematode maturity index. In Abstract Book of Promare 2017, Romania, p. 45.

Watson, C.H., J.I. Carvajal, N.G. Sergeeva, F. Pleijel, and G.W. Rouse. 2016. Free–living *Calamyzin chrysopetalids* (Annelida) from methane seeps, anoxic basins, and whale falls. Zoological Journal of the Linnean Society, 177: 700-719.

Wieser, W. 1953. Die beziehung zwschen mundhöhlengestalt, Ernährungsweise und vorkommen bei freilebenden marinen nematoden. Arkiv. Zool., 2(4): 439-484.

Yakubova, L.I. 1948. Features of Biology of the Bosporus area of the Black Sea, (in Russian), 6: 275-285. In V.V. Yanko, and L.V. Vorobyova (eds.), Proceedings of the Sevastopol Biological Station, 1991. Foraminifera of the Bosphorus and the Black Sea. Ekologiya Morya, 39: 47-51.

Zaika, V.E., N.G. Sergeeva, and M.I. Kiseleva. 1999. Two polychaetes species bordering deep anoxic waters in the Black Sea. Tavrichesky Medical–Biological Vestnik, 1-2(99): 56-60.

Zaika, V.E. 2008. Is there animal life at the Black sea great depths?, (in Russian). Marine Ecological Journal, 7: 5-11.

Zaika, V.E. and N.G. Sergeeva. 2008. The boundary change of benthic settlement of polychaetes *Protodrilus* sp. and *Vigtorniella zaikai* in the Black Sea, (in Russian). Marine Ecological J. 7(2): 49-53.

Zaika, V.E. and N.G. Sergeeva. 2009. The vertical distribution of the deep-water ciliates in the Black Sea. Marine Ecological Journal, 8(1): 32-36.

Zaika, V.E. and N.G. Sergeeva. 2012. Deep–water benthic polychaetes (*Vigtorniella zaikai* and *Protodrilus* sp.) in the Black Sea as indicators of the hydrogen sulfide zone Boundary. Vestnik Zoology, 46: 19-27.

Zaitsev, Y.P. 2008. An Introduction to the Black Sea Ecology, 228 pp. Smil Edition and Publishing Agency Ltd., Odessa, Ukraine.

Zeppilli, D., J. Sarrazin, D. Leduc, *et al.* 2015. Is the meiofauna a good indicator for climate change and anthropogenic impacts? Marine Biodiversity, 45(3): 505-535.

MACROZOOBENTHOS IN THE BLACK SEA

Murat SEZGİN [1] and Güley KURT-ŞAHİN [2]

[1]Faculty of Fisheries, Dept. of Hydrobiology, Sinop University, Sinop, Turkey
[2]Faculty of Arts and Sciences, Dept. of Biology, Sinop University, Sinop, Turkey
gkurtsahin@sinop.edu.tr

The coastline of Turkey which is surrounded by the Mediterranean, Aegean, Marmara and Black Seas is about 8,500 km in length, excluding islands. This extensive marine and coastal fringe supports a rich and important biodiversity. However, the coastal and marine biodiversity of the Turkish Black Sea is constantly under serious threat due to the pressures exerted by mankind. The major threats are posed by the destruction of marine habitats and ecosystems, over-exploitation of marine resources and the loss of coastal habitats through mass urbanization (Öztürk *et al.* 2013).

The Turkish coast of the Black Sea was poorly investigated in terms of zoobenthic groups. The studies carried out on the Black Sea coast of Turkey were mainly focused on the pre-bosphoric region published by various authors (Jakubova 1948, Demir 1952, Marinov 1959, Dimitrescu 1960, 1962, Rullier 1963, Caspers 1968, Kiseleva 1981, Gillet and Ünsal 2000, Uysal *et al.* 2002). The Anatolian Region of the Black Sea was studied by Kocatas and Katagan (1980), Ates (1997), Mutlu *et al.* (1992; 1993), Sezgin *et al.* (2001), Gonlugur (2003), Ozturk *et al.* (2004), Çinar and Gonlugur-Demirci (2005), Gonlugur-Demirci (2006), Kirkim *et al.* (2006), Sezgin and Katagan (2007), Bilgin *et al.* (2007), Agirbas *et al.* (2008), Gozler *et al.* (2009), Dagli (2012), Kurt-Sahin and Çinar (2012), Kus and Kurt-Sahin (2015), and Kurt-Sahin *et al.* (2017a).

When the up-to-present studies at the Black Sea coasts of Turkey (Açik 2014, Bakir *et al.* 2014, Çinar 2014, Çinar *et al.* 2014a,b, Evcen *et al.* 2016, Koçak and Onen 2014, Kus and Kurt-Sahin 2015, Kurt-Sahin *et al.* 2017a,b, Oztoprak *et al.* 2014, Ozturk *et al.* 2014, Topaloglu and Evcen 2014) are considered, 788 species belonging to 12 zoobenthic taxa (Porifera, Cnidaria, Platyhelminthes, Nematoda, Nemertea, Bryozoa, Sipuncula, Annelida, Phoronida, Arthropoda, Mollusca and Echinodermata) have been recorded at the samplings by 2017 (Figures 1, 2). According to the 2001-2007 State of Environment Report, 385 species were reported in 2000-2007 period and 731 species were reported until 2014 (Figure 3).

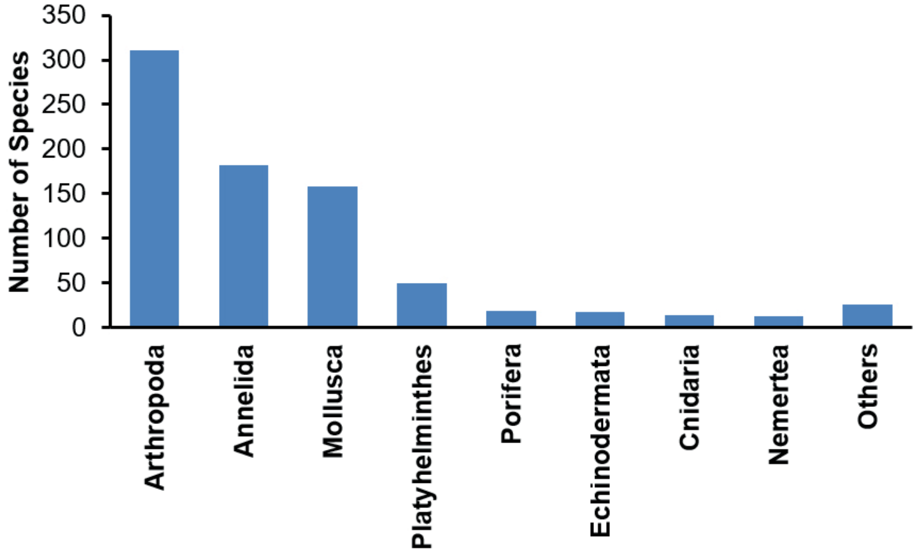

Figure 1. Number of species in the macrozoobenthic taxa reported from the Turkish coasts of the Black Sea

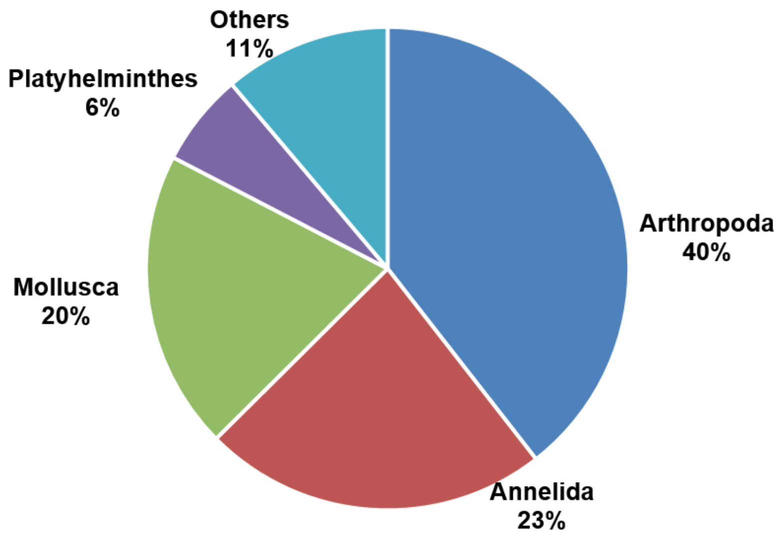

Figure 2. Relative percentages of the zoobenthic taxa reported from the Turkish coasts of the Black Sea

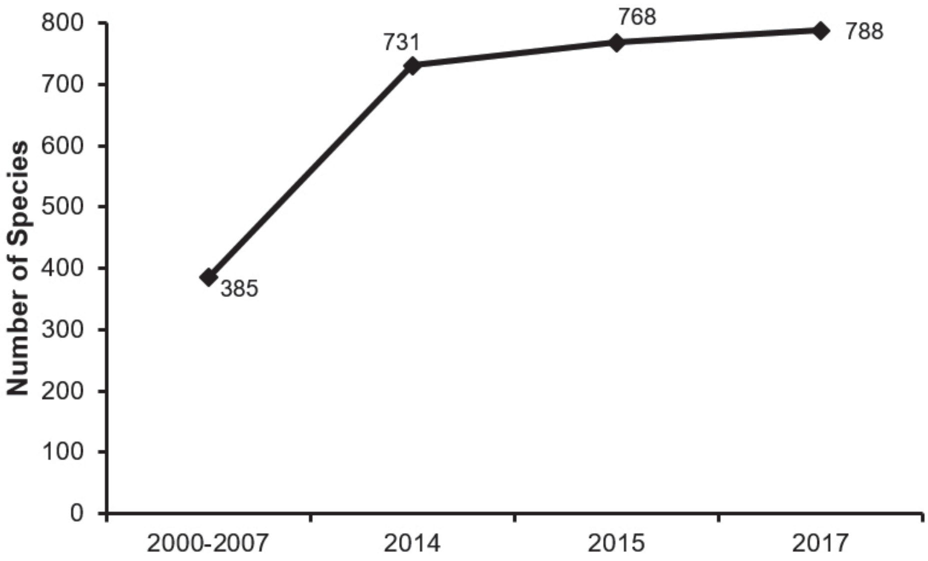

Figure 3. Annual changes in the number of species of macrozoobenthos along the Turkish coasts of the Black Sea

Among these species, 9 alien species were reported from the Turkish coast of the Black Sea up to date (Table 1). Besides, *Cerithium vulgatum* Bruguière, 1792 and *Pholas dactylus* Linnaeus, 1758 are recognized as endangered or threatened according to the IUCN Red List and Barcelona/ Bern Conventions (Ozturk *et al.* 2014).

Table 1. Alien species reported from the Turkish coasts of the Black Sea

Polychaeta	**References**
Capitellethus dispar (Ehlers, 1907)	Rullier 1963
Prionospio pulchra Imajima, 1990	Dagli & Çinar 2011
Crustacea	
Callinectes sapidus Rathbun, 1896	Yaglioglu *et al.* 2014
Pilumnus minutus De Haan, 1835	Gonlugur-Demirci 2006
Mollusca	
Anadara kagoshimensis (Tokunaga, 1906)	Albayrak 2003
Mya arenaria Linnaeus, 1758	Uysal *et al.* 1998
Rapana venosa (Valenciennes, 1846)	Fischer-Piette 1960
Teredo navalis Linnaeus, 1758	Gonlugur-Demirci 2005
Echinodermata	
Asterias rubens Linnaeus, 1758	Karhan *et al.* 2008

Total 20 stations located at 7-70 m water depths were investigated along the Black Sea coasts of Turkey in 2016 in the scope of the Black Sea Monitoring Project for the Determination of Ecological Quality Status within the Integrated Monitoring Activities in Turkish Seas (a cooperation between Republic of Turkey Ministry of Environment and Urbanization and TÜBİTAK-MAM). As a result of this study, the ecological quality status (EcoQ) at each station was determined using two different biotic indices such m-AMBI (Muxika *et al.* 2007, Borja *et al.* 2008) and TUBI (Çinar *et al.* 2015) (Figure 4). A general evaluation inferred from the map prepared according to the index values of the stations implies that the ecological quality status of the stations are at good and moderate level.

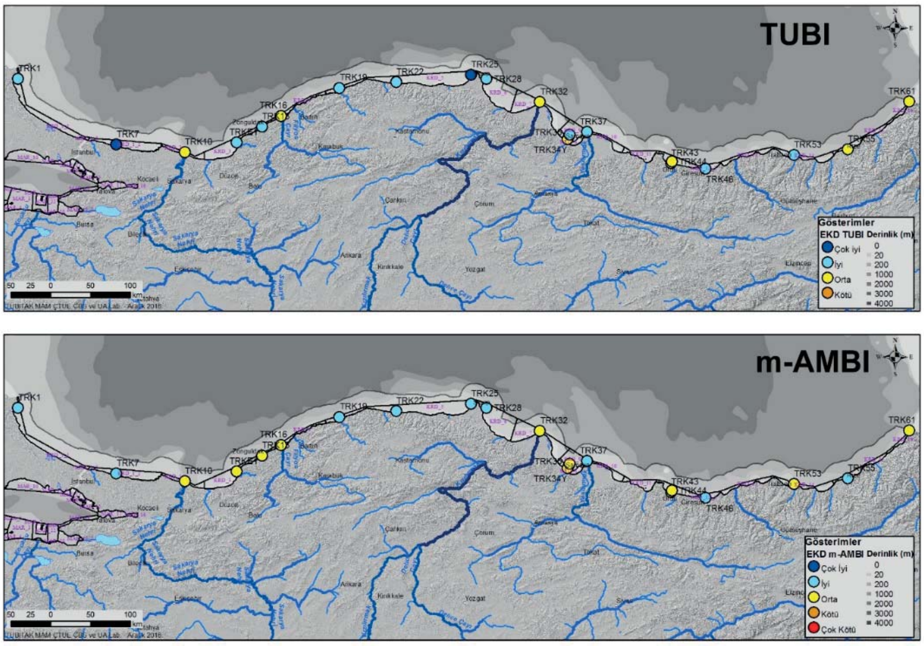

Figure 4. TUBI and m-AMBI results of the stations along the Turkish coast of the Black Sea in 2016

Habitat structure of the Turkish Black Sea coasts was presented by European Marine Observation and Data Network (EMODnet) in their 2015 report. Accordingly, the infralittoral rocky substratum of the benthic zone is covered by photophilic algae and the main components are *Cystoseira barbata, Ulva rigida, Polysiphonia subulifera, Cladophora spp., Ulva rigida, Ulva intestinalis* and *Gelidium* spp. Key components of the infralittoral sandy and muddy-sand substrata are listed as follows: shallow fine sands with *Lentidium mediterraneum, m*edium to coarse sands with *Donax trunculus,* infralittoral sand with *Chamelea gallina* (with *Cerastoderma glaucum, Lucinella divaricata, Gouldia minima*) (depends on the region), muddy sand with burrowing thalassinid *Upogebia pusilla/Pestarella candida*. The circalittoral rocky substratum is reported to be composed of Scyaphilic algae *(Phyllophora* spp., *Polysiphonia* spp., *Zanardinia* spp., *Gelidium* spp.), sponges and hydroids. Shallow circalittoral mud and organogenic sandy mud at the circalittoral zone is characterized by muds with *Abra prismatica - Pitar rudis - Spisula subtruncata, Acanthocardia paucicostata and Nephtys hombergii* and sandy muds with *Dipolydora* meadows and *Mytilus*. Deep circalittoral coarse mixed sediments are known to be composed of shelly muds with *Modiolula phaseolina*. It is obvious that more areas and depths should be investigated in order to clearly reveal the zoobenthic diversity and the community structure of the Black Sea coasts of Turkey.

The Black Sea is an enclosed system encompassing the largest anoxic basin on the planet, due to the limited water renewal and exchange with the Mediterranean Sea and Atlantic Ocean through the Istanbul (Bosphorous) Strait This unique property renders the Black Sea ecosystem rather vulnerable to anthropogenic pressures and require special protection for its biodiversity. One of the most effective solutions for the recovery of a marine ecosystem is to designate Marine Protected Areas (MPAs) in certain areas of ecological or biological significance in the given sea according to the Convention of Biological Diversity (CBD). The main goals of assigning such protected areas are to preserve biological diversity and maintain essential ecological processes to both ensure the sustainable use of species and ecosystems and to protect environmental quality, the health and safety of coastal communities and of resource users (Öztürk *et al.* 2013).

Öztürk *et al.* (2013) recommended five ecologically important sites (İğneada, Şile-Kefken, Doğanyurt, Kızılırmak and Yeşilırmak, Mezgit Reef) to be designated as Marine Protected Areas (MPA) along the Turkish Black Sea coast, where currently no MPAs exist.

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References

Açik, S. 2014. Checklist of Sipuncula from the coasts of Turkey. Turkish Journal of Zoology, 38: 723-733.

Agirbas, E., A.M. Gozler, C. Sahin, and N. Hacimurtazaoglu. 2008. Doğu Karadeniz'de Dağılım Gösteren *Ulva* fasiesinin Poliket Faunası. Journal of Fisheries Science, 2, 427-431.

Albayrak, S. 2003. On the Mollusca fauna of the Black Sea near Istanbul. Zoology in the Middle East, 30: 69-75.

Ates, A.S. 1997. A study on the decapod crustacean fauna of the coast of Gerze-Hamsaroz (Sinop) (in Turkish with English abstract), Ms.C. Thesis, University of Ondokuz Mayis, Samsun, pp.1-57.

Aydin, M., U. Karadurmus, and E. Tunca. 2014. Morphometric aspects and growth modeling of exotic bivalve blood cockle *Scapharca inaequivalvis* from the Black Sea, Turkey. Biologia, 69 (12): 1707-1715.

Bakir, A.K., T. Katagan, H.V. Aker, T. Özcan, M. Sezgin, A.S. Ates, C. Koçak, and F. Kirkim. 2014. The marine arthropods of Turkey. Turkish Journal of Zoology, 38: 765-831.

Borja, A., D.M. Dauer, R. Diaz, R.J. Llansó, I. Muxika, J.G. Rodriquez, and L. Schaffner. 2008. Assessing estuarine benthic quality conditions in Chesapeake Bay: A comparison of three indices. Ecological indicators, 8: 395-403.

Bilgin, S., A.S. Ates, and E.S. Çelik. 2007. The Brachyura (Decapoda) community of *Zostera marina* meadows in the coastal area of the Southern Black Sea (Sinop Peninsula, Turkey). Crustaceana, 80 (6): 717-730.

Caspers, H. 1968. La macrofaune benthique du Bosphore et les problèmes de l'infiltration des éléments Méditerranées dans la mer Noire. Rapp Com int Mer Médit 19: 107-115.

Çinar, M.E. 2014. Checklist of the phyla Platyhelminthes, Xenacoelomorpha, NematodaAcanthocephala, Myxozoa, Tardigrada, Cephalorhyncha, Nemertea, Echiura, Brachiopoda, Phoronida, Chaetognatha, and Chordata (Tunicata, Cephalochordata, and Hemichordata) from the coasts of Turkey. Turkish Journal of Zoology, 38: 698-722.

Çinar, M.E., E. Dağlı, and G. Kurt Sahin. 2014a. Checklist of Annelida from the coasts of Turkey. Turkish Journal of Zoology, 38: 734-764.

Çinar, M.E., B. Yokes, S. Açik and A.K. Bakir. 2014b. Checklist of Cnidaria and Ctenophora from the coasts of Turkey. Turkish Journal of Zoology, 38: 677-697.

Çinar M.E, K. Bakır, B. Öztürk, T. Katağan, E. Dağlı, S. Açık, A. Doğan, and B. Bitlis Bakir. 2015. TUBI (Turkish Benthic Index): A new biotic index for assessing impacts of organic pollution on benthic communities. J. Black Sea Medit. Env. 21: 135-168.

Dagli, E. and M.E. Cinar. 2011. Species of the subgenus *Minuspio* (Polychaeta: Spionidae: *Prionospio*) from the southern coast of Turkey (Levantine Sea, eastern Mediterranean), with the description of two new species. Zootaxa, 3043: 35-53.

Dagli, E. 2012. A new record of the Polychaeta fauna of the Black Sea: *Prionospio* (*Minuspio*) *maciolekae* Dagli and Çinar, 2011 (Polychaeta: Spionidae). Ege J. Fish Aqua. Sci. 28: 29-34.

Demir, M. 1952. Benthic Invertebrates of the Coasts of Bosphorus and Islands (in Turkish). Hydrobiology Research Institute, Istanbul University Pres., 2A: 1-654.

Dumitrescu, E. 1960. Contributions à la connaissance des Polychètes de la Mer Noire, spécialement des eaux prébosphoriques. Trav Mus Natl Hist Nat Grigore Antipa 2 : 69-85.

Dumitrescu, E. 1962. Nouvelle contribution à l'étude des Polychètes de la Mer Noire. Trav Mus Natl Hist Nat Grigore Antipa 3: 61-68.

Evcen, A., M.E. Çinar, M. Zengin, S. Süer and M. Rüzgar. 2016. New records of five sponge species (Porifera) for the Black Sea. Zootaxa, 4103(3): 267-275.

Fischer-Piette, E. 1960. *Rapana bezoar* I. sur la cote Turquie de la mer Noire, (in French). Hydrobiologi, Serie B5 1-2: 51.

Gillet, P. and M. Unsal. 2000. Rèsultats de la campagne ocèanographique de "Bilim": annèlides polychètes de la Mer de Marmara, du Bosphore et des règions prèbosphoriques de la Mer Noire. Mèsogèe, 58: 85-91.

Gonlugur, G. 2003. Qualitative and quantitative investigations on some facies of the upper-infralittoral zone of the Western Black Sea (Sinop) shores (in Turkish), Ph.D. Thesis, Institute of Natural and Applied Sciences, Ege University, Izmir, pp. 1-323.

Gönlügür-Demirci, G. 2005. Mollusca fauna of Sinop Peninsula (Middle Black Sea). Science and Eng. J. of Fırat Univ., 17: 565-572.

Gonlugur-Demirci, G. 2006. Crustacea fauna of the Turkish Black Sea coasts: a check list. Crustaceana, 79: 1129-1139.

Gozler, A.M., E. Agirbas, and C. Sahin. 2009. Spatial and temporal distribution of Nereidae (Polychaeta: Annelida) along the coast of Turkish eastern Black Sea in the upper-infralittoral zone. J. Anim. Vet. Adv., 8: 229-234.

Jakubova, L.I. 1948. Features of the biology of Prebosphoric sector of the Black Sea. Trudy Sevastopol'skoj, Biologicheskoj Stantsii, 6: 274-285.

Karhan, S.Ü., E. Kalkan, and M.B. Yokeş. 2008. First record of the Atlantic starfish, *Asterias rubens* (Echinodermata: Asteroidea) from the Black Sea. JMBA 2 Biodiversity Records, 1: 1-3.

Kırkım, F., M. Sezgin, T. Katağan, L. Bat, and E. Aydemir. 2006. Some benthic soft-bottom crustaceans along the Anatolian coast of the Black Sea. Crustaceana, 79(11): 1323-1332.

Kiseleva, M.I. 1981. Soft-bottom benthos of the Black Sea, (in Russian). Kiev, Naukova Dumka, pp.168.

Koçak, F. and S. Aydın Önen. 2014. Checklist of Bryozoa on the coasts of Turkey. Turkish Journal of Zoology, 38: 765-831.

Kocataş, A. and T. Katağan. 1980. Benthic Amphipods of Turkish Black Sea Coasts (in Turkish with English abstract), In: Proceedings of the VIIth Science Congress, Kuşadası, 6-10 October 1980, Ege University Press, Aydin, pp.285-296.

Kurt Sahin, G. and M.E. Çinar. 2012. A check-list of polychaete species (Annelida: Polychaeta) from the Black Sea. J. Black Sea/Medit. Envir., 18: 10-48.

Kurt-Sahin, G., E. Dagli, and M. Sezgin. 2017a. Spatial and temporal variations of soft bottom polychaetes of Sinop Peninsula (southern Black Sea) with new records. Turkish Journal of Zoology, 41: 89-101.

Kurt-Şahin, G., M. Sezgin, F. Ünlüer, B. Öztürk, E. Cavdar, and E. Dağlı. 2017b. Macrozoobenthic community structure of İğneada region in Turkey (the southwestern Black Sea). Oceanological and Hydrobiological Studies, 46(3): 340-349.

Kus, S. and G. Kurt-Sahin. 2015. Temporal Changes in the Polychaeta (Annelida) - community associated with *Cystoseira* beds of Sinop Peninsula (Southern Black Sea). Turkish Journal of Fisheries and Aquatic Sciences, 16(1): 61-68.

Marinov, T. 1959. Sur la faune de Polychètes des amas de moules de la mer Noire. Compt Acad Bulg Sci, 12: 443-446.

Mutlu, E., M. Unsal, and F. Bingel. 1992. A preliminary view on the faunal assemblage of softbottom crustaceans along the nearshores of the Turkish Black Sea. Acta Adriatica, 33(1/2): 177-189.

Mutlu, E., M. Unsal, and F. Bingel. 1993. Faunal community of soft-bottom mollusc of the Turkish Black Sea. Turkish Journal of Zoology, 17: 189-206.

Muxika, I., A. Borja, and J. Bald. 2007. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European water framework directive. Marine Pollution Bulletin, 55: 16-29.

Ozturk, B., M. Çulha, and D. Urkmez. 2004. Bivalvia Fauna of the Sinop Peninsula and its vicinity. Turkish Journal of Aquatic Life, 2(2): 71-80.

Ozturk, B., B. Topaloglu, A. Kideys, L. Bat, Ç. Keskin, M. Sezgin, A.A. Ozturk and A.C. Yalciner. 2013. A proposal for new marine protected areas along the Turkish Black Sea coast. J. Black Sea/Mediterranean Environment, 19(3): 365-379.

Ozturk, B., A. Dogan, B. Bitlis-Bakir, and A. Salman. 2014. Marine molluscs of the Turkish coasts: an updated checklist. Turkish Journal of Zoology, 38: 832-879.

Rullier, F. 1963. Les Annelides polychetes du Bosphore, de la Mer de Marmara et de la Mer Noire, en relation avec celles de la Mediterranee, (in French). Ext Rapp Pro-verb reun CIESM, 17: 161-260.

Sezgin, M., A. Kocataş, and T. Katagan. 2001. Amphipod fauna of the central Black Sea region. Turkish Journal of Zoology, 25: 57-61.

Sezgin, M. and T. Katagan. 2007. An account of our knowledge of the amphipod fauna of the Black Sea. Crustaceana, 80(1): 1-11.

Topaloğlu, B. and A. Evcen. 2014. Updated checklist of sponges (Porifera) along the coasts of Turkey. Turkish Journal of Zoology, 38, 665-667.

Uysal, A., A. Yüksek and E. Okuş. 1998. Diversity and distribution of Benthic Organisms at Marmara and Black Sea entrances of the Istanbul Strait (in Turkish). Symposium of Wastewater Management and Marine Pollution Control in Metropolitans, İSKİ, Istanbul, pp. 139-157.

Uysal, A., A. Yuksek, E. Okus, and N. Yilmaz. 2002. Benthic community structure of the Bosphorus and surrounding area. Water Sci. Tech., 46: 37-44.

Yağlıoğlu D., C. Turan, and T. Oğreden. 2014. First record of blue crab *Callinectes sapidus* (Rathbun, 1896) (Crustacea, Brachyura, Portunidae) from the Turkish Black Sea coast. Journal of Black Sea/Mediterranean Environment, 20: 13-17.

FISHES OF THE BLACK SEA

Yakup ERDEM

Sinop University, Faculty of Fisheries, Sinop, Turkey
yakuperdem@gmail.com

1. Introduction

The Black Sea is in a constant change since the day it was formed, which can be described as an evolution. Fish that live in the Black Sea have also taken their share of this evolution which started during the Tethys Ocean period and is still ongoing (Van der Voo 1993). We see the traces of the geological origins of the Black Sea in present sturgeon and some of the shad species (Helfman *et al.* 2009). The physical, chemical and biological changes in the Black Sea can be defined as "Mediterranization", which continue today to turn it into the Red Sea with the contribution of the Suez Canal and global climate changes (Oral 2010, Yankova *et al.* 2013). In addition, introduction of new fish species was observed to the fish fauna of the Black Sea every new day by means of maritime transportation, aquaculture and fishkeeping activities. Thus, the Black Sea fish fauna is becoming more and more cosmopolitan than its original ecosystem.

The Black Sea fishes have different origins including freshwater species, brackish Ponto-Caspian relicts, cold-water species with Boreal-Atlantic origin and warm-water species with Mediterranean origin. The last two groups include the most widely spread and commercially important species in the Black Sea (Bat *et al*. 2005). Recent studies reported the total number of the Black Sea fish species as about 180. Keskin (2010) reported 161 species and Bilecenoğlu *et al.* (2014) stated that the fish fauna of the Black Sea Turkish coasts was composed of 153 species whereas by Yankova *et al.* (2013) 180 species were reported for all the Black Sea, 109 of which are Atlanto-Mediterranean origin, 11 are cosmopolitans, 23 are Mediterranean endemics, 34are Black Sea endemics, and 3 species are introduced.

The Black Sea was the most important spawning and feeding area for so many commercial pelagic fish species, which migrated for spawning or feeding from the Mediterranean. These fish species form the basis of the Black Sea fisheries. In the Black Sea, the situation of small pelagic fish (mainly sprat and anchovy) has recovered somewhat from the drastic decline suffered in the 1990s, probably as a consequence of unfavourable oceanographic conditions. However, they are still considered overfished, an assessment shared with turbot, while most other stocks are probably fully fished to overfished. In general, the Mediterranean and the Black Sea had 52 percent of assessed stocks fished at unsustainable levels, and 48 percent fully or underfished in 2011 (FAO 2014). Fishing pressure is the greatest of many threats to the Black Sea biodiversity and fish stocks. Each year another fish species enters the endangered species list or landings of a fish species falls below the economic limit because of overfishing.

2. Fishes in Major Groups

The total number of reported fish in the Black Sea fish varies between 150 and 200. According to Yankova *et al.* (2014) there are 189 fish species in 56 different families in the fauna, including 10 species of elasmobranchii (sharks and rays), 7 species of chondrostei (sturgeons and paddlefishes) and 172 species of teleostei (bony fishes) belonging to 48 families. There are some ambiguous or synonym names according to Eschmeyer *et al*. (2017) in the list. They have been presented in the chapter with as much adjusting as possible.

Because of its low salinity the Black Sea is considered as brackish water (Affholder and Valiron 2001). Some freshwater fishes are found in the Black Sea, which belong to Cyprinidae, Gasterosteidae, Acipenseridae, Centrarchidae, Cyprinodontidae, Gobiidae and Salmonidae families. The freshwater fish species live in coastal waters associated with rivers, lagoons and estuaries. The Black Sea fishes are mostly associated with sea bottom, including 81% of demersal and semipelagic species. The Black Sea ichtiofauna is composed of bathydemersal, benthopelagic, demersal, pelagic, pelagic-neritic, pelagic – oceanic and reef-associated species according to Froese and Pauly (2017) in fish base records (Figure 1.).

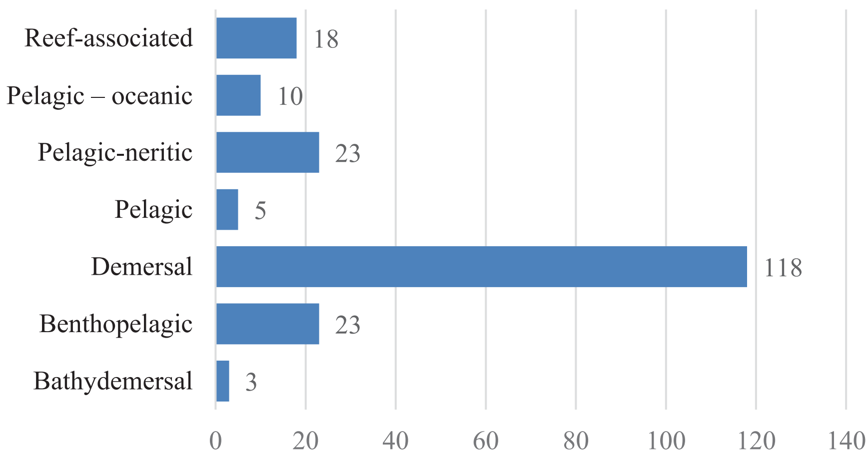

Figure 1. Distribution of the habitat of Black Sea fishes (Froese and Pauly 2015)

2.1. Cartilaginous Fishes (Chondrichthyes) of the Black Sea

There are 10 cartilaginous fishes in the Black Sea (Table 1). Two of them, the picked dogfish (*Squalus acanthias*) and the thornback ray (*Raja clavata*) have significant stocks and commercial importance. Although *Dasyatis pastinaca* is also a common fish species, it is not of commercial value. The rest of the cartilaginous fish species are found rare in the Black Sea. Landings of picked dogfish in catch statistics was changing year after year between 70 and 250 tons, and for thornback ray between 150 and 500 tons (FAO 2017).

Table 1. Cartilaginous fishes of the Black Sea fauna (Bilecenoğlu *et al.* 2014)

Family	***Species***	**Common Names**
Hexanchidae	*Hexanchus griseus* (Bonnaterre, 1788)	Bluntnose sixgill shark
Alopiidae	*Alopias vulpinus* (Bonnaterre, 1788)	Thresher
Scyliorhinidae	*Scyliorhinus canicula* (Linnaeus, 1758)	Lesser spotted dogfish
Triakidae	*Mustelus asterias* Cloquet, 1821	Starry smooth-hound
Squalidae	*Squalus acanthias* Linnaeus, 1758	Picked dogfish
Squalidae	*Squalus blainville* (Risso, 1827)	Longnose spurdog
Squatinidae	*Squatina squatina* (Linnaeus, 1758)	Angelshark
Rajidae	*Raja clavata* Linnaeus, 1758	Thornback ray
Dasyatidae	*Dasyatis pastinaca* (Linnaeus, 1758)	Common stingray
Gymnuridae	*Gymnura altavela* (Linnaeus, 1758)	Spiny butterfly ray

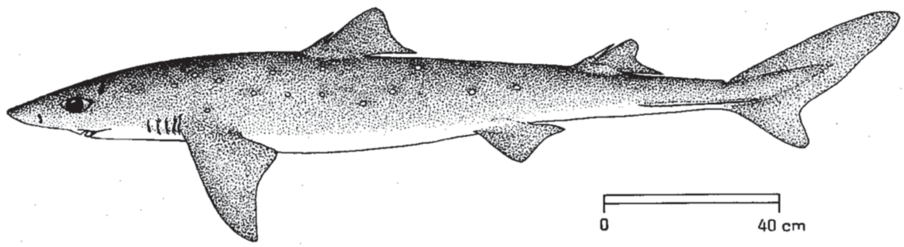

Figure 2. Picked dogfish (*Squalus acanthias*) (Compagno, 1984)

2.2. Sturgeons (Chondrostei) of the Black Sea

Sturgeon is the common name for the 27 species of fish belonging to the family Acipenseridae. Their evolution dates back to the Triassic, some 245 to 208 million years ago. The family is grouped into four genera and two of them, including *Acipenser* and *Huso,* live in the Black Sea basin. Sturgeons have the highest commercial value and the threats faced by this fish include overfishing, damming of the rivers, loss of spawning areas and water pollution. Sturgeons mature and reproduce slowly, making them highly vulnerable to fishing. Yankova *et al.* (2014) reported that a total of 7 sturgeon species in the Black Sea fish fauna, along with *Acipenser ruthenus* and *Acipenser persicus*; belong to fresh waters and the Caspian Sea.

Table 2. Sturgeon fishes species of the Black Sea (Yankova *et al.* 2014)

Species	Common Names
Acipenser gueldenstaedtii Brandt & Ratzeburg, 1833	Danube sturgeon
Acipenser nudiventris Lovetsky, 1828	Fringebarbel sturgeon
Acipenser stellatus Pallas, 1771	Starry sturgeon
Acipenser sturio Linnaeus, 1758	Common sturgeon
Acipenser ruthenus Linnaeus, 1758	Sterlet sturgeon
Acipenser persicus Borodin,1897	Persian sturgeon
Huso huso (Linnaeus, 1758)	Beluga

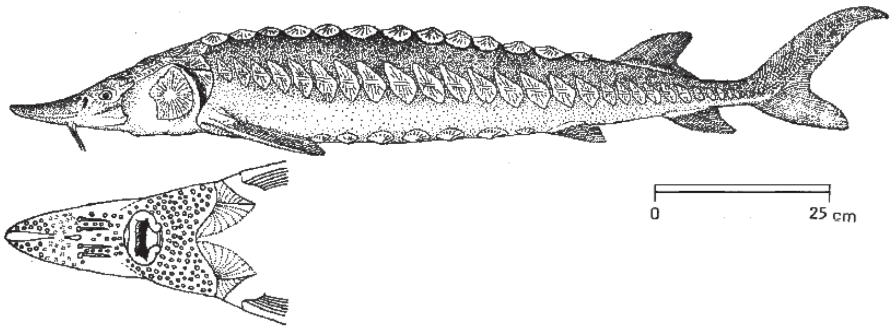

Figure 3. Common sturgeon (*Acipenser sturio*) (Fischer *et al.* 1987)

Figure 4. A sturgeon (*Acipenser* sp.) photographed in the coast of Sinop

2.3. Bony Fishes (Teleostei) of the Black Sea

Bony fish make up 96% of all fish of the entire world and 91% of the Black Sea fish fauna. According to the recent studies, about 175 bony fish members are arranged in 17 orders and 48 families (Yankova *et al.* 2014, Froese and Pauly 2017). Gobiidae is the most crowded (35 species) family followed by Sparidae, Blenniidae and Clupeidae (Table 3).

Figure 5. Red-mouthed goby (*Gobius cruentatus* Gmelin, 1789) in a rock cavity

Table 3. Bony Fish Orders and Families of the Black Sea

Order	Family	No of Sp.	Order	Family	No of Sp.
Anguilliformes	Anguillidae	1		Ammodytidae	1
	Congridae	1		Blenniidae	10
Atheriniformes	Atherinidae	2		Callionymidae	4
Beloniformes	Belonidae	1		Carangidae	4
Clupeiformes	Clupeidae	9		Chaetodontidae	1
	Engraulidae	1		Echeneididae	1
Gadiformes	Gadidae	2		Gobiidae	35
	Merlucciidae	1		Labridae	8
	Phycidae	1		Moronidae	2
Gasterosteiformes	Gasterosteidae	2		Mullidae	3
Gobiesociformes	Gobiesocidae	5		Percidae	2
Lophiiformes	Lophiidae	2	Perciformes	Pomacentridae	1
Mugiliformes	Mugilidae	6		Pomatomidae	1
Ophidiiformes	Ophidiidae	2		Sciaenidae	3
Pleuronectiformes	Bothidae	3		Scombridae	6
	Pleuronectidae	1		Serranidae	3
	Scophthalmidae	3		Sparidae	16
	Soleidae	4		Sphyraenidae	2
Salmoniformes	Salmonidae	4		Trachinidae	1
Scorpaeniformes	Dactylopteridae	1		Trichiuridae	1
	Scorpaenidae	2		Tripterygiidae	1
	Triglidae	3		Uranoscopidae	1
Syngnathiformes	Syngnathidae	8		Xiphiidae	1
Tetraodontiformes	Balistidae	1	Zeiformes	Zeidae	1
Total		**66**			**109**

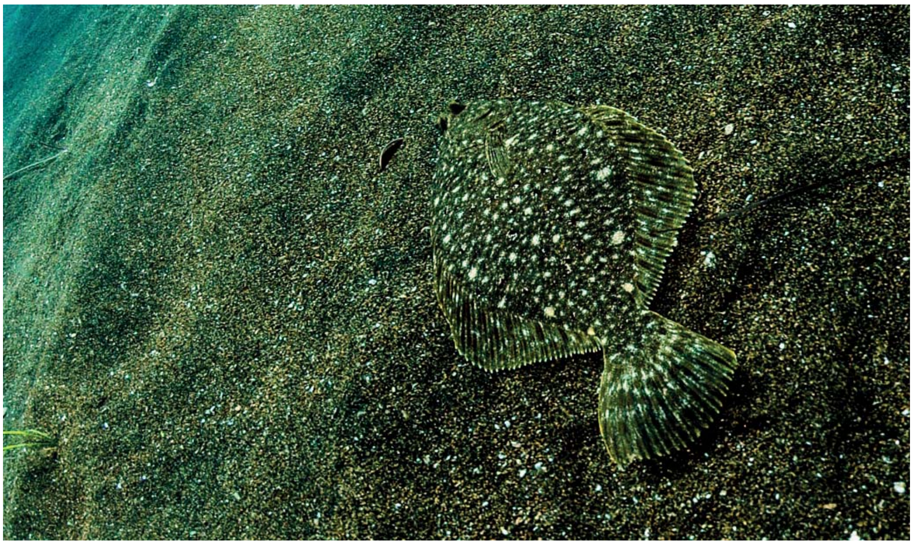

Figure 6. European flounder (*Platichthys flesus* (Linnaeus, 1758)) on sandy sea bottom

Pelagic fish such as anchovy, sprats, horse mackerel, bluefish and Atlantic bonito form the basis of the Black Sea fisheries. 26 bony fish species are commonly seen in landings and fish markets and form the major part of fish trade in the Black Sea (Table 4).

Capture production follows a tumultuous course in the Black Sea and total landing of fish amounted to about 550.000 tons at 2015. Turkey has the largest shares in the Black Sea fisheries with over 70%, followed by Russian Federation (17.2%) and Ukraine (6.2%). The Black Sea countries are mainly fish importers because they have more fish imports than exports, and the total volume of fish trades are about 3 million US dollars (FAO 2017). Fish stocks are insufficient for fish needs of the Black Sea countries. Supply and demand imbalance in production of fish can be reduced through development of aquaculture production and achievement of sustainability of wild fish stocks in the Black Sea.

Table 4. List of commercial bony fishes of the Black Sea

Species	Common Names	Species	Common Names
Alosa spp.	Shads	*Mullus barbatus ponticus*	Pontic red mullet
Atherina spp.	Sand smelts	*Platichthys flesus*	European flounder
Belone belone	Garfish	*Pomatomus saltatrix*	Bluefish
Chelidonichthys lucerna	Tub gurnard	*Sarda sarda*	Atlantic bonito
Clupeonella cultriventris	Black Sea sprat	*Sardina pilchardus*	European pilchard
Dicentrarcus labrax	European seabass	*Sciaena umbra*	Brown meagre
Diplodus annularis	Annular seabream	*Scophthalmus maximus*	Turbot
Diplodus puntazzo	Sharpsnout seabream	*Scorpaena porcus*	Black scorpionfish
Engraulis engrasicholus	European anchovy	*Solea solea*	Common sole
Gobiidae	Gobies	*Spicara maena*	Blotched picarel
Liza aurata	Golden grey mullet	*Sprattus sprattus*	European sprat
Merlangius merlangus	Whiting	*Trachurus* spp.	Horse mackerel
Mugil cephalus	Flathead grey mullet	*Umbrina cirrosa*	Shi drum

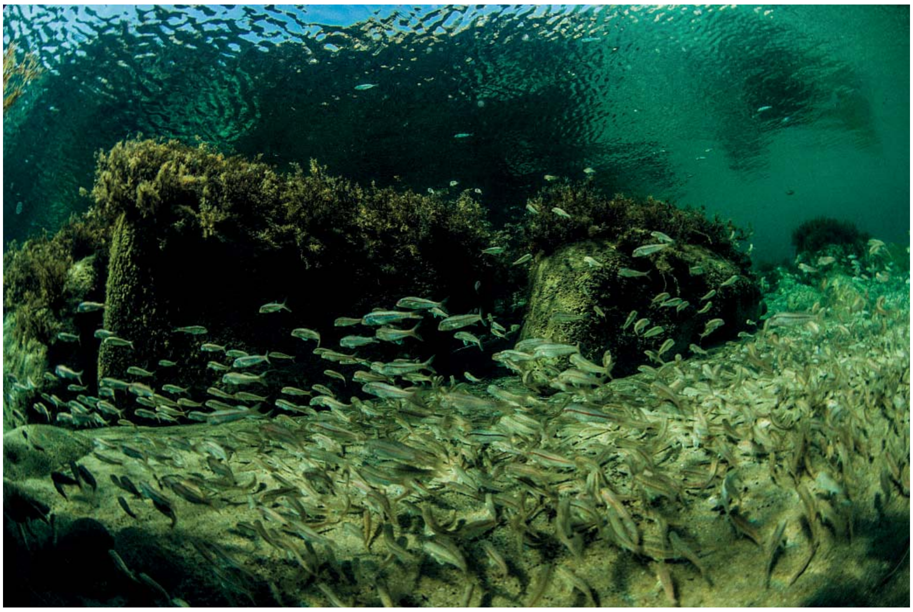

Figure 7. Black Sea red mullets (*Mullus barbatus ponticus* Essipov, 1927) in the coast of Sinop

3. Conservation Status of Marine Fishes of the Black Sea

Overfishing, environmental issues like pollution, global climate changes put the fish fauna of the Black Sea under heavy pressure. Aside from that, it's geographic and geologic features and the fact that it is a moderate sea which is highly productive, makes the Black Sea an important target for invasive species. All these factors change the biodiversity of the Black Sea, and as new species are introduced, endemic species face extinction.

Figure 8. Brown meagre (*Sciaena umbra* Linnaeus, 1758) in the coast of Sinop

Ten fish species in the Black Sea ichtiofauna are protected by CITES against over-exploitation through international trade, one species of them classified as international trade banned (App. I) and another 9 fish species as international trade monitored (App. II) (Table 5).

Table 5. CITES Status of the Black Sea Ichtiofauna (CITES 2017)

Species	CITES Status
Acipenser sturio	Appendix I
Acipenser gueldenstaedtii	Appendix II
Acipenser nudiventris	Appendix II
Acipenser stellatus	Appendix II
Acipenser ruthenus	Appendix II
Acipenser persicus	Appendix II
Huso huso	Appendix II
Anguilla anguilla	Appendix II
Hippocampus guttulatus	Appendix II
Hippocampus hippocampus	Appendix II

Among the 173 fish species listed by IUCN, 10 species are given as critically endangered, 2 as endangered, 6 as near threatened, 11 as vulnerable, 128 as least concern, 16 as data deficient while 21 species are not included in the list.

Table 6. Number and percentage of species in each IUCN Red List category for fish species in the Black Sea (IUCN 2017)

Red List Category	Number of species	Percentage in category
Critically Endangered (CR)	10	5.7
Endangered (EN)	2	1.2
Vulnerable (VU)	11	6.4
Near Threatened (NT)	6	3.5
Least Concern (LC)	128	74.0
Data Deficient (DD)	16	9.2
Total	**173**	**100.0**

Yankova *et al.* (2014) overviewed that the high percentage of data deficiency and underevaluated fish species in the Black Sea indicates the necessity for additional careful study of these species, because some of them could be threatened species. Red List is prepared from a global perspective and it can be said that some insufficiencies may arise while representing specific local distortions. For example, IUCN Red List considers mackerel as “least concern”, however its stock is completely extinct in the Black Sea.

According to IUCN, stocks of 27 fish species are decreasing, stocks of 55 species are stable and one stock is increased. Unfortunately, there are no data about 111 stocks in the list. There should be specific approaches to the extinction of stocks for the sustainability of fishing resources in the Black Sea. It is necessary to take urgent conservation and protection measures for endangered species. It is also important to implement further monitoring and appropriate managements and recovery plans for each species.

References

Affholder, M. and F. Valiron. 2001. Descriptive Physical Oceanography, CRC Press, 370 p.

Bat, L., Y. Erdem, S. Ustaoğlu, Ö. Yardım, and H.H. Satılmış. 2005. A study on the fishes of the central Black Sea coast of Turkey. Journal of the Black Sea/Mediterranean Environment, 11(3), 287-302.

Bilecenoğlu, M., M. Kaya, B. Cihangir, and E. Çiçek. 2014. An updated checklist of the marine fishes of Turkey. Turkish Journal of Zoology, 38(6): 901-929.

CITES, 2017. The CITES species. Appendices I, II and III, valid from 2 January 2017, https://cites.org/sites/default/files/notif/E-Notif-2016-068-A.pdf. Accessed 03 Apr 2017.

Compagno, L.J.V. 1984. FAO Species Catalogue. Vol. 4. Sharks of the World. An Annotated and Illustrated Catalogue of Shark Species Known to Date. Part 1 - Hexanchiformes to Lamniformes. FAO Fish. Synop., Rome: FAO, 125 (4/1):1-249.

Eschmeyer, W.N., R. Fricke, and R. van der Laan [eds.] 2017. Catalog of fishes: genera, species, references. (http://researcharchive.calacademy.org/research/ichthyology/catalog/fishcatmain.asp). Accessed 01 Oct 2016.

FAO, 2014. The State of World Fisheries and Aquaculture, Opportunities and Challenges, FAO, Rome.

FAO, 2017. FAO global capture production 1950-2015, online query, http://www.fao.org/fishery/statistics/global-capture-production/query/en. Accessed 03 Apr 2017

Fischer, W., M. Schneider, and M.L. Bauchot. 1987. Guide Fao d'Identification des espèces pour les besoins de la pêche, Méditerranée et Mer Noire - zone de pêche 37, Volume 2: Vertébrés, FAO Rome, 1987.

Froese, R. and D. Pauly [eds.]. 2017. FishBase. WWW electronic publication. www.fishbase.org, version (02/2017).

Helfman, G. S., B. B. Collette, D. E. Facey, and B.W. Bowen. 2009. The Diversity of Fishes: Biology, Evolution, and Ecology, 2nd edition.

IUCN, 2017. The IUCN Red list of threatened species. Version 2016-3. http://www.IUCNredlist.org. Accessed 01 Apr 2017

Keskin, Ç. 2010. A review of fish fauna in the Turkish Black Sea. J. Black Sea/Mediterranean Environment, 16(2): 195-210.

Oral, M. 2010. Alien fish species in the Mediterranean – Black Sea Basin, J. Black Sea/Mediterranean Environment, 16(1): 87-132.

Van der Voo, R. 1993. Paleomagnetism of the Atlantic, Tethys and Iapetus Oceans. Cambridge University Press.

Yankova, M., D. Pavlov, P. Ivanova, E. Karpova, A. Boltachev, L. Bat, M. Oral, and M. Mgeladze. 2013. Annotated check list of the non-native fish species (Pisces) of the Black Sea. J. Black Sea/Mediterranean Environment, 19(2): 247-255.

Yankova, M., D. Pavlov, P. Ivanova, E. Karpova, A. Boltachev, B. Öztürk, L. Bat, M. Oral, and M. Mgeladze. 2014. Marine fishes in the Black Sea: recent conservation status. Mediterranean Marine Science, 15(2): 366-379.

BIRDS OF THE BLACK SEA

Arzu GÜRSOY ERGEN [1] and Evrim SÖNMEZ [2]

[1]Ondokuz Mayıs University, Faculty of Science Literature, Samsun, Turkey
[2]Sinop University, Faculty of Education, Sinop, Turkey
agursoy@omu.edu.tr

1. Introduction

A worldwide total of over 10,000 different species of bipedal, warm-blooded, egg-laying birds are recognised the majority (c.80%) occurring in continental regions, the remainder on islands. Birds occupy a huge variety of habitats and are found at the extreme latitudes and land elevations. This great diversity of land, water and seabird species is distributed across the world, and some of the smallest nations have rich bird faunas.

Turkey zoogeographically is a part of Palearctic region and located at the intersection of three continents (Asia, Africa, and Europe) therefore located on important bird migration routes. Because of the different types of climate, ecology and topography, Turkey has a rich flora and, consequently, many animal species can find suitable habitats for themselves. European deciduous forests, Mediterranean scrub and wetlands, Arabian semi-desert, Caucasian mountains, and central Asian steppe all meet each other in Turkey (Roselaar 1995). All these diverse ecological factors are reflected in the rich diversity of the avifauna. Turkey has acquired the character of a small continent from the point of biological diversity.

Turkey is home to an impressive number of species of birds that vary from residents, which stay all year around, to breeding birds, migrants who pass through Turkey. Located on bird migration routes, Turkey is a key country for many bird species. Bird species in Turkey are quite well known and thus the number of described extant species is at around 482 (Ambarlı *et al.* 2016).

1.1. The Factors Leading the Bird Diversity in the Black Sea Region

Turkey is divided into seven geographical regions (three inner regions and four coastal regions), of the regions Black Sea and Marmara have bounded on the north by the Black Sea and is at the intersection of three phytogeographical regions (Euro-Siberian, Irano-Turanian, and Mediterranean). Of the biogeographical zones, the Euro-Siberian Biogeographical Zone extends throughout Northern Anatolia and it is in those parts of the Thracian Region which face the Black Sea. Black Sea Region has forest, mountain, steppe, wetland, coastal and marine ecosystems and different forms and combinations of these systems.

Turkey's highly varied topography is one of the main causes of its climatic diversity. In the Black Sea climate, there is rainfall in every season; summers are not very hot, winters are not very cold. The fact that there is an oceanic climate at the mountanious parts, Mediterranean climate at some coastal and inner parts and terrestrious climate at more inner parts shows that the Black Sea has a rich flora and fauna.

The main features of the Black Sea coast are that, it is less indented and parallel to the mountains. The Black Sea has an area of 420 thousand km^2 and it is an inland sea having connection with the Sea of Marmara and the Mediterranean Sea via straits (Sundseth 2009). With a total volume of 537 km^3, the average depth of the basin is 1300 m. Black Sea is surrounded by Russia and Ukraine in the north, Georgia in the east, Romania and Bulgaria in the west and, Turkey in the south. The link to Azov Sea is provided via Kerch Strait. Freshwaters of the Black Sea arrives at the Mediterranean through the straits by surface current and salty water of the Mediterranean flow into Black Sea by way of undercurrent. The fresh water is carried by the rivers of Sakarya, Kızılırmak, Yeşilırmak, Filyos, Çoruh and both large and small streams passing through different regions, flowing into the Black Sea.

2. The Key Habitats of The Black Sea Region

2.1. Vegetation / Forest and Mountain Ecosystems

Turkey is surrounded on the north by the Northern Anatolia Mountains which run parallel to the Black Sea coast. North Anatolian Mountains consisting of the results of the orogenic movements determines the general character of the region. The altitude differences that range between 0 and 4,000 meters. Elevations of the mountain stretches west along the Black Sea is about 2000 m., is down to 1000 m in the central Black Sea, east rises to the altitude of 4000 m.

The region is divided in two in terms of vegetation; the part that includes the region on the west of Ordu is called Euxine, while the part that includes the region on the east is called Colchis (Kalem 2001). In the areas of the region where there is a lot of rainfall, vegetation consists of deciduous types. While there is forest vegetation in all of the places below timberline, there is a formation that consists of trees-bushes and hemicryptophyte (perennial herbaceous plants) at places where the forest vegetation is harmed. Besides European-Siberian types, sclerophyllous Mediterranean vegetation in pieces and characteristic types of Hirano-Euxine flora regions that cover the southern Caucasian and Caspian coasts can be seen at central and western coasts.

The higher parts of the Eastern Black Sea Mountains is dominated by sub-alpine and alpine meadows and the high mountain floors of other regions by steppe and meadow ecosystems. Forest ecosystems that differ according to regions begin as the altitude decreases.

Coastal mountains and interior mountain ranges split down the Coruh and Kelkit valley to the west with a threshold of Bayburt plain.

2.2. Wetland Ecosystems

The existence of different types of aquatic bodies such as the sea, lakes, rivers, and fresh water, salt water and mineral water lakes make the Black Sea region one of Turkey's richest regions in terms of water resources. The wetlands are of great importance for biological diversity, especially for water birds. The deltas such as Kızılırmak and Yeşilırmak, which discharges into the Black Sea, have great importance especially for migratory birds that pass directly over the Black Sea. Extremely active bird mobility can be observed in these two deltas. Sarıkum Lake is a complex of dune, lake and forest habitat in a broad valley at sea level (Magnin 1997). In addition, lakes in high mountain sections isolated from each other having different characteristics form special habitats. The seasonal or permanent alpine lakes exist in the higher parts of the Eastern Black Sea Region and their size generally are not large. However, they are far from human influence and create clean, safety habitats for the species dependent on wetlands. The total length of 376 km of Coruh is one of the world's highest river flow also located in this region. A great majority of the invertebrates living in river ecosystems are important for feeding of birds.

2.3. Coastal and Marine ecosystems

Coastal ecosystems are highly special ecosystems as they are important sudden transition zones (ecotones) where marine and terrestrial ecosystems intersect. The Black Sea is the largest enclosed sea of the world and the most isolated one from oceans. It has resulted in the diversification of the biological resources it contains. There are a few small islands along the Black Sea coast. Giresun and Hoynat islands hold significant breeding population of the European Shag and Yellow-legged Gull.

The fact that the patterns in which mountains come down to the sea, and the coastal topography, differ from each other in the coastal areas of Turkey have resulted in various coastal ecosystems such as dunes, caves, deltas, lagoons, marshes and calcareous terraces. The coastal areas in the Black Sea Region has rich ecosystems with very high flora and fauna diversity.

3. Birds of the Black Sea

Turkey, as well as the Black Sea, is of crucial importance for thousands of sea birds, waterbirds, raptors and passerines. Twice a year, thousands of millions of Palaearctic birds migrate between the Palearctic (Europe and Asia) and Afrotropical (sub-Saharan Africa) regions and also the Black Sea is a key area in relation to the distribution and movements of many bird species in the Western Palaearctic. Black Sea region of Turkey is considered as a part of the transcontinental wild bird migration routes from northern Asia and Europe to the Mediterranean, Africa, and southwest Asia. Black Sea Region lies on the northern edge of the Black Sea and includes the second largest autumn migratory route in Europe for raptors, passerines, seabirds and wide range of water birds.

In winter, strong northern and northeastern winds blow over the sea, while in summer the weather is predominantly stable and clear, with gentle winds. Moving air currents from the high pressure center formed at north - northeast of Volga and Don rivers basin to the low pressure center formed over the Black Sea cause storms. The storms lead to an increase in species diversity. Thousands of long distance migrants try to cross the Black Sea twice a year (Figure 1). Wetlands in the Black Sea ensures vital resting and feeding opportunities to the species migrating directly over the sea. Even in the most harsh winter conditions, the Black Sea temperate wetlands provide winter shelter and food to hundreds of thousands of water birds.

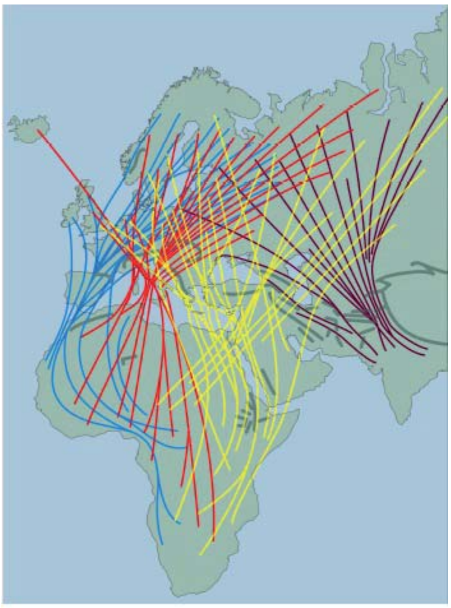

Figure 1. Migration flyways of birds (source SEEN)

392 bird species have regularly been seen in the Black Sea Region, and 43 species are globally threatened. Of these, two species are listed as as critically endangered, four species as endangered, 14 species as vulnerable and 23 species as near threatened. Two species which are endemic for Caucasus region, the Caucasian Grouse and Caucasian Chiffchaff breed in Turkey (Stattersfield *et al.* 1998): Caucasian Grouse uses subalpine and alpine meadows, slopes with Rhododendron and juniper Juniperus; birch forest edge

in spring and winter. Caucasian Chiffchaff uses coniferous and mixed forest and subalpine bush (mainly Rhododendron).

Another characteristic of Turkey is that, it is an uninterrupted land bridge for migratory species. Through Bosphorus, ten thousands of storks, hawks and eagles can pass to Anatolia and to the Middle East and Africa from there. Similarly, thousands of hawks, honey buzzards and eagles can pass to Eastern Anatolia only through Çoruh Valley. While all of these cause bird diversity to be rich and full of surprises in almost every season, they also explain why Turkey has a big importance in terms of researching and protecting bird species.

The bird list has been created according to provinces bordering the Black Sea coastline.

3.1. Marine birds

Pelagic seabirds are those species which spend long periods away from land and obtain all or most of their food from the sea while flying, swimming, or diving (Nettleship 1991) and come to land only to breed (Croxall 2012).

There are 34 seabird species that regularly use the Black Sea. Six seabird families under 4 orders occur within the Black Sea area, either as winter visitors and passage migrants or as breeding populations. These species belong to Procellariiformes (Procellariidae), Pelecaniformes (Pelecanidae), Suliformes (Phalacrocoracidae) and Charadriiformes (Scolopacidae, Stercorariidae, Laridae) respectively (Ertan 2013; Güçlüsoy 2014).

Of the 34 seabird species considered here, 2 are vulnurable, 1 in the category of near threatened and a further 31 least concern globally. At the Turkish scale 2 are listed as endangered, 6 as vulnurable, 4 as near threatened, 2 as data deficient and 5 as least concern.

These sea birds generally prefer coastal habitats, islands, deltas, and rocky shores to a lesser extent (Nankinov 1996). The first valid record of European Herring Gull is thus very recent; 2 individuals were observed at Samsun (Black Sea) on 30 January 2014 (Güçlüsoy 2014). Long-tailed Jaeger is a rare visitor or vagrant in Turkey as well as in the Black Sea. The records from Terkos Lake very close to the Black Sea coastline was in late September 1888 and at Bosphorus (Marmara) on 23 September 1979.

The seabirds are more threatened than other comparable groups of birds. Priority species include Dalmatian Pelican (VU), Yelkouan Shearwater (VU) and Armenian Gull (NT).

The Southern Black Sea coast holds internationally important populations of Yelkouan Shearwater and the Mediterranean sub-species of the European Shag. The Yelkouan Shearwater nests in the Mediterranean Sea and winters in the Mediterranean and Black Sea, however breeding have not yet been recorded in the Black Sea. This species has been up-listed to vulnerable globally while data deficient in Turkey as it is estimated to be undergoing a rapid population decline, caused by extremely low breeding success and adult survival owing to fisheries by-catch and predation by introduced mammals. Gulls and terns are found in the coastal shallow waters all year around.

European Shags are bred on Hoynat Island. This species is also bred at Kozlu and Amasra coastline and Sinop Peninsula coastal cliffs.

3.2. Waterbirds

Black Sea has over 1700 km of coastline, covering sandy beaches, cliffs, river deltas, estuaries, lagoons and nearshore inland wetlands. This coastline is home to many species of water birds.

Wetlands are the most important ecosystems for water birds. At Black Sea Region, there are several important wetlands such as Kizilirmak, Yeşilırma, Sakarya, and Sarıkum which can host water birds.

111 waterbird species belonging to 15 families and 8 orders were recorded at the Black Sea coastline. The number of species per family were as follows: Gaviidae (2), Podicipedidae (5), Ardeidae (9), Ciconiidae (2), Thereskiornithidae (2), Phoenicopteridae (1), Anatidae (33), Rallidae (8), Gruidae (2), Haematopodidae (1), Recurvirostridae (2), Burhinidae (1), Glareolidae (2), Charadriidae (13), and Scolopacidae (28).

Of these water bird species found in the Black Sea region, 21 threatened or near-threatened species were identified and listed as two CR, one EN, seven VU and 11 NT.

Among these species, Lesser White-fronted Goose, Red-breasted Goose, Common Pochard, Velvet Scoter are listed as VU while Sociable Lapwing and Slender-billed Curlew are listed as CR.

It is known that the important number of the Turkish population of the White-headed Duck which is classified as EN was wintering in the wetlands at the Black Sea Region.

3.3. Raptors

During migration in the spring and fall, tens of thousands of migratory raptors pass through the region. Çoruh Valley remains as the most important flyway for bird migration on Eastern Black Sea Mountains. Mountains and the Black Sea have forced the raptors to follow the valleys of the north-south direction. Therefore, thousands of raptors are concentrated in this region.

Çoruh Valley holds the status of *Important Bird Area* not only due to its location being on the migratory route of Honey Buzzards, Buzzards, Blackkite but also for hosting birds like Lammergeier, Griffon Vulture, Black Vulture, Caucasian Black Grouse and Caspian Snowcock which reproduce in the valley.

3.4. Passerines

Black Sea Region offers excellent opportunities to many passerine birds as a breeding, foraging and stopover site. The Passerine species of the Black Sea Region is abundant and 166 species have been recorded. The wetlands are also home to a large number of passerines. Following a major flyway, more than 100 species pass through Black Sea on the way to and from their wintering grounds in the Middle East and Africa. Arctic Warbler and Black Throated Accentor, which was first recorded in Turkey in 2002 and 2014 respectively, the Kızılırmak Delta remains the only known place in the country where the species were observed. *Sylvia* species are seen here more frequently and regularly. Breeding species of this region also include Barn Swallow, Common Nightingale, Great Reed Warbler, Spotted Flycatcher, Eastern Olivaceous Warbler, Garden Warbler, Red-backed Shrike, and Pale Rockfinch, irregularly Eastern Orphean Warbler. Common breeders here are Water Pipit, White-throated Dipper, and Common Blackbird. The examples of passege migrants are Red-throated Pipit, Bluethroat, Pied Wheatear, Barred Warbler, Icterine Warbler and Willow Warbler.

Among the birds that are all year round in the region are the Song Thrush, Cetti`s Warbler, Sardinian Warbler, Jay, Robin, Great Tit, Goldcrest, Eurasian Treecreeper and Hawfinch.

4. Threats

Primary threats in the region are factors such as hunting, uncontrolled agricultural practices, illegal lumbering, overgrazing, forest fires, unplanned housing, tableland tourism in winter and summer months, winter sports, tourism, habitat destruction in regions where birds breed or stop over.

Black Sea coastal road that passes through IBA affects the natural coastal ecosystem and causes serious harms to marine and waterbird diversity. In addition, sand, pebble and stone pits to be used in these road constructions harm biodiversity besides bird populations. Trolling, invasive species and sea pollution are other important threats for marine and coastal birds.

In addition to these, dam constructions and hydroelectric power stations and the constructions planned especially on rivers in the Eastern Black Sea Region are also threats for bird populations in the region.

5. The Black Sea Region Bird Check List

Order	Family	Scientific	Turkish	English	IUCN
Anseriformes	Anatidae	*Anser fabalis*	Tarla Kazı	Taiga Bean Goose	LC
		Anser anser	Boz Kaz	Greylag Goose	LC
		Anser albifrons	Sakarca	Greater White-fronted Goose	LC
		Anser erythropus	Küçük Sakarca	Lesser White-fronted Goose	VU
		Branta leucopsis	Ak Yanaklı Kaz	Barnacle Goose	LC
		Branta ruficollis	Sibirya Kazı	Red-breasted Goose	VU
		Cygnus olor	Kuğu	Mute Swan	LC
		Cygnus columbianus	Küçük Kuğu	Tundra Swan	LC
		Cygnus cygnus	Ötücü Kuğu	Whooper Swan	LC
		Tadorna tadorna	Suna	Common Shelduck	LC
		Tadorna ferruginea	Angıt	Ruddy Shelduck	LC
		Anas strepera	Boz Ördek	Gadwall	LC
		Anas penelope	Fiyu	Eurasian Wigeon	LC
		Anas platyrhynchos	Yeşilbaş	Mallard	LC
		Anas clypeata	Kaşıkgaga	Northern Shoveler	LC
		Anas acuta	Kılkuyruk	Northern Pintail	LC
		Anas querquedula	Çıkrıkçın	Garganey	LC
		Anas crecca	Çamurcun	Eurasian Teal	LC
		Marmaronetta angustirostris	Yaz Ördeği	Marbled Duck	VU
		Netta rufina	Macar Ördeği	Red-crested Pochard	LC
		Aythya ferina	Elmabaş Patka	Common Pochard	VU
		Aythya nyroca	Pasbaş Patka	Ferruginous Duck	NT
		Aythya fuligula	Tepeli Patka	Tufted Duck	LC
		Aythya marila	Karabaş Patka	Greater Scaup	LC
		Somateria mollissima	Pufla	Common Eider	NT
		Melanitta fusca	Kadife Ördek	Velvet Scoter	VU
		Melanitta nigra	Kara Ördek	Common Scoter	LC
		Clangula hyemalis	Telkuyruk	Long-tailed Duck	VU
		Bucephala clangula	Altıngöz	Common Goldeneye	LC

		Mergellus albellus	Sütlabi	Smew	LC
		Mergus merganser	Büyük Tarakdiş	Common Merganser	LC
		Mergus serrator	Tarakdiş	Red-breasted Merganser	LC
		Oxyura leucocephala	Dikkuyruk	White-headed Duck	EN
Galliformes	Phasianidae	*Lyrurus mlokosiewiczi*	Dağhorozu	Caucasian Grouse	NT
		Tetraogallus caspius	Urkeklik	Caspian Snowcock	LC
		Alectoris chukar	Kınalı Keklik	Chukar Partridge	LC
		Perdix perdix	Çilkeklik	Grey Partridge	LC
		Coturnix coturnix	Bıldırcın	Common Quail	LC
		Phasianus colchicus	Sülün	Common Pheasant	LC
Gaviiformes	Gaviidae	*Gavia stellata*	Kızıl Gerdanlı Dalgıç	Red-throated Loon	LC
		Gavia arctica	Kara Gerdanlı Dalgıç	Black-throated Loon	LC
Procellariiformes	Procellariidae	*Calonectris diomedea*	Boz Yelkovan	Scopoli`s Shearwater	LC
		Puffinus yelkouan	Yelkovan	Yelkouan Shearwater	VU
Podicipediformes	Podicipedidae	*Tachybaptus ruficollis*	Küçük Batağan	Little Grebe	LC
		Podiceps grisegena	Kızıl Boyunlu Batağan	Red-necked Grebe	LC
		Podiceps cristatus	Bahri	Great Crested Grebe	LC
		Podiceps auritus	Kulaklı Batağan	Horned Grebe	VU
		Podiceps nigricollis	Kara Boyunlu Batağan	Black-necked Grebe	LC
Phoenicopteriformes	Phoenicopteridae	*Phoenicopterus roseus*	Flamingo	Greater Flamingo	LC
Ciconiiformes	Ciconiidae	*Ciconia nigra*	Kara Leylek	Black Stork	LC
		Ciconia ciconia	Leylek	White Stork	LC
Pelecaniformes	Thereskionithidae	*Plegadis falcinellus*	Çeltikçi	Glossy Ibis	LC
		Platalea leucorodia	Kaşıkçı	Eurasian Spoonbill	LC
	Ardeidae	*Botaurus stellaris*	Balaban	Eurasian Bittern	LC
		Ixobrychus minutus	Küçük Balaban	Little Bittern	LC
		Nycticorax nycticorax	Gece Balıkçılı	Black-crowned Night Heron	LC
		Ardeola ralloides	Alaca Balıkçıl	Squacco Heron	LC
		Bubulcus ibis	Sığır Balıkçılı	Western Cattle Egret	LC
		Ardea cinerea	Gri Balıkçıl	Grey Heron	LC
		Ardea purpurea	Erguvani Balıkçıl	Purple Heron	LC
		Egretta garzetta	Küçük Ak Balıkçıl	Little Egret	LC

		Ardea alba	Büyük Ak Balıkçıl	Great Egret	LC
	Pelecanidae	*Pelecanus onocrotalus*	Ak Pelikan	Great White Pelican	LC
		Pelecanus crispus	Tepeli Pelikan	Dalmatian Pelican	VU
Suliformes	Phalacrocoracidae	*Microcarbo pygmeus*	Küçük Karabatak	Pygmy Cormorant	LC
		Phalacrocorax aristotelis	Tepeli Karabatak	European Shag	LC
		Phalacrocorax carbo	Karabatak	Great Cormorant	LC
Accipitriformes	Pandionidae	*Pandion haliaetus*	Balık Kartalı	Western Osprey	LC
	Accipitridae	*Elanus caeruleus*	Ak Çaylak	Black-winged Kite	LC
		Gypaetus barbatus	Sakallı Akbaba	Bearded Vulture	NT
		Neophron percnopterus	Küçük Akbaba	Egyptian Vulture	EN
		Pernis apivorus	Arı Şahini	European Honey Buzzard	LC
		Pernis ptilorhyncus	Tepeli Arı Şahini	Crested Honey Buzzard	LC
		Gyps fulvus	Kızıl Akbaba	Griffon Vulture	LC
		Aegypius monachus	Kara Akbaba	Cinereous Vulture	NT
		Circaetus gallicus	Yılan Kartalı	Short-toed Snake Eagle	LC
		Clanga pomarina	Küçük Orman Kartalı	Lesser Spotted Eagle	LC
		Clanga clanga	Büyük Orman Kartalı	Greater Spotted Eagle	VU
		Hieraaetus pennatus	Küçük Kartal	Booted Eagle	LC
		Aquila nipalensis	Bozkır Kartalı	Steppe Eagle	EN
		Aquila heliaca	Şah Kartal	Eastern Imperial Eagle	VU
		Aquila chrysaetos	Kaya Kartalı	Golden Eagle	LC
		Aquila fasciata	Tavşancıl	Bonelli`s Eagle	LC
		Accipiter brevipes	Yaz Atmacası	Levant Sparrowhawk	LC
		Accipiter nisus	Atmaca	Eurasian Sparrowhawk	LC
		Accipiter gentilis	Çakırkuşu	Northern Goshawk	LC
		Circus aeruginosus	Saz Delicesi	Western Marsh Harrier	LC
		Circus cyaneus	Gökçe Delice	Hen Harrier	LC
		Circus macrourus	Bozkır Delicesi	Pallid Harrier	NT
		Circus pygargus	Çayır Delicesi	Montagu`s Harrier	LC
		Milvus milvus	Kızıl Çaylak	Red Kite	NT

		Milvus migrans	Kara Çaylak	Black Kite	LC
		Haliaeetus albicilla	Ak Kuyruklu Kartal	White-tailed Eagle	LC
		Buteo lagopus	Paçalı Şahin	Rough-legged Buzzard	LC
		Buteo buteo	Şahin	Common Buzzard	LC
		Buteo rufinus	Kızıl Şahin	Long-legged Buzzard	LC
Falconiformes	Falconidae	*Falco naumanni*	Küçük Kerkenez	Lesser Kestrel	LC
		Falco tinnunculus	Kerkenez	Common Kestrel	LC
		Falco vespertinus	Aladoğan	Red-footed Falcon	NT
		Falco eleonorae	Ada Doğanı	Eleonora`s Falcon	LC
		Falco columbarius	Boz Doğan	Merlin	LC
		Falco subbuteo	Delice Doğan	Eurasian Hobby	LC
		Falco biarmicus	Bıyıklı Doğan	Lanner Falcon	LC
		Falco cherrug	Ulu Doğan	Saker Falcon	EN
		Falco peregrinus	Gökdoğan	Peregrine Falcon	LC
Otidiformes	Otididae	*Otis tarda*	Toy	Great Bustard	VU
		Tetrax tetrax	Mezgeldek	Little Bustard	NT
Gruiformes	Rallidae	*Rallus aquaticus*	Sukılavuzu	Water Rail	LC
		Crex crex	Bıldırcınkılavuzu	Corn Crake	LC
		Porzana parva	Bataklık Suyelvesi	Little Crake	LC
		Porzana pusilla	Küçük Suyelvesi	Baillon`s Crake	LC
		Porzana porzana	Benekli Suyelvesi	Spotted Crake	LC
		Porphyrio porphyrio	Sazhorozu	Purple Swamphen	LC
		Gallinula chloropus	Sutavuğu	Common Moorhen	LC
		Fulica atra	Sakarmeke	Eurasian Coot	LC
	Gruidae	*Grus virgo*	Telli Turna	Demoiselle Crane	LC
		Grus grus	Turna	Common Crane	LC
Charadriiformes	Burhinidae	*Burhinus oedicnemus*	Kocagöz	Eurasian Stone-curlew	LC
	Haematopodidae	*Haematopus ostralegus*	Poyrazkuşu	Eurasian Oystercatcher	NT
	Recurvirostridae	*Himantopus himantopus*	Uzunbacak	Black-winged Stilt	LC
		Recurvirostra avosetta	Kılıçgaga	Pied Avocet	LC
	Charadriidae	*Vanellus vanellus*	Kızkuşu	Northern Lapwing	NT
		Vanellus spinosus	Mahmuzlu Kızkuşu	Spur-winged Lapwing	LC
		Vanellus gregarius	Sürmeli Kızkuşu	Sociabla Lapwing	CR

		Vanellus leucurus	Ak Kuyruklu Kızkuşu	White-tailed Lapwing	LC
		Pluvialis apricaria	Altın Yağmurcun	European Golden Plover	LC
		Pluvialis fulva	Küçük Altın Yağmurcun	Pacific Golden Plover	LC
		Pluvialis squatarola	Gümüş Yağmurcun	Grey Plover	LC
		Charadrius hiaticula	Halkalı Cılıbıt	Common Ringed Plover	LC
		Charadrius dubius	Halkalı Küçük Cılıbıt	Little Ringed Plover	LC
		Charadrius alexandrinus	Akça Cılıbıt	Kentish Plover	LC
		Charadrius leschenaultii	Büyük Cılıbıt	Greater Sand Plover	LC
		Charadrius asiaticus	Doğu Cılıbıtı	Caspian Plover	LC
		Charadrius morinellus	Dağ Cılıbıtı	Eurasian Dotterel	LC
	Scolopacidae	*Scolopax rusticola*	Çulluk	Eurasian Woodcock	LC
		Lymnocryptes minimus	Küçük Suçulluğu	Jack Snipe	LC
		Gallinago media	Büyük Suçulluğu	Great Snipe	NT
		Gallinago gallinago	Suçulluğu	Common Snipe	LC
		Limosa limosa	Çamurçulluğu	Black-tailed Godwit	NT
		Limosa lapponica	Kıyı Çamurçulluğu	Bar-tailed Godwit	NT
		Numenius arquata	Kervançulluğu	Eurasian Curlew	NT
		Numenius phaeopus	Sürmeli Kervançulluğu	Whimbrel	NT
		Tringa erythropus	Kara Kızılbacak	Spotted Redshank	LC
		Tringa totanus	Kızılbacak	Common Redshank	LC
		Tringa stagnatilis	Bataklık Düdükçünü	Marsh Sandpiper	LC
		Tringa nebularia	Yeşilbacak	Common Greenshank	LC
		Tringa flavipes	Küçük Sarıbacak	Lesser Yellowlegs	LC
		Tringa ochropus	Yeşil Düdükçün	Green Sandpiper	LC
		Tringa glareola	Orman Düdükçünü	Wood Sandpiper	LC
		Xenus cinereus	Terek Düdükçünü	Terek Sandpiper	LC
		Actitis hypoleucos	Dere Düdükçünü	Common Sandpiper	LC
		Arenaria interpres	Taşçeviren	Ruddy Turnstone	LC
		Calidris canutus	Büyük Kumkuşu	Red Knot	NT
		Calidris alba	Ak Kumkuşu	Sanderling	LC
		Calidris minuta	Küçük kumkuşu	Little Stint	LC

		Calidris temminckii	Sarı Bacaklı Kumkuşu	Temminck`s Stint	LC
		Calidris ferruginea	Kızıl Kumkuşu	Curlew Sandpiper	NT
		Calidris alpina	Kara Karınlı Kumkuşu	Dunlin	LC
		Limicola falcinellus	Sürmeli Kumkuşu	Broad-billed Sandpiper	LC
		Philomachus pugnax	Döğüşkenkuş	Ruff	LC
		Phalaropus tricolor	Büyük Denizdüdükçünü	Wilson`s Phalarope	LC
		Phalaropus lobatus	Denizdüdükçünü	Red-necked Phalarope	LC
	Glareolidae	*Glareola pratincola*	Bataklıkkırlangıcı	Collared Pratincole	LC
		Glareola nordmanni	Karakanatlı Bataklıkkırlangıcı	Black-winged Pratincole	NT
	Laridae	*Rissa tridactyla*	Kara Ayaklı Martı	Black-legged Kittiwake	LC
		Chroicocephalus genei	İnce Gagalı Martı	Slender-billed Gull	LC
		Chroicocephalus ridibundus	Karabaş Martı	Black-headed Gull	LC
		Hydrocoloeus minutus	Küçük Martı	Little Gull	LC
		Ichthyaetus ichthyaetus	Büyük Karabaş Martı	Pallas`s Gull	LC
		Ichthyaetus melanocephalus	Akdeniz Martısı	Mediterranean Gull	LC
		Larus canus	Küçük Gümüş Martı	Mew Gull	LC
		Larus marinus	Büyük Kara Sırtlı Martı	Great Black-backed Gull	LC
		Larus hyperboreus	Kutup Martısı	Glaucous Gull	LC
		Larus argentatus	Kuzey Gümüş MartısI	European Herring Gull	LC
		Larus cachinnans	Hazar Martısı	Caspian Gull	LC
		Larus michahellis	Gümüş Martı	Yellow-legged Gull	LC
		Larus armenicus	Van Gölü Martısı	Armenian Gull	NT
		Larus fuscus	Kara Sırtlı Martı	esser Black-backed Gull	LC
		Gelochelidon nilotica	Gülen Sumru	Gull-billed Tern	LC
		Hydroprogne caspia	Hazar Sumrusu	Caspian Tern	LC
		Thalasseus sandvicensis	Kara Gagalı Sumru	Sandwich Tern	LC
		Sternula albifrons	Küçük Sumru	Little Tern	LC
		Sterna hirundo	Sumru	Common Tern	LC
		Sterna paradisaea	Kutup Sumrusu	Arctic Tern	LC
		Chlidonias hybrida	Bıyıklı Sumru	Whiskered Tern	LC

		Chlidonias leucopterus	Ak Kanatlı Sumru	White-winged Tern	LC
		Chlidonias niger	Kara Sumru	Black Tern	LC
	Stercorariidae	*Stercorarius pomarinus*	Küt Kuyruklu Korsanmartı	Pomarine Skua	LC
		Stercorarius parasiticus	Korsanmartı	Parasitic Jaeger	LC
		Stercorarius longicaudus	Uzun Kuyruklu Korsanmartı	Long-tailed Jaeger	LC
Columbiformes	Columbidae	*Columba livia*	Kaya Güvercini	Rock Dove	LC
		Columba oenas	Gökçe Güvercin	Stock Dove	LC
		Columba palumbus	Tahtalı	Common Wood Pigeon	LC
		Streptopelia turtur	Üveyik	European Turtle Dove	VU
		Streptopelia decaocto	Kumru	Eurasian Collared Dove	LC
		Spilopelia senegalensis	Küçük Kumru	Laughing Dove	LC
		Oena capensis	Kap Kumrusu	Namaqua Dove	LC
Cuculiformes	Cuculidae	*Clamator glandarius*	Tepeli Guguk	Great Spotted Cuckoo	LC
		Cuculus canorus	Guguk	Common Cuckoo	LC
Strigiformes	Tytonidae	*Tyto alba*	Peçeli Baykuş	Western Barn Owl	LC
	Strigidae	*Otus scops*	İshakkuşu	Eurasian Scops Owl	LC
		Bubo bubo	Puhu	Eurasian Eagle-Owl	LC
		Strix aluco	Alaca Baykuş	Tawny Owl	LC
		Athene noctua	Kukumav	Little Owl	LC
		Asio otus	Kulaklı Orman Baykuşu	Long-eared Owl	LC
		Asio flammeus	Kır Baykuşu	Short-eared Owl	LC
Caprimulgiformes	Caprimulgidae	*Caprimulgus europaeus*	Çobanaldatan	European Nightjar	
Apodiformes	Apodidae	*Tachymarptis melba*	Ak Karınlı Ebabil	Alpine Swift	LC
		Apus apus	Ebabil	Common Swift	LC
		Apus pallidus	Boz Ebabil	Pallid Swift	LC
Coraciiformes	Coraciidae	*Coracias garrulus*	Gökkuzgun	European Roller	LC
	Alcedinidae	*Alcedo atthis*	Yalıçapkını	Common Kingfisher	LC
	Meropidae	*Merops apiaster*	Arıkuşu	European Bee-eater	LC
		Merops persicus	Yeşil Arıkuşu	Blue-cheeked Bee-eater	LC
Bucerotiformes	Upupidae	*Upupa epops*	İbibik	Eurasian Hoopoe	LC
Piciformes	Picidae	*Jynx torquilla*	Boyunçeviren	Eurasian Wryneck	LC
		Dendrocopos minor	Küçük Ağaçkakan	Lesser Spotted Woodpecker	LC

		Dendrocopos medius	Ortanca Ağaçkakan	Middle Spotted Woodpecker	LC
		Dendrocopos leucotos	Ak Sırtlı Ağaçkakan	White-backed Woodpecker	LC
		Dendrocopos syriacus	Alaca Ağaçkakan	Syrian Woodpecker	LC
		Dendrocopos major	Orman Alaca Ağaçkakanı	Great Spotted Woodpecker	LC
		Dryocopus martius	Kara Ağaçkakan	Black Woodpecker	LC
		Picus viridis	Yeşil Ağaçkakan	European Green Woodpecker	LC
		Picus canus	Küçük Yeşil Ağaçkakan	Grey-headed Woodpecker	LC
Psittaciformes	Psittacidae	*Psittacula eupatria*	İskender Papağanı	Alexandrine Parakeet	NT
		Psittacula krameri	Yeşil Papağan	Rose-ringed Parakeet	LC
Passeriformes	Laniidae	*Lanius collurio*	Kızıl Sırtlı Örümcekkuşu	Red-backed Shrike	LC
		Lanius isabellinus	Kızıl Kuyruklu Örümcekkuşu	Isabelline Shrike	LC
		Lanius minor	Kara Alınlı Örümcekkuşu	Lesser Grey Shrike	LC
		Lanius excubitor	Büyük Örümcekkuşu	Great Grey Shrike	LC
		Lanius senator	Kızıl Başlı Örümcekkuşu	Woodchat Shrike	LC
		Lanius nubicus	Maskeli Örümcekkuşu	Masked Shrike	LC
	Oriolidae	*Oriolus oriolus*	Sarıasma	Eurasian Golden Oriole	LC
	Corvidae	*Garrulus glandarius*	Alakarga	Eurasian Jay	LC
		Pica pica	Saksağan	Eurasian Magpie	LC
		Nucifraga caryocatactes	Göknar Kargası	Spotted Nutcracker	LC
		Pyrrhocorax pyrrhocorax	Kırmızı Gagalı Dağkargası	Red-billed Chough	LC
		Pyrrhocorax graculus	Sarı Gagalı Dağkargası	Alpine Chough	LC
		Coloeus monedula	Küçük Karga	Western Jackdaw	LC
		Corvus frugilegus	Ekin Kargası	Rook	LC
		Corvus cornix	Leş Kargası	Hooded Crow	LC
		Corvus corax	Kuzgun	Northern Raven	LC
	Bombycillidae	*Bombycilla garrulus*	İpekkuyruk	Bohemian Waxwing	LC
	Paridae	*Periparus ater*	Çam Baştankarası	Coal Tit	LC
		Poecile lugubris	Ak Yanaklı Baştankara	Sombre Tit	LC
		Poecile palustris	Kayın Baştankarası	Marsh Tit	LC

		Cyanistes caeruleus	Mavi Baştankara	Eurasian Blue Tit	LC
		Parus major	Büyük Baştankara	Great Tit	LC
	Remizidae	*Remiz pendulinus*	Çulhakuşu	Eurasian Penduline Tit	LC
	Panuridae	*Panurus biarmicus*	Bıyıklı Baştankara	Bearded Reedling	LC
	Alaudidae	*Lullula arborea*	Orman Toygarı	Woodlark	LC
		Alauda arvensis	Tarlakuşu	Eurasian Skylark	LC
		Galerida cristata	Tepeli Toygar	Crested Lark	LC
		Eremophila alpestris	Kulaklı Toygar	Horned Lark	LC
		Calandrella brachydactyla	Bozkır Toygarı	Greater Short-toed Lark	LC
		Melanocorypha calandra	Boğmaklı Toygar	Calandra Lark	LC
		Alaudala rufescens	Çorak Toygarı	Lesser Short-toed Lark	LC
	Hirundinidae	*Riparia riparia*	Kum Kırlangıcı	Sand Martin	LC
		Hirundo rustica	Kır Kırlangıcı	Barn Swallow	LC
		Ptyonoprogne rupestris	Kaya Kırlangıcı	Eurasian Crag Martin	LC
		Delichon urbicum	Ev Kırlangıcı	Common House Martin	LC
		Cecropis daurica	Kızıl Kırlangıç	Red-rumped Swallow	LC
	Cettiidae	*Cettia cetti*	Kamış Bülbülü	Cetti`s Warbler	LC
	Aegithalidae	*Aegithalos caudatus*	Uzun Kuyruklu Baştankara	Long-tailed Tit	LC
	Phylloscopidae	*Phylloscopus trochilus*	Söğütbülbülü	Willow Warbler	LC
		Phylloscopus collybita	Çıvgın	Common Chiffchaff	LC
		Phylloscopus sindianus	Kafkas Çıvgını	Mountain Chiffchaff	LC
		Phylloscopus bonelli	Boz Çıvgın	Eastern Bonelli`s Warbler	LC
		Phylloscopus sibilatrix	Orman Çıvgını	Wood Warbler	LC
		Phylloscopus fuscatus	Esmer Çıvgın	Dusky Warbler	LC
		Phylloscopus proregulus	Çalıkuşu Çıvgını	Pallas`s Leaf Warbler	LC
		Phylloscopus inornatus	Sarıkaşlı Çıvgın	Yellow-browed Warbler	LC
		Phylloscopus borealis	Kuzey Çıvgını	Arctic Warbler	LC
		Phylloscopus nitidus	Yeşil Çıvgın	Green Warbler	LC
		Phylloscopus throchiloides	Yeşilimsi Çıvgın	Greenish Warbler	LC
	Acrocephalidae	*Acrocephalus arundinaceus*	Büyük Kamışçın	Great Reed Warbler	LC

		Acrocephalus melanopogon	Bıyıklı Kamışçın	Moustached Warbler	LC
		Acrocephalus paludicola	Sarı Kamışçın	Aquatic Warbler	VU
		Acrocephalus schoenobaenus	Kındıra Kamışçını	Sedge Warbler	LC
		Acrocephalus agricola	Doğu Kamışçını	Paddyfield Warbler	LC
		Acrocephalus dumetorum	Kuzey Kamışçını	Blyth`s Reed Warbler	LC
		Acrocephalus scirpaceus	Saz Kamışçını	Eurasian Reed Warbler	LC
		Acrocephalus palustris	Çalı Kamışçını	Marsh Warbler	LC
		Iduna caligata	Küçük Mukallit	Booted Warbler	LC
		Iduna pallida	Ak Mukallit	Eastern Olivaceous Warbler	LC
		Iduna opaca	Batı Ak Mukallidi	Western Olivaceous Warbler	LC
		Hippolais icterina	Sarı Mukallit	Icterine Warbler	LC
	Locustellidae	*Locustella naevia*	Çekirge Kamışçını	Common Grasshopper Warbler	LC
		Locustella fluviatilis	Ağaç Kamışçını	River Warbler	LC
		Locustella lusciniodies	Bataklık Kamışçını	Savi`s Warbler	LC
	Cisticolidae	*Cisticola juncidis*	Yelpazekuyruk	Zitting Cisticola	LC
	Sylviidae	*Sylvia atricapilla*	Kara Başlı Ötleğen	Eurasian Blackcap	LC
		Sylvia borin	Boz Ötleğen	Garden Warbler	LC
		Sylvia nisoria	Çizgili Ötleğen	Barred Warbler	LC
		Sylvia curruca	Küçük Ak Gerdanlı Ötleğen	Lesser Whitethroat	LC
		Sylvia crassirostris	Ak Gözlü Ötleğen	Eastern Orphean Warbler	LC
		Sylvia nana	Çöl Ötleğeni	Asian Desert Warbler	LC
		Sylvia communis	Ak Gerdanlı Ötleğen	Common Whitethroat	LC
		Sylvia cantillans	Bıyıklı Ötleğen	Subalpine Warbler	LC
		Sylvia melanocephala	Maskeli Ötleğen	Sardinian Warbler	LC
		Sylvia ruppeli	Kara Boğazlı Ötleğen	Rüppell`s Warbler	LC
	Regulidae	*Regulus ignicapilla*	Sürmeli Çalıkuşu	Common Firecrest	LC
		Regulus regulus	Çalıkuşu	Goldcrest	LC
	Troglodytidae	*Troglodytes troglodytes*	Çitkuşu	Eurasian Wren	LC

	Sittidae	*Sitta europaea*	Sıvacı	Eurasian Nuthatch	LC
		Sitta krueperi	Anadolu Sıvacısı	Krüper`s Nuthatch	LC
		Sitta neumayer	Kaya Sıvacısı	Western Rock Nuthatch	LC
	Tichodromidae	*Tichodroma muraria*	Duvar Tırmaşıkkuşu	Wallcreeper	LC
	Certhiidae	*Certhia familiaris*	Orman Tırmaşıkkuşu	Eurasian Treecreeper	LC
		Certhia brachydactyla	Bahçe Tırmaşıkkuşu	Short-toed Treecreeper	LC
	Sturnidae	*Acridotheres tristis*	Çiğdeci	Common Myna	LC
		Pastor roseus	Alasığırcık	Rosy Starling	LC
		Sturnus vulgaris	Sığırcık	Common Starling	LC
	Turdidae	*Turdus torquatus*	Boğmaklı Ardıç	Ring Ouzel	LC
		Turdus merula	Karatavuk	Common Blackbird	LC
		Turdus atrogularis	Kara Gerdanlı Ardıç	Black-throated Thrush	LC
		Turdus pilaris	Tarla Ardıcı	Fieldfare	LC
		Turdus iliacus	Kızıl Ardıç	Redwing	NT
		Turdus philomelos	Öter Ardıç	Song Thrush	LC
		Turdus viscivorus	Ökse Ardıcı	Mistle Thrush	LC
	Muscicapidae	*Cercotrichas galactotes*	Çalıbülbülü	Rufous-tailed Scrub Robin	LC
		Muscicapa striata	Benekli Sinekkapan	Spotted Flycatcher	LC
		Erithacus rubecula	Kızılgerdan	European Robin	LC
		Luscinia svecica	Mavigerdan	Bluethroat	LC
		Luscinia luscinia	Benekli Bülbül	Thrush Nightingale	LC
		Luscinia megarhynchos	Bülbül	Common Nightingale	LC
		Irania gutturalis	Taş Bülbülü	White-throated Robin	LC
		Ficedula hypoleuca	Kara Sinekkapan	European Pied Flycatcher	LC
		Ficedula albicollis	Halkalı Sinekkapan	Collared Flycatcher	LC
		Ficedula semitorquata	Alaca Sinekkapan	Semicollared Flycatcher	LC
		Ficedula parva	Küçük Sinekkapan	Red-breasted Flycatcher	LC
		Phoenicurus ochruros	Kara Kızılkuyruk	Black Redstart	LC
		Phoenicurus phoenicurus	Kızılkuyruk	Common Redstart	LC
		Monticola saxatilis	Taşkızılı	Common Rock Thrush	LC
		Saxicola rubetra	Çayır Taşkuşu	Whinchat	LC

		Saxicola rubicola	Taşkuşu	European Stonechat	LC
		Saxicola maurus	Sibirya Taşkuşu	Siberian Stonechat	LC
		Oenanthe oenanthe	Kuyrukkakan	Northern Wheatear	LC
		Oenanthe isabellina	Boz Kuyrukkakan	Isabelline Wheatear	LC
		Oenanthe deserti	Çöl Kuyrukkakanı	Desert Wheatear	LC
		Oenanthe hispanica	Kara Kulaklı Kuyrukkakan	Black-eared Wheatear	LC
		Oenanthe cypriaca	Kıbrıs Kuyrukkakanı	Cyprus Wheatear	LC
		Oenanthe pleschanka	Alaca Kuyrukkakan	Pied Wheatear	LC
	Cinclidae	*Cinclus cinclus*	Derekuşu	White-throated Dipper	LC
	Passeridae	*Passer domesticus*	Serçe	House Sparrow	LC
		Passer hispaniolensis	Söğüt Serçesi	Spanish Sparrow	LC
		Passer montanus	Ağaç Serçesi	Eurasian Tree Sparrow	LC
		Rock Sparrow	Kaya Serçesi	Petronia petronia	LC
	Prunellidae	*Prunella collaris*	Büyük Dağbülbülü	Alpine Accentor	LC
		Prunella montanella	Sibirya Dağbülbülü	Siberian Accentor	LC
		Prunella ocularis	Sürmeli Dağbülbülü	Radde`s Accentor	LC
		Prunella atrogularis	*Kara Boğazlı Dağbülbülü*	Black-throated Accentor	LC
		Prunella modularis	Dağbülbülü	Dunnock	LC
	Motacillidae	*Motacilla flava*	Sarı Kuyruksallayan	Western Yellow Wagtail	LC
		Motacilla citreola	Sarı Başlı Kuyruksallayan	Citrine Wagtail	LC
		Motacilla cinerea	Dağ Kuyruksallayanı	Grey Wagtail	LC
		Motacilla alba	Ak Kuyruksallayan	White Wagtail	LC
		Anthus richardi	Mahmuzlu İncirkuşu	Richard`s Pipit	LC
		Anthus campestris	Kır İncirkuşu	Tawny Pipit	LC
		Anthus pratensis	Çayır incirkuşu	Meadow Pipit	NT
		Anthus trivialis	Ağaç İncirkuşu	Tree Pipit	LC
		Anthus hodgsoni	Yeşil Sırtlı İncirkuşu	Olive-backed Pipit	LC
		Anthus cervinus	Kızıl Gerdanlı İncirkuşu	Red-throated Pipit	LC
		Anthus spinoletta	Dağ İncirkuşu	Water Pipit	LC
	Fringillidae	*Fringilla coelebs*	İspinoz	Common Chaffinch	LC

		Fringilla montifringilla	Dağ İspinozu	Brambling	LC
		Coccothraustes coccothraustes	Kocabaş	Hawfinch	LC
		Pyrrhula pyrrhula	Şakrak	Eurasian Bullfinch	LC
		Bucanetes githagineus	Küçük Alamecek	Trumpeter Finch	LC
		Carpodacus erythrinus	Çütre	Common Rosefinch	LC
		Chloris chloris	Florya	European Greenfinch	LC
		Linaria flavirostris	Sarı Gagalı Ketenkuşu	Twite	LC
		Linaria cannabina	Ketenkuşu	Common Linnet	LC
		Acanthis flammea	Huş İsketesi	Common Redpoll	LC
		Loxia curvirostra	Çaprazgaga	Red Crossbill	LC
		Carduelis carduelis	Saka	European Goldfinch	LC
		Serinus pusillus	Kara İskete	Red-fronted Serin	LC
		Serinus serinus	Küçük İskete	European Serin	LC
		Spinus spinus	Kara Başlı İskete	Eurasian Siskin	LC
	Emberizidae	*Emberiza calandra*	Tarla Çintesi	Corn Bunting	LC
		Emberiza citrinella	Sarı Çinte	Yellowhammer	LC
		Emberiza leucocephalos	Akbaşlı Çinte	Pine Bunting	LC
		Emberiza cia	Kaya Çintesi	Rock Bunting	LC
		Emberiza cineracea	Boz Çinte	Cinereous Bunting	NT
		Emberiza hortulana	Kirazkuşu	Ortolan Bunting	LC
		Emberiza caesia	Kızıl Kirazkuşu	Cretzschmar`s Bunting	LC
		Emberiza cirlus	Bahçe Çintesi	Cirl Bunting	LC
		Emberiza pusilla	Küçük Çinte	Little Bunting	LC
		Emberiza melanocephala	Karabaşlı Çinte	Black-headed Bunting	LC
		Emberiza schoeniclus	Bataklık Çintesi	Common Reed Bunting	LC
		Calcarius lapponicus	Mahmuzlu Çinte	Lapland Longspur	LC
		Plectrophenax nivalis	Alaca Çinte	Snow Bunting	LC

References

Avibase, 2015. Downloaded from the World Bird Database, http://avibase.bsceoc.org/checklist.jsp?region=GRas&list=howardmoore

Croxall, J.P., H.M.S. Butchart, B. Lascelles, A.J. Stattersfield, B. Sullivan, A. Symes, and P. Taylor. 2012. Seabird conservation status, threats and priority actions: a global assessment. Bird Conservation International, 22: 1-34.

Ebird, 2016. Downloaded from the Turkish bird Database:www.ebird.org/

Ertan, A. 2013. Marine and coastal birds of the Istanbul Strait. J. Black Sea/Mediterranean Environment, 19(2): 274-277

Güçlüsoy, H., E.S. Karauz, C.O. Kıraç, and M. Bilecenoğlu. 2014. Checklist of marine tetrapods (reptiles, seabirds, and mammals) of Turkey. Turk J Zool., 38: 930-938.

http://marinebio.org/oceans/marine-vertebrates/

http://www.birdlife.org/datazone/country/bulgaria/marine

http://www.seen-net.eu/

Kalem, S. 2001. UNDP Capacity Building Lacture Notes (In Turkish).

Kusbank, 2015. Downloaded from the Turkish bird Database: www.kusbank.com.tr

Nankinov, D.N. 1996. Coastal parks and reserves along the Black Sea and their importance for seabird. Marine Ornithology, 24: 31-34.

Nettleship, D.N. 1991. Seabird management and future research. Colonial Waterbirds 14(2): 77-84.

Roselaar, C.S. 1995. Taxonomy, Morphology and Distribution of the Songbirds of Turkey; an Atlas of Biodiversity of Turkish Passerine Birds, Pica Press, UK.

Sundseth, K. and S. Barova. 2009. Black Sea Region, 12 pp. In S. Wegefelt [ed.], Natura, 2000.

The RNBWS World Seabird Checklist www.rnbws.org.uk

www.iucn.org

MARINE MAMMALS IN THE TURKISH COAST OF THE BLACK SEA

Arda M. TONAY, Ayhan DEDE and Ayaka Amaha ÖZTÜRK

Faculty of Aquatic Sciences, Istanbul University, Ordu St., No: 200, 34470, Laleli, Istanbul, Turkey
Turkish Marine Research Foundation (TUDAV), P.O. Box: 10, Beykoz, Istanbul, Turkey
atonay@istanbul.edu.tr

1. Marine mammal species of the Black Sea

There are four marine mammal species in the Black Sea; three of them are cetaceans *Phocoena phocoena* (Linnaeus, 1758) (harbour porpoise), *Tursiops truncatus* (Montagu, 1821) (bottlenose dolphin) and *Delphinus delphis* Linnaeus, 1758 (short-beaked common dolphin), and one of them is a pinniped *Monachus monachus* (Mediterranean monk seal) (Öztürk 1999).

Fur seal *Arctocephalus pusillus* (Schreber, 1775) and Beluga *Delphinapterus leucas* (Pallas, 1776) are alien species escaped (released) from the Black Sea coasts of the former USSR and recorded in the Turkish Black Sea (Güçlüsoy *et al.* 2014). A grey seal, *Halichoerus grypus* (Fabricius, 1791) has also been encountered in the northeastern Black Sea however not observed in Turkish Black Sea coasts (Gladilina *et al*. 2013).

2. Distribution and population size

2.1. Black Sea harbour porpoise (*Phocoena phocoena relicta*)

According to Çelikkale *et al*. (1989) harbour porpoises were found all along the Turkish Black Sea coast, and particularly dominant in the eastern coast where several rivers enter the Black Sea (Figure 1).

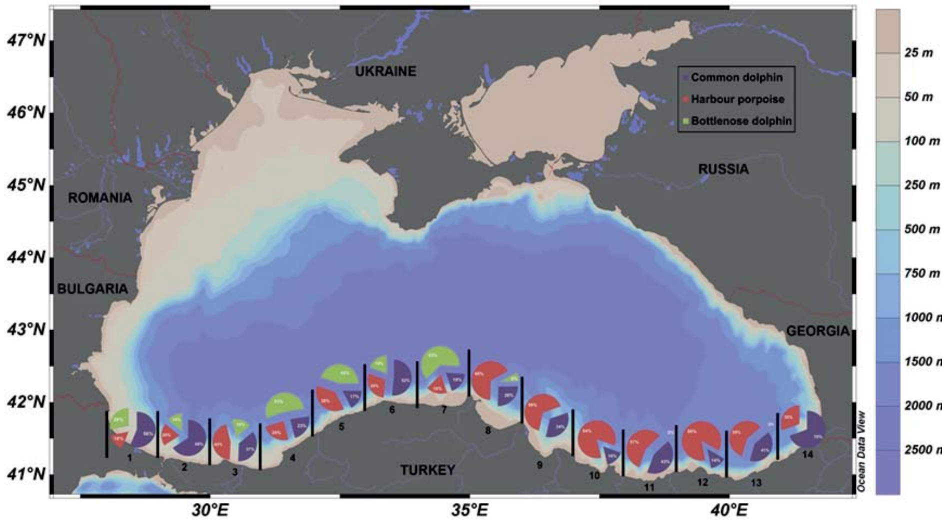

Figure 1. Distribition map of cetaceans in the Turkish Black Sea in spring and summer of 1997 (after Çelikkale *et al.* 1989)

All Turkish Black Sea coasts are important habitats for harbour porpoises. Major habitats are shallow seas over the continental shelf, and especially Kızılırmak and Trabzon regions in the Black Sea. Prebosphoric area in the Black Sea and also the Istanbul Strait are important areas for the pelagic fish migration, consequently for fisheries, especially purse seiners, and for cetaceans as their feeding area. The primary overwintering area of Black Sea harbour porpoises is the southeastern Black Sea that covers southern territorial waters of Georgia and eastern Turkish territorial waters (Birkun 2008).

The western Black Sea coast is where the continental shelf is widening as an important area for turbot fishery, which causes bycatch of this species. Besides, several observations of live animals and strandings have been recorded also in the Turkish Straits System (TSS) and Aegean Sea (Tonay and Dede 2013, Cucknell *et al.* 2016, Dede *et al.* 2016).

Previous region-wide estimates of cetacean abundance in the Black Sea, based on line transect surveys, were made in the Turkish territorial water and EEZ in 1987 (Çelikkale *et al*. 1989). Between the eastern and western border, two surveys were conducted in April and July from the Turkish coastline. According to Çelikkale *et al*. (1989), harbour porpoises were the most abundant cetacean species (59%) in the Turkish coast in April and the second most abundant (32%) in July. The mean density was calculated as 1.09 (0.05-5.48) dolphin per square km. The total cetacean population was estimated however, this estimate made by Çelikkale *et al*. (1989) has been discredited by the Scientific Committee of the International Whaling Commission (IWC) due to irremediable methodological and interpretative problems (Bjorge *et al*. 1994, Birkun 2008). According to Birkun (2008), the population size of harbour porpoises in the Black Sea is at least several 1000s or, rather, some 10,000s.

Cetacean sighting data were collected on a research cruise carried out in autumn 2007 in the western Black Sea between Istanbul (Turkey) and Constanta (Romania). The overall encounter rate was 3.83 sightings/100nmiles. The harbour porpoise (6%) was the least observed species in this study (Dede and Tonay 2010) (Figure 2).

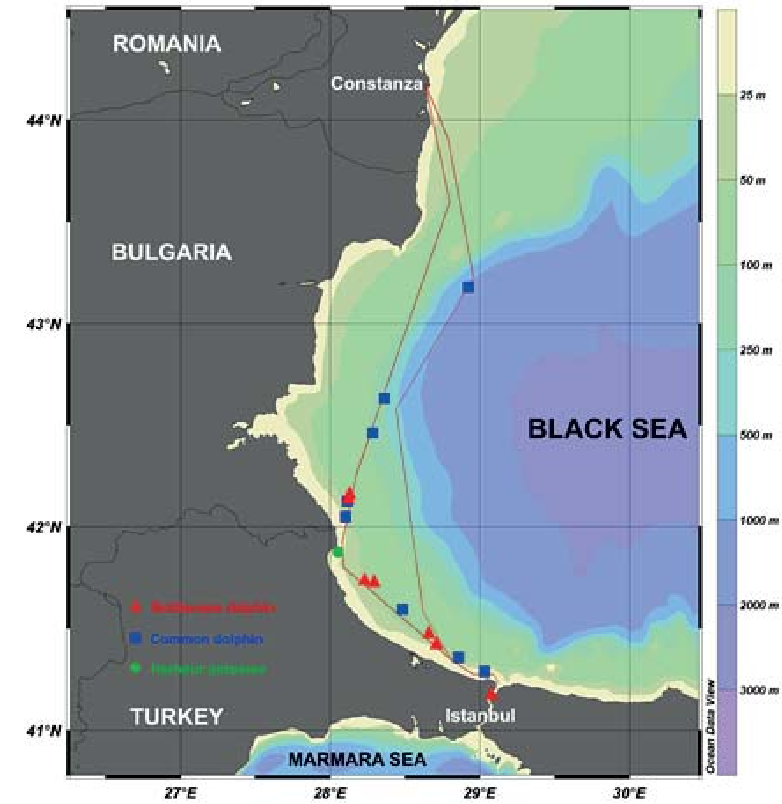

Figure 2. Survey track line and sighting locations in autumn 2007 survey (Dede and Tonay 2010)

2.2. Short-beaked common dolphin (*Delphinus delphis*)

According to Çelikkale *et al*. (1989) common dolphins were present all along the Turkish Black Sea coast, especially abundant in the eastern coast and pelagic waters (Figure 1). Common dolphins occurred mainly in deep waters and in areas where the sea surface temperature was low in the Black Sea (Sánchez-Cabanes *et al.* 2017).

All Turkish Black Sea coast, especially pelagic waters are important for the common dolphins. Major habitats are over the continental shelf, especially off Kızılırmak, Samsun and Giresun and near Istanbul. Prebosphoric area in the Black Sea and the Istanbul Strait are important for common dolphins as their feeding area. The overwintering area of common dolphins is the southeastern Black Sea like the harbour porpoises (Birkun 2008).

According to Çelikkale *et al*. (1989), the common dolphin was the most common cetacean species (53%) in the Turkish coast in July and the second most common (26%) in April. According to Birkun (2008), the population size of common dolphins in the Black Sea is at least several 10,000s.

Dede and Tonay (2010) reported that the common dolphin was the most often observed species (50%) in the western Black Sea in autumn.

2.3. Bottlenose dolphin (*Tursiops truncatus*)

The coastal areas are important for the bottlenose dolphin. Major habitats are shallow sea and over the continental shelf, especially around Zonguldak and Sinop area. There is no detailed information on habitats of this species in Turkish waters, except that they are rare in the eastern coast of the Turkish Black Sea. The prebosphoric area in the Black Sea and particularly the Istanbul Strait are important areas for bottlenose dolphins.

According to Çelikkale *et al*. (1989), the bottlenose dolphins were found in the western and central Turkish Black Sea coast, but rearly seen in the eastern Black Sea coast (Figure 1). There were also some records in the eastern Turkish Black Sea between March and May 2010 (Sánchez-Cabanes *et al.* 2017), but none in July and October 2014 (Saydam 2015).

The bottlenose dolphin is the least common cetacean species (15% in April and in July) in the Turkish coast (Çelikkale *et al*. 1989). According to Birkun (2008), the population size of bottlenose dolphin in the Black Sea is not less than several 1000s. Dede and Tonay (2010) reported the bottlenose dolphin was the second most commonly observed species (44%) in the western Black Sea in autumn.

2.4. Mediterranean Monk Seal (*Monachus monachus*)

The historical distribution of the monk seal in the Black Sea extends from the enterance of the Istanbul Strait eastwards to Sinop and northwards to Crimea. The monk seal population of the Black Sea has always been small but has fallen to dangerously low levels during the 1970s (Öztürk 1999). Berkes *et al*. (1978) stated that there were 15 individuals along the Turkish coast of the Black Sea. According to Öztürk (1993, 2007), based on field observations and inquiries, two seals have been reported along the coast between Cide, Çatalzeytin, İnebolu, Abana and Doğanyurt during 1986-1994. However, Mediterranean monk seals are believed to be extinct since 1997 (Kiraç and Savas 1996, Kiraç 2001) although the last sighting was in 2005 in Çatalzeytin (Öztürk 2007). There had been no sightings 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). This might also be the case in the Black Sea.

3. Strandings

Periodical stranding surveys are carried out on the Turkish Western Black Sea coast. All information collected by periodical stranding surveys, İÜ-TUDAV Cetacean Stranding Network and media during 2003-2016 are shown in Table 1. During the surveys, stranded cetaceans were photographed, measured, sex and species were identified and recorded. Besides, the tissue samples were collected for further studies. In total, 1243 stranded cetaceans (harbour porpoises 77%, bottlenose dolphins 10%, common dolphins 7% and unidentified 6%) were recorded. Strandings of harbour porpoises, the most negatively affected species by turbot fishery, were observed at high rate during spring and summer, which coincides with the illegal turbot fishing season. In the summers of 2003 and 2009, unusual mass stranding events occurred, but the causes could not be identified. High mortality of harbour porpoise neonates (total 60 individuals) was observed in June and July 2010-2012 (Öztürk *et al.* 2012, Tonay *et al*. 2013). This may be related with turbot fishery's indirect effect. Because of the death of lactating and nursing mothers in turbot nets, neonates may have starved to death and stranded ashore. In July 2016, another unusual mass stranding of harbour porpoise's neonates was recorded on the Turkish and Bulgarian coast in the western Black Sea. Any reason for such mortality was not detected, however, due to the advanced stage of decomposition of almost all specimens. Highest cetacean stranding rate was recorded (7.1 ind./km) in Turkey since 2003 compared to normal rates ranging between 0.1 and 1.1 (ind./km) in summer months (Öztürk *et al.* 2017).

Table 1. Stranding studies on the Turkish Western coast

Year	Period	Species				Total	Reference
		Pp	Dd	Tt	unid.		
2003-2005	Early summer (43km by walk)	175	22	10	4	211	Tonay *et al*. (2008)
2007 Jun-2009 Aug	Seasonal (2007: 43km by walk, 2008-09 123km by ATV)	77	15	22	50	164	Tonay *et al*. (2012a, 2012b)
2009 Sep-2010 Aug	Monthly (45km by ATV)	40	9	11	1	61	Tonay *et al*. (2012c)
2010 Sep-2012 Sep	Monthly (45km by ATV and 600km network)	155	14	32	10	211	Tonay *et al*. (2013)
2012 Oct-2013 Sep	Monthly (45km by ATV and 800km network)	19	11	22	2	54	Tonay (2016a)
2013 Oct-2016 Oct	Monthly (22km by ATV and 800km network)	489	15	27	11	542	Tonay *et al*. (2016a)
TOTAL		**955**	**86**	**124**	**78**	**1243**	

4. Population Structure

Morphological and genetic differences between Black Sea harbour porpoises and other populations of the harbour porpoise have been well studied and resulted in the confirmation of a subspecies, *Phocoena phocoena relicta* Abel, 1905 (Rosel *et al*. 1995, 2003, Fontaine *et al*. 2007, 2010, Viaud-Martinez *et al*. 2007, Galatius and Gol'din 2011, Tonay *et al*. 2016b).

The Black Sea population of common dolphin has been suggested to be the subspecies *D. delphis ponticus* Barabash-Nikiforov, 1935 due to its genetic (Natoli *et al*. 2008, Rosel *et al*. 1994) and morphological differences (Amaha 1994). Moreover, genetic differentiation of the Black Sea and TSS population was detected based on haplotype frequencies, supporting the previous inference that common dolphins have been differentiated from those in the Atlantic. At the same time, common dolphins in the Turkish Black Sea and TSS have some degree of genetic connectivity to the Mediterranean populations (Tonay *et al*. 2017).

The Black Sea population of bottlenose dolphin has been suggested to be the subspecies *Tursiops truncatus ponticus* Barabash-Nikiforov, 1960 due to its genetic and morphological differences (Natoli *et al*. 2005, Viaud-Martinez *et al.* 2008). Tonay *et al.* (2017) suggested there might be two subpopulations in the Turkish Black Sea; one might have originated from the Mediterranean Sea, whereas the other might have been initially present in the Black Sea, and subsequently migrated south to the Aegean and the Mediterranean Sea.

5. Diet

Stomach contents of three common dolphins, six harbour porpoises, and two bottlenose dolphins were studied in the eastern Turkish Black Sea coast. Horse mackerel (*Trachurus trachurus*) and anchovy (*Engraulis encrasicolus*) in common dolphins and harbour porpoises; horse mackerel and whiting (*Merlangius merlangus euxinus*) in bottlenose dolphins were identified (Çelikkale *et al*. 1988).

According to the study on the stomach contents of 70 bycaught harbour porpoises in spring and early summer in the western Turkish Black Sea, sprat (*Sprattus sprattus*) and whiting (*Merlangus merlangus euxinus*) are the most important prey species for the harbour porpoise (Tonay and Öz 1999, Tonay *et al*. 2007). Beside them, five fish species were identified; sole (*Solea* spp.), gobies (Gobiidae), European hake (*Merluccius merluccius*), anchovy (*Engraulis encrasicolus*), red mullet (*Mullus barbatus*) as well as crustaceans (Tonay *et al*. 2007). Meanwhile, plastic debris was found in five porpoises. One animal was found with the stomach full of plastic bags and sheeting weighing of 40.9g in dry weight (Tonay *et al*. 2007) (Figure 3).

Figure 3. Plastic debris in the stomach of the harbour porpoise (Background grid 15x15cm).

According to Bilgin *et al*. (2013), who studied the stomach content of 48 bycaught and 4 stranded cetaceans in spring in the eastern Turkish Black Sea, anchovy and whiting are the most important fish species for harbour porpoises. The other fish species identified in harbour porpoises are horse mackerel (*Trachurus trachurus)* and seahorse (*Hippocampus hippocampus*). Anchovy, horse mackerel and whiting were found in stomach content of six common dolphins.

6. Body length

Body length distribution of 232 bycaught (Tonay and Öz 1999, Tonay and Öztürk 2003, Tonay 2016) and stranded harbour porpoises (Tonay *et al.* 2008, 2012b) between 1999 and 2009 in the Turkish western Black Sea is shown in Figure 4 (Tonay 2010). The highest frequency (67 individuals) was found in the 121-130 cm interval. Whereas the maximum length range of males was 111-120 cm and that of females was 121-130 cm. No harbour porpoise bigger than 140 cm was found. But Karaçam *et al.* (1990) collected specimens with lengths up to 160–166 cm from the northern coast of Turkey (Table 2). Gol'din (2004) mentioned that they may be related to migrating specimens from the Sea of Azov because of the size. The harbour porpoises in the Black Sea region are at present the smallest representatives of harbour porpoises in the world (Gol'din 2004) which can be explained by intensive dolphin fishery and bycatch.

Table 2. Average length of harbour porpoise by sex in Turkish Black Sea studies

Numbe of samples	Average length (cm)		Referance
	Female	Male	
14(6F, 8M)	129,08	112,69	Çelikkale *et al*. 1988
12	147.58±4.350		Karaçam *et al.* 1990
48 (24F, 24M)	115,76	115,46	Tanabe *et al*. 1997a
92	132,1*		Gönener and Bilgin, 2009
232	121,1±22,37	111,1±28,93	Tonay 2010

* measured from the tip of rostrum to the tip of flukes; F: Female, M: Male

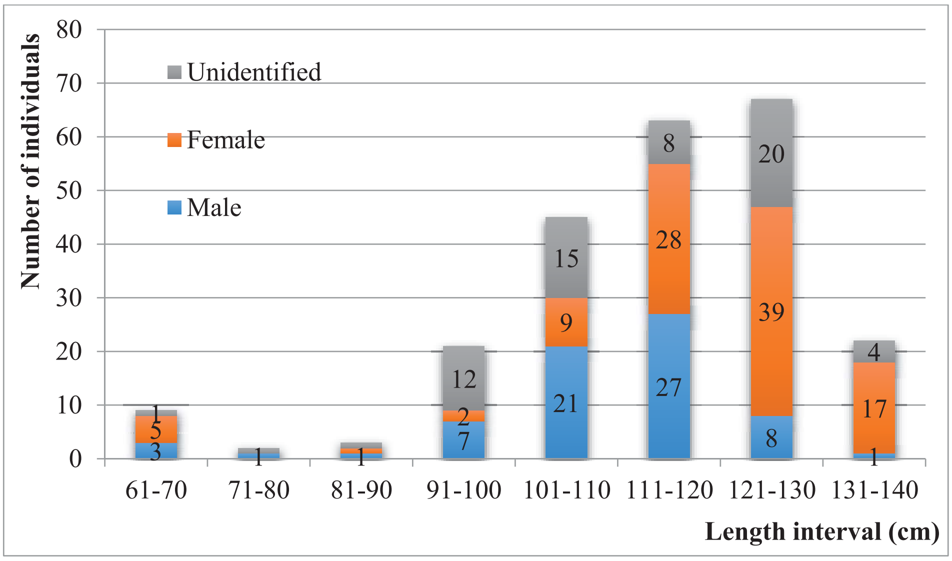

Figure 4. Length distribution of harbour porpoise specimens during 1999-2009 in the Turkish western Black Sea

7. Threats

In the past, the most serious threats for the Black Sea cetaceans were commercial dolphin fishery and live capture. Presently, the most apparent threats affecting the Black Sea cetaceans are accidental mortality in fishing gear (bycatch in bottom nets especially for harbour porpoises); habitat degradation causing the reduction of prey resources; water pollution and epizootics resulting in cetacean mass mortality events (Öztürk 1996, Birkun 2008). Effects of underwater noise (recently increased seismic surveys for oil and gas), military operations, and shipping effects are still unknown.

7.1. Dolphin Fishery and Live Capture

The Black Sea has a long history of cetacean fishery. This fishery is the main cause for the decline in the cetacean populations in the Black Sea. According to the review paper by Tonay and Öztürk (2012), the cetacean fishery began in ancient times in Anatolia and continued for over 2,300 years, until 1966 in USSR, Bulgaria and Romania, and 1983 in Turkey, when the fishery was banned. In the 20th century, the catch increased, peaked in the 1930's, and later in the 1950's in other Black Sea countries. It was increased, especially in the 50's and 70's, in Turkey because the Meat and Fish Institution (EBK) Fish Meal and Oil Factory was established in Trabzon in 1952 and was modernized in 1962. Before petroleum-based industries were developed, dolphin oil was essential for the people of the Black Sea. They used it for pharmacy, lamp oil, currier's oil, engine oil, lubricating oil, drugs containing vitamin D, albumin, paints, varnishes, soap, cosmetics, tinned meat and sausage, leather shoe wares, fish meal as feed to poultry, bone fertilizer and glue in all Black Sea countries (Acara 1965, Birkun 2008). The produced oil was used domestically as well as exported. After the cetacean fishery was banned in 1983 they used bycaught cetaceans in bottom nets until the 1990's.

According to TUIK (Turkish Statistical Institute) data between 1967 and 1983, a total of 44,178 t of dolphins were caught (Öztürk *et al.* 2004, Arpa 2012). According to the report of the sub-committee on small cetaceans, International Whaling Commission, in 1983, harbour porpoises were believed to account for 80%, common dolphins 15-16%, bottlenose dolphins 2-3% of the total catch of dolphin fisheries in Turkey from 1976 to 1981 (Bjørge *et al.* 1994). In the 20th century, it is estimated that a total of 4-5 million cetaceans were killed in the whole Black Sea (Birkun 2006). The strong reduction in the population of Black Sea harbour porpoise (approximately 90%) within the past 50 years was related to massive dolphin fishery and bycatch (Fontaine *et al.* 2012).

Since the 1960s, approximately 1000 bottlenose dolphins have been live-captured, not in the Turkish waters, but in the former USSR (such as Russia and Ukraine) and Romania for military, commercial (for dolphinarium) and scientific purposes. Until 2002, the live-capture of 10-20 animals took place annually in May-June in the Kerch Strait (Birkun 2008). According to CITES statistics, at least 92 individuals were removed from the Black Sea between 1990 and1999 (Reeves and Notarbartolo di Sciara 2006).

7.2. Fishery interactions

There are several cetacean bycatch studies in the Turkish Black Sea, such as Öztürk *et al.* (1999), Tonay and Öz (1999), Tonay and Öztürk (2003), Gönener and Bilgin (2009), Bilgin *et al.* (2013), Tonay (2016b). Many cetaceans are drowned in bottom gill nets some of which strand ashore as a result of incidental catch during the sole, turbot and sturgeon fishing between early April and June in the Turkish Black Sea (Öztürk 1996). Sturgeon fishery was banned in 1997. Nowadays, the most hazardous gear is bottom nets (trammel and gillnets) for turbot fishery. Turbot fishing area is within 100m isobath in the Turkish Black Sea in general (Tonay and Öztürk 2003). During the periodical stranding surveys, it was found that the fin and tail flukes of some stranded individuals were partly missing, which may have been removed during fishing operations due to bycatch (Tonay *et al.* 2012b and 2013). These carcases were found especially in spring and early summer which coincided with the turbot fishing season and also in autumn when other types of fishing were common. Turbot fishery makes impacts mainly on harbour porpoises (98%) among three cetacean species living in the Turkish western Black Sea waters (Table 3). It was observed that 76% of the bycatch occurred during May and June, when turbot fishery was banned. Turbot fishing carried out by using bottom nets, especially in that period is a threat to the sustainability of harbour porpoise populations (Tonay 2016b). It was estimated by Öztürk (1996) that at least 2000-3000 individuals of two species (harbour porpoise and bottlenose dolphin) were bycaught in the Turkish Black Sea each year. Bycatch rates in Turkish turbot fishery are shown in Table 4.

Table 3. List of the cetacean species in the bycatch studies in the Turkish Black Sea

Year	Region	Pp	Tt	Dd	Total	References
1993-1997	Western	62	-	1	**63**	Öztürk *et al.* (1999)
1999	Western	28	-	-	**28**	Tonay and Öz (1999)
2002-2003	Western	40	1	1	**42**	Tonay and Öztürk (2003)
2006	Centre	94	-	-	**94**	Gönener and Bilgin (2009)
2007-2008	Western	24	1	-	**25**	Tonay (2016)
2010-2012	Eastern	79	-	4	**103**	Bilgin *et al.* (2013)
	Total	**327**	**2**	**6**	**355**	

Pp: Harbour porpoise, Tt: Bottlenose dolphin, Dd: Common dolphin

Table 4. Harbour porpoise bycatch rates in turbot fishery studies in the Black Sea

Area in the Black Sea	Bycatch rate (individuals/km)	References
Middle of Southern coast	4.14	Gönener and Bilgin (2009)
West Southern coast	0.33	Tonay and Öztürk (2003)*
West Southern coast	0.19	Tonay (2016b)
East Southern coast	0.43**	Bilgin *et al.* (2013)

*The figure was recalculated based on the data presented in the paper.
** CPUE; ind/km x 24hour

Tonay (2016b) estimated that the number of harbour porpoises died were; 167(±153) (SE) (CV: 0.92) in 2007; 329(±220) (SE) (CV: 0.67) in 2008 during the legal period (April and July) and 2011(±742) (SE) (CV: 0.37) in 2007; 2249(±806) (SE) (CV: 0.35) in 2008 during legal and illegal periods of turbot fishing season. In conclusion, the estimated number of bycaught harbour porpoises in turbot fishery on the Turkish western Black Sea coast would be a combination of these two estimates. The bycaught harbour porpoises were between 1-8 years of age and 78% were physically immature individuals (Tonay 2016b). Gönener and Bilgin (2009) demonstrated that pingers were effective in reducing bycatch in turbot gill net fisheries and also emphasized the necessity of long term studies to determine the negative effects of pingers such as habituation, habitat exclusion etc.

In summer of 2010-2012, 50 harbour porpoise neonates were found stranded on the western coast of the Turkish Black Sea. Usually there was no net mark or cut observed on these stranded neonates, which implied that these were not bycaught animals. Considering the period of events and their small body size, they were probably still suckling at the time of death and it is unlikely that they were diving to the sea bottom to feed as adult animals do. Therefore, it is assumed that they had died and stranded from starvation as they had lost their mothers which were accidentally caught by turbot nets. It may be considered as indirect effects of turbot fishery (Öztürk *et al*. 2012, Tonay *et al*. 2013).

Gönener and Özdemir (2012) carried out a study in Sinop Bay (centre of Turkish Black Sea coast) between April 2007 and February 2008 where intensive red mullet (*Mullus barbatus*) fishing activities were conducted with bottom gill nets. Average loss was calculated for each fishing boat throughout the season due to depredation by bottlenose dolphins. During the last 30 years, complaints of small coastal fishermen in the Black Sea have been increasing. They accused the bottlenose dolphins for stealing the fish from the nets and damaging the nets. This interraction is strictly related with decreasing good environmental status of the Black Sea because of pollution and overfishing thus causing habitat loss and declining fish population.

7.3. Habitat degradation

The stocks of the small pelagic fish in the Black Sea showed drastic fluctuations especially within the last three decades. These changes are believed to be driven by four major factors; the changes in the climatic regime; changes in the trophic structure in ecosystem due to eutrophication, and malfunctioning of food web; deterioration of prey-predator relations due to selective and overfishing; and introduction of invasive alien species (Gücü 2012). No fish remains were found in 12 % of the stomach content of bycaught harbour porpoises (Tonay *et al*. 2007). Based on the available information as above, deterioration of cetacean habitats due to the decrease of prey fish is inevitable.

7.4. Water pollution and epizootics

High concentrations of organochlorines and relatively low concentrations of toxic trace elements have been detected in harbour porpoises in the Turkish Black Sea (Madhusree *et al*. 1997, Tanabe *et al.* 1997a, b). The contamination of harbour porpoises by DDTs and HCHs in the 1990s was higher than that reported for this species elsewhere in the world (Tanabe *et al*. 1997a).

Of two mass mortality events that eliminated large numbers of common dolphins in 1990 and 1994, one was considered to be due to the result of a morbillivirus epizootic in the Black Sea (Birkun *et al.*1999). The reduced prey availability concurred with two mass mortality events (in 1989 and 1990) impacted on all three Black Sea cetacean species but mostly on harbour porpoises. The malnutrition along with bioaccumulation of POPs could provoke epizootics, suppressing the resistance of cetacean to pathogens (Birkun 2002).

Macroscopic parasites were found in 81% of the stomach contents of 42 harbour porpoises in the western Turkish Black Sea. So far, findings related to larval forms of *Contraceacum* spp. have been found (Danyer *et al*. 2010). *Halocercus invaginatus*, *Stenurus minor* were reported in harbour porpoises from the coast of Turkish Black Sea (Veryeri 2012, Pekmezci *et al.* 2013, Aytemiz *et al*. 2014). Severe verminous pneumonia, cellular pneumonia, hemorrhage, edema and emphysema lesions were detected in the porpoise's lungs by histopathological examination (Aytemiz *et al.* 2014).

8. Status and Conservation

The Black Sea subpopulations of marine mammal species are all listed in the IUCN Red List of Threatened Species (IUCN, 2016); Mediterranean monk seal, harbour porpoise and bottlenose dolphin are EN (Endangered), common dolphin is VU (Vulnerable).

In the 20th century, the abundance of Black Sea cetaceans was considerably reduced by massive direct killing until 1983. According to Birkun (2008), it could be suspected also that the populations did not recover adequately during the subsequent period (1983-2006) and their population size was even diminished or showed very little recovery owing to the escalation of ongoing major threats, such as bycatch, habitat degradation, and mass mortality events. Anthropogenic problems appeared more recently, such as bycatch, especially in bottom nets, and overfishing of pelagic fish. Long-term researches on reducing cetacean entanglement, dolphin-safe fishing methods, fishing gears and technology (pingers and acoustically reflective nets), adopted and recommended in the "Conservation Plan for Black Sea Cetaceans" in 2006 and "Strategic Action Plan for the Environmental Protection and Rehabilitation of the Black Sea" in 2009, should be started as soon as possible. It is also noted that Turkey should elaborate and implement its own "Conservation Plan for Cetaceans" in its national waters. Several MPA sites which are important for marine mammals are suggested by Öztürk (1999) and Öztürk *et al*. (2013) in the Black Sea. Turkey accedes to several international agreements such as ACCOBAMS (Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and contiguous Atlantic area) being the latest one.

In the Black Sea, detailed studies are deemed necessary especially on abundance estimation, population genetics, and habitat preferences. In the meantime, a national stranding network for dead and live strandings or by-catch animals as well as a rehabilitation center for cetaceans should be established urgently.

References

Acara, A. 1965. Evaluation of Black Sea dolphins in the industry. Hidrobiyoloji Mecmuası. Istanbul University Hydrobiology Research Institute Publications Vol 3, No 1, Istanbul (in Turkish).

Amaha, A. 1994. Geographic Variation of the Common Dolphin, *Delphinus delphis* (Odontoceti: Delphinidae). (PhD thesis) Tokyo University of Fisheries, Japan.

Arpa, H. 2012. Short Stories about Fishmen and Fisheries from Yakakent. Yakakent Municipality Culture Publications, Samsun, 328 p (in Turkish).

Aytemiz, I., E. Danyer, F. Yildirim, and A. Gurel. 2014. A preliminary pathological and parasitological study on cetaceans in Turkey: Five cases from the western Black Sea coast. p. 97. Abstract book of 28th Annual Conf. European Cetacean Society, Liege, Belgium.

Berkes, F., A. Anat, H. Esenel, and M. Kışlalıoğlu. 1978. Distribution and ecology of *Monachus monachus* on Turkish coasts. Proceeding of the First International Conference, Rhodos Greece.

Bilgin, S., C. Şahin, F. Kalayci, Ö. Köse, T. Yeşilçiçek, Y. Ceylan, H. Bal and B. Taşçi. 2013. Interaction between the Black Sea dolphins and fisheries: Stranded dolphins (Rize and Artvin coasts) and the effect of bottom gill nets for turbot. T.C. Recep Tayyip Erdoğan University (in Turkish).

Birkun, A., Jr., T. Kuiken, S. Krivokhizhin, D.M. Haines, A.D.M.E. Osterhaus, M.W. van de Bildt, C.R. Joiris, and U. Siebert. 1999. Epizootic of morbilliviral disease in common dolphins (*Delphinus delphis ponticus*) from the Black Sea. Vet. Rec. 144(4): 85-92.

Birkun, A., Jr. 2002. Natural mortality: Black Sea, p. 181-193. In G. Notarbartolo di Sciara [ed.], Cetaceans of the Mediterranean and Black Seas: State of Knowledge and Conservation Strategies, ACCOBAMS, Monaco.

Birkun, A. Jr. 2006. Black Sea Cetaceans: an overview of research and conservation aspects. Abstract book of the Black Sea Ecosystem 2005 and Beyond. 1st Biannual Scientific Conference. 8-10 May 2006, Istanbul, Turkey. Commission on the Protection of the Black Sea Against Pollution pp. 110-113.

Birkun, A. Jr. 2008. The state of cetacean populations, pp.365-395. In T. Oğuz [ed.], State of the Environment of the Black Sea (2001-2006/7). Publication of the Commission on the Protection of the Black Sea Against Pollution (BSC), Istanbul, Turkey.

Bjørge, A., Jr. R. L. Brownell, G.P. Donovan, and W.F. Perrin. 1994. Significant direct and incidental catches of small cetaceans. 629 pp. In: W.F. Perrin, G. P. Donovan, J.

Barlow [Eds.], Gillnets and Cetaceans. Reports of the International Whaling Commission (Special Issue) 15, Cambridge.

Cucknell, A., A. Frantzis, O. Boisseau, M. Romagosa, C. Ryan, M.A. Tonay, P. Alexiadou, A.A. Öztürk, and A. Moscrop. 2016. Harbour porpoises in the Aegean Sea, Eastern Mediterranean: the species' presence is confirmed. Marine Biodiversity Records, 9(72): 1-13.

Çelikkale, S., S. Ünsal, F.H. Durakanoğlu, H. Karaçam, and E. Düzgüneş. 1988. Project report on the determination of dolphin stocks in the Black Sea and their biological characteristics, 98 pp. Ministry of Agriculture, Forestry and Rulal Affairs, Ankara (in Turkish).

Çelikkale, M. S., H. Karaçam, E. Düzgüneş, S. Ünsal, and H.F. Durukanoğlu. 1989. Size and distribution of dolphin populations in the Black Sea. Turk. J. Zoolog., 13(3): 189-196.

Danyer, E., İ. Aytemiz, A.M. Tonay, A. Dede, and H. Akkaya. 2010. Preliminary study of identification of macroscopic parasites in the stomach content of the harbour porpoises (*Phocoena phocoena*) bycaught and stranded in the Turkish Western Black Sea. 75 pp.12. International Veterinary Medicine Students Scientific Research Congress.

Dede, A. and A. M. Tonay. 2010. Cetacean sightings in the western Black Sea in autumn 2007. Journal of Environmental Protection and Ecology, 11(4): 1491-1494.

Dede, A., A.M. Tonay, A.A. Öztürk, and B. Öztürk. 2016. Status of the marine mammals population of the Sea of Marmara. pp. 863-879. In M.N. Çağatay, E. Özsoy, N. Balkıs, N. Balkıs, B. Öztürk [Eds.], The Sea of Marmara Marine Biodiversity, Fisheries, Conservation and Governance. Turkish Marine Research Foundation Publication no: 42.

Fontaine, M.C., S.J.E. Baird, S. Piry, N. Ray, K.A. Tolley, S. Duke, A.Jr. Birkun, M. Ferreira, T. Jauniaux, A. Llavona, B. Ozturk, A.A. Ozturk, V. Ridoux, E. Rogan, M. Sequeira, U. Siebert, G.A. Vikingsson, J-M. Bouquegneau, and J.R. Michaux. 2007. Rise of oceanographic barriers in continuous populations of a cetacean: the genetic structure of harbour porpoises in old world waters. BMC Biology, 5: 30.

Fontaine, M. C., K.A. Tolley, J.R. Michaux, A.Jr. Birkun, M. Ferreira, T. Jauniaux, A: Llavona, B. Ozturk, A.A. Ozturk, V. Ridoux, E. Rogan, M. Sequeira, J-M. Bouquegneau, and S.J.E. Baird. 2010. Genetic and historic evidence for climate-driven population fragmentation in a top Cetacean predator: the harbour porpoises in European Water. Proc. R. Soc., 277: 2829-2837.

Fontaine, M.C., A. Snirc, A. Frantzis, E. Koutrakis, B. Öztürk, A.A. Öztürk, and A. Austerlitz. 2012. History of expansion and anthropogenic collapse in a top marine predator of the Black Sea estimated from genetic data. PNAS, 2569-2576.

Galatius, A. and P.E. Gol'din. 2011. Geographic variation of skeletal ontogeny and skull shape in the harbour porpoise (*Phocoena phocoena*). Canadian Journal of Zoology, 89(9): 869-879.

Gladilina, E., O. Kovtun, A. Kondakov, A. Syomik, K. Pronin, and P. Gol'din. 2013. Grey seal *Halichoerus grypus* in the Black Sea: The first case of long-term survival of an exotic pinniped. Marine Biodiversity Records, 6.

Gönener, S. and S. Bilgin. 2009. The effect of pingers on harbour porpoise, *Phocoena phocoena* bycatch and fishing effort in the turbot gill net fishery in the Turkish Black Sea Coast. Turkish Journal of Fisheries and Aquatic Sciences, 9: 151-157.

Gönener, S. and S. Özdemir. 2012. Investigation of the interaction between bottom gillnet fishery (Sinop, Black Sea) and bottlenose dolphins (*Tursiops truncatus*) in terms of economy. Turkish Journal of Fisheries and Aquatic Sciences, 12: 115-126.

Gücü, A.C. 2012. Small pelagic fish and fisheries in Turkey, pp. 1-17. In A. Tokaç, A.C. Gücü, B.Öztürk [Eds.], The State of the Turkish Fisheries. Publication Number: 34, Turkish Marine Research Foundation, Istanbul, Turkey.

Güçlüsoy, H., E.S. Karauz, C.O. Kirac, and M. Bilecenoğlu. 2014. Checklist of marine tetrapods (reptiles, seabirds, and mammals) of Turkey. Turkish Journal of Zoology 38(6): 930-938.

Inanmaz, Ö.E., Ö. Değirmenci, and A.C. Gücü. 2014. A new sighting of the Mediterranean Monk Seal, *Monachus monachus* (Hermann, 1779), in the Marmara Sea (Turkey). Zoology in the Middle East, 60(3): 278-280.

IUCN 2016. The IUCN Red List of Threatened Species. Version 2015-4. <http://www.iucnredlist.org>. Downloaded on 27 Sept. 2016.

Karaçam, H., E. Düzgüneş, and H.F. Durukanoğlu. 1990. A study on the age-weight, age-length composition of dolphins and porpoises in the Black Sea, (in Turkish). Istanbul University Journal of Aquatic Products, 4(2): 35-44.

Kıraç, C. and Y. Savaş. 1996. Status of the monk seal *Monachus monachus* in the neighbourhood of Ereğli, Black Sea coast of Turkey. Zoology in the Middle East, 12: 5-12.

Kıraç, C.O. 2001. Witnessing the monk seal's extinction in the Black Sea. The Monachus Guardian 4 (2): http://www.monachus-guardian.org/mguard08/08editor.htm

Madhusree, B., S. Tanabe, A.A. Öztürk, R. Tatsukawa, N. Miyazaki, E. Özdamar, O. Aral, O. Samsun, and B. Öztürk. 1991. Contamination by butyltin compounds in harbour porpoise (*Phocoena phocoena*) from the Black Sea. Fresenius J. Anal. Chem., 359: 244-2410.

Natoli, A., A. Birkun, A. Aguilar, A. Lopez, and A.R. Hoelzel. 2005. Habitat structure and the dispersal of male and female bottlenose dolphins (*Tursiops truncatus*). Proc. R. Soc. B: Biological Sciences, 272: 1217-1226.

Natoli, A., A. Canadas, C. Vaquero, E. Politi, P. Fernandez-Navarro, and A.R. Hoelzel. 2008. Conservation genetics of the short-beaked common dolphin (*Delphinus delphis*) in the Mediterranean Sea and in the eastern North Atlantic Ocean. Conservation Genetics, 9: 1479-1487.

Öztürk, A.A., B. Öztürk, A.M. Tonay, and M. Kececi. 2004. History of dolphin fishery in the Turkish Black Sea during 1970-1983, pp. 438-439. Marine Mammals of the Holarctic, Koktebel, Crimea, Ukraine.

Öztürk, A.A., A.M. Tonay, V. Raykov, and A. Dede. 2012. High mortality of harbour porpoise neonates in the southwestern Black Sea in 2010 and 2011, 90pp. 26th Annual Conf. European Cetacean Society, Galway, Ireland.

Öztürk, A.A., A.M. Tonay, A. Dede, E. Danyer, I. Aytemiz Danyer, and D. Popov. 2017. Unusual mass mortality of harbour porpoises on the coast of the western Black Sea (Bulgaria and Turkey) in summer 2016, 297pp. 31st European Cetacean Society Conference, Middelfart, Denmark.

Öztürk, B. 1993. Investigation on the distribution of the Mediterranean monk seal *Monachus monachus* (Hermann, 1779) in the Black Sea. Istanbul University Journal of Aquatic Products, 1-2: 95-104.

Öztürk, B. 1996. Whales and Dolphins, Introduction of Cetology, (in Turkish). 136p. Anahtar Kitapları Yayinevi, Istanbul.

Öztürk, B. 1999. Black Sea Biological Diversity: Turkey. GEF Black Sea Environmental Programme, United National Publications, New York.

Öztürk, B., A.A. Öztürk, and A. Dede. 1999. Cetacean by-catch in the western coast of the Turkish Black Sea in 1993-1997, 134 pp. 13rd European Cetacean Society Conference, Valencia, Spain.

Öztürk, B. 2007. Mediterranean Monk Seal and Conservation.Yalıkavak Environment and Monk Seal Research Association, (in Turkish). 132pp.

Öztürk, B., B. Topaloğlu, A. Kıdeyş, L. Bat, Ç. Keskin, M. Sezgin, A.A. Öztürk, and A.C. Yalçiner. 2013. A proposal for new marine protected areas along the Turkish Black Sea coast. J. Black Sea/Mediterranean Environment, 19(3): 365-379.

Pekmezci, G.Z., B. Yardımcı, A.T. Gürler, C.S. Bölükbaş, M. Açıcı, and Ş. Umur. 2013. Survey on the presence of Nematodes and associated with pathology in marine mammals from Turkish waters. Journal of Faculty of Veterinary Medicine, Kafkas University, 19(6): 1035-1038.

Reeves, R.R. and G. Notarbartolo di Sciara. 2006. The Status and Distribution of Cetaceans in the Black Sea and Mediterranean Sea, 137 p. IUCN Centre for Mediterranean Cooperation, Malaga, Spain.

Rosel, P.E, A.E. Dizon, and J.E. Heyning. 1994. Genetic analysis of sympatric morphotypes of common dolphins (genus *Delphinus*). Marine Biology, 119: 159-167.

Rosel, P.E., A.E. Dizon, and M.G. Haygood. 1995. Variability of the mitochondrial control region in populations of the harbour porpoise, Phocoena, on interoceanic and regional scales. Canadian Journal of Fisheries and Aquatic Sciences, 52(6): 1210-1219.

Rosel, P.E., A. Frantzis, C. Lockyer, and A. Komnenou. 2003. Source of Aegean Sea harbour porpoises. Mar. Ecol. Prog. Ser., 247: 257-261.

Sánchez-Cabanes, A., M. Nimak-Wood, N. Harris, and R. de Stephanis. 2017. Habitat preferences among three top predators inhabiting a degraded ecosystem, the Black Sea. Scientia Marina, 10.3989/scimar.04493.07A.

Saydam, G. 2015. Cetacean distribution in the southern Black Sea: An acoustıc approach. Master Thesis, 164p. The Graduate School of Marine Sciences of Middle East Technical University.

Tanabe, S., B. Madhusree, A.A. Öztürk, R. Tatsukawa, N. Miyazaki, E. Özdamar, O. Aral, O. Samsun, and B. Öztürk. 1997a. Persistent organochlorine residues in harbour porpoise (*Phocoena phocoena*) from the Black Sea. Mar. Pollut. Bull., 34(5): 338-347.

Tanabe, S., B. Madhusree, A.A. Öztürk, R. Tatsukawa, N. Miyazaki, E. Özdamar, O. Aral, O. Samsun, and B. Öztürk. 1997b. Isomer-specific analysis of polychlorinated biphenyls in harbour porpoise (*Phocoena phocoena*) from the Black Sea. Mar. Pollut. Bull., 34(9): 712-720.

Tonay, A.M. and I.M. Öz. 1999. Stomach contents of the harbour porpoise bycatches in the Western Black Sea (in Turkish). pp. 92-98. Underwater Sci. and Technol. Meet., Istanbul.

Tonay, A.M. and B. Öztürk. 2003. Cetacean bycatches in turbot fishery on the western coast of the Turkish Black Sea, pp. 131-138. In I. K. Oray, M.S. Çelikkale, G. Özdemir [Eds.]. International Symposium of Fisheries and Zoology (In memory of Ord. Prof. Dr. Curt KOSSWIG in His 100th Birth Anniversary), Istanbul.

Tonay, A.M., A. Dede, A.A. Öztürk, and B. Öztürk. 2007. Stomach content of harbour porpoises (*Phocoena phocoena*) from the Turkish western Black Sea in spring and early summer. Rapp. Comm. int. Mer Médit., 38: 616.

Tonay, A.M., A. Dede, and A.A. Ozturk. 2008. Cetacean strandings in the Turkish western Black Sea coast during spring months in 2003-2005. 22nd European Cetacean Society Conf., Egmond aan Zee, the Netherlands.

Tonay A.M. 2010. Interaction with the Cetacean strandings and turbot fisheries in the western Black Sea, Ph.D Thesis (in Turkish). 117 pp. Istanbul University, the Institute of Science.

Tonay, A.M. and A.A. Öztürk. 2012. Historical records of cetacean fishery in the Turkish seas. J. Black Sea/Mediterr. Environ., 18(3): 388-399.

Tonay, A.M., A. Dede, A.A. Öztürk, D. Ercan, and A. Fernández. 2012a. Unusual mass mortality of cetaceans on the coast of the Turkish Western Black Sea in summer 2009. J. Black Sea/Mediterr. Environ., 18(1): 65-75.

Tonay, A.M., A. Dede, A.A. Öztürk, and B. Öztürk. 2012b. Cetacean strandings in the Turkish Western Black Sea coast during 2007-2009. J. Black Sea/Mediterr. Environ., 18(2): 246-250.

Tonay, A.M., A. Dede, and A.A. Öztürk. 2012c. Cetacean stranding records on the Turkish Western Black Sea coast during September 2009-August 2010 on a monthly basis, 327pp. 26th Annual Conference of European Cetacean Society. Galway, Ireland.

Tonay, A.M. and A. Dede. 2013. First stranding record of a harbour porpoise (*Phocoena phocoena*) in the Southern Aegean Sea. J. Black Sea/Mediterr. Environ. 19(1): 132-137.

Tonay, A.M., A. Dede, and A.A. Öztürk. 2013. Cetacean stranding records on the Turkish Western Black Sea coast during September 2010-September 2012, 389pp. 27th European Cetacean Society Conf., Setubal, Portugal.

Tonay, A.M. 2016a. Cetacean stranding records in the Turkish Western Black Sea coast during October 2012 - September 2013, (in Turkish). Ege Journal of Fisheries and Aquatic Sciences, 33(4): 343-345.

Tonay, A.M. 2016b. Estimates of cetacean bycatch in the turbot fishery on the Turkish Western Black Sea coast in 2007 and 2008. Journal of the Marine Biological Association of the United Kingdom, 96(4): 993-998.

Tonay, A.M., A. Dede, A.A. Öztürk, E. Danyer, I. Aytemiz, B. Uzun, R. Bilgin, and B. Öztürk. 2016a. Cetacean strandings monitoring studies on the Turkish western Black Sea coast during 2003-2016, pp.156-159. I. National Marine Monitoring and Assessment Symposium, Ankara.

Tonay, A.M., Yazıcı, Ö., Dede, A., Bilgin, S., Danyer, E., Aytemiz, I., Maracı, Ö., Öztürk, A.A., Öztürk, B. and R. Bilgin 2016b. Is there a distinct harbor porpoise subpopulation in the Marmara Sea? Mitochondrial DNA Part A, 28(4): 558-564.

Tonay, A.M., B. Uzun, A. Dede, E. Danyer, I. Aytemiz Danyer, A.A. Öztürk, B. Öztürk, and R. Bilgin. 2017. Genetic investigation on the short-beaked common dolphin (*Delphinus delphis*) and bottlenose dolphin (*Tursiops truncatus*) in the Turkish seas based on mtDNA sequences, 181p. 31st European Cetacean Society Conference, Middelfart, Denmark.

Veryeri, N.G. 2012. Postmortem examinations of stranded dolphins found at Black Sea coast near Ordu City (Mammalia: Cetacea). Zoology in the Middle East, 55(1): 129-132.

Viaud-Martinez, K.A., M.V. Milmer, E.P. Goldin, V. Ridoux, A.A. Ozturk, B. Ozturk, P.E. Rosel, A. Frantzis, A. Komnenou, and A.J. Bohonak. 2007. Morphological and genetic differentiation of the Black sea harbour porpoise *Phocoena phocoena*. Marine Ecology Progress Series, 338: 281-294.

Viaud-Martinez, K.A., Jr. R.L. Brownell, A. Kommenou, and A.J. Bohonak. 2008. Genetic isolation and morphological divergence of Black Sea bottlenose dolphins, Biological Conservation, 141: 1600-1611.

PARASITE DIVERSITY OF THE BLACK SEA FISHES IN TURKISH COASTAL AREAS

Ahmet ÖZER and Türkay ÖZTÜRK

Sinop University, Faculty of Fisheries and Aquatic Sciences, 57000 Sinop, Turkey
aozer@sinop.edu.tr

1. Introduction

Parasites are among the most significant components of aquatic environment and it seems unlikely for any fish species to escape being parasitised in their complete life histories. As such, much of biodiversity (species richness) may be viewed as a diversity of hosts for parasites (Littlewood 2005). Fish species play a role for parasites as primary, secondary (intermediate) and/or final hosts. Some parasite groups reach their adulthood in or on the definitive or final host while secondary (intermediate) host harbours parasites for only one stage of their life cycle. Rohde (2005) divided parasites into several types, life cycles and hosts; *ectoparasites, endoparasites, obligate parasites, facultative parasites, temporary parasites, permanent parasites, larval parasites, periodic parasites, hyperparasites, microparasites* and *macroparasites.* Fish parasites are represented within two main groups, protista and metazoa. Protistan parasites requires only one fish host in their simple life histories while metazoans need several host including fish in their developmental stages. These parasites are separated to be ecto- and endoparasites and most of them are cosmopolitan throughout aquatic environment all over the world and major fish parasites are represented by the members of Mastigophora (flagellates), Sarcodina (amoebae), Haplosporidia, Apicomplexa, Microsporidia and Ciliophora (ciliates). On the other hand, metazoan parasites comprise more diverse groups belonging to Monogenea, Trematoda, Cestoda, Nematoda, Acanthocephala and Crustacea, some having more complex life cycle strategies including several hosts including fish in their development. Littlewood (2005) mentioned that not every organism was a suitable host for every parasite, but to understand fully the taxonomic range of host-parasite interactions, obligate and facultative interactions, and even the paratenic hosts must be considered to help to bridge trophic gaps. Many of the lineages in the tree of life are exclusively marine, but considerably fewer are exclusively parasitic and marine parasitism is generally restricted to marine hosts (Littlewood 2005).

Despite many parasitological reports of marine fishes living at the coastal areas of the Turkish Black Sea, there is a need to obtain an up to date checklist on fish parasites for current and further studies. Thus, the main purpose of the present study is to provide a comprehensive list of parasites, including the members of all different phyla, reported in fish species collected from Turkish coastal areas of the Black Sea.

2. Materials and Methods

The list of parasite species, excluding myxosporeans, of the Black Sea fishes collected from Turkish coastal areas is based on published papers and presentations and the checklist provides a complete list of references. For each parasite species, their hosts and geographical locality are listed with references for published records. Each publication is numbered and explanations are provided underneath of the checklist table for easy follow-up. Developmental stages of some parasites having complex life cycles involving two or more hosts are indicated next to the parasite's name as larvae or adult if provided in the publication. The scientific names of fish hosts follow Froese and Pauly (2015).

3. Results

The present checklist of fish parasites reported from the Turkish Black Sea coasts includes 115 parasite species from 44 host fish and shellfish species (Table 1). Brief details of all parasitic higher taxa and their host reports in this particular part of the Black Sea are provided below;

3.1. Protista

3.1.1. Apicomplexa (Coccidia)

The phylum Apicomplexa is a huge group including rather different protozoan parasites which have a special cell organelle, the apical complex, which facilitates invasion of the host cell. Fish apicomplexans are divided into two major groups; one host involving *Coccidia* and heteroxenous two hosts involving *Coccidia* sensu lato. Most of the known coccidians develop in the gut but there are species developing in inner organs of spleen, liver, kidney and swimbladder (Nowak 2005). Members of genera *Eimeria* and *Gaussia* are the most reported parasites in fishes. However, despite so many parasitological studies on the parasite diversity of Black Sea fishes, only one species namely *Eimeria sardinae* has been reported from whiting *Merlangius merlangus* in Sinop coasts of the Black Sea by Özer *et al.* (2014a) (Table 1). This species is a cosmopolitan coccidian that has been reported from Clupeiformes, including twaite shad *Alosa fallax*, Pacific herring *Clupea harengus*, European anchovy *Engraulis engrasicolus* in the Black Sea and Özer *et al.* (2014a) reported their data led them to conclude that *E. sardinae* oocytes presented in the intestine of whiting due to ingestion of European sprat or European anchovy as food fish and *M. merlangus* was not a true host for the oocysts.

3.1.2. Ciliophora (Ciliates)

Among the protozoans, ciliophorans are the most specious parasites (Lom and Dyková 1992). Free-living species inhabit a range of aquatic and terrestrial environments, and other species live in various symbiotic relations with aquatic animals including fish. They are either epibiotic, ectoparasitic or endozoic in fishes. Ciliates display a wide range of adaptations to a symbiotic way of life, ranging from facultative parasites to innocuous symphobionts to true parasites (Nowak 2005). Scuticociliate parasites such as *Philasterides* and *Uronema* are known as facultative parasite especially in fish cultures. They attack the skin and gills first, hampering respiration, and then make their way into the internal body organs, disintegrating them and causing mortalities (Lom and Dyková 1992). Species of the peritrichous genus *Trichodina,* causative agents of trichodiniasis on fish, are common inhabitants of the surface of some freshwater and marine fish species (Lom 1995). Trichodinids are probably the most commonly encountered protozoan parasites on wild and cultured fishes in marine as well as freshwater environments (Urawa 1992). There are many studies on the occurrence of ciliophoran parasites such as the members of genus *Trichodina,* as well as parasites belonging to *Philasterides, Riboscyphidia, Ambiphrya* and *Vorticella* despite being rare, on the Black Sea fishes (Table 1). Thus far, a total of 10 trichodinid species have been reported from many different fish hosts collected from Turkish Black Sea coasts by several authors (see Table 1 for details). Of these reported trichodinids, *T. domerguei* had the most diverse fish host range (6), followed by *T. puytoraci* (3) and *T. lepsii* (2). On the other hand, members of genera *Philasterides, Riboscyphidia, Ambiphrya* and *Vorticella* were represented by only one host species (Table 1). *Philasterides dicentrarchi* is the causative agent of scuticociliatosis in cultured turbot *Psetta maxima*.

3.2. Metazoa

3.2.1. Platyhelminthes

3.2.1.1. Monogenea

Monogeneans are the most diverse group of ectoparasites of fish belonging to two main groups, Monopisthocotylea and Polyopisthocotylea. The Polyopisthocotylea is a large group of monogeneans, with about 1000 described species which occur in all seas of the world, from the littoral zone to open oceanic waters, from the poles to the tropics, and from surface waters to the depths of the sea (Whittington 2005). These parasites are oviparous in general, only some being viviparous in their life cycle. Members of both groups have direct life cycles (i.e. they infect only a single host). Both groups typically live on the external surfaces of the gills, skin and fins of their fish hosts or oral cavity, and attach using a unique disc-like haptor. Marine Polyopisthocotylea feed on blood of host fish. High host specificity is a well-known pattern for both groups. Their special structure named haptor and opishaptor organised with hooks and clumps for attachment to respective organ of their hosts (Nowak 2005). The number of haptoral clamps in most groups is fixed at three or four pairs and in a few groups, clamps are more numerous, ranging from tens of pairs, to over 200 pairs depending on parasite species. Unlike Polyopisthocotylea, the haptor of Monopisthocotylea comprises a single, symmetrical attachment unit called haptor comprise 14 or 16 small hooklets. The approximately 1000 marine monopisthocotylean species has been reported worldwide (Whittington 2005). There are many monogenean parasite species reported from the Black Sea fishes throughout Turkish coastal areas and these parasites are represented by 7 different genera (Table 1). Members of the genus *Ligophorus,* including *L. cephali* and *L. mediterraneus*, are strictly specific to mugilids as was found by Özer and Yılmaz Kırca (2013, 2015) (Table 1). The most of the members of the genus *Lamellodiscus* are known to be gill parasites of sparid fish and two species namely *Lamellodiscus elegans* and *L. fraternus* have been reported from a sparid fish species in the Black Sea by Özer *et al.* (2015b) (Table 1). *Gyrodactylus* are viviparous parasites and infect a wide range of teleost and amphibian hosts and live as ectoparasites on the skin, fins and gills of fish. This genus has been represented by 5 species on the Black Sea fishes (Table 1). On the other hand, members of *Mazocraes, Axine, Solostamenides* and *Diplectanum* have been reported by only one species from their specific hosts in the Black Sea (Table 1).

3.2.1.2. Trematoda

The Class Trematoda is the most abundant group of parasitic platyhelminthes (Niewiadomska and Pojmanska 2011) and due to so large number of individuals belonging to about 70 families occurring in teleost fishes and well over 5000 species known from all fishes (including freshwater species), members of this group have difficulties in their classification (Cribb 2005). They have complex life cycles involving several larval stages some of which multiply in the intermediate hosts. Sexual adults infect all classes of marine vertebrates, asexual reproduction occurs in molluscs, and metacercariae occur in many groups of invertebrates and vertebrates such as fish (Cribb 2005). Their life cycle involves generation of eggs, miracidium, sporocycts, redia, cercaria, metarcercaria and sexual adults in at least two hosts, and all these steps take place exclusively in either entirely aquatic environment, a semi-aquatic environment or a terrestrial environment (Cribb 2005, Niewiadomska and Pojmanska 2011). These parasites can be found primarily in the gut, however, they can also occur under the scales, on the gills, in the swim bladder, body cavity, urinary bladder, gall bladder, flesh, ovary and circulatory system of fish (Cribb 2005). Despite the tremendous diversity in fishes, about ten groups dominate the fauna by accounting for about two-thirds of records of digeneans in fishes (Cribb 2005). Digenean trematodes are one of the most specious parasitic group that has been reported in the Black Sea fishes of Turkish coastal areas with 32 identified parasites to species level and 4 identified to generic level (Table 1). Of the reported parasites, most were found to be in their adult stages while the rest were in metacercarial stage. *Parvatrema duboisi* is the only species reported from the gonads, hepatopancreas and gill filaments of Mediterranean mussel *Mytilus galloprovincialis* (Table 1).

3.2.1.3. Cestoda

According to Caira and Reyda (2005), two major subgroups are recognised: the Cestodaria, consisting of the orders Gyrocotylidea and Amphilinidea, and the Eucestoda, consisting of the remaining 11 cestode orders. Three of the 11 orders of eucestodes are exclusively marine: the Diphyllidea, Lecanicephalidea and Tetrabothriidea; three of the most speciose orders are predominantly marine: Pseudophyllidea, Trypanorhyncha and Tetraphyllidea. The body of eucestodes possess a distinct anterior holdfast organ called the scolex and posterior linear series of segments named proglottids. The life cycles of marine cestodes are poorly known, in general, their developmental stages involve the first mollusc and arthropod hosts; the second and paratenic hosts such as osteichthyes and chondrichthyes and adult stages in vertebrate definitive hosts such as osteichthyes and chondrichthyes and cetaceans. Over 1400 species of cestodes are known to occur in marine habitats (Caira and Reyda 2005). A total of 10 cestode species, 8 of which were identified to species level, have been reported from a wide range of teleost and cartilaginous fishes in the Turkish coastal areas of the Black Sea (Table 1). *Scolex pleuronectis*, at its plerocercoid stage, has been the most reported cestode from 14 different teleost fish host species while some cestode species e.g. *Tetrarhynchobothrium tenuicolle, Echeneibothrium variabile, Acanthobothrium coronatum*, were found only one cartilaginous fish species (Table 1).

3.2.1.4. Rhabditophora

Members of the class Rhabditophora are the most primitive group within the phylum Platyhelminthes and *Ursatoma cyprinae* is the only species reported from *Mytilus galloprovincialis* in Sinop coasts of the Black Sea (Table 1).

3.2.2. Nematoda

The Phylum Nematoda (roundworms) is one of the most diverse and frequent group of parasites of fishes in the freshwater, brackish-water and marine environments throughout the world. According to Roberts and Janovy (2005), the phylum Nematoda is comprised of two classes: the Enoplea and the Rhabditea, and marine parasitic nematodes are found in three dorylaimian (Enoplea) orders the Trichurida, Dioctophymatida and Mermithida, and four rhabditian orders, the Strongylata, Ascaridida, Oxyurida and Spirurida. Their life cycles could be either monoxenous or heteroxenous. *Hysterothylacium aduncum* is a generalist nematode registered from many marine fish species (Andersen 1993) and it has been reported from 29 different fish species collected from the Turkish Black Sea (Table 1). They live as sexually mature adults in the digestive tracts of marine teleost fishes (Navone *et al.* 1998) and their larvae are known to occur in marine invertebrates and in fish (Koie 1993). The 3rd-stage larvae have been found encapsulated in the mesentery and viscera of a wide range of fishes that act as transport hosts (Berland 1961, Koie 1993). The first intermediate hosts for *H. aduncum* are crustaceans, such as copepods, amphipods, decapods, shrimps, euphasiids, and isopods (Koie 1993, Marcogliese 1996). Gadoids are generally believed to be the main final hosts (Berland 1961) and Black Sea whiting *Merlangius merlangus* was reported to host both larval and adult stages of this parasite species (Özer *et al.* 2016). Along with *Hysterothylacium,* members of 9 different genera, *Contraceacum, Cucullanus, Anisakis, Philometra, Ascarophis, Dichelyne, Spiroxys, Capillaria, Spinitectus*, have also been reported from wide range of marine fishes at the Turkish Black Sea coasts (Table 1).

3.2.3. Acanthocephala

According to Garcia-Varela *et al.* (2002), the Phylum Acanthocephala comprises four subtaxa: Palaeacanthocephala, Eoacanthocephala, Polyacanthocephala and Archiacanthocephala which differ in morphology, life cycles and several ecological features. The body of a typical acanthocephalan consists of the metasoma (trunk) lying inside the intestinal lumen of the host, and the presoma (proboscis and neck) inserted into the intestinal wall (Taraschewski 2005). The proboscis is one of the most significant part of these parasites and hooks on the proboscis must be counted in fully everted situations. Their life cycle involve amphipoda, fish and seals as internediate, paratenic and definitive hosts. There are about 1000 parasite species reported from all over the world. A total of 4 acanthocephalan species has been reported from 9 host fish species in the Turkish coastal are of the Black Sea (Table 1). *Acanthocephaloides irregularis* is the only species that has 4 different host species (Table 1).

3.2.4. Crustacea

The Phylum Crustacea is one of the most speciose group of metazoan ectoparasites of marine fishes and they infect a wide range of marine invertebrates (Rohde 2005). Crustacean parasites include species of copepods, isopods, branchiurans, amphipods and barnacles in marine environment. Crustaceans are oviparous, first laying eggs which later develop into several free-living nauplius stages including nauplic, metanauplic and young crustacean stages and then subsequent molting which results with adult parasitic stage. These ectoparasites infest the skin and gills of their fish hosts. Nearly 30 families of copepods contain parasites that utilise fishes as hosts and most are found exclusively on fishes (Boxshall 2005). Parasitic isopods are typically marine, and usually inhabit the warmer seas. There are three major groups: cymothoids, epicaridians and gnathiids. Most parasitic isopods are ectoparasites and feed on host blood or host haemolymph (Lester 2005). Branchiurans are primarily ectoparasites of fishes and the Branchiura comprises about 175 species classified in four genera placed in a single family, the Argulidae, but only the genus *Argulus* occurs in the marine environment (Boxshall 2005). Crustaceans, however, can be found parasitic on fishes from all over the world. A total of 7 crustacean species, belonging to genera *Ergasilus, Mothocya, Nerocila, Livoneca, Caligus, Lernantropus*, have been reported from 8 different host fish species in the Turkish coastal areas of the Black Sea (Table 1).

3.2.5. Annelida

Members of the class Polychaeta are common marine annelids belonging to the Phylum Annelida that have special armatures in their morphology. *Polydora ciliata* is an infective spionid polychaeta and considered to be the causative agent of the lower fecundity in mussels due to the reduction in mantle tissues, the main repository of gametes, and reduced flesh content as a consequence of lowered condition index (Kent 1979). This species has been reported from *Mytilus galloprovincialis* collected from Turkish coasts of the Black Sea (Table 1).

3.2.6. Microsporidia

Microsporidian parasites belonging to phylum Microsporidia have been reported from marine freshwater fishes worldwide. Currently, microsporidia are considered atypical fungi without mitochrondria (Thomarat *et al.* 2004, Xiang *et al.* 2014). More than 1200 species are described, some of which are able to infect multiple host species (Life cycles of these parasites may be simple or complex, however, the complete life cycles for most species remain unknown. On the other hand, many fish microsporidian parasites are transmitted directly by ingestion (e.g. *Nucleospora salmonis, Glugea* spp. and *Loma* spp.). Members of the genera *Glugea* and *Loma* are among the most reported parasites in fishes by enlarged tumour-like host cells filled with spores, however, thus far there is only one *Loma* species reported from *Mullus barbatus ponticus* in Sinop coasts of the Black Sea (Table 1).

3.2.7. Myzozoa

These parasites are known to parasitize commercially important marine molluscs and especially gregarines parasitize bivalves. Nematopsis legeri is the only member that has been reported from *Mytilus galloprovinciali*s from Sinop coasts of the Black Sea (Table 1).

4. Discussion

This study provided an up to date checklist of reported parasites of fishes collected from the coastal areas of the Turkish Black Sea. It is obvious from this checklist that Black Sea fishes have a wide range of parasites yielding a total of 115 parasites from 44 different host fish species. Some parasites such as *Trichodina lepsii, Ligophorus cephali, L. mediterraneus,* were reported to be host specific to mugilids while *Hysterothylacium aduncum* was reported to be a generalist parasite infecting a very wide range of fish hosts belonging to different genera. These reports are in accordance to previous reports elsewhere in the world. It can also be seen from this checklist that someof the literatures provided first occurrence of some parasites in this particular part of the Black Sea and it can be said that, considering a total of about 160 fish species reported from Turkish coastal areas of the Black Sea, more studies on fish parasites will provide more insight to our knowledge.

Table 1. Checklist of parasite species reported from Black Sea fishes collected from Turkish coastal areas. **Si:** Sinop coasts, **Sa:** Samsun coasts, **Ea**: Eastern coasts, **Tr:** Trabzon coasts, **Tmc:** Trabzon Marine Research Center

Parasite Species	Host species	Area	Ref.
APICOMPLEXA			
Eimeria sardinae (Thélohan, 1890) Reichenow, 1921	*Merlangius merlangus*	Si	32
CILIOPHORA			
Trichodina domerguei Wallengren, 1897	*Merlangius merlangus*	Si	21
	Neogobius fluviatilis	Sa	29
	Pomatoschistus marmoratus	Sa	29
	Gasterosteus aculeatus	Si	6
	Neogobius melanostomus	Si	7
	Platichthyes flesus	Si	12
	Mullus barbatus ponticus	Si	35
Trichodina puytoraci Lom, 1962	*Mugil cephalus*	Si	8
	Mugil cephalus	Sa	39
	Merlangius merlangus	Ea	18
	Liza aurata	Si	14, 28
	Liza aurata	Sa	24
Trichodina jadranica Raabe, 1958	*Platichthyes flesus*	Si	12
Trichodina claviformis Dobberstein & Palm, 2000	*Merlangius merlangus*	Ea	18
Trichodina gobii Raabe, 1959	*Merlangius merlangus*	Si	40
Trichodina tenuidens Faure-Fremiet, 1944	*Gasterosteus aculeatus*	Si	6
Trichodina lepsii Lom, 1962	*Mugil cephalus*	Si	8
	Mugil cephalus	Sa	39
	Liza aurata	Si	8, 14, 28
	Liza aurata	Sa	23
Trichodina heterodentata Duncan, 1977	*Neogobius fluviatilis*	Sa	29
	Pomatoschistus marmoratus	Sa	29
	Proterorhinus marmoratus	Sa	29
Paratrichodina corlissi Lom et Haldar, 1977	*Neogobius fluviatilis*	Sa	29

Peniculistoma mytili (Morgan, 1925) Jankowski, 1964	*Mytilus galloprovincialis*	Si	38
Philasterides dicentrarchi Dragesco, Dragesco, Coste, Gasc, Romestand, Raymond & Bouix, 1995	*Psetta maxima*	Tmc	16
Trichodina sp.	*Merlangius merlangus*	Ea	18
	Belone belone	Si	25
	Psetta maxima	Tr	5
	Mullus barbatus ponticus	Si	35
Paratrichodina sp.	*Mullus barbatus ponticus*	Si	35
Riboscyphidia sp.	*Platichthyes flesus*	Si	12
Ambiphrya sp.	*Platichthyes flesus*	Si	12
Riboscyphidia sp.	*Platichthyes flesus*	Si	12
Ambiphrya sp.	*Platichthyes flesus*	Si	12
Vorticella sp.	*Platichthyes flesus*	Si	12
MONOGENEA			
Ligophorus cephali Rubtsova et Euzet, 2006	*Liza aurata*	Sa	24
	Liza aurata	Si	28
	Mugil cephalus	Sa	39
	Liza saliens	Si	49
Ligophorus mediterraneus (Sarabeev et Euzet, 2005)	*Liza aurata*	Sa	24
	Liza aurata	Si	28
	Mugil cephalus	Sa	39
Ligophorus mugilinus (Hargis, 1955) Euzet & Suriano, 1977	*Liza aurata*	Si	14
Lamellodiscus elegans Bychowsky, 1957	*Diplodus annularis*	Si	41
Lamellodiscus fraternus Bychowsky, 1957	*Diplodus annularis*	Si	41
Gyrodactylus alviga Dmitrieva et Gerasev, 2000	*Merlangius merlangus*	Si	42
	Merlangius merlangus	Si	50
Gyrodactylus proterorhini Ergens, 1967	*Neogobius melanostomus*	Si	10
	Proterorhinus marmoratus	Sa	34
	Neogobius fluviatilis	Sa	34
	Pomatoschistus marmoratus	Sa	34
Gyrodactylus arcuatus Bychowsky, 1933	*Gasterosteus aculeatus*	Si	9
	Gasterosteus aculeatus	Sa	34
Gyrodactylus flesi Malmberg, 1957	*Platichthyes flesus*	Si	12
Mazocraes alosae (Herman, 1782)	*Alosa immaculata*	Si	26
Axine belones Abildgaard, 1794	*Belone belone*	Si	25
Solostamenides mugilis (Vogt, 1879)	*Mugil cephalus*	Sa	27
	Liza aurata	Sa	27
	Liza aurata	Si	28
Microcotyle mugilis Vogt, 1878 (Syn; *Solostamenides mugilis*)	*Liza aurata*	Sa	24
	Liza aurata	Si	14
	Mugil cephalus	Sa	39

Diplectanum aequans (Wagener, 1857)	*Dicentrarchus labrax*	Ea	20
Gyrodactylus sp.	*Liza aurata*	Si	14
TREMATODA			
Ascocotyle (Phagicola) longa Ransom, 1920	*Liza aurata*	Sa	24
	Mugil cephalus	Sa	39
Ascocotyle mugilis	*Liza aurata*	Si	14
Haplosplanchnus pachysomus (Eysenhardt, 1829) Looss, 1902	*Liza aurata*	Sa	24
	Mugil cephalus	Sa	39
Diplostomum spathaceum (Rudolphi, 1819) Olsson, 1876	*Mugil cephalus*	Sa	39
Tylodelphys clavata Nordmann, 1832	*Liza aurata*	Sa	24
	Mugil cephalus	Sa	39
Parvatrema duboisi (Dollfus, 1923)	*Mytilus galloprovincialis*	Si	38
Pronoprymna ventricosa (Rudolphi, 1891)	*Alosa immaculata*	Si	26
Lecithaster confusus Odhner, 1905	*Alosa immaculata*	Si	26
Anisocladium fallax (Rudolphi, 1819)	*Uranoscopus scaber*	Ea	36
Lecithaster confusus Odhner, 1905	*Uranoscopus scaber*	Si	26
Anisocladium gracile (Looss, 1901)	*Uranoscopus scaber*	Ea	36
Anisocoelium capitellatum (Rudolphi, 1819)	*Uranoscopus scaber*	Ea	36
Stephanostomum minutum (Looss, 1901) Manter, 1940	*Uranoscopus scaber*	Si	48
Helicometra fasciata (Rudolphi, 1819) Odhner, 1902	*Mesogobius bathriocephalus*	Si	46
	Neogobius melanostomus	Si	46
	Neogobius kessleri	Si	46
	Gobius niger	Si	46
	Scorpaena porcus	Si	48
	Symphodus cinereus	Si	48
Lecithochirium musculus (Looss, 1907) Nasir & Diaz, 1971	*Ophidion rochei*	Si	48, 45
	Solea solea	Si	45
	Triglia lucerna	Si	45
	Scorpaena porcus	Si	45
	Gaidropsarus mediterraneus	Si	45
	Mesogobius bathriocephalus	Si	45
Pygidiopsis genata Looss, 1907	*Neogobius melanostomus*	Si	10, 44
Prodistomum polonii (Molin, 1859)	*Trachurus trachurus*	Si	53
Lasiotocus typicus (Nicoll, 1912)	*Trachurus trachurus*	Si	53
Ectenurus lepidus Looss, 1907	*Trachurus trachurus*	Si	53
Monascus filiformis (Rudolphi 1819)	*Trachurus trachurus*	Si	53
	Trachurus trachurus	Si	53

Stephanostomum cesticillum (Molin, 1858) Looss, 1899	*Parablennius tentacularis*	Si	48
Cryptocotyle concava (Creplin, 1825)	*Neogobius melanostomus*	Si	53
	Proterorhinus marmoratus	Si	53
Ascocotyle felippei Travassos, 1929	*Neogobius melanostomus*	Si	53
	Proterorhinus marmoratus	Si	53
	Gasterosteus aculeatus	Si	53
	Platichthyes flesus	Si	53
	Liza aurata	Si	53
Arnola microcirrus (Vlasenko, 1931)	*Diplodus annularis*	Si	48
Monarchis parvus Looss, 1902	*Diplodus annularis*	Si	48
Bucephalus marinum Vlasenko, 1931 mtc	*Parablennius tentacularis*	Si	48
Phyllodistomum acceptum Looss, 1901	*Parablennius tentacularis*	Si	48
Stephanostomum minitum (Looss, 1901) Manter, 1940	*Uranoscopus scaber*	Si	48
Stephanostomum bicoronatum (Stossich, 1883) Fuhrmann, 1928 mtc.	*Neogobius melanostomus*	Si	48
	Gaidropsarus mediterraneus	Si	51
Galactosomum lacteum (Jagerskiöld, 1896)	*Mullus barbatus*	Si	35
	Neogobius melanostomus	Si	46
	Gobius niger	Si	46
	Gaidropsarus mediterraneus	Si	51
Rhipidocotyle genovi Dimitrov, Kostadinova & Gibson, 1996	*Gaidropsarus mediterraneus*	Si	51
Metadena pauli (Vlasenko, 1931) Yamaguti, 1958	*Gaidropsarus mediterraneus*	Si	51
Magnibursatus skrjabini (Vlasenko, 1931)	*Gaidropsarus mediterraneus*	Si	51
	Mesogobius bathriocephalus	Si	46
Proctotrema bacilliovatum Odhner, 1911	*Mesogobius bathriocephalus*	Si	35
Derogenes sp.	*Mesogobius bathriocephalus*	Si	46
	Gobius niger	Si	46
Ascocotyle sp.	*Neogobius melanostomus*	Si	44
	Platichthyes flesus	Si	44
	Liza aurata	Si	28
Digenea gen. sp.	*Neogobius melanostomus*	Si	10
Cainocreadium sp.	*Gaidropsarus mediterraneus*	Si	51
CESTODA			
Grillotia erinaceus (van Beneden, 1858) plerocercoid	*Merlangius merlangus*	Si	33

Progrillotia dasyatidis Beveridge, Neifar & Euzet, 2004 plerocercoid	*Merlangius merlangus*	Ea	36
	Uranoscopus scaber	Ea	36
	Ophidion rochei	Ea	36
	Ophidion rochei	Si	46
	Mullus barbatus	Ea	36
	Mullus barbatus	Si	35, 46
	Gobius niger	Ea	35
	Gobius niger	Si	46
	Gaidropsarus mediterraneus	Ea	35
	Gaidropsarus mediterraneus	Si	46
	Neogobius melanostomus	Si	46
	Mesogobius bathriocephalus	Si	46
	Solea solea	Si	46
	Scorpaena porcus	Si	46
Scolex pleuronectis Müller, 1788 plerocercoid	*Merlangius merlangus*	Si	42, 46
	Ophidion rochei	Ea	35
	Trachurus trachurus	Si	37
	Gaidropsarus mediterraneus	Si	37, 46
	Spicara flexuosa	Si	37
	Zosterizessor ophiocephalus	Si	37
	Neogobius melanostomus	Si	37, 46
	Mullus barbatus	Si	35
	Neogobius kessleri	Si	46
	Mesogobius bathriocephalus	Si	46
	Gobius niger	Si	46
	Solea solea	Si	46
	Trigla lucerna	Si	46
	Spicara smaris	Si	46
Bothriocephalus scorpii (Müller, 1776)	*Psetta maxima*	Si	23
Paradilepis scolecina (Rudolphi, 1819)	*Platichthyes flesus*	Si	12
Tetrarhynchobothrium tenuicolle Diesing, 1850	*Raja clavata*	Si	52
Echeneibothrium variabile Van Beneden, 1850	*Raja clavata*	Si	52
	Squalus acanthias	Si	52
Acanthobothrium coronatum (Rudolphi, 1819)	*Raja clavata*	Si	52
Bothriocephalus sp.	*Raja clavata*	Si	52
Diphyllobothrium sp.	*Belone belone*	Si	25
NEMATODA			

Hysterothylacium aduncum (Rudolphi, 1802)	*Merlangius merlangus*	Si	3, 15, 21, 23, 50
	Merlangius merlangus	Ea	2
	Merlangius merlangus	Sa	1
	Neogobius melanostomus	Si	10, 45
	Mesogobius bathriocephalus	Si	45
	Gobius niger	Si	45
	Solea solea	Si	47
	Alosa pontica	Si	11
	Platichthyes flesus	Si	12
	Maena smaris	Si	15
	Belone belone	Si	25
	Belone belone	Ea	31
	Mullus barbatus ponticus	Ea	30
	Mullus barbatus ponticus	Si	35
	Trachurus trachurus	Ea	30
	Caspialosa sp.	Ea	31
	Engraulis encrasicholus	Ea	31
	Gaidropsarus mediterranes	Ea	31
	Gobius niger	Ea	31
	Merlangius merlangus	Ea	31
	Mullus barbatus	Ea	31
	Neogobius melanostomus	Ea	31
	Ophidion rochei	Ea	31
	Platichthys flesus	Ea	31
	Sarda sarda	Ea	31
	Sciaena umbra	Ea	31
	Scorpaena porcus	Ea	31
	Solea vulgaris	Ea	31
	Spicara smaris	Ea	31
	Syngnathus acus	Ea	31
	Trachinus draco	Ea	31
	Trachurus mediterraneus	Ea	31
	Uranoscopus scaber	Ea	31
Hysterothylacium fabri (Rudolphi, 1819)	*Mullus barbatus ponticus*	Si	35
Cucullanus campanae Lebre & Petter, 1984	*Solea solea*	Si	47
Anisakis pegreffii Campana-Rouget & Biocca, 1955	*Trachurus mediterraneus*	Ea	31
Philometra globiceps (Rudolphi, 1819)	*Trachurus mediterraneus*	Ea	31
	Uranoscopus scaber	Ea	31

Ascarophis valentina Ferrer, Aznar, Balbuena, Kostadinova, Raga & Moravec, 2005	*Mullus barbatus ponticus*	Si	35
Dichelyne minutus (Rudolphi, 1819)	*Neogobius melanostomus*	Si	10
	Platichthyes flesus	Si	12
Spiroxys contortus	*Platichthyes flesus*	Si	12
Capillaria gracilis (Bellingham, 1840)	*Solea solea*	Si	47
Spinitectus tamari Naidenova, 1966	*Gaidropsarus mediterranes*	Si	52
Spiroxys sp.	*Neogobius melanostomus*	Si	10
Capillaria sp.	*Platichthyes flesus*	Si	12
Capillaria sp.	*Mullus barbatus ponticus*	Si	35
Capillaria sp.	*Gobius niger*	Si	46
Capillaria sp.	*Neogobius kessleri*	Si	46
Contraceacum sp.	*Mullus barbatus ponticus*	Si	35
Ascarophis sp.	*Scorpaena porcus*	Ea	31
ACANTHOCEPHALA			
Neoechinorhynchus rutili (Müller, 1780)	*Neogobius melanostomus*	Si	10
	Platichthyes flesus	Si	12
Neoechinorhynchus agilis Rudolphi, 1819	*Liza aurata*	Sa	24
	Liza aurata	Ea	31
	Mugil cephalus	Sa	39
Acanthocephaloides irregularis Amin et Kvach, 2011	*Scorpaena porcus*	Ea	31
	Mullus barbatus	Si	35
	Neogobius kessleri	Si	46
Acanthocephaloides irregularis Amin et Kvach, 2011	*Mesogobius bathriocephalus*	Si	46
Solearhynchus kostylewi (Meyer, 1932) Kvach & Oguz, 2010	*Solea solea*	Si	47
CRUSTACEA			
Ergasilus lizae Kroyer 1863	*Liza aurata*	Sa	24
	Liza aurata	Si	14
	Liza aurata	Si	28
	Mugil cephalus	Sa	39
Mothocya epimerica Costa, 1851	*Atherina boyeri*	Si	4
Nerocila bivittata (Risso, 1816)	*Parablennius sanguinolentus*	Sa	22
	Diplodus annularis	Tr	13
Nerocila orbignys (Guerin-Meleville, 1832)	*Solea solea*	Si	47
Livoneca punctata (Uljanin, 1872)	*Alosa pontica*	Si	11
Caligus minimus Otto, 1821	*Dicentrarchus labrax*	Si	19
Lernantropus kroyeri Van Beneden, 1851	*Dicentrarchus labrax*	Or	17
ANNELIDA			
Polydora ciliata (Johnston, 1838)	*Mytilus galloprovincialis*	Si	38

MYZOZOA			
Nematopsis legeri de Beauchamp, 1910	*Mytilus galloprovincialis*	Si	38
MICROSPORIDIA			
Loma sp.	*Mullus barbatus ponticus*	Si	35
RHABDITOPHORA			
Urastoma cyprinae (Graff, 1882)	*Mytilus galloprovincialis*	Si	38

1. Doğanay (1994), 2. Ismen and Bingel (1999), 3. Özer *et al.* (2000), 4. Özer (2002), 5. Aksungur (2003), 6. Özer (2003a), 7. Özer (2003b), 8. Özer and Öztürk (2004), 9. Özer *et al.* (2004), 10. Özer (2007), 11. Özer *et al.* (2007), 12. Öztürk and Özer (2008), 13. Kayış *et al.* (2009), 14. Öztürk and Özer (2009), 15. Özer *et al.* (2009), 16. Kayış *et al.* (2010), 17. Öktener *et al.* (2010), 18. Öğüt and Altuntaş (2011), 19. Özer and Öztürk (2011), 20. Öğüt and Uzun (2012), 21. Özer *et al.* (2012), 22. Alaş *et al.* (2013), 23. Özer and Olguner (2013), 24. Özer and Yılmaz Kırca (2013), 25. Özer and Yurakhno (2013), 26. Özer *et al.* (2013a), 27. Özer et al (2013b), 28. Öztürk (2013), 29. Öztürk and Çam (2013), 30. Pekmezci *et al.* (2013), 31. Tepe and Oğuz (2013), 32. Özer *et al.* (2014a), 33. Özer *et al.* (2014b), 34. Öztürk and Özer (2014), 35. Öztürk and Yeşil (2014), 36. Tepe *et al.* (2014), 37. Güneydağ *et al.* (2015), 38. Özer and Güneydağ (2015), 39. Özer and Yılmaz Kırca (2015), 40. Özer *et al.* (2015a), 41. Özer *et al.* (2015b), 42. Özer *et al.* (2015c), 43. Özer *et al.* (2015d), 44. Öztürk and Özer (2015), 45. Çam and Öztürk (2016a), 46. Çam and Öztürk (2016b), 47. Çam and Öztürk (2016c), 48. Kornyychuk *et al.* (2016), 49. Özer and Acar (2016), 50. Özer *et al.* (2016), 51. Öztürk and Çam (2016a), 52. Öztürk and Çam (2016b), 53. Öztürk and Özer (2016).

References

Aksungur, N. 2003. Observation of growing properties (in cages and ponds) of turbot (*Psetta maxima*) in the Black Sea region. CFRI YUNUS Res Bull, 3: 9-11.

Alaş, A., A. Öktener, A. İşçimen, and J.P. Trilles. 2013. New host record, *Parablennius sanguinolentus* (Teleostei, Perciformes, Blenniidae) for *Nerocila bivittata* (Crustacea, Isopoda, Cymothoidae). Parasitol Res., 102: 645-646

Azevedo, C. and E. Matos. 1999. Description of *Nematopsis mytella* n. sp. (Apicomplexa), parasite of the mussel *Mytella guyanensis* (Myteiidae) from the Amazon estuary and description of its oocysts. European Journal of Protistology, 35: 427-433.

Berland, B. 1961. Nematodes from some Norwegian marine fishes. Sarsia, 2: 1-52.

Boxshall, G. 2005. Copepoda (copepods), p. 123-138. In C. Rohde [ed.], Marine Parasitology. CBI Publishing,

Cribb, T.H. 2005. Digenea (endoparasitic flukes), p. 76-87. In C. Rohde [ed.], Marine Parasitology. CBI Publishing,

Çam, A. and T. Öztürk. 2016a. The presence of *Lecithochirium musculus* Looss, 1907 in some fish species from the Black Sea. EMOP XII, 20-24 July, Turku, Finland.

Çam, A. and T. Öztürk. 2016b. The metazoan parasites of four gobiid fishes (Actinopterygii: Gobiidae) from Turkish Coasts of Black Sea. EMOP XII, 20-24 July, Turku, Finland.

Çam, A. and T. Öztürk. 2016c. The metazoan parasites of *Solea solea* (Actinopterygii: Soleidae) from Turkish coasts of Black Sea. International Symposium on Fisheries and Aquatic Sciences, 3-5 November, Antalya, Turkey

Doğanay, A. 1994. A record of *Hysterothylacium aduncum* (Rudolphi, 1802) in cod-fish (*Gadus* sp.) from Black Sea, (in Turkish with English summary). Ankara Univ. J. Vet. Fac., 41: 208-217.

Froese R. and D. Pauly. 2015. FishBase. www.fishbase.org

Güneydağ, S., A. Özer, and H. Özkan. 2015. *Scolex pleuronectis* (Cestoda) infections in some teleost fishes collected from Sinop coasts of the Black Sea. 18th National Fisheries Symposium, 1-4 September, İzmir, Turkey.

İşmen, A. and F. Bingel. 1999. Nematode infection in the whiting *Merlangius merlangus euxinus* off Turkish Coast of the Black Sea. Fish. Res., 42: 183-189.

Kayış, Ş., T. Özcelep, E. Çapkın, and İ. Altınok. 2009. Protozoan and metazoan parasites of cultured fish in Turkey and their applied treatments. The Israeli Journal of Aquaculture – Bamidgeh, 61: 93-102.

Kayış, Ş., İ. Yandı, İ. Altınok, and E. Çapkın. 2010. Treatment by Vinegar of *Philasterides dicentrarchi* (Ciliophora: Scuticociliatida) Infestation in Cultured Juvenile Turbot (*Psetta maxima*). The Israeli Journal of Aquaculture - Bamidgeh, 63: 627-631.

Kent, R.M.L. 1979. The influence of heavy infestations of *Polydora ciliata* on the flesh content of *Mytilus edulis*. Journal of the Marine Biological Association of the United Kingdom, 59: 289-297.

Koie, M. 1993. Aspects of the life cycle and morphology of *Hysterothylacium aduncum* (Rudolphi, 1802) (Nematoda, Ascaridoidea, Anisakidae). Can. J. Zool., 71: 1289-1296.

Kornyychuk, Y.M., A. Özer, S. Güneydağ, and H. Özkan. 2016. New data on digenean parasites of fishes in Sinop region of the Black Sea, 242 p. In K.V. Galaktionov, A.V. Gaevskaya [eds.], Contemporary Problems of Theoretical and Marine Parasitology: Collection of Scientific Papers. Sevastopol: Bondarenko Publishing.

Lawler, A.R. 1980. Studies on *Amyloodinium ocellatum* (Dinoflagellata) in Mississippi Sound: natural and experimental hosts. Gulf Research Reports, 6: 403-413.

Lester, R.J.G. 2005. Isopoda (isopods), p. 138-144. In C. Rohde [ed.], Marine Parasitology. CBI Publishing.

Littlewood, D.T.J. 2005. Marine parasites and the tree of life, p. 1-9. In C. Rohde [ed.], Marine Parasitology. CBI Publishing.

Marcogliese, D.J. 1996. Larval nematodes infection marine crustaceans in eastern Canada. 3. *Hysterothylacium aduncum*. J. Helm. Soc. Wash., 63:12-18.

Mathis, A., R. Weber, and P. Deplazes. 2005. Zoonotic potential of the microsporidia. Clinical Microbiology Reviews, 18: 423-445.

Navone, G.T., N.H. Sardella, and J.T. Timi. 1998. Larvae and adults of *Hysterothylacium aduncum* (Rudolphi, 1802) (Nematoda: Anisakidae) in fishes and crustaceans in the South West Atlantic. Parasite, 5:127-136.

Niewiadomska, K. and T. Pojmańska. 2011. Multiple strategies of digenean trematodes to complete their life cycles. Wiadomooeci Parazytologiczne, 57: 233-241.

Öğüt, H. and C. Altuntaş. 2011. Monthly variation in the morphological characteristics of *Trichodina* sp. (Ciliophora: Peritrichida) found on whiting *Merlangius merlangus euxinus*. Revista de Biologia Marina y Oceanografia, 46: 269-274.

Öğüt, H. and E. Uzun. 2012. Incidence and prevalence of *Diplectanum aequans* and its influence on the fitness of juvenile sea bass (*Dicentrarchus labrax*) in the Black Sea. Aquaculture Research, 1-7.

Özer, A., T. Öztürk, and O. Erdem. 2000. A study on the *Hysterothylacium aduncum* (Nematoda: Anisakidae) infections in the whiting *Merlangius merlangus euxinus*, p. 632-641. In National Fisheries Symposium 2000, Sinop, Proceedings and Abstract Book.

Özer, A. 2002. An epizootiological study on *Mothocya epimerica* Costa, 1851 (Flabellifera: Cymothoidae) infestations in sand smelt, *Atherina boyeri* Risso, 1810 (Perciformes: Atherinidae) found in the Sinop coasts of the Black Sea. Turkish Journal of Marine Sciences, 8: 9-16.

Özer, A. 2003a. The occurrence of *Trichodina domerguei* Wallengren, 1897 and *Trichodina tenuidens* Faure-Fremiet, 1944 (Peritrichia) on three-spined stickleback, *Gasterosteus aculeatus* L., 1758 found in a brackish and freshwater environment. Acta Protozoologica, 42: 41-46.

Özer, A. 2003b. *Trichodina domerguei* Wallengren, 1897 (Ciliophora: Peritrichia) infestations on the Round Goby, *Neogobius melanostomus* Pallas, 1811 in relation to seasonality and host factors. Comparative Parasitology, 70: 132-135.

Özer, A., T. Öztürk, and M.O. Öztürk. 2004. Prevalence and intensity of *Gyrodactylus arcuatus* Bychowsky, 1933 (Monogenea) infestations on the three-spined stickleback, *Gasterosteus aculeatus* L., 1758. Turkish Journal of Veterinary and Animal Sciences, 28: 807-812.

Özer, A. and T. Öztürk. 2004. *Trichodina puytoraci* Lom, 1962 and *Trichodina lepsii* Lom, 1962 (Peritrichida: Ciliophora) infestations on mugilids caught at the Black Sea coast of Sinop in Turkey. Turkish Journal of Zoology, 28: 179-182.

Özer, A. 2007. Metazoan parasite fauna of the round goby *Neogobius melanostomus* Pallas, 1811 (Perciformes: Gobiidae) collected from the Black Sea coast at Sinop, Turkey. Journal of Natural History, 41: 483-492.

Özer, A, G. Ünsal, and A.M. Olguner. 2007. *Hysterothylacium aduncum* (Rudolphi, 1802) and *Livoneca punctata* (Uljanin, 1872) infections in *Alosa pontica* Eichwald, 1838, collected from Sinop Coasts of Turkey. (In Turkish). XIV. National Fisheries Symposium, 4-7 September, Muğla, Turkey.

Özer, A., A.M. Olguner, and G. Ünsal. 2009. Comparative infections of *Hysterothylacium aduncum* (Rudolphi, 1802) in *Merlangius merlangus* and *Maena smaris* collected from Sinop coasts of Turkey, p. 293. In XV. National Fisheries Symposium 2009, Rize, Proceedings and Abstract Book (Abstract only).

Özer, A. and T. Öztürk. 2011. First report of sea bass (*Dicentrarachus labrax*) parasites *Ceratomyxa* sp. (Myxozoa) from the Eagean Sea and *Caligus minimus* (Copepoda) from the Black Sea (In Turkish). 16th National Fisheries Symposium, Antalya, Turkey. 16th National Fisheries Symposium, Antalya, Turkey.

Özer, A., Y. Kornyychuk, T. Öztürk, V. Yurakhno, and V. Kornyushin. 2012. Parasite fauna of the Black Sea whiting, *Merlangius merlangus* L., 1758 and it's dynamics in relation with some host factors, p. 395. In XI European Multicolloquium of Parasitology (EMOP XI) (Cluj-Napoca, Romania, July 25-29 (Abstract only).

Özer, A. and A.M. Olguner. 2013. Metazoan parasites of some marine fish species collected at the Sinop coasts of the Black Sea. Ege J. Fish. Aquat. Sci., 30: 93-97.

Özer, A. and D. Yılmaz Kırca. 2013. Parasite fauna of Golden Grey Mullet *Liza aurata* (Risso, 1810) collected from Lower Kızılırmak Delta in Samsun, Turkey. Helminthologia, 50: 269-280.

Özer, A. and V. Yurakhno. 2013. Parasite Fauna of garfish *Belone belone* (Linnaeus, 1761) Collected in Sinop Coasts of the Black Sea, Turkey. Bulletin of European Association for Fish Pathologists, 33(6): 171-180.

Özer, A., T. Öztürk, and Y. Kornyychuk. 2013a. First Report of *Mazocraes alosae* (Herman, 1782), *Pronoprymna ventricosa* (Rudolphi, 1891) and *Lecithaster confusus* Odhner, 1905 in pontic shad *Alosa immaculata* Bennet, 1835 in Turkish coasts of the Black Sea. Lucrari Sciintifice- Seria Zootechie, 59: 311-314.

Özer, A., T. Öztürk, D. Yılmaz Kırca, and A. Çam. 2013b. Light and SEM observations on *Solostamenides mugilis* (Vogt, 1879) (Microcotylidae: Monogenea). 17th National Fisheries Symposium, 3-6 September, İstanbul University, İstanbul, Turkey.

Özer, A., T. Öztürk, V. Yurakhno, and Y. Kornyychuk. 2014a. First report of *Eimeria sardinae* (Apicomplexa: Coccidia) near Turkish coasts of the Black Sea. Ege Journal of Fisheries and Aquatic Sciences, 31: 151-153.

Özer, A., T. Öztürk, V. Kornyushin, Y. Kornyychuk, and V. Yurakhno. 2014b. *Grillotia erinaceus* (van Beneden, 1858) (Cestoda: Trypanorhyncha) from whiting in the Black Sea, with observations on seasonality and host-parasite interrelationship. Acta Parasitologica, 59(3): 420-425.

Özer, A. and S. Güneydağ. 2015. Seasonality and host-parasite interrelationship of *Mytilus galloprovincialis* parasites in Turkish Black Sea coasts. Journal of Marine Biological Association of the United Kingdom, 95(8): 1591-1599.

Özer, A. and D. Yılmaz Kırca. 2015. Parasite fauna of the grey mullet *Mugil cephalus* L. 1758, collected from fish lakes in Lower Kızılırmak Delta located by the Black Sea, Turkey. Journal of Natural History, 49 (15-16): 933-956.

Özer, A., T. Öztürk, Y. Kornyychuk, and V. Yurakhno. 2015a. *Trichodina gobii* (Ciliophora: Trichodinidae) on whiting *Merlangius merlangus* with a checklist from Turkish and Russian coasts of the Black Sea. Acta Zoologica Academiae Scientarum Hungaricae, 61: 119-134.

Özer, A., H. Özkan, S. Güneydağ, and V. Yurakhno. 2015b. First Reports of several myxosporean (Myxozoa) and monogenean parasites from fish species collected from Sinop coast of the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 15: 741-749.

Özer, A., T. Öztürk, Y. Kornyychuk, and V. Yurakhno. 2015c. Comparative analysis of parasite fauna of whiting, *Merlangius merlangus* L., 1758, collected from northern and southern zones of the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 15: 285-294.

Özer, A., T. Öztürk, B. Baki, S. Güneydağ, G. Acar, A. Çam, and D. Kaya. 2015d. Comparative infection levels of *Diplectanum eequans* on *Dicentrarchus labrax* collected from the Black Sea and Aegean Sea (In Turkish). 18th National Fisheries Symposium, 1-4 September, İzmir, Turkey. (Poster Presentation)

Özer, A. and G. Acar. 2016. Microhabitat selection, seasonality and host dependent occurrences of *Ligophorus cephali* (Monogenea) on the gills of *Liza saliens*. EMOP XII, 20-24 July, Turku, Finland.

Özer, A., Y.M. Kornyychuk, V. Yurakhno, and T. Öztürk. 2016. Seasonality and host-parasite interrelationship of *Hysterothylacium aduncum* in the whiting *Merlangius merlangus* off the Turkish and Russian coasts of the Black Sea. Helminthologia, 53: 248-256.

Öztürk, T. and A. Özer. 2008. Parasitic fauna of the flounder, *Platichthyes flesus* L., 1758 caught in the Sarıkum Lagoon Lake in Sinop (Turkey) and the occurrence of parasites in relation to host factors. Journal of FisheriesSciences, 2: 403-418.

Öztürk, T. and A. Özer. 2009. Parasite fauna of golden grey mullet (*Liza aurata* Risso, 1890) in Sarıkum lagoon lake in Sinop. (In Turkish). XV. National Fisheries Symposium, 1-4 July, Rize, Turkey (Oral Presentation).

Öztürk, T. 2013. Parasites of juvenile golden grey mullet *Liza aurata* Risso, 1810 in Sarıkum Lagoon Lake at Sinop, Turkey. Acta Parasitol, 58: 531-540.

Öztürk T. and A. Çam. 2013. Trichodinid parasites (Protozoa: Ciliophora: Peritrichida) of invasive gobiid fish inhabiting the Lower Kızılırmak Delta in Samsun, Turkey. Pakistan Journal of Zoology, 45: 1517-1524.

Öztürk, T. and A. Özer. 2014. Monogenean fish parasites, their host preferences and seasonal distributions in the Lower Kızılırmak Delta (Turkey). Turkish Journal of Fisheries and Aquatic Sciences, 14: 367-378.

Öztürk, T. and A. Yeşil. 2014. Parasite fauna of the red mullet, *Mullus barbatus ponticus* Essipov, 1927, and its dynamics in relation with some host and seasonal factors. 49th European Marine Biology Symposium, 8-12 September. St. Petersburg, Russia

Öztürk, T. and A. Özer. 2015. Comparative infection levels and histological findings of digenean parasites on their host fishes collected from Sarıkum lake (In Turkish). 18th National Fisheries Symposium, 1-4 September, İzmir, Turkey.

Öztürk, T. and A. Özer. 2016. Digenean parasites of Atlantic horse mackerel (*Trachurus trachurus*) in the Turkish Black Sea coast. Ege Journal of Fisheries and Aquatic Sciences, 33(1): 35-40.

Öztürk, T. and A. Çam. 2016a. Metazoan parasites of shore rockling, *Gaidropsarus mediterranneus* L., 1758 collected from Turkish coasts of the Black Sea. International Symposium on Fisheries and Aquatic Sciences, 3-5 November, Antalya, Turkey.

Öztürk, T. and A. Çam. 2016b. Parasitic cestodes of some fishes from Sinop coasts of the Black Sea. International Symposium on Fisheries and Aquatic Sciences, 3-5 November, Antalya, Turkey.

Pekmezci, G.Z., C.S. Bölükbaş, A.T. Gürler, and E.E. Onuk. 2013. Occurrence and molecular characterization of *Hysterothylacium aduncum* (Nematoda: Anisakidae) from *Merlangius merlangus euxinus* and *Trachurus trachurus* off the Turkish coast of Black Sea. Parasitol. Res., 112: 1031-1037.

Richter, B., I. Graner, and J. Csokai. 2014. *Heterosporis anguillarum* infection in a garter snake (*Thamnophis sirtalis*). Journal of Comparative Pathology, 150: 332-335.

Rohde, C. 2005. The nature of parasitism, p. 1-9. In C. Rohde [ed.], Marine Parasitology. CBI Publishing.

Taraschewski, H. 2005. Acanthocephala (thorny or spiny-headed worms), p. 116-121. In C. Rohde [ed.], Marine Parasitology. CBI Publishing.

Tepe, Y. and M.C. Oğuz. 2013. Nematode and acanthocephalan parasites of marine fish of the eastern Black Sea coasts of Turkey. Turkish J. Zool., 37: 753-760.

Tepe, Y., M.C. Oğuz, and R.A. Heckmann. 2014. Digenean and cestode parasites of teleost fish from the Eastern Black Sea Region. Turkish Journal of Zoology, 38: 209-215.

Thomarat, F., C.P. Vivarès, and M. Gouy 2004. Phylogenetic analysis of the complete genome sequence of *Encephalitozoon cuniculi* supports the fungal origin of microsporidia and reveals a high frequency of fast-evolving genes. Journal of Molecular Evolution, 59: 780-791.

Urawa, S. 1992. *Trichodina truttae* Mueller, 1937 (Ciliophora: Peritrichida) on juvenile chum salmon (*Oncorhynchus keta*): pathogenicity and host–parasite interactions. Gyobyo Kenkyu., 27: 29-37.

Xiang, H., R. Zhang, D, de Koeyer, G. Pan, T. Li, T. Liu, and Z. Zhou. 2014. New evidence on the relationship between microsporidia and fungi: A genome-wide analysis by darkhorse software. Canadian. Journal of. Microbiology, 60: 557-568.

BACTERIOLOGY OF THE BLACK SEA

Mine ÇARDAK [1] and Pelin S. ÇİFTÇİ TÜRETKEN [2]

[1]School of Applied Science Canakkale, Department of Fisheries Technology, Canakkale 18 Mart University, Canakkale, Turkey
[2]Faculty of Aquatic Sciences, Istanbul University, Istanbul, Turkey
mine_bio98@hotmail.com.tr

1. Introduction

Due to the key role that bacteria play in the marine biogeochemical cycling and food-webs, advances in the study of the marine bacterial diversity will certainly provide fundamental information for a better understanding of the marine ecosystem functioning and the implementation of predictive models. Fast and reliable screening of taxonomic bacterial diversity have provided us with data showing a huge bacterial diversity in all marine environments that have been studied up to date.

As a sample, Black Sea has become a focus of concern regarding the potential effects on its ecosystem of contaminant substances introduced from the industrialized areas along its coastline. In addition to natural processes, the increasing input of nutrients from the rivers and the discharge of wastes especially in the northwestern shelf are the main sources of nutrients (Cociasu *et al.* 1996) in the coastal Black Sea. In the open ecosystem, primary production is mainly sustained by the influx of nutrients from the oxic/suboxic lower layers by vertical mixing which is limited due to the presence of a strong pycnocline at 50-200m. (Yilmaz *et al.* 1998). Coastal region is P-limited while N limited production occurs in the central Black Sea. In addition to common spring and autumn blooms, recently, additional summer blooms have frequently been observed in the entire basin (Yilmaz *et al.* 1998).

In spring, stratification of the water column starts to develop and organic-rich aggregates, which accumulate at or around the pycnocline, are rapidly colonized by bacteria (Rath *et al.* 1998). With the breakdown of water column stability occurring in the autumn, the organic-rich aggregates sink down the water column, carrying with them high concentrations of microorganisms. Increased production and sedimentation of organic material has led to a greater incidence of marked oxygen depletion and even anoxia in near bottom waters of the northwestern shelf (Friedl *et al.* 1998).

Moreover, the recent discovery of the bacterial anaerobic ammonium and methane oxidation pathways has allowed the creation of more balanced C, N cycling flow charts that efficiently explain the main chemical traits of some peculiar sites (*e.g.* the over-exceeding N_2 concentration in the sub-oxic layer of the Black Sea).

The pollution levels in the Marmara Sea have increased as a result of the effects of the Black Sea due to opposite water currents between the Black Sea and the Aegean Sea (Topcuoglu 2000). Part of the domestic and industrial waste waters of Istanbul province are discharged into the Marmara Sea after undergoing a waste water treatment process. This waste water is discharged into the lower layer undercurrent with the aim of having it curried via undercurrents to the Black Sea. However a portion of this waste water mixes with the upper layer due to the hydrodynamic characteristic of the Istanbul Strait and as a result returns to the Marmara Sea (Tasdemir 2002).

This chapter sets the scene for the summaries of the bacteriology studies conducted in the Black Sea.

2. Bacterial Pollution

The bacteria entered in the marine environment via domestic, industrial wastes and marine transportation are known as a part of *Enterobacteriacea* family and they accepted as the bacterial pollution indicator. The indicator bacteria analysis is a classical method for the determination of bacteriological pollution levels and the presence potantial pathogen bacteria in the marine environments. The presence of the coliform bacteria having an optimum growth temperature at 37 °C and entering the environment as a result of human activities shows an external contamination from the marine environment (Ashbolt 2001, Glassmeyer *et al.* 2005). There are many studies about the reltionships between indicator bacteria and pathogenic bacteria such as *Vibrio cholerae* (cause of colera disease), *Yersinia enterocolitica* (gastroenteritis), *Shigella* sp. (gastroenteritis), *Listeria* sp. (Flu-like symptoms), *Salmonella* (gastroenteritis, typhoid), *Campylobacter* (gastroenteritis) (Hendricks 1978). Coliform bacteria were identified as an aerobic, spore-forming, Gram (-) bacilli shaped and growing temperature are 35±2°C by APHA (American Public Health Association).

Determination of the pathogenic bacteria separately in the marine envirnonment is a time consuming and non-ecological method. Therefore the indicator bacteria giving the hint about contamination are used to assess the bacteriological pollution in the marine environment. (Ashbolt 2001). Sharing the same environment with pathogenic bacteria, being more numerous than the pathogenic bacteria, their easier and more economic determination, the higher viability of pathogens, and the fact that they are harmless for humans and animals are the reasons for choosing indicator bacteria (Altuğ 2005).

Degradation of organic matter by natural bacteria is an important process controlling water quality, especially in marine ecosystems which receive high amounts of allochthonous organic matter and nutrients. An excess of organic matter may cause an increase in bacterial production (Rheinheimer 1985).

This stuation creates the potential for pathogenic bacteria from entering the environment and this is undesirable in terms of ecosystem and public health. This situation creates the potential for pathogenic bacteria from entering the environment and this is undesirable in terms of ecosystem and public health.

There are many studies focusing on indicator bacteria levels and source tracking of fecal pollution from rivers to the Black Sea (Stoica *et al.* 2004, Kavka *et al.* 2006, Wilson *et al.* 2008, Simeonova *et al.* 2010, Çiftçi *et al.* 2011, Janelidze 2011). Stoica *et al.* (2004) investigated the bathing water quality data observing from 1970 to 2000 the Romanian coastal zone of the Black Sea. They reported that the indicator bacteria levels have been recorded because of the waste water discharges and touristic activities. The Danube River is Europe's second-longest river and its microbiological quality was studied in detail (Kavka *et al.* 2006). The results showed higher levels of faecal pollution in the middle part of the Danube while lower bacterial pollution could be observed in the upper Danube. Wilson *et al.* (2008) studied the sediment samples taken between spring 2003 and summer 2004 from the northern (Sevastopol Bay, Ukraine) and eastern (Batumi aquatoria, Georgia) part of the Black Sea. They reported that the microbial status was generally good but the samples taken from urbanized regions did not comply with EC Bathing Water Directive standards.

Indicator bacteria and *Salmonella* spp. were investigated in both *Chamelea gallina* and seawater from six stations on the coastline of the western part of the Black Sea (Şile), Turkey (Altug and Bayrak 2002). The studies were carried out for 15 days and one hundred samples of seawater and 96 groups of *C. gallina* were collected from the study stations from June to December in 1998-1999. Altug and Bayrak reported that faecal coliform and *E. coli* values in July and August showed the highest values compared to the other months and that water carries less faecal coliform and *E. coli* than *C. gallina* samples. The authors also emphasized that these areas must be observed and protected for ecological and sanitary purposes (Altug and Bayrak 2002).

A study that investigated the physicochemical and microbiological characteristics of the bathing waters in Varna’s Black Sea coastal area showed that most of the parameters did not exceed the guideline limits (Simeonova *et al.* 2010). Çiftçi et al. (2011) reported that the bacterial count found in the Karasu region of the Sakarya River was higher than the count in the seawater samples taken from the entrance to the Black Sea from the Sakarya River. This situation contributed to the rise of bacterial pollution of the Black Sea. Janelidze *et al.* (2011) monitored the microbial quality and *Vibrio* bacteria, and *Escherichia coli*- and *Vibrio*-specific bacteriophages levels of the Georgian coast of the Black Sea. High microbial pollution levels were observed particularly in the summer months.

The observed results showed high frequency of indicator bacteria and poor microbial quality at various parts of the Black sea and indicated increasing human activities and terrestrial pollution sources.

3. Bacterial Diversity

Marine areas constitute a unique environment in terms of the examination of bacterial communities because of their hydrological and geochemical characteristics. Determination of the bacterial diversity and investigation of alternative energy sources or bioactive compounds in biotechnology and industrial works are the important sources for “bioremediation" and "Green Chemistry" studies (Giuliano 2003). Bacteria have an important role in marine environments in the cycle of decomposition of organic material and nutrients due to their various metabolic characteristics. The basic bio-geochemical processes in the water column of marine environment is associated with the heterotrophic bacteria activities (Pomeroy 1980, Azam *et a*l. 1983, Azam and Fuhrman 1985). In addition, the study of microbial communities provide the basic data about the marine environment and habitats. The bacteria give quick responses to changes in the environment and the biotic and abiotic factors in the environment are known to determine the composition and abundance of bacteria (Sansers *et al.* 1992, Jürgens and Gude 1994). Marine bacterial studies have provided a comprehensive inventory of the group of commonly found bacteria in the water column and sediment (Giovannoni and Rappé 2000, Hagström *et al.* 2002).

The studies with cultural methods are commonly used in the determination of bacterial diversity and the obtained marine bacteria strains with these studies are expressed as an important part of the bacterial biomass in sea water (Rehnstam *et al.* 1993, Pinhassi *et al.* 1997). Culturable bacterial diversity studies continue in a comprehensive manner in the Turkish seas (Altug *et al.* 2011, Altug *et al.* 2013, Turetken and Altug 2016).

The Black Sea is characterized by the largest anoxic basin in the world. Becasuse of this unique property, there are limited microbial community structure studies. Merkel *et al.* (2015) studied the qualitative and quantitative analysis of the structure of the archaeal community of the photic zone of the Black Sea water column. The phylum *Euryarchaeota* (1.2–1.7x10^4 cells/mL) and *Thaumarchaeota* (7.7 x10^3 cells/mL) were founded as the most numerous archaeal groups in this study, respectively and methanogens weren’t found in spite of the detected methane in the samples.

The sediments underlying the oxic, suboxic, and anoxic waters were collected with remotely operated vehicles (ROVs) in the southern Black Sea off Sinop and Ereğli, Turkey during the Nautilus expedition in summer 2011 and 2012. The samples were placed in a -80°C freezer until they were transported to Istanbul University at the end of the expedition. The oxic, suboxic, and anoxic sediment samples taken from the southern

Black Sea of Turkey were analysed with culture-dependent and independent methods (Altug *et al.* 2014). The highest archeal ratio result was reported to be as 16% in the deepest sample taken from 190 m.

Durisch-Kaiser *et al.* (2005) reported that aerobic methane oxidation responsible bacteria are the most abundant group living in the aerobic Black Sea water column. *Pseudoalteromonas*-like groups (oxic sediment samples), ε-*Proteobacteria* (oxic/anoxic transition zone) δ-Proteobacteria and ANME-2-like archaeal clones (anoxic zone) have been found dominant in a study and they observed difference between sediment samples taken from various depths of the Black Sea (Vetriani *et al.* 2003).

4. Heavy Metal and Antibiotic Resistant Bacteria-mine

An increase in the resistant fraction of culturable heterotrophic bacteria in the aquatic ecosystems is due to the growth primarily of the resistant bacteria (Barkay and Olson 1986, Muller *et al.* 2001, Rasmussen and Sorensen, 1998). So, as pathogens develop resistance we must find new antibiotics to replace the old ones in treatment regimes. Ecological studies have reported that metal and antibiotic resistance is becoming a global phenomena, with the Black Sea not being exempted, as the frequency of occurrence of plasmid-borne bacteria was high in sea bacteria (Kobori *et al.* 1984). Plasmids are known to carry resistance to antibiotics and metals (Smith *et al.* 1993, Rasmussen and Sorensen 1998, Sobecky 1999). Hence the possibility of Black Sea isolated bacteria to harbor antibiotic/metal resistance traits via horizontal transformation can be anticipated. Marine bacteria adsorb, accumulate and transform heavy metals (Chan and Dean 1988) in most food chains. With the present rate at which some of the heavy metals bioaccumulate, (Guhathakurta and Kaviraj 2000) including the marine environment, it is pertinent to understand their effect at the primary microbial level especially in regions more affected by anthropogenic influences.

In a study, Altuğ and Onac-Icoz (2005) investigated the frequency of antibiotic resistance in Enterobacteriaceae for the first time in the surface and deeper waters of the Western Turkish Black Sea. They reported higher bacterial contamination and bacterial metabolic activity in the Black Sea than the the Eastern Marmara Sea samples. Beta-lactam antibiotic resistance frequency of *Enterobacteriaceae* family members against Imipenem, Cefotaxim, Ampicillin, Ceftriaxon and Ceftazidim isolated from the sea water of the western part of the Turkish Black Sea was reported to be higher than the Sea of Marmara.

In a study by Altuğ *et al.* (2008), sea water samples taken from the western part of the Black Sea, Turkey were investigated. The bacteria belonging to *Enterobacteriaceae* members were identified using cultivable methods. *E.coli*, *Klebsiella* spp., *Citrobacter freundii*, *Proteus vulgaris* and *Enterobacter cloacae* were used for the beta-lactam antibiotic resistance test. The percentage of chosen bacteria in the samples which exhibited antibiotic resistance was measured with Imipenem (10 μg/mL), Ampicillin (10 μg/mL), Cefotaxim (30 μg/mL), Ceftriaxon (30 μg/mL) and Ceftazidim (10 μg/mL) media. The frequencies of resistance of the isolated were found to be highly resistant to Ampicillin and Imipenem. The results also indicated that the resistant strains which were isolated from sea water samples of the western region of the Black Sea, Turkey have been increasing with time. They said increase in resistant strains and the coliform bacteria counts were associated with negative environmental conditions.

In a study by Akkan and Mutlu (2016) it was indicated that the resistance of 200 *Enterobacteriaceae* isolates recovered from seawater in Giresun Coasts (Black Sea) to 9 different antibiotics was investigated by agar diffusion methods. Antibiotic resistance levels of isolates was determined respectively, Erythromycin (E): 82%, Cefazolin (CZ): 46.50%, Cefotaxime (CTX): 50.50%, Amikacin (AK): 41.50%, Nalidixic acid (NA): 34.50%, Tetracycline (TE): 30.50%, Chloramphenicol (C): 36.50%, Cefuroxime (CXM): 35.50% and Ampicillin (AM): 15.50%. It was found that 2 isolates were resistant to all antibiotics, 5 isolates were sensitive and 91% of all isolates' multiple antibiotic resistance (MAR) index values were higher than 0.2. It was concluded that the bacteriological quality in Giresun coastal area could cause public health problems due to lack of necessary hygiene and sanitation conditions.

In another study about the determination of bacterial identification, the species of *Vibrio*-like bacteria (VLO) were isolated from the seawater and sand of marine recreation beach located on the southern coast of the Baltic Sea and their antibiotic resistance was studied. According to susceptibility test, planktonic, and benthic VLO were most resistant to β-lactam (ampicillin and penicillin) and lincosamide (clindamycin) antibiotics, while most susceptible to tetracycline and aminoglycosides (gentamycin). Moreover, the results showed that *Vibrio*-like bacteria inhabiting sand were more antibiotic-resistant than those isolated from seawater. In general, there was no difference in antibiotic resistance between VLO isolated from the surface and subsurface sand layers. More than 90% of planktonic and benthic *Vibrio*-like bacteria showed multiple antibiotic resistance (Mudryk *et al.* 2013).

Sipahi *et al.* (2013) carried out another study to investigate the level of antibiotic and heavy metal resistance of *Enterobeacteriaceae* isolated from some retail fishes in Giresun. A total of 134 bacteria were isolated from samples collected from different fish markets in central town. Antibiotic resistance of bacterial strains was determined by the agar diffusion test and 9 different antibiotic discs (representing 6 classes of antibiotics). Antibiotic resistance levels of isolates were determined to be respectively as Erythromycin E (85.07%), Cefazolin CZ (79.85%), Cefotaxime CTX (78.36%),Cefuroxime CXA (71.64%), Nalidixic acid NA (60.45%), Ampicillin AM (58.96%), Amikacin AK (53.73%), Tetracycline TE (47.76%) and Streptomycin S (17.91%). 88.05% of all isolates' Multiple antibiotic resistance (MAR) index values were higher than 0.2. In addition, all isolates of the *Enterobacteriace* were resistant to copper while they were resistant to manganese by 61.94% and lead by 46.27%. In plasmid DNA analyses, it was determined that 1 strain did not contain any plasmid DNA, while other strains included plasmid DNA bands ranging from 1 to 4. The molecular weights of these plasmids were found to be in various sizes from 28329 to 876 bp.

Bacterial resistance to antibiotics, due to the wide availability of antibiotics, and their improper usage and disposal, is an emerging public health concern (Davis and Amabile-Cuevas, 2003). In the past, the uncontrolled and extensive use of pharmaceutical substances, mainly antibiotics, in human and veterinary medicine, animal husbandry, agriculture and aquaculture have increased the introduction of antimicrobial agents into the aquatic environment. Antibiotic and metal resistance of bacteria may be related through the linkage of genetic determinants and shared resistance mechanisms (Baker *et al.* 2006, Martinez 2009). High frequencies of bacteria resistant to antibiotics can be viewed as an indicative of environmental pollution, and aquatic systems are considered to be major reservoirs of resistance genes, important for their maintenance, mixing, and mobilization (Zhang *et al.* 2009, Nithya and Pandian 2010).

In coastal waters and sediments, two sources of antibiotic resistant bacteria and residence genes can be identified: one from terrestrial bacteria originating from anthropogenic activities of the surrounding environments and another one from indigenous estuarine or coastal marine bacteria. Both groups of bacteria can enter the seawater with antibiotic resistant plasmids that are responsible for the prevalence of resistant genes in the marine environment (Metcalfe *et al.* 2003, Dang *et al.* 2008).

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References

Akkan, T. and C. Mutlu. 2016. Determination of antibiotic resistance levels in Enterobacterioceae isolated from the Giresun coasts (Black Sea). Turkish Journal of Agriculture-Food Science and Technology, 4(8): 646-650.

Altuğ, G. and Y. Bayrak. 2002. Determination of the levels of indicator bacteria and *Salmonella* spp. in *Chamelea gallina*, L. and seawater on the coastline of Sile, Turkey. Journal of the Marine Biology United Kingdom Association (JMBA), 82(4): 673-674.

Altuğ, G. 2005. Bacterial marine pollution, p. 225-274. In K.C. Güven, B. Öztürk [eds.], Marine Pollution. TUDAV Press, Istanbul (in Turkish).

Altuğ, G. and Onac-Icoz, I. 2005. Antibiotic Resistant Strain and Bacterial Metabolic Activity In The Western Black Sea,Turkey, 1st Biannual Scientific Conference Black Sea Ecosystem 2005 and Beyond., Istanbul, Turkey, 9 May 2005, pp.32-32

Altuğ, G., M. Cardak, and P.S. Ciftci. 2008. The levels of indicator bacteria and antibiotic resistance strains of western region of the Black Sea, Turkey. pp. 43-46. Climate change in the Black Sea - Hypothesis, Observations, Trends, Scenarios and Mitigation Strategy for the Ecosystem, BS-HOT, Bulgaria, 6-9 September 2008.

Altuğ, G., Y. Aktan Turan, M. Oral, B. Topaloğlu, A. Dede, Ç. Keskin, M. İşinibilir Okyar, M. Çardak, and P.S. Çiftçi. 2011. Biodiversity of the Northern Aegean Sea and Southern part of the Sea of Marmara, Turkey. Mar. Biodiver. Rec., 4: 1-17.

Altuğ, G., M. Çardak, P.S. Çiftçi, and S. Gürün. 2013. First records and microgeographical variations of culturable heterotrophic bacteria in an Inner Sea (The Sea of Marmara) between the Mediterranean and the Black Sea, Turkey, Turk. J. Biol., 37: 184-190.

Altuğ, G., A. Sarac, B. Erguner, B. Yuceturk, B. Yuksel, S.M. Sağıroğlu, G. Albayrak, E. Yörük, P. Ciftci Turetken, S. Gurun, and S. Kalkan. 2014. Black Sea microbiology and results from Nautilus sampling:The microbial diversity of metagenomic samples of sediments at oxic, anoxic and suboxic zones, Archaeological Oceanography in the Mediterranean and Black Sea, A Symposium on the E/V Nautilus and STS Bodrum Expeditions to Turkey, 2009-2013. Bodrum, Turkey. 19-20, October, 2014.

Ashbolt, N.J., W.O.K. Grabow, and M. Snozzi. 2001. Indicators of microbial water quality, p. 289-316. In L. Fewtrell, J. Bartram [eds.], Water quality: Guidelines, Standarts and Health. World Health Organization (WHO), IWA, London, UK.

Azam, F., T. Fenchel, J.G. Field, J.S. Gray, L.A. Meyer-Reil, and F. Thingstad. 1983. The ecological role of water column microbes in the sea. Mar. Ecol. Prog. Ser., 10: 257-263.

Azam, F. and J.A. Fuhrman. 1985. Measurement of bacterioplankton growth in the sea and its regulation by environmental conditions, p. 1798-196. In Hobbie, J.E., P.J.leB. Wfiams [eds.], Heterotrophic Activity in the Sea. Plenum. New York.

Baker-Austin, C, M.S. Wright, R. Stepanauskas, and J.V. McArthur. 2006. Co-selection of antibiotic and metal resistance. Trends Microbiol., 14: 176-182.

Barkay, T. and B.H. Olson. 1986. Phenotypic and genotypic adaptation of aerobic heterotrophic sediment bacterial communities to mercury stress. Applied Environmental Microbiology, 63: 4267-4271.

Chan, K.Y. and A.C.R. Dean. 1988. Effects of cadmium and lead on growth, respiration and enzyme activity of the marine bacterium *Pseudomonas marina*. Chemosphere, 17: 597-607.

Çiftçi, P.S., M. Çardak, and G. Altuğ. 2011. The levels of indicator bacteria transported to the Black Sea by the Sakarya River (Karasu Region). J. Black Sea/Mediterranean Environment, 17(1): 56-66.

Cociasu, A., L. Dorogan, C. Humborg, and L. Popa. 1996. Long-term ecological changes in Romanian coastal waters of the Black Sea. Marine Pollution Bulletin, 32: 32-38.

Dang, H., X. Zhang, X. Song, L. Y. Chang, and Yang, G. 2006. Molecular characterizations of oxytetracycline resistant bacteria and their resistance genes from mariculture waters in China. Mar. Pollut. Bull., 52: 1494-1503.

Dang, H., J. Ren, L. Song, S. Sun, and L. An. 2008. Diverse tetracycline resistant bacteria and resistance genes from coastal waters of Jiaozhou Bay. Microb. Ecol., 55: 237-246.

Davis, J.W. and C.F. Amabile-Cuevas. 2003. The rise of antibiotic resistance, p. 1-7. In C.F. Amabile-Cuevas [ed.], Multiple Drug Resistant Bacteria. Horizon Scientific Press, Wiltshire, UK.

Durisch-Kaiser, E., L. Klauser, B. Wehrli, and C. Schubert. 2005. Evidence of intense archaeal and bacterial methanotrophic activity in the Black Sea water column. Appl. Environ. Microbiol., 71(12): 8099-8106.

Friedl, G., C. Dinkel, and B. Wehrli. 1998. Benthic fluxes of nutrients in the northwestern Black Sea. Marine Chemistry, 62: 77-88.

Giovannoni, S. and M. Rappé. 2000. Evolution, diversity and molecular ecology of marine prokaryotes, p. 47-84. In D. Kirchman [ed.], Microbial Ecology of the Oceans. Wiley-Liss, New York, N.Y.

Giuliano, L. 2003. Bacterial Diversity in the Mediterranian and the Black Seas: A Comparative Approach. International Conference on the Sustainable Development of the Mediterranian and Black Sea Environment, 1-3, Greece.

Glassmeyer, S.T., E.T. Furlong, D.W. Kolpin, J.D. Cahill, S.D. Zaugg, S.L. Werner, M.T. Meyer, and D.D. Kryak. 2005. Transport of Chemical and Microbial Compounds from Known Wastewater Discharges: Potential for Use as Indicators of Human Fecal Contamination. Environ. Sci. Technol., 39: 5157-5169.

Guhathakurta, H. and A. Kaviraj. 2000. Heavy metal concentration in water, sediment, shrimp (*Penaeus monodon*) and mullet (*Liza parsia*) in some brackish water ponds of Sunderban, India. Marine Pollution Bulletion, 40: 914-920.

Hagström, Å., T. Pommier, F. Rohwer, K. Simu, W. Stolte, D. Svensson, and U.L. Zweifel. 2002. Use of 16S ribosomal DNA for delineation of marine bacterioplankton species. Appl. Environ. Microbiol., 68: 3628-3633.

Hendricks, C.V. 1978. Exceptations to the coliform and fecal coliform tests, p. 99. In G. Berg [ed.], Indicators of Viruses in Water and Food.

Janelidze, N., E. Jaiani, N. Lashkhi, A. Tskhvediani, T. Kokashvili, T. Gvarishvili, D. Jgenti, E. Mikashavidze, R. Diasamidze, S. Narodny, R. Obiso, C.A. Whitehouse, A. Huq, and M. Tediashvili. 2011. Microbial water quality of the Georgian coastal zone of the Black Sea. Mar. Pol. Bull., 62: 573-580.

Jürgens, K. and H. Güde. 1994. The potential importance of grazing-resistant bacteria in planktonic system, Mar. Ecol. Prog. Ser. 112: 169-188.

Kavka, G.G., G.D. Kasimir, and A.H. Farnleitner. 2006. Microbiological water quality of the River Danube (km 2581 - km 15): Longitudinal variation of pollution as determined by standard parameters. p. 415-421. 36th International Conference: Danube River Life.

Kobori, H., C.W. Sullivan, and H. Shizuya. 1984. Bacterial plasmids in Antarctic natural microbial assemblages. Applied Environmental Microbiology, 48: 515-518.

Martinez, J.L. 2009. Environmental pollution by antibiotics and by antibiotic resistance determinants. Environ Pollut., 157: 2893-2902.

Merkel, A.Y., V.A. Korneeva, I.Yu. Tarnovetskii, A.L. Bryukhanov, V.K. Chasovnikov, E.A. Taranov, S.V. Toshchakov, and N.V. Pimenova. 2015. Structure of the archaeal community in the Black Sea photic zone. Microbiol., 84(4): 570-576.

Metcalfe, C.D., X.S. Miao, B.G. Koenig, and J. Struger. 2003. Distribution of acidic and neutral drugs in surface waters near sewage treatment plants in the lower Great Lakes, Canada. Environ. Toxicol. Chem., 22: 2881-2889.

Mudryk, Z.J., A. Kosiorek, and A. Perlinski. 2013. In vitro antibiotic resistance of Vibrio-like organisms isolated from seawater and sand of marine recreation beach in the southern Baltic Sea. Hydrobiologia, 702: 141-150.

Muller, K.A, L.D. Rasmussen, and S.J. Sorensen. 2001. Adaptation of the bacteria community to mercury contamination. FEMS Microbiology Letter, 204: 49-53.

Nithya, C. and S.K. Pandian. 2010. Isolation of heterotrophic bacteria from Palk Bay sediments showing heavy metal tolerance and antibiotic production. Microbiol Res., 165: 578-593.

Pomeroy, L.R. 1980. Microbial roles in aquatic food webs, p. 85-109. In R.R. Colwell [ed.], Aquatic Microbial Ecology. Univ. Maryland Press, College Park.

Rasmussen, L.D. and S.J. Sorensen. 1998. The effect of long-term exposure to mercury on the bacteria community in the marine sediment. Current Microbiology, 36: 291-297.

Rath, J., K.Y. Wu, G.J. Herndl, and E.F. Delong. 1998. High phylogenic diversity in a marine-snow-associated bacterial assemblage. Aquatic Microbial Ecology, 14: 261-269.

Rehnstam, A.S., S. Bäckman, D.C. Smith, F. Azam, and Å. Hagström. 1993. Blooms of sequencespecific cultivable bacteria in the sea. FEMS Microbiol. Ecol., 102:161-166.

Rheinheimer, G. 1985. Aquatic Microbiology, John Wiley & Sons, Germany.

Sansers, R.W., D.A. Caron, and U.G. Berninger. 1992. Relationships between bacteria and heterotrophic nanoplankton in marine and fresh waters: an interecosystem comparison. Mar. Ecol. Prog. Ser., 86: 1-14.

Simeonova, A.K., R.Z. Chuturkova, and V.B. Bojilova. 2010. Bathing water quality monitoring of Varna Black Sea coastal zone Bulgaria. Water Resour., 37(4): 520-527.

Sipahi, N., C. Mutlu, and T. Akkan. 2013. Antibiotic and heavy metal resistance levels of Enterobactericeae isolated from retail fishes in Giresun (in Turkish). Journal of Food, 38(6): 343-349.

Smith, J.J., J.P. Howington, and G.A. McFeters. 1993. Plasmid maintenance and expression in *Escherichia coli* exposed to the Antarctic marine environment. Antart-J-U.S., 28:123-124.

Sobecky, P.A. 1999. Plasmid ecology of marine sediment microbial communities. Hydrobiologia, 401: 9-18.

Stoica, E., A. Cociasu, V. Coatu, A. Oros, and V. Piescu. 2004. Present state of the Romanian Black Sea bathing waters quality. Cercetari marine, 35: 109-121.

Tankéré, S.P.C., F.L.L. Muller, J.D. Burton, P.J. Statham, C. Guieu, and J.-M. Martin. 2001. Trace metal distributions in shelf waters of the Northwestern Black Sea. Continental Shelf Research, 21: 1501-1532.

Taşdemir, Y. 2002. Sea of Marmara: pollutants and precautions in terms of environmental issues (in Turkish), Uludağ Univ J. Fac. Eng. Arch., 7: 39-45.

Topcuoglu, S., D. Kut, N. Esen, E Ölmez Eğilli, R. Küçükcezzar, A. Başsarı, N. Güngör, and Ç. Kırbaşoğlu. 2000. Heavy metal concentrations in sediments and organisms of the

Marmara Sea. p. 561-565. In B. Öztürk, M. Kadıoğlu, H. Öztürk [ed.], The Marmara Sea 2000. TUDAV Publication no: 5.

Turetken, P.S. and G. Altuğ. 2016. Bacterial pollution, activity and heterotrophic diversity of the northern part of the Aegean Sea, Turkey. Environ. Monit. Assess. 188(2): 127.

Vetriani, C., H.V. Tran, and L.J. Kerkhof. 2003. Fingerprinting microbial assemblages from the oxic/anoxic chemocline of the Black Sea. Appl. Environ. Microbiol., 69(11): 6481-6488.

Wilson, J.G., A. Komakhidze, T. Osadchaya, S. Alyomov, A. Romanov, and M. Tediashvili. 2008. Evaluating ecological quality in the north-eastern Black Sea coastal zone. Mar. Poll. Bull., 57: 202-207.

Yılmaz, A. and S. Tugrul. 1998. The effect of cold- and warm-core eddies on the distribution and stoichiometry of dissolved nutrients in the northeastern Mediterranean, Journal of Marine Systems, 16: 253-268.

Zhang, X.X, T. Zhang, and H.H. Fang. 2009. Antibiotic resistance genes in water environment. Appl Microbiol Biotechnol, 82: 397-414.

THE CONTAMINATION STATUS OF HEAVY METALS IN FISH FROM THE BLACK SEA, TURKEY AND POTENTIAL RISKS TO HUMAN HEALTH

Levent BAT

University of Sinop, Fisheries Faculty, Department of Hydrobiology, Sinop, Turkey
leventbat@gmail.com

1. Introduction

Degradation of the marine ecosystems, particularly coastal areas, occurs because of land- and sea-based activities polluting the environment, altering the ecological surroundings and causing degradation such as habitat loss. Several elements are necessary for understanding the impacts of human activities on marine ecosystems. Sources of marine pollution contain the land-based sources and industrial activities, shipping and fishing activities and aquaculture, domestic wastes, dumping, seabed activities both coastal and offshore, touristic activities, and atmospheric sources. Land-based activities create the greatest origins of pollution in the marine coastal environment (Ünsal *et al.* 1995, Bakan and Büyükgüngör 2000, Altas and Büyükgüngör 2007, Bat *et al.* 2009, Büyükgüngör *et al.* 2014). In shipping, oil pollution increases due to occurrence of tanker grounding and clash has been an important international attention (Alkan and Boran 2014). This anxiety has interpolated dangerous and deleterious substances (Förstner and Wittmann 1983, Mance 1987, Depledge *et al.* 1994, Bat 2014), ballast water discharge and antifouling paints (Bellinger and Benham 1978, Young 1979, Paradas *et al.* 2007). Marine pollution as defined by Štirn (1981) and Clark (1986) is the "introduction by man, directly or indirectly, of substances or energy into the marine environment (including estuaries) resulting in such deleterious effects as harm to living resources, hazards to human health, hindrance to marine activities including fishing, impairment of quality for use of sea water, and reduction of amenities". Coastal degradation, climate changeability and increased industrialization will rise jeopardize of mobilization of anthropogenically derived and natural toxic agents in the marine environment and thus their transfer to humans.

2. The Black Sea

The Black Sea is a semi closed and one of the most exceptional regional seas in the world. Kovalev *et al.* (1999) described the Black Sea with the following sentences: "The Black Sea is one of the most interesting seas of the world both in scientific and non-scientific aspects. Its history is full of romantic and dramatic events. Its diverse marine fauna has been influenced by the long and short term (geological, climatic, hydrological) natural and anthropogenic processes of the last three decades". It is located between SE

Europe and Asia, connected with the Mediterranean Sea by the Bosphorus, the Sea of Marmara, and the Dardanelles. It is about 2212 m deep with a volume of 550000 km^3 and is an estuarine type basin due to the large river discharge, especially on its north-western shelf area (Zaitsev and Mamaev 1997). The Black Sea is enclosed by Bulgaria and Romania on the west, Ukraine and Russia on the north, Georgia on the east, and Turkey on the south. Along the Black Sea, the heavily salty bottom layer which originates in inflowing the Mediterranean waters, has a very slow motion and contains hydrogen sulphide; it has no eukaryotic marine life. About 87 % of the Black Sea is entirely anoxic and contains high amounts of hydrogen sulphide (Zaitsev and Mamaev 1997), a solvable toxic gas mostly associated with the smell of rotten eggs (Mee 2005). The top layer, much less saline, flows in a counter clockwise direction around the sea. There is little tidal action. Every year, about 350 km^3 of river water enter into the Black Sea from an area covering almost a third of continental Europe and including significant areas of seventeen countries, namely Austria, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Germany, Hungary, Moldova, Slovakia, Slovenia, Romania, Russia, Turkey, Ukraine, and Yugoslavia (Mee 2005) including about 170 million people (Köse *et al.* 2013). Europe's second, third and fourth rivers (the Danube, Dnieper and Don) all flow into the Black Sea. The Bosphorus has a two layer flow, carrying about 300 km^3 of seawater to the Black Sea from the Mediterranean along the bottom layer and returning a mixture of seawater and freshwater with twice this volume in the upper layer (Mee 2005). The increasing human population in coastal areas of the Black Sea continue to increase pressure on the region. Eutrophication or over fertilization is the most visible danger facing the Black Sea and also has the greatest impact. Nitrogen and phosphorus compounds are major nutrients. Troubles began in the end of 1960s with "green revolution" which was observed as theincreasing eutrophication in the sea due tonutrient inputs from the rivers (Mee 2005). The Danube River constituted nearly 75 percent of the total input (Zaitsev and Mamaev 1997). Death and subsequent decay used up the oxygen in the water (Mee 1992). These death zones on the seabed are but one symptom of the sickness that is afflicting the Black Sea.

Heavy metals do not seem to contaminate the entire Black Sea but appear as "hot spots" near well-identified sources (Mee 2005). They are usually related to waste from heavy industry and the ash retraining from burning coal for generating electricity. On the other hand, as a consequence of economic decline the usage of these substances has decreased considerably and no more presents a major hazard in the sea, except where their use was very intensive in the past (Mee 2005). Mee (2005) strongly emphasized that "the Black Sea is seriously ill but certainly isn't dead".

3. Definition of heavy metals

Heavy metal is the generic term for metallic elements having an atomic weight higher than 40.04. They are chemical elements with a specific gravity that is about 5 times the specific gravity of water which is 1 at 4°C. Clearly stated, specific gravity is a measure of density of a given amount of a solid material when it is compared to a same amount of water. Some well-known toxic metallic elements with a specific gravity that is 5 or more times that of water are Hg (13.546), Cd (8.65), Pb (11.34) and As (5.7) (Appenroth 2010). Of the 92 naturally consisting elements, nearly 30 metals and metalloids are potentially toxic to humans such as Hg, Cd, Pb, As, Cu, Mn, Co, Ni, *etc*. The term of heavy metals has been replaced in years by a classification scheme that considers their chemistry rather than relative density (Nieboer and Richardson 1980). Separation of some essential and non-essential metal ions of importance as pollutants into class A (oxygen-seeking) including Ca, Mg, Mn, K, Sr, Na, class B (sulphur or nitrogen-seeking) including Zn, Pb, Fe, Cr, Co, Ni, As, V and borderline elements including Cd, Cu, Hg, Ag are based on the classification scheme of Nieboer and Richardson (1980).

4. Importance of heavy metals

All pollutants affect the coastal ecosystem. Heavy metals are among the most important of these pollutants. All heavy metals occur naturally in the marine environment, however their levels are greatly increased where they have been extracted and are used for industrial activities. Heavy metals are a group of elements with a wide range of chemical properties and biological effects. Some of them, such as Zn, Cu and Mn, are essential trace elements in the diet and their absence can lead to serious illness. Others, such as Hg, Cd and Pb, have no biological function and their presence in all but very small quantities can cause poisoning. Hg, Cd, Pb, Cr, Cu, Ni and As are the very common heavy metals, and Hg, Cd and Pb are of the supreme concern. The issues posed by heavy metals vary. Aquatic organisms, including fish, concentrate heavy metals in their tissues even in edible muscles, becoming extremely toxic in the course. A number of land-based waste products, notably toxic heavy metals, exert a direct effect on commercial fish-stocks. Especially Hg, Cd and Pb turn into a concentrated structure thanks to the food-chains, posing a toxic risk to species in higher trophic levels in the food web. Especially, people who are living in the coastal areas are the most sensitive and the most affected by these contaminants. It is well known that heavy metal accumulation impact human health. Perhaps the best famous case was in Minamata Bay in Japan when Hg discharged by a factory was passed up the marine food chain to fish, which formed the main diet of local people (The Earth Report-3 1992). The form of Hg involved was methylmercury which was poisoning and known to cause Minamata disease. The first cases of Minamata disease were diagnosed in 1953. Brain damage, delirium, spasms, blurred vision, and death were caused while exposed women produced physical deformities in new-born babies. By 1966, 43 people had died and a further 68 were permanently disabled from neurological effects. By 1983 more than 300 people had died and over 1500 were officially recognised but some 6000 claimed to have been effected and it has been predicted that a considerable broad number may have been exposed to unsafe levels of Hg. It is still in use even in children’s toys (The Earth Report-3 1992).

Cd is a toxic heavy metal with harmful effects on human health such as Hg. Chronic Cd poisoning causes damage to the kidneys and heart. Long term exposure results in a loss of calcium off the bone, which then become brittle and break easily. In Japan, again, a whole village was afflicted with Cd poisoning known as “itai-itai” disease meaning “it hurts-it hurts” after industrial effluent contaminated rice supplies. Cd is naturally available in phosphate fertilizers and is drained to the marine environment when they are refined. It is utilization in metal plating, in certain plastics as a colour and in some rechargeable batteries (The Earth Report-3 1992).

Pb is also a highly toxic heavy metal which has caused considerable damage to human health. Pb is much more common than Hg in the Earth's crust and has been in widespread use for thousands of years. Like other heavy metals, Pb can accumulate in the food web and species such as fish of prey at the top of the chain may contain great quantities. Acute Pb is poisonous and the disease is called saturnism which causes stomach pains, headaches, tremor, irritability and in severe cases, comma and death. It is also known to affect the nerves and the brain at very low concentrations (The Earth Report-3 1992).

5. Disturbance of heavy metals in the sea

When a contaminant such as chemical discharges is let into the marine environment, advection will occur far from its source by the equated large-scale current while at the same time undergoing mixing by small-scale turbulent eddies. The mixing process causes the first contaminant patch to increase with time, thereby reducing levels within the patch. As the patch continues to increase, the size of eddies that can act on it also rises. In general, eddies larger than the patch act to advent the contaminant away from its source, while eddies the same size as or smaller than it produce turbulent mixing. Turbulent mixing, or diffusion, increases with time in rate to patch size.

The Black Sea is characterized by a predominantly cyclonic and vigorously time-dependent basin wide circulation that follows almost the continental slope around the basin (Figure 1). The Sakarya, Sinop and Kızılırmak eddies of the south coast become to be not as quasi-persistent structures as the Batumi and Bosphorus eddies. They may create recurrently once or twice a year for about a season. When they are enough massive, the Sinop and Kızılırmak eddies may be combined and form a single entity. The presence of these three eddies usually bounds up with spread characteristics of the meanders superimposed on the Rim Current system (Korotaev *et al.* 2003). Korotaev *et al.* (2003) also pointed out that a chain of eddies throughout the Anatolian coast have more intermittent character and travel slowly eastward along the coast. The Sakarya, Sinop and Kizilirmak eddies incline to display more quasi-permanent character owing to controls exerted by regional topographies.

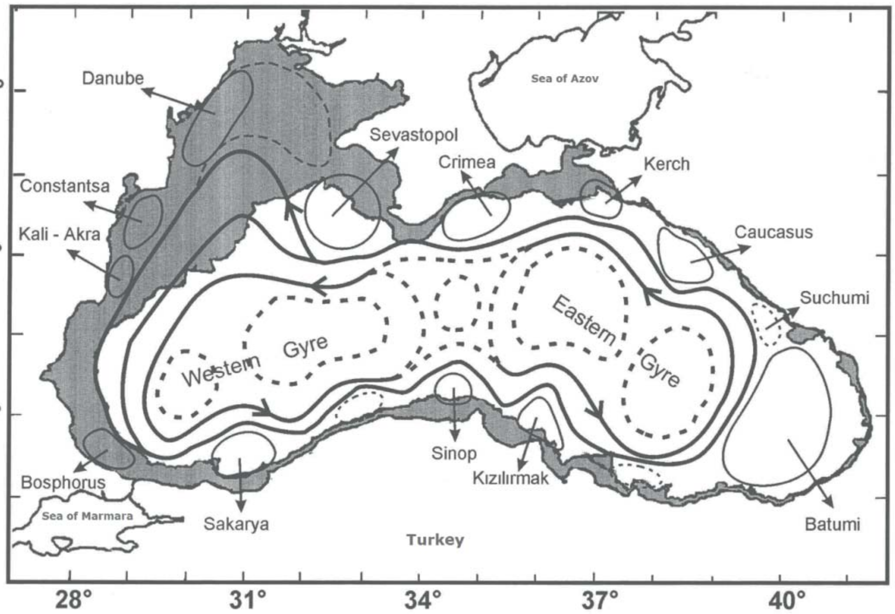

Figure 1. The main features of the upper layer circulation in the Black Sea (Its original was given by Oguz *et al.* 1993 and 2009)

Once released into the marine environment, heavy metals can remain in the water for very long periods. They can reach dangerous levels in fish species. As a result, food security and pollution are some of the main issues in the world. It would appear that bioaccumulation in edible tissues of the fish is a certain problem. Contaminants especially heavy metals have become an increasing concern on food security mainly fish.

6. Importance of heavy metals in fish

Heavy metals have also become the focus of particular interest in recent decades within the Marine Strategy Framework Directive 2008/56/EC (MSFD) which lists the thematic qualitative descriptors for pollutants including heavy metals for determining Good Environmental Status (GES) within Descriptors 8 and 9. Descriptor 8 states that "concentrations of contaminants are at levels not giving rise to pollution effects" while Descriptor 9 states that "contaminants in fish and other sea food for human consumption do not exceed levels established by Community legislation or other relevant standards". Monitoring of heavy metals in fish is required in order to improve knowledge of the health state of the ecosystem and the threats, if there are any, against human population, and also in order to enable Turkey as candidate country to fulfil its international obligations under EC Directives (Marine Strategy Framework Directive 2008/56/EC). In order to the final achieving GES in the Black Sea by the year 2020, metal levels in the environment near background values for naturally occurring substances and close to zero for man-made synthetic substances, further studies will be necessary both at national and European levels. Connecting the health of the Black Sea with that of human health is a long term struggle that will require remarkable effort and resources. All of these issues are vital to ensure sustainable development of coastal and marine resources. The main objectives in any assessment of marine environmental health on a national scale are to provide information necessary to safeguard human health.

Toxic metals, lack of oxygen, too many nutrients and overfishing make life hard for the fish of the Black Sea. Fishes in the Turkish Black Sea coasts are one of the main protein sources. Heavy metals in the food web are threatening all fishing communities that still depend on seafood for their subsistence. Increasing sea water temperature is suspected to be a contributing factor to this unconventional status. The unsuitable use, storage and transport of all types of waste, including toxic and dangerous materials especially heavy metals, are growing problems all around the Black Sea. Fish can be contaminated with heavy metals at any stage from the captured until it is consumed.

Heavy metals are readily absorbed with food, but they are not easily excreted, and even organisms low in the food web can be affected by them. The higher the position in the food chain and the longer-lived the individual organism, the more metal it accumulates. Top predators including fish can gather levels of heavy metals millions of times greater than those in the surrounding water. These may kill them directly, or reduce their ability to cope with disease. Heavy metal concentrations in fish may be changed from year to year and seasonally.

7. Importance of fish consume

EFSA (European Food Safety Authority) (2014 and 2015) concluded that fish is a source of energy and protein with high biological value, and concludes to the intake of essential nutrients, with well-established health utilities. Fish also supplies n-3 long-chain polyunsaturated fatty acids (LCPUFA), and is a component of dietary patterns associated with good health (Domingo *et al.* 2007, Sioen *et al.* 2007). Many European guidelines and scientists suggest a minimum of two servings of fish per week for big children and adults (Domingo *et al.* 2007, EFSA 2014, 2015). Suggestions for children and pregnant women attribute to the type of fish and are also based on safety considerations. Consumption of more or less 1-2 servings of fish per week and up to 3-4 servings per week during pregnancy has been associated with better functional outcomes of neurodevelopment in children compared to no fish (EFSA 2014, 2015). Moreover, consumption of fatty fish might reduce the risk of prostate cancer (Domingo *et al.* 2007, Terry *et al.* 2001) and decrease in mild hypertension (Sioen *et al.* 2007). Such quantities have also been associated with a lower risk of coronary heart disease (Cohen *et al.* 2005, Sioen *et al.* 2007, Gladyshev *et al.* 2009) and stroke disease (Cohen *et al.* 2005) mortality, in adults and are suitable for these intakes and recommendations in many countries including European Union and Turkey considered. No additional benefits on neurodevelopmental outcomes and no benefit on coronary heart disease mortality risk might be expected at higher intakes. The health benefits of seafood consumption in reducing the risk of coronary heart disease mortality are probably owing to the content of n-3 LCPUFA in fish (Cohen *et al.* 2005, Sioen *et al.* 2007, Gladyshev *et al.* 2009, EFSA 2014, 2015).

8. Maximum Permitted Limits (MPL) of heavy metals in fish

It should not be forgotten that among all the animal species, fish are natural marine residents; therefore they cannot get away the harmful effects of heavy metals. Fish are exposed to heavy metals in polluted and contaminated waters. Heavy metals from the human activities and sources are continually released into marine coastal ecosystems. Thus they are serious health risks due to their toxicity, long persistence, bio-accumulation and bio-magnifications in the food web. Now, it is well understood that fish are used as a biological model to assess the health of marine ecosystems since heavy metals accumulate in edible muscles.

The Maximum Permitted Limits of any toxic metal, the level that is thought to be safe, is called the threshold limit value. The MPLs for metals in fish are shown in Table 1.

Table 1. The tolerable values of measured metals in the fish (mg/kg wet wt.)

Standards	As	Cd	Pb	Cu	Zn	Hg
MAFF (1995) The Food Safety	--	<0.2	2.0	20	50	--
Turkish Legislation (1995)	1.0	0.1	1.0	20	50	0.5
EC (2001) The Commission Regulation	--	0.05	0.2	--	--	0.5
Georgian Food Safety Rules (2001)	2.0	0.2	1.0	10	40	0.5
TFC (2002) Turkish Food Codex	1.0	0.05 (0.10)[1]	0.2 (0.4)[2]	20	50	0.5 (1.0)[3]
GAIN Report (2006) Russian Federation	2.0	0.2	1.0	10	40	0.5
Commission Regulation (EC) 2006	--	0.05	0.3	--	--	0.5
TFC (2008) Turkish Food Codex	--	0.05 (0.10)[4](0.30)[5]	0.3	--	--	0.5 (1.0)[6]
TFC (2009) Turkish Food Codex	--	0.05	0.3	--	--	0.5
Australia and New	2.0	--	0.5	--	--	0.5

Zealand Food Standards (2011)						
Turkish Legislation (2011)	--	0.05 (0.10)[7](0.20)[8](0.30)[9]	0.3	--	--	0.5 (1.0)[10]
Commission Regulation (EU) 2014	--	0.05 (0.10)[11](0.15)[12](0.25)[13]	--	--	--	--
Commission Regulation (EU) 2015	--	--	0.3	--	--	--

1) *Dicologoglossa cuneata, Anguilla anguilla, Engraulis encrasicholus, Luvarus imperialis, Trachurus trachurus, Mugil labrosus labrosus, Diplodus vulgaris, Sardina pilchardus, Sardine* spp., *Sarda sarda*, *Thunnus* and *Euthynnus* spp.

2) *Dicologoglossa cuneata, Anguilla anguilla, Dicentrarchus punctatus, Trachurus trachurus, Mugil labrosus labrosus, Diplodus vulgaris, Pomadasys benneti, Sardina pilchardus, Sardine* spp., *Sarda sarda, Thunnus* and *Euthynnus* spp.

3) *Lophius* spp.*, Anarhicdas lupus, Dicentrarchus labrax, Molva dipterygia, Sarda sarda, Anguilla* spp.*, Hoplostethus atlanticus,Coryphaenoides rupestris, Hippoglossus hippoglossus, Makaira* spp.*, Esox lucius, Orcynopsis unicolor, Centroscymnes coelolepis, Raja* spp.*, Sebastes marinus, S.mentella, S. viviparus, Istiophorus platypterus, Lepidopus caudatus, Aphanopus carbo,* Dogfish (all species), *Lepidocybium flavobrunneum, Ruvettus pretiousus, Gempylus serpens, Acipenser* spp.*, Xiphias gladius, Thunnus* spp. and *Euthynnus* spp.

4) *Engraulis* sp.*, Sarda sarda, Diplodus vulgaris, Anguilla anguilla, Mugil labrosus labrosus, Trachurus* sp.*, Luvarus imperialis, Sardina pilchardus, Sardinops* sp.*, Thunnus* sp. and *Euthynnys* sp.*, Katsuwonus pelamis, Dicologoglossa cuneata*.

5) *Xiphias gladius*.

6) *Lophius* spp., *Anarhichas lupus, Sarda sarda, Anguilla* spp., *Hoplostethus* spp., *Coryphaenoides rupestris, Hippoglossus hippoglossus, Makaria* sp., *Lepidorhombus* sp., *Mullus* sp., *Esox lucius, Orcynopsis unicolor, Tricopterus minutes, Centroscymnes coelolepis, Raja* spp., *Sebastes marinus, S. mentella, S. viviparus, Istiophorus platypterus, Lepidopus caudatus, Aphanopus carbo, Pagellus* sp., Dogfish (all species), *Lepidocybium flavobrunneum, Ruvettus pretiosus, Gempylus serpens, Acipenser* spp., *Xiphias gladius, Thunnus* spp. and *Euthynnus* spp., *Katsuwonus pelamis*.

7) *Sarda sarda, Diplodus vulgaris, Anguilla anguilla, Mugil labrosus labrosus,Trachurus* sp., *Luvarus imperialis, Scomber* sp., *Sardina pilchardus, Sardinops* sp.*, Thunnus* sp. and *Euthynnys* sp., *Katsuwonus pelamis, Dicologoglossa cuneata*.

8) *Auxis* sp.

9) *Xiphias gladius, Engraulis* sp.

10) *Lophius* spp., *Anarhichas lupus, Sarda sarda, Anguilla* spp., *Hoplostethus* spp., *Coryphaenoides rupestris, Hippoglossus hippoglossus, Genypterus capensis, Makaria* sp., *Lepidorhombus* sp., *Mullus* sp., *Genypterus blacodes, Esox lucius, Orcynopsis unicolor, Tricopterus minutes, Centroscymnes coelolepis, Raja* spp., *Sebastes marinus, S. mentella, S. viviparus, Istiophorus platypterus, Lepidopus caudatus, Aphanopus carbo, Pagellus* sp., Dogfish (all species), *Lepidocybium flavobrunneum, Ruvettus pretiosus, Gempylus serpens, Acipenser* spp., *Xiphias gladius, Thunnus* spp. and *Euthynnus* spp., *Katsuwonus pelamis*.

11) *Scomber* spp., *Thunnus* spp., *Katsuwonus pelamis, Euthynnus* spp., *Sicyopterus lagocephalus*.

12) *Auxis* spp.

13) *Engraulis* spp., *Xiphias gladius, Sardina pilchardus*.

What makes the heavy metals toxic, is not their essential characteristics, but the amounts that may occur, and most importantly, the type of shape given on distinctive environment; its risk is increased by not being chemically or biologically decomposed, once emitted metals can reside in the marine environment for hundreds of years, and thereof, they are incorporated into marine organisms, like fish, as free metal cations being absorbed through the gills and going straight to the blood, they can also be absorbed by the body and then spread passively through bloodstream.

9. Intake metal levels calculation

It is possible that short-term over exposure in low concentrations to heavy metals do not make direct health threats to humans. At the end, on the other hand, it could induce heart and liver damage, anaemia, weight loss, respiratory and digestive problems, and may have negative effects on blood and kidneys. With regard to health risk, the tolerable weekly intakes were estimated by means of references for edible tissues of fishes consumed by people. The annual quantity of fish consumed was 6.2 kg/person in 2015 (TUIK 2016), which is equivalent to nearly 17 g/day for Turkey. However, there is a large variation in the amount of fish consumed across regions in Turkey and age groups, as well as in the type of species eaten.

The acceptable daily intake is inappropriate for any metal that causes cancer by a mutagenic route - and perhaps by other routes too - because with those metals it cannot be assumed that there is any threshold level below which they can safely be used. Acceptable daily intake is the amount of mg of a heavy metal that can safely be consumed every day by an average human, for each kg of body wt. The Estimated Weekly Intake (EWI) and values were estimated by assuming that a 70-kg person would consume 17 g fish/day which is equal to 119 g fish/week.

The EWI of metals was determined using the following equation:

$$EWI = C_{metal} \times W_{fish} / Bwt.$$

Where: C_{metal} is the average concentrations of metals in fish; W_{fish} represents the weekly average consumption of fish; Bwt. is the body wt. of an adult (kg).

The Estimated Daily Intake (EDI) values were calculated from EWI values. Intake estimates were expressed as per unit body weight (mg/kg body wt. /weekly and daily). The tolerable weekly intake of heavy metals as PTWI (Provisional Tolerable Weekly Intake), are set by the Food and Agriculture Organization/World Health Organization (FAO/WHO) Joint Expert Committee on Food Additives (JECFA). PTWI is the maximum level of a metal to which a person can be exposed per week over a lifetime without an unacceptable risk of health effects (National Academy of Sciences 1989, WHO 1996, Council of Europe 2001, FAO/WHO 2010, EFSA 2010, 2012a, b, c).

The European Food Safety Authority's (EFSA) in its 2012b scientific opinion revised the provisional tolerable weekly intake (PTWI) of methylmercury to 1.3 μg/kg body wt. and set a PTWI of 4 μg/kg body wt. for inorganic Hg.

However, Joint FAO/WHO Expert Committee on Food Additives and Contaminants (JECFA) evaluation, health-based guidance values for these heavy metals are: No PTWI is health protective for inorganic As, 25 μg/kg body wt. provisional tolerable monthly intakes (PTMI), no PTWI is health protective for Pb, 4 μg/kg body wt. PTWI as inorganic Hg applies to all foods except fish and shellfish, 1.6 μg/kg body wt. PTWI applies to fish (FAO/WHO 2010, EFSA 2010, 2012a, b, c, 2014, 2015).

10. Calculations of Hazard Quotient (HQ) for benefit-risk ratio

Risk from metals intake through ingestion may be characterized using a Hazard Quotient (HQ) as the ratio of the estimated metal dose (D mg/kg of body wt. per day) and the reference dose (Rf. D mg/ kg).

Rf. D values were taken from US EPA table developed for ingestion as estimates of daily exposures to a substance that are likely to be without a discernible risk of deleterious effects to the general population during a lifetime of exposure.

If HQ > 1.0, then the EDI of a particular metal exceeds the Rf. D, indicating that there is a potential risk associated with that metal. The EDI depends on both the metal concentration level and the amount of consumption of fish.

11. Heavy metal concentrations in fish species from the Black Sea coasts of Turkey

The following parts give information about the heavy metals in edible muscles of fish species from the southern Black Sea. The quality of available data from different studies should be kept in view when interpreting the results and conclusions presented in this review.

The Hg, Cd, Pb, As, Cu, Zn, Co, Cr, Ni, Mn and Fe in the edible tissues of commercial fish species are given in Tables 2-12 with means or minimum and maximum values. The mean values of the heavy metals concentrations in the muscles of the fish species are compared with Maximum Permitted Limits in Figures 2-12. However heavy metal analysis in edible tissues of fish is generally given on the dry wt. but the legal limits are given as wet wt. which requires converting dry into wet weights. For this purpose if heavy metal concentrations in this review were given as dry wt., they were converted to wet wt. dividing by 4 as factor and all results are expressed on a wet wt. basis as mg/kg. There were big differences between the heavy metal levels in the edible tissues of different fish species.

12. Mercury (Hg)

Hg is a naturally occurring metal which has several forms (ATSDR 1999). Metallic Hg is used to produce chlorine gas and caustic soda, utilized in electrochemical processes and is also used in dental fillings, switches, light bulbs, batteries thermometers, barometers and instruments for measuring blood pressure (Järup 2003, Martin and Griswold 2009). The nervous system is very sensitive to all forms of Hg. Also exposure to high amounts of Hg permanently effects the brain, kidneys, and developing foetuses (Martin and Griswold 2009). The highest total Hg content was found in the muscle tissue of *Trachurus* sp. (0.30 mg /kg wet wt.) caught in Sakarya (Ünsal *et al.* 1993). High levels (0.12 mg /kg wet wt.) was obtained in *M. barbatus* from the Black Sea by Ergül and Aksan (2013). Similar result (0.1 mg /kg wet wt.) was given in *M. merlangus* from Kastamonu and Zonguldak by Ünsal (1993). Tüzen (2009) also found high level (0.084 mg /kg wet wt.) in the muscle tissue of *M. merlangus* caught in the Black Sea (see Table 2). The data obtained for Hg content in the analyzed fish species were confirmed with the European Commission Regulation (EC) No. 1881/2006 that the maximum allowed level of Hg (0.5 mg /kg wet wt.) can be tolerated in the following fish species such as *Trachurus* sp., *M. merlangius* and *M. barbatus*. In the obtained data the overall mean Hg content was below the maximum permissible level of 0.5 mg/ kg wet wt. and in the Turkish Black Sea coasts this does not represent risk for consumers (see Figure 2).

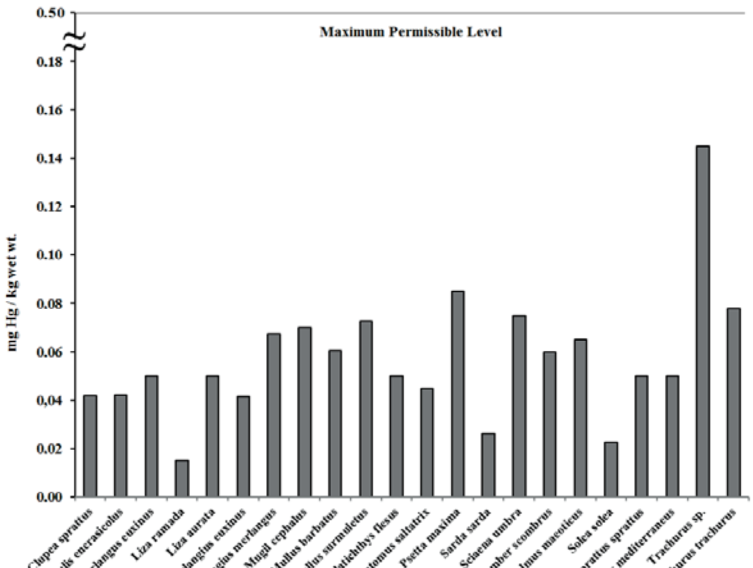

Figure 2. Overall mean concentrations of Hg in the edible tissues of fish species from the Turkish Black Sea coasts

Table 2. Mercury (Hg) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean± SD	Min-Max	Method	Locations	References
Clupea sprattus	0.042 ± 0.002		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	0.02 ± 0.02		wet wt.	İnebolu, Filyos	Ünsal *et al.* 1993
	0.055 ± 0.003		wet wt.	Black Sea	Tüzen 2009
	<0.05		wet wt.	Sinop, Samsun, Fatsa, Batumi	*Bat et al.* 2014
Gadus merlangus euxinus	<0.05		wet wt.	Sinop, Samsun	Das *et al.* 2009
Liza aurata	<0.05		wet wt.	Sinop	Bat *et al.* 2015
Liza ramada	0.06 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius merlangus	0.1 0.035		wet wt.	Kastamonu, Zonguldak	Ünsal *et al.* 1993
	0.084 ± 0.005		wet wt.	Black Sea	Tüzen 2009
	0.33 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
	<0.05		wet wt.	Sinop	Bat *et al.* 2015
Merlangius merlangus euxinus	0.08	0.01-0.15	dry wt.	Trabzon, Black Sea	Alkan *et al.* 2012
	0.03	0.01-0.05			
	0.167	<0.01-0.5	dry wt.	Terkos, Sakarya, Bafra, Ordu	Balkis *et al.* 2012
Mugil cephalus	0.070 ± 0.004		wet wt.	Black Sea	Tüzen 2009
Mullus barbatus	<0.05		wet wt.	Sinop, Samsun	Das *et al.* 2009
	0.036 ± 0.002		wet wt.	Black Sea	Tüzen 2009
	0.47 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
	<0.05		wet wt.	Sinop	Bat *et al.* 2015
Mullus barbatus ponticus		0.07-0.18	dry wt.	Trabzon	Alkan *et al.* 2012
Mullus surmuletus	0.29 ± 0.04		dry wt.	Black Sea	Ergül and Aksan 2013
Platichthys flesus	<0.05		wet wt.	Sinop	Das *et al.* 2009
Pomatomus saltator	0.062 ± 0.003		wet wt.	Black Sea	Tüzen 2009

Pomatomus saltatrix	0.11 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
Psetta maxima	0.045 ± 0.002	wet wt.	Black Sea	Tüzen 2009
	0.50 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
Sarda sarda	0.025 ± 0.002	wet wt.	Black Sea	Tüzen 2009
	0.11 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
Sciaena umbra	0.30 ± 0.02	dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	0.060 ± 0.003	wet wt.	Black Sea	Tüzen 2009
Scopthalmus maeoticus	0.065 ± 0.004	wet wt.	Sinop	Das *et al.* 2009
Solea solea	0.09 ± 0.02	dry wt.	Black Sea	Ergül and Aksan 2013
Sprattus sprattus	<0.05	wet wt.	Samsun, Sinop	Bat and Arıcı 2016b
Trachurus mediterraneus	<0.05	wet wt.	Sinop	Bat *et al.* 2015
Trachurus sp.	0.11 0.30 ± 0.24 0.09 ± 0.09 0.08	wet wt.	Filyos, Sakarya, İğneada, İnebolu	Ünsal *et al.* 1993
Trachurus trachurus	0.078 ± 0.005	wet wt.	Black Sea	Tüzen 2009

13. Cadmium (Cd)

Cd which is a very toxic metal is a naturally occurring non-essential metal and its tendency to constantly accumulate in fish may be in dangerous amounts which raises environmental concern. All soils and rocks, including coal and mineral fertilizers, include some Cd. Cd has many uses, with the inclusion of batteries, pigments, metal coatings, and plastic stabilizers. It is extensively utilized in electroplating and thus leads to contamination of marine ecosystems. Martin and Griswold (2009) emphasize that Cd and its compounds are human carcinogens. It is well known that ingesting very high amounts of Cd seriously irritates the stomach, leading to vomiting and diarrhoea and long-term exposure to lower levels of Cd leads to a collapse in the kidneys and likely kidney disease, lung harm, and fragile bones (Martin and Griswold 2009).

Table 3 shows Cd levels in the edible muscles of fish species from the Turkish Black Sea coasts. The highest Pb content was found in *P. flesus* (0.88 mg /kg) sampled in Sinop (Das *et al.* 2009) followed by *T. trachurus* (0.76 mg /kg) from Giresun (Akaydın 2014) and *B. belone* (0.60 mg /kg) from Rize (Akaydın 2014). It can be seen from Figure 3 that maximum Cd levels in some species were higher than MPL. However these values were exceptional.

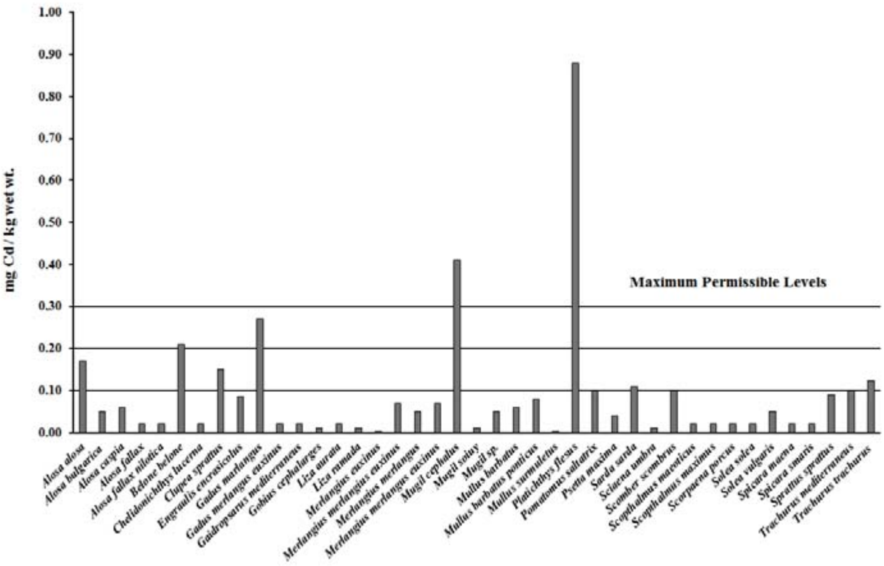

Figure 3. Overall mean concentrations of Cd in the edible tissues of fish species from the Turkish Black Sea coasts

Table 3. Cadmium (Cd) concentrations in the edible muscles of fish from the Turkish Black Sea coasts

Species	Mean± SD	Min-Max	Method	Locations	References
Alosa alosa	0.18 ± 0.06 0.22 ± 0.10		wet wt.	Trabzon, Rize	Akaydın 2014
	0.12 ± 0.03		wet wt.	Samsun	Türkmen and Dura 2016
Alosa bulgarica	0.33	0.19-0.47	dry wt.	Sinop	Bat 1992
	0.19 ± 0.056		dry wt.	Sinop	Öztürk and Bat 1994
Alosa caspia	0.34 ± 0.08 0.35 ± 0.05		dry wt.	Samsun	Tüzen 2003

	0.02		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Alosa fallax	<0.02		wet wt.	Sinop	Bat *et al.* 2017
Alosa fallax nilotica	0.02		wet wt.	Sinop	Bat and Sezgin 2015
Belone belone	0.05 ± 0.007		dry wt.	Sinop	Bat *et al.* 1998
	0.05	0.04-0.06	dry wt.	Sinop	Bat *et al.* 2013
	0.12 ± 0.02 0.42 ± 0.19 0.60 ± 0.27		wet wt.	Trabzon, Giresun, Rize	Akaydın 2014
	0.08 ± 0.00 0.08 ± 0.03 0.40 ± 0.11		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Chelidonichthys lucerna	<0.02		wet wt.	Sinop	Bat *et al.* 2017
Clupea sprattus	0.30 ± 0.15 0.30 ± 0.28		dry wt.	Samsun	Tüzen 2003
	0.30 ± 0.03		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	0.025 ± 0.005		dry wt.	Sinop	Bat *et al.* 1996
	0.1		wet wt.	Amasra	Topçuoğlu *et al.* 2002
	0.18 ± 0.02 0.20 ± 0.03		dry wt.	Samsun	Tüzen 2003
	2.25 ± 0.21		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
	0.65		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.02 ± 0.00 0.03 ± 0.01 0.06 ± 0.02		wet wt. wet wt. wet wt.	Sinop, Trabzon, Bartın	Türkmen *et al.* 2008b
	0.124 ± 0.018		dry wt.	Black Sea	Turan *et al.* 2009
	0.27 ± 0.02		wet wt.	Black Sea	Tüzen 2009

	0.04		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.2 ± 0.05		dry wt.	Samsun	Aygun and Abanoz 2011
	0.30 ± 0.03		dry wt.	Trabzon	Alkan *et al.* 2013
	0.13	0.09-0.17	dry wt.	Sinop	Bat *et al.* 2013
	0.04 ± 0.02 0.15 ± 0.05 0.31 ± 0.15		wet wt.	Trabzon, Giresun, Rize	Akaydın 2014
	<0.03		wet wt.	Sinop, Samsun, Fatsa, Batumi	Bat *et al.* 2014
	0.02		wet wt.	Sinop	Bat and Sezgin 2015
	0.02 ± 0.01 0.05 ± 0.01 0.09 ± 0.02 0.16 ± 0.00 0.19 ± 0.07 0.23 ± 0.04 0.24 ± 0.04 0.27 ± 0.00		dry wt.	Sinop	Gündoğdu *et al.* 2016
	0.06 ± 0.01 0.08 ± 0.06 0.19 ± 0.17		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	1.08 ± 0.09		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
Gadus merlangus euxinus	<0.02		wet wt.	Sinop, Samsun	Das *et al.* 2009
Gaidropsarus mediterraneus	0.02 ± 0.00		wet wt.	Sinop	Ateş *et al.* 2015
Gobius cephalarges	0.02		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Liza aurata	<0.02		wet wt.	Sinop	Bat *et al.* 2015
Liza ramada	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013

Merlangius euxinus	0.002		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Merlangius merlangus	<0.02		wet wt.	Perşembe, Rize	Topçuoğlu *et al.* 2002
	0.0131		wet wt.	Black Sea	Dalman *et al.* 2006
	0.01 ± 0.00 0.02 ± 0.00 0.04 ± 0.01		wet wt.	Trabzon, Bartın, Sinop	Tepe *et al.* 2008
	0.192 ± 0.020		dry wt.	Black Sea	Turan *et al.* 2009
	0.21 ± 0.02		wet wt.	Black Sea	Tüzen 2009
	0.18		wet wt.	Black Sea	Mendil *et al.* 2010a
	0.18 ± 0.02		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
	0.40 ± 0.29	0.15-0.89	wet wt.	Bartın	Fındık and Çiçek 2011
	0.03 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.05 ± 0.00 0.08 ± 0.02 0.12 ± 0.03		wet wt.	Giresun, Rize, Trabzon	Akaydın 2014
	<0.02		wet wt.	Sinop	Bat *et al.* 2015
	0.031	0.01-0.05	dry wt.	Samsun, Ordu	Alkan *et al.* 2016
	0.03		wet wt.	Sinop	Bat and Arıcı 2016a
	0.05 ± 0.003 0.06 ± 0.01 0.06 ± 0.02		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	0.60		dry wt.	Black Sea	Boran *et al.* 2000
	0.36		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.2 ± 0.03		dry wt.	Samsun	Aygun and Abanoz 2011
	0.12 0.04	0.01-0.22	dry wt.	Trabzon	Alkan *et al.* 2012

	0.22	0.07-0.35	dry wt.	Terkos, Sakarya, Bafra, Ordu	Balkis *et al.* 2012
	0.13	0.08-0.18	dry wt.	Sinop	Bat *et al.* 2013
	0.02		wet wt.	Sinop	Bat and Sezgin 2015
	0.35 ± 0.03		wet wt.	Black Sea	Tüzen 2009
Mugil cephalus	0.30 ± 0.17 0.57 ± 0.27		wet wt.	Rize, Giresun	Akaydın 2014
Mugil soiuy	<0.01 ± 0.00		wet wt.	Sinop	Ateş *et al.* 2015
Mugil sp.	0.18		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.023 ± 0.002		dry wt.	Sinop	Bat *et al.* 1996
	0.23 0.227		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.017		wet wt.	Black Sea	Dalman *et al.* 2006
	0.45		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.02 ± 0.00 0.03 ± 0.00		wet wt.	Trabzon, Sinop	Tepe *et al.* 2008
	<0.02		wet wt.	Sinop, Samsun	Das *et al.* 2009
	0.208 ± 0.017		dry wt.	Black Sea	Turan *et al.* 2009
	0.17 ± 0.02		wet wt.	Black Sea	Tüzen 2009
Mullus barbatus	0.23		wet wt.	Black Sea	Durali *et al.* 2010
	0.02		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.11 ± 0.13	0.02-0.55	wet wt.	Bartın	Fındık and Çiçek 2011
	0.02		dry wt.	Sinop	Bat *et al.* 2013
	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.04 ± 0.00 0.09 ± 0.02 0.12 ± 0.03		wet wt.	Giresun, Rize, Trabzon	Akaydın 2014
	0.03		wet wt.	Sinop	Bat and Sezgin 2015

	<0.02		wet wt.	Sinop	Bat *et al.* 2015
	0.018	0.01-0.03	dry wt.	Samsun, Ordu	Alkan *et al.* 2016
	0.03 ± 0.01 0.04 ± 0.00 0.06 ± 0.01 0.10 ± 0.03 0.12 ± 0.01 0.13 ± 0.03 0.18 ± 0.03 0.19 ± 0.01		dry wt.	Sinop	Gündoğdu *et al.* 2016
	0.06 ± 0.005 0.07 ± 0.02 0.20 ± 0.11		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Mullus barbatus ponticus	0.23 ± 0.02		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
	0.02 0.06	0.01-0.11	dry wt.	Trabzon	Alkan *et al.* 2012
Mullus surmuletus	0.01 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Platichthys flesus	0.88 ± 0.01		wet wt.	Sinop	Das *et al.* 2009
Pomatomus saltator	0.05 ± 0.004		dry wt.	Sinop	Bat *et al.* 1998
	0.34		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.60		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.23 ± 0.02		wet wt.	Black Sea	Tüzen 2009
	0.02		wet wt.	Sinop	Bat and Sezgin 2015
Pomatomus saltatrix	0.03		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.08	0.07-0.09	dry wt.	Sinop	Bat *et al.* 2013
	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013

	0.04 ± 0.02 0.05 ± 0.02 0.20 ± 0.03		wet wt.	Trabzon, Rize, Giresun	Akaydın 2014
	0.14 ± 0.04 0.19 ± 0.06 0.25 ± 0.08		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	0.27		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.10 ± 0.01		wet wt.	Black Sea	Tüzen 2009
	0.02		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.01 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.03		wet wt.	Sinop	Bat and Sezgin 2015
Sarda sarda	0.09 ± 0.02 0.10 ± 0.01		dry wt.	Samsun	Tüzen 2003
	0.98 ± 0.10		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
	0.031		wet wt.	Sinop	Bat *et al.* 2006
	0.90 ± 0.07		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.13 ± 0.01		wet wt.	Black Sea	Tüzen 2009
	0.35		wet wt.	Black Sea	Mendil *et al.* 2010a
	0.35 ± 0.04		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
	0.03 0.025 ± 0.005		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.026	0.023-0.028	wet wt.	Sinop	Bat *et al.* 2012
	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.04 ± 0.00		wet wt.	Giresun, Rize, Trabzon	Akaydın 2014
	0.05 ± 0.01 0.11 ± 0.02		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

	0.13 ± 0.03			
Sciaena umbra	0.03 ± 0.00	dry wt.	Marmara and Black Sea	Acar *et al*. 2010
	0.02 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	0.17	dry wt.	Sinop	Bat and Gündoğdu 2003
	0.15 ± 0.01	wet wt.	Black Sea	Tüzen 2009
Scopthalmus maeoticus	<0.02	wet wt.	Sinop	Das *et al*. 2009
Scopthalmus maximus	<0.02	wet wt.	Sinop	Bat *et al*. 2017
Scorpaena porcus	<0.02	wet wt.	Sinop	Bat *et al*. 2017
Solea solea	0.02 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
	0.03	wet wt.	Sinop	Bat and Sezgin 2015
Solea vulgaris	0.22	dry wt.	Sinop	Bat and Gündoğdu 2003
Spicara maena	<0.02	wet wt.	Sinop	Bat *et al*. 2017
Spicara smaris	0.02 ± 0.00	wet wt.	Trabzon	Türkmen *et al*. 2008b
	0.04	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.25 ± 0.02	dry wt.	Trabzon	Alkan *et al*. 2013
	<0.02	wet wt.	Samsun, Sinop	Bat and Arıcı 2016b
Trachurus mediterraneus	0.03 ± 0.00 0.30 ± 0.04	wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	0.25 ± 0.03	dry wt.	Black Sea	Alkan *et al*. 2013
	<0.02	wet wt.	Sinop	Bat *et al*. 2015
Trachurus trachurus	0.028 ± 0.002	dry wt.	Sinop	Bat *et al*. 1996
	0.47 ± 0.10 0.48 ± 0.08	dry wt.	Samsun	Tüzen 2003
	1.59 ± 0.14	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.50	dry wt.	Black Sea	Uluozlu *et al*. 2007
	0.32 ± 0.03	wet wt.	Black Sea	Tüzen 2009

0.22		wet wt.	Black Sea	Mendil *et al.* 2010a
0.22 ± 0.02		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
0.01		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
0.03	0.02-0.03	dry wt.	Sinop	Bat *et al.* 2013
0.15 ± 0.05 0.16 ± 0.04 0.76 ± 0.27		wet wt.	Rize, Trabzon, Giresun	Akaydın 2014
0.02		wet wt.	Sinop	Bat and Sezgin 2015
0.01 ± 0.00 0.04 ± 0.00 0.04 ± 0.01 0.05 ± 0.01 0.06 ± 0.02 0.08 ± 0.02 0.13 ± 0.02		dry wt.	Sinop	Gündoğdu *et al.* 2016
0.11 ± 0.03 0.11 ± 0.04 0.13 ± 0.05		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

14. Lead (Pb)

Pb is naturally found in small levels in the earth’s crust but it can be found in all parts of our environment. As a result of human activities including burning fossil fuels, mining, and manufacturing, its compounds can be found in all parts of our environment (ATSDR 2007). Pb has many different uses such as battery production, ammunition, metal products like solder and pipes, and X-ray shielding devices (Martin and Griswold 2009). It is a highly toxic and persistent metal and, has been characterized as a priority hazardous substance (Authman *et al.* 2015). Exposure to high Pb amounts can heavily damage the brain and kidneys and at last cause death (Martin and Griswold 2009).

M. merlangus tissue had the highest Pb content (6.80 ± 5.88 mg/ kg wet wt.) from Bartın (Fındık and Çiçek 2011) followed by *B. belone* with 4.61 and 4.31 from Sinop and Samsun (Türkmen and Dura 2016), *E. encrasicolus* with 4.87 from Giresun (Akaydın, 2014) and 4.58 from Kocaeli (Türkmen and Dura 2016) which these values much exceeded the maximum allowed level of Pb (0.3 mg/ kg wet wt.) for customer safety and health (Table 4). These fish species are carnivorous; feeding mainly on crustaceans and this may be the reason of higher storage of Pb in their tissues. It can be seen from Figure 4 that overall mean Pb values in many fish species from the Turkish Black Sea had high concentrations.

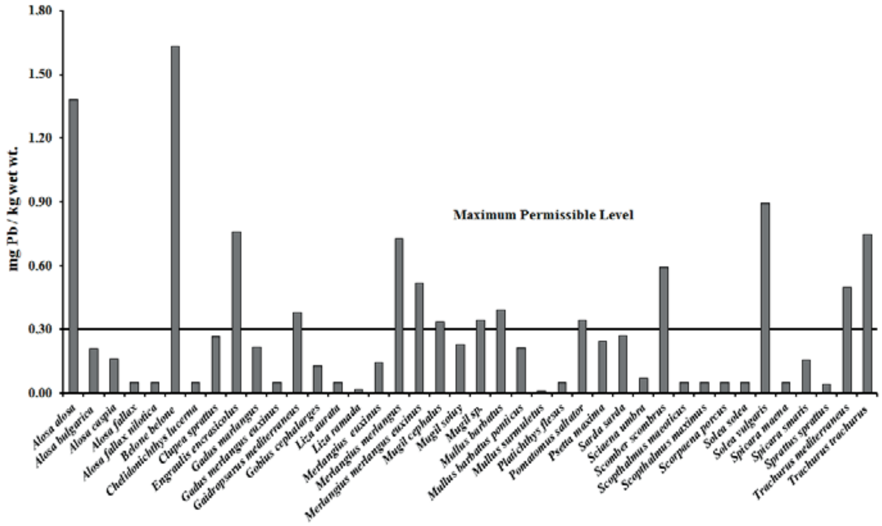

Figure 4. Overall mean concentrations of Pb in the edible tissues of fish species from the Turkish Black Sea coasts

Table 4. Lead (Pb) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	0.85 ± 0.22 2.32 ± 0.76		wet wt.	Trabzon, Rize	Akaydın 2014
	0.98 ± 0.21		wet wt.	Samsun	Türkmen and Dura 2016
Alosa bulgarica	0.46	0.18-0.74	wet wt.	Sinop	Bat 1992
	0.18 ± 0.02		dry wt.	Sinop	Öztürk and Bat 1994

Alosa caspia	0.52 ± 0.16 0.51 ± 0.21		dry wt.	Samsun	Tüzen 2003
	0.86		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Alosa fallax	<0.05		wet wt.	Sinop	Bat *et al.* 2017
Alosa fallax nilotica	0.05		wet wt.	Sinop	Bat and Sezgin 2015
Belone belone	0.63	0.43-0.82	wet wt.	Sinop	Bat *et al.* 2013
	1.12 ± 0.48 0.37 ± 0.02 0.81 ± 0.25		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	4.31 ± 0.17 4.61 ± 0.41 1.04 ± 0.36		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	0.51 ± 0.08		dry wt.	Sinop	Bat *et al.* 1998
Chelidonichthys lucerna	<0.05		wet wt.	Sinop	Bat *et al.* 2017
Clupea sprattus	0.74 ± 0.11 0.68 ± 0.17		dry wt.	Samsun	Tüzen 2003
	0.46 ± 0.04		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	0.33	0.06-0.60	wet wt.	Sinop	Ünsal *et al.* 1993
	0.78 ± 0.04		dry wt.	Sinop	Bat *et al.* 1996
	<0.05		wet wt.	Amasra	Topçuoğlu *et al.* 2002
	0.38 ± 0.02 0.39 ± 0.07		dry wt.	Samsun	Tüzen 2003
	1.23 ± 0.09		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
	0.33		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.12 ± 0.03 0.27 ± 0.05		wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al.* 2008b

	0.87 ± 0.40			
	0.329 ± 0.302	dry wt.	Black Sea	Turan *et al.* 2009
	0.30 ± 0.02	wet wt.	Black Sea	Tüzen 2009
	0.7	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.4 ± 0.2	dry wt.	Samsun	Aygun and Abanoz 2011
	0.03 ± 0.01	dry wt.	Black Sea	Alkan *et al.* 2013
	0.70 ± 0.07	wet wt.		Bat *et al.* 2013
	4.87 ± 1.04 3.85 ± 0.57 2.99 ± 0.37	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	<0.05	wet wt.	Sinop, Samsun, Fatsa, Batumi	Bat *et al.* 2014
	0.05	wet wt.	Sinop	Bat and Sezgin 2015
	0.88 ± 0.00 1.23 ± 0.06 0.76 ± 0.04 0.48 ± 0.04 1.27 ± 0.01 0.45 ± 0.02 0.39 ± 0.00 1.42 ± 0.06	dry wt.	Sinop	Gündoğdu *et al.* 2016
	4.07 ± 0.70 2.98 ± 0.63 4.58 ± 0.54	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	0.87 ± 0.05	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
Gadus merlangus euxinus	<0.05	wet wt.	Sinop, Samsun	Das *et al.* 2009
Gaidropsarus mediterraneus	0.38 ± 0.07	wet wt.	Sinop	Ateş *et al.* 2015

Gobius cephalarges	0.51		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Liza aurata	<0.05		wet wt.	Sinop	Bat *et al.* 2015
Liza ramada	0.07 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius euxinus	0.58		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Merlangius merlangus	0.07 1.16	0.02-0.11 0.05-2.26	wet wt.	Sinop	Ünsal *et al.* 1993
	<0.05		wet wt.	Perşembe, Rize	Topçuoğlu *et al.* 2002
	0.088		wet wt.	Black Sea	Dalman *et al.* 2006
	0.25 ± 0.07 0.46 ± 0.08 0.18 ± 0.04		wet wt.	Trabzon, Sinop, Bartın	Tepe *et al.* 2008
	0.502 ± 0.104		dry wt.	Black Sea	Turan *et al.* 2009
	0.53 ± 004		wet wt.	Black Sea	Tüzen 2009
	0.46		wet wt.	Black Sea	Mendil *et al.* 2010a
	0.46 ± 0.05		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
	6.80 ± 5.88	2.69-17.11	wet wt.	Bartın	Fındık and Çiçek 2011
	0.05 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.66 ± 0.08 1.30 ± 0.31 1.29 ± 0.21		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	<0.05		wet wt.	Sinop	Bat *et al.* 2015
	0.024	0.02-0.03	dry wt.	Samsun, Ordu	Alkan *et al.* 2016
	<0.05		wet wt.	Sinop	Bat and Arıcı 2016a
	1.41 ± 0.23 0.63 ± 0.06 0.69 ± 0.12		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

Merlangius merlangus euxinus	0.9	0.03-1.76	wet wt.	Sinop	Ünsal *et al.* 1992
	1.078		dry wt.	Black Sea	Boran *et al.* 2000
	2.184		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.9 ± 0.2		dry wt.	Samsun	Aygun and Abanoz 2011
	0.13	0.01-0.25	dry wt.	Trabzon	Alkan *et al.* 2012
	13.5	12-15	dry wt.	Terkos, Sakarya, Bafra, Ordu	Balkis *et al.* 2012
	0.02		wet wt.	Sinop	Bat *et al.* 2013
	0.05		wet wt.	Sinop	Bat and Sezgin 2015
Mugil cephalus	0.68 ± 0.05		wet wt.	Black Sea	Tüzen 2009
	0.02 ± 0.01 0.90 ± 0.32		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	0.23 ± 0.07		wet wt.	Sinop	Ateş *et al.* 2015
Mugil sp.	1.367		dry wt.	Sinop	Bat and Gündoğdu 2003
Mullus barbatus	0.28 ± 0.06		dry wt.	Sinop	Bat *et al.* 1996
	1.276		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.077		wet wt.	Black Sea	Dalman *et al.* 2006
	0.84		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.22 ± 0.08 0.39 ± 0.03		wet wt.	Trabzon, Sinop	Tepe *et al.* 2008
	0.0525 ± 0.0025 0.0515 ± 0.0005 0.0815 ± 0.0025		wet wt.	Sinop Samsun	Das *et al.* 2009
	0.727 ± 0.141		dry wt.	Black Sea	Turan *et al.* 2009
	0.36 ± 0.03		wet wt.	Black Sea	Tüzen 2009
	0.4		wet wt.	Black Sea	Mendil *et al.* 2010a
	0.92		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	1.11 ± 1.60	0.09-7.00	wet wt.	Bartın	Fındık and Çiçek 2011

	0.2	0.09-0.31	wet wt.	Sinop	Bat *et al.* 2013
	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.45 ± 0.05 1.03 ± 0.10 1.30 ± 0.16		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.11		wet wt.	Sinop	Bat and Sezgin 2015
	<0.05		wet wt.	Sinop	Bat *et al.* 2015
	0.02	0.02-0.02	dry wt.	Samsun, Ordu	Alkan *et al.* 2016
	0.22 ± 0.04 0.14 ± 0.03 0.45 ± 0.01 0.21 ± 0.02 0.29 ± 0.00 0.01 ± 0.000 0.01 ± 0.00 0.44 ± 0.04		dry wt.	Sinop	Gündoğdu *et al.* 2016
	1.76 ± 0.40 2.94 ± 0.81 0.88 ± 0.12		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Mullus barbatus ponticus	0.40 ± 0.04		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
	0.11	0.01-0.20	dry wt.	Trabzon	Alkan *et al.* 2012
Mullus surmuletus	0.04 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Platichthys flesus	<0.05		wet wt.	Sinop	Das *et al.* 2009
Pomatomus saltator	0.55 ± 0.08		dry wt.	Sinop	Bat *et al.* 1998
	2.253		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.38		dry wt.	Black Sea	Uluozlu *et al.* 2007

	0.87 ± 0.07		wet wt.	Black Sea	Tüzen 2009
	0.05		wet wt.	Sinop	Bat and Sezgin 2015
Pomatomus saltatrix	1.26		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	1.08	0.64-1.51	wet wt.	Sinop	Bat *et al.* 2013
	0.01 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.18 ± 0.04 0.28 ± 0.04 0.13 ± 0.03		wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	1.14 ± 0.28 0.78 ± 0.18 0.49 ± 0.05		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	2.72		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.28 ± 0.02		wet wt.	Black Sea	Tüzen 2009
	0.73		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	*Nisbet et al.* 2010
	0.02 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
	0.08		wet wt.	Sinop	Bat and Sezgin 2015
Sarda sarda	0.22 ± 0.04 0.26 ± 0.07		dry wt.	Samsun	Tüzen 2003
	1.31 ± 0.11		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
	0.537		wet wt.	Sinop	Bat *et al.* 2006
	0.76 ± 0.05		dry wt.	Black Sea	Uluozlu *et al.* 2007
	0.61 ± 0.04		wet wt.	Black Sea	Tüzen 2009
	0.28		wet wt.	Black Sea	Durali *et al.* 2010
	0.28 ± 0.03		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al.* 2010b
	0.90 ± 0.11		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	0.16	0.13-0.19	wet wt.	Sinop	Bat *et al.* 2012

	0.03 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
	0.52 ± 0.23 0.37 ± 0.20 0.29 ± 0.09	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.35 ± 0.07 0.29 ± 0.04 0.25 ± 0.06	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Sciaena umbra	0.54 ± 0.10	dry wt.	Marmara and Black Sea	Acar *et al*. 2010
	0.01 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	2.948	dry wt.	Sinop	Bat and Gündoğdu 2003
	0.45 ± 0.03	wet wt.	Black Sea	Tüzen 2009
Scopthalmus maeoticus	<0.05	wet wt.	Sinop	Das *et al*. 2009
Scopthalmus maximus	<0.05	wet wt.	Sinop	Bat *et al*. 2017
Scorpaena porcus	<0.05	wet wt.	Sinop	Bat *et al*. 2017
Solea solea	0.03 ± 0.01	dry wt.	Black Sea	Ergül and Aksan 2013
	0.09	wet wt.	Sinop	Bat and Sezgin 2015
Solea vulgaris	3.571	dry wt.	Sinop	Bat and Gündoğdu 2003
Spicara maena	<0.05	wet wt.	Sinop	Bat *et al*. 2017
Spicara smaris	0.15 ± 0.04	wet wt.	Trabzon	Türkmen *et al*. 2008b
	0.67	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sprattus sprattus	0.01 ± 0.01	dry wt.	Black Sea	Alkan *et al*. 2013
	<0.05	wet wt.	Samsun, Sinop	Bat and Arıcı 2016b
Trachurus mediterraneus	0.63 ± 0.25 1.31 ± 0.34	wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	0.02 ± 0.01	dry wt.	Black Sea	Alkan *et al*. 2013
	<0.05	wet wt.	Sinop	Bat *et al*. 2015

	0.74 ± 0.21		dry wt.	Sinop	Bat *et al*. 1996
Trachurus trachurus	0.04	0.02-0.06	wet wt.	Sinop	Ünsal *et al*. 1993
	0.85 ± 0.16 0.83 ± 0.36		dry wt.	Samsun	Tüzen 2003
	1.73±0.14		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.68		dry wt.	Black Sea	Uluozlu *et al*. 2007
	0.82 ± 0.06		wet wt.	Black Sea	Tüzen 2009
	0.64		wet wt.	Black Sea	Durali *et al*. 2010
	0.64 ± 0.06		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.6		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.78	0.63-0.93	wet wt.	Sinop	Bat *et al*. 2013
	1.81 ± 1.08 0.76 ± 0.16 2.49 ± 0.67		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.05		wet wt.	Sinop	Bat and Sezgin 2015
	0.04 ± 0.00 0.02 ± 0.00 0.71 ± 0.05 0.53 ± 0.05 1.05 ± 0.22 0.44 ± 0.01 1.08 ± 0.00 0.15 ± 0.01		dry wt.	Sinop	Gündoğdu *et al*. 2016
	1.02 ± 0.34 1.50 ± 0.30 3.63 ± 0.74		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

15. Arsenic (As)

As enters marine coastal ecosystems by a variety of sources including manufacturing companies, mineral or strip mines, smelting operations, and power plants. One major agricultural source is the manufacture and usage of arsenical defoliants and pesticides (Authman *et al.* 2015). Svobodova *et al.* (1993) pointed out that As is able to accumulate in high levels in the sediments on the bed of water courses and reservoirs, and in aquatic organisms, especially in fish. As is odourless and tasteless and is a reputed carcinogen and can cause cancer of the skin, lungs, liver and bladder (Martin and Griswold 2009).

Some of the tested organisms had levels of As reaching the maximum permissible limit (see Table 5). Figure 5 shows the overall mean concentrations of As in fish species from the Turkish Black Sea coasts. The UK previously imposed a limit of 1 mg/kg for As in food with separate limits applicable to certain food categories. These regulations were revoked in 2002. There is no maximum level set for As in foods at EU level. However the levels are different from the international standards (see Table 1).

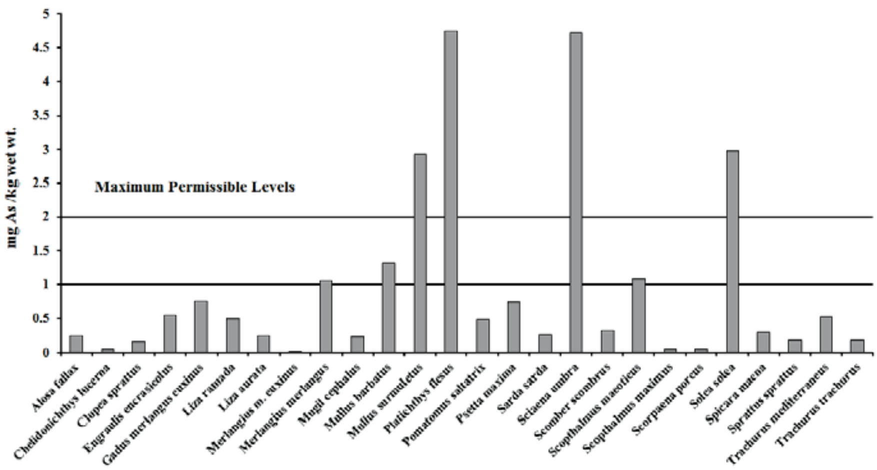

Figure 5. Overall mean concentrations of As in the edible tissues of fish species from the Turkish Black Sea coasts

Table 5. Arsenic (As) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa fallax	0.25		wet wt.	Sinop	Bat *et al*. 2017

Chelidonichthys lucerna	<0.05		wet wt.	Sinop	Bat *et al*. 2017
Clupea sprattus	0.17 ± 0.01		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	1.85 ± 0.17		dry wt.	Black Sea	Alkan *et al*. 2013
	0.69 ± 0.166 0.53 ± 0.127		wet wt.	Sinop	Bat *et al*. 2014
	0.65 ± 0.156 0.67 ± 0.161		wet wt.	Samsun	Bat *et al*. 2014
	0.67 ± 0.161 0.41 ± 0.098		wet wt.	Fatsa	Bat *et al*. 2014
	0.60 ± 0.144 0.61 ± 0.146		wet wt.	Batumi	Bat *et al*. 2014
	0.25 ± 0.02		wet wt.	Black Sea	Tüzen 2009
Gadus merlangus euxinus	1.085 ± 0.035 0.63 ± 0.04 0.58 ± 0.01		wet wt.	Sinop Samsun Sinop	Das *et al*. 2009
Liza aurata	0.25		wet wt.	Sinop	Bat *et al*. 2015
Liza ramada	2.01 ± 0.10		dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius merlangus	0.17 ± 0.01		wet wt.	Black Sea	Tüzen 2009
	4.90 ± 0.23		dry wt.	Black Sea	Ergül and Aksan 2013
	1.24		wet wt.	Sinop	Bat *et al*. 2015
	6.34	4.92-7.12	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
Merlangius merlangus euxinus	5.86	2.05-9.66	dry wt.	Trabzon	Alkan *et al*. 2012
	0.07	0.03-0.1	dry wt.	Terkos, Sakarya, Bafra, Ordu	Balkis *et al*. 2012
Mugil cephalus	0.23 ± 0.02		wet wt.	Black Sea	Tüzen 2009
Mullus barbatus	2.375 ± 0.015 1.76 ± 0.02		wet wt.	Sinop Sinop	Das *et al*. 2009

	1.33 ± 0.02			Samsun	
	0.11 ± 0.01		wet wt.	Black Sea	Tüzen 2009
	12.7 ± 1.29		dry wt.	Black Sea	Ergül and Aksan 2013
	1.3		wet wt.	Sinop	Bat *et al*. 2015
	14.75	12.61-17.87	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.11 0.09 0.28 0.39		wet wt.	İğneada, Sinop, Samsun, Trabzon	Bat and Arıcı 2016c
Mullus barbatus ponticus	15.43	6.04-24.82	dry wt.	Trabzon	Alkan *et al*. 2012
Mullus surmuletus	11.7 ± 0.32		dry wt.	Black Sea	Ergül and Aksan 2013
Platichthys flesus	4.75 ± 0.25		wet wt.	Sinop	Das *et al*. 2009
Pomatomus saltator	0.27 ± 0.02		wet wt.	Black Sea	Tüzen 2009
Pomatomus saltatrix	2.87 ± 0.11		dry wt.	Black Sea	Ergül and Aksan 2013
Psetta maxima	0.15 ± 0.01		wet wt.	Black Sea	Tüzen 2009
	5.42 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
Sarda sarda	0.14 ± 0.01		wet wt.	Black Sea	Tüzen 2009
	1.48 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
Sciaena umbra	18.9 ± 0.77		dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	0.32 ± 0.02		wet wt.	Black Sea	Tüzen 2009
Scopthalmus maeoticus	0.59 ± 0.02 1.56 ± 0.02		wet wt.	Sinop	Das *et al*. 2009
Scopthalmus maximus	<0.05		wet wt.	Sinop	Bat *et al*. 2017
Scorpaena porcus	<0.05		wet wt.	Sinop	Bat *et al*. 2017
Solea solea	11.9 ± 0.14		dry wt.	Black Sea	Ergül and Aksan 2013
Spicara maena	0.29		wet wt.	Sinop	Bat *et al*. 2017
Sprattus sprattus	2.56 ± 0.08		dry wt.	Black Sea	Alkan *et al*. 2013
	0.05 0.06		wet wt.	Samsun Sinop	Bat and Arıcı 2016b

	0.06		Samsun	
	0.07		Sinop	
Trachurus mediterraneus	2.58 ± 0.10	dry wt.	Black Sea	Alkan *et al*. 2013
	0.39	wet wt.	Sinop	Bat *et al*. 2015
Trachurus trachurus	0.18 ± 0.02	wet wt.	Black Sea	Tüzen 2009

16. Copper (Cu)

Cu is an essential metal and micronutrient for cellular metabolism in living organisms by virtue of existence as a principal component of metabolic enzymes. Agency for Toxic Substances and Disease Registry (ATSDR) (2004a) stated that Cu is an abundant element which occurs naturally throughout the environment, in rocks, soil, water, and air. Cu is necessary for us to live (ATSDR 2004a), but it can be extremely toxic to aquatic organisms at high concentrations.

Cu pollution is through extensive use of fungicides, algaecides, insecticides and discharge of wastes (Authman *et al*. 2015) and in agriculture to treat plant diseases like mildew, for water treatment and, as preservatives for wood, leather, and fabrics (ATSDR 2004a). Cu discharged into the marine environment usually binds to particles made of organic matter, clay, or sediment and its' compounds can break down and release free Cu into the water and foods in the marine ecosystem (ATSDR 2004a). It is also noted that ingesting high levels of copper can induce nausea, vomiting, and diarrhoea and remarkable amounts of Cu can cause damage to liver and kidneys, and can even cause death (ATSDR 2004a).

None of the tested organisms had levels of Cu reaching the maximum permissible limit (20 mg/kg wet wt.) (Table 6). Figure 6 shows the overall mean concentrations of Cu in fish species from the Turkish Black Sea coasts. Cu is an essential constituent of many enzymes, carefully regulated by physiological mechanisms in most organisms. It is an essential element in daily human nutrition. However, it can also be toxic at high concentrations. The intake of Cu in fish from the southern Black Sea coasts would not pose any risk for the average consumer.

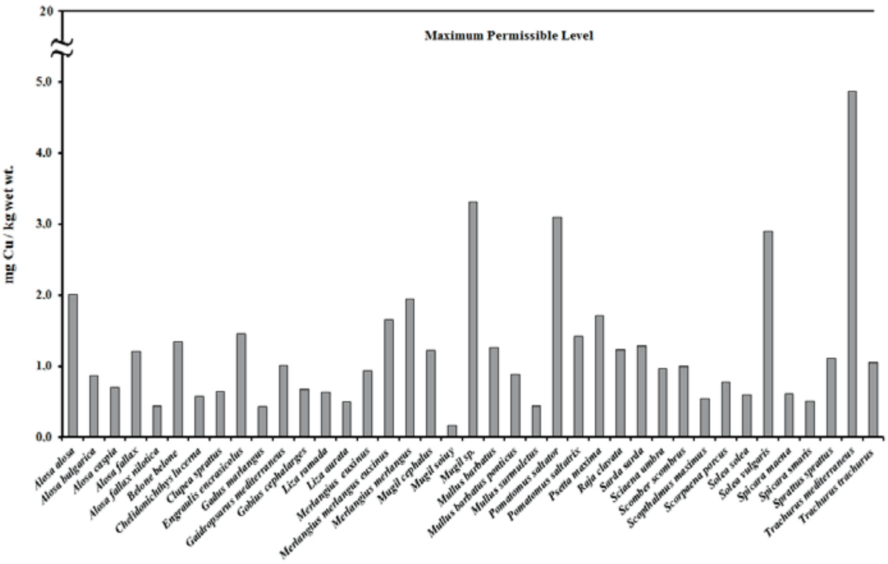

Figure 6. Overall mean concentrations of Cu in the edible tissues of fish species from the Turkish Black Sea coasts

Table 6. Copper (Cu) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	**Mean ± SD**	**Min-Max**	**Method**	**Locations**	**References**
Alosa alosa	3.00 ± 0.86 1.74 ± 0.16		wet wt.	Trabzon, Rize	Akaydın 2014
	1.28 ± 0.15		wet wt.	Samsun	Türkmen and Dura 2016
Alosa bulgarica	0.39	0.26-0.52	dry wt.	Sinop	Bat 1992
	0.26 ± 0.056		dry wt.	Sinop	Öztürk and Bat 1994
Alosa caspia	2.93 ± 0.18 2.90 ± 0.31		dry wt.	Samsun	Tüzen 2003
	2.62		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Alosa fallax	1.21		wet wt.	Sinop	Bat *et al*. 2017
Alosa fallax nilotica	0.44		wet wt.	Sinop	Bat and Sezgin 2015

Belone belone	0.6	0.49-0.71	dry wt.	Sinop	Bat *et al*. 2013
	0.65 ± 0.23 2.41 ± 0.13 0.82 ± 0.31		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	1.11 ± 0.05 3.13 ± 0.18 2.31 ± 0.23		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	0.54 ± 0.05		dry wt.	Sinop	Bat *et al*. 1998
Chelidonichthys lucerna	0.58		wet wt.	Sinop	Bat *et al*. 2017
Clupea sprattus	0.79 ± 0.62 0.83 ± 0.44		dry wt.	Samsun	Tüzen 2003
	1.52 ± 0.12		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	1.01	0.68-1.33	wet wt.	Sinop	Ünsal *et al*. 1993
	0.69 ± 0.06		dry wt.	Sinop	Bat *et al*. 1996
	2.21		wet wt.	Amasra	Topçuoğlu *et al*. 2002
	1.94 ± 0.10 1.96 ± 0.17		dry wt.	Samsun	Tüzen 2003
	1.47 ± 0.12		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.95		dry wt.	Black Sea	Uluozlu *et al*. 2007
	0.88 ± 0.10 1.12 ± 0.16 8.58 ± 2.15		wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al*. 2008b
	1.96 ± 0.14		wet wt.	Black Sea	Tüzen 2009
	2.73		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	3.7 ± 1.6 3.8 ± 1.9		dry wt.	Samsun	Aygun and Abanoz 2011

	1.40 ± 0.06		dry wt.	Black Sea	Alkan *et al*. 2013
	3.02	1.88-4.16	dry wt.	Sinop	Bat *et al*. 2013
	2.31 ± 0.28 2.21 ± 0.36 2.42 ± 0.15		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	<0.5		wet wt.	Sinop, Samsun, Fatsa, Batumi	Bat *et al*. 2014
	1.87		wet wt.	Sinop	Bat and Sezgin 2015
	3.86 ± 0.02 3.10 ± 0.39 5.48 ± 0.18 5.85 ± 0.24 5.37 ± 0.21 5.38 ± 0.80 6.88 ± 0.81 5.61 ± 0.00		dry wt.	Sinop	Gündoğdu *et al*. 2016
	2.04 ± 0.11 2.08 ± 0.27 2.44 ± 0.23		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	1.72 ± 0.17		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
Gaidropsarus mediterraneus	1.01 ± 0.18		wet wt.	Sinop	Ateş *et al*. 2015
Gobius cephalarges	2.72		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Liza aurata	<0.5		wet wt.	Sinop	Bat *et al*. 2015
Liza ramada	2.52 ± 0.00		dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius euxinus	3.72		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Merlangius merlangus	1.94 4.05	0.62-3.25 0.37-7.72	wet wt.	Sinop	Ünsal *et al*. 1993

	1.86 4.54		wet wt.	Perşembe, Rize	Topçuoğlu *et al*. 2002
	1.3		wet wt.	Black Sea	Dalman *et al*. 2006
	0.88 ± 0.12 2.90 ± 0.78 0.77 ± 0.07		wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	1.32 ± 0.11		wet wt.	Black Sea	Tüzen 2009
	1.8		wet wt.	Black Sea	Mendil *et al*. 2010a
	1.8 ± 0.2		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	8.53 ± 2.14	6.30-11.83	wet wt.	Bartın	Fındık and Çiçek 2011
	2.50 ± 0.06		dry wt.	Black Sea	Ergül and Aksan 2013
	2.40 ± 0.25 1.62 ± 0.25 1.65 ± 0.26		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	<0.5		wet wt.	Sinop	Bat *et al*. 2015
	1.5	1.04-1.96	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.13		wet wt.	Sinop	Bat and Arıcı 2016a
	1.28 ± 0.09 0.92 ± 0.08 1.46 ± 0.18		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	1.06	0.12-2.00	wet wt.	Sinop	Ünsal *et al*. 1992
	2.71		dry wt.	Black Sea	Boran *et al*. 2000
	18.54		dry wt.	Sinop	Bat and Gündoğdu 2003
	4.93	0.91-8.95	dry wt.	Sinop	Türk Çulha *et al*. 2007
	2.3 ± 0.7 2.7 ± 0.7		dry wt.	Samsun	Aygun and Abanoz 2011
	0.78	0.10-1.45	dry wt.	Trabzon	Alkan *et al*. 2012

	4.06	2.85-5.26	dry wt.	Sinop	Bat *et al*. 2013
	1.03		wet wt.	Sinop	Bat and Sezgin 2015
Mugil cephalus	2.14 ± 0.15		wet wt.	Black Sea	Tüzen 2009
	0.57 ± 0.20 0.95 ± 0.29		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	0.16 ± 0.05		wet wt.	Sinop	Ateş *et al*. 2015
Mugil sp.	13.22		dry wt.	Sinop	Bat and Gündoğdu 2003
Mullus barbatus	0.76 ± 0.07		dry wt.	Sinop	Bat *et al*. 1996
	26.98		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.01		wet wt.	Black Sea	Dalman *et al*. 2006
	1.55	0.38-2.71	dry wt.	Sinop	Türk Çulha *et al*. 2007
	0.98		dry wt.	Black Sea	Uluozlu *et al*. 2007
	1.30 ± 0.13 0.87 ± 0.09		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	0.96 ± 0.08		wet wt.	Black Sea	Tüzen 2009
	1.4		wet wt.	Black Sea	Mendil *et al*. 2010a
	3.14		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	4.08 ± 2.79	1.23-9.21	wet wt.	Bartın	Fındık and Çiçek 2011
	6.34	4.93-7.74	dry wt.	Sinop	Bat *et al*. 2013
	1.00 ± 0.18		dry wt.	Black Sea	Ergül and Aksan 2013
	1.99 ± 0.18 1.74 ± 0.13 1.81 ± 0.15		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.88		wet wt.	Sinop	Bat and Sezgin 2015
	<0.5		wet wt.	Sinop	Bat *et al*. 2015
	1.35	1.18-1.52	dry wt.	Samsun, Ordu	Alkan *et al*. 2016

	3.36 ± 0.51 2.79 ± 0.13 2.85 ± 0.07 5.45 ± 0.35 3.15 ± 0.21 2.91 ± 0.22 3.96 ± 0.30 4.43 ± 0.63		dry wt.	Sinop	Gündoğdu *et al*. 2016
	1.27 ± 0.19 2.38 ± 0.12 1.40 ± 0.12		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	0.81 0.69 1.35 1.73		wet wt.	İğneada, Sinop, Samsun, Trabzon	Bat and Arıcı 2016c
Mullus barbatus ponticus	1.4 ± 0.1		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	1.53	0.74-2.32	dry wt.	Trabzon	Alkan *et al*. 2012
Mullus surmuletus	1.77 ± 0.25		dry wt.	Black Sea	Ergül and Aksan 2013
Pomatomus saltator	0.58 ± 0.08		dry wt.	Sinop	Bat *et al*. 1998
	35.60		dry wt.	Sinop	Bat and Gündoğdu 2003
	1.83		dry wt.	Black Sea	Uluozlu *et al*. 2007
	2.78 ± 0.21		wet wt.	Black Sea	Tüzen 2009
	3.2		wet wt.	Sinop	Bat and Sezgin 2015
Pomatomus saltatrix	2.86		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.63	0.43-0.83	dry wt.	Sinop	Bat *et al*. 2013
	2.29 ± 0.19		dry wt.	Black Sea	Ergül and Aksan 2013
	2.52 ± 0.14 1.89 ± 0.19		wet wt.	Rize, Giresun, Trabzon	Akaydın 2014

	2.24 ± 0.30				
	1.73 ± 0.11 1.47 ± 0.27 1.48 ± 0.13		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	26.14		dry wt.	Sinop	Bat and Gündoğdu 2003
	0.75 ± 0.05		wet wt.	Black Sea	Tüzen 2009
	2.13		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.70 ± 0.03		dry wt.	Black Sea	Ergül and Aksan 2013
	0.55		wet wt.	Sinop	Bat and Sezgin 2015
Raja clavata	4.93	0.50-9.36	dry wt.	Sinop	Türk Çulha *et al*. 2007
Sarda sarda	1.28 ± 0.14 1.29 ± 0.32		dry wt.	Samsun	Tüzen 2003
	1.34 ± 0.14		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.659		wet wt.	Sinop	Bat *et al*. 2006
	0.84 ± 0.05		dry wt.	Black Sea	Uluozlu *et al*. 2007
	1.43 ± 0.12		wet wt.	Black Sea	Tüzen 2009
	1.9		wet wt.	Black Sea	Durali *et al*. 2010
	1.9 ± 0.2		dry wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	1.74 ± 0.18		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	3.44	2.75-4.12	wet wt.	Sinop	Bat *et al*. 2012
	2.49 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
	2.96 ± 0.11 2.75 ± 0.32 3.78 ± 0.92		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	2.97 ± 0.18 4.13 ±0.42		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

	3.46 ± 0.21				
Sciaena umbra	6.48 ± 1.57		dry wt.	Marmara and Black Sea	Acar *et al*. 2010
	1.20 ± 0.11		dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	3.62		dry wt.	Sinop	Bat and Gündoğdu 2003
	1.10 ± 0.10		wet wt.	Black Sea	Tüzen 2009
Scopthalmus maximus	0.54		wet wt.	Sinop	Bat *et al*. 2017
Scorpaena porcus	0.77		wet wt.	Sinop	Bat *et al*. 2017
Solea solea	2.05 ± 0.06		dry wt.	Black Sea	Ergül and Aksan 2013
	0.68		wet wt.	Sinop	Bat and Sezgin 2015
Solea vulgaris	11.58		dry wt.	Sinop	Bat and Gündoğdu 2003
Spicara maena	0.61		wet wt.	Sinop	Bat *et al*. 2017
Spicara smaris	2.39	0.61-4.16	dry wt.	Sinop	Türk Çulha *et al*. 2007
	0.83 ± 0.10		wet wt.	Trabzon	Türkmen *et al*. 2008b
	0.35		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sprattus sprattus	2.11 ± 0.12		dry wt.	Black Sea	Alkan *et al*. 2013
	0.87 1.56 0.95 1.63		wet wt.	Samsun, Sinop Samsun, Sinop	Bat and Arıcı 2016b
Trachurus mediterraneus	16.7 ± 2.08 1.68 ± 0.11		wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	1.71 ± 0.04		dry wt.	Black Sea	Alkan *et al*. 2013
	0.67		wet wt.	Sinop	Bat *et al*. 2015
Trachurus trachurus	0.79 ± 0.06		dry wt.	Sinop	Bat *et al*. 1996
	0.52 2.02 0.15	0.36-0.68 1.24-2.80 0.06-0.24	wet wt.	Sinop	Ünsal *et al*. 1993
	1.52 ± 0.35		dry wt.	Samsun	Tüzen 2003

	1.55 ± 0.26				
	1.58 ± 0.13		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.95		dry wt.	Black Sea	Uluozlu *et al*. 2007
	0.65 ± 0.05		wet wt.	Black Sea	Tüzen 2009
	2.4		wet wt.	Black Sea	Mendil *et al*. 2010a
	2.4 ± 0.2		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	1.79		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.42	0.19-0.65	dry wt.	Sinop	Bat *et al*. 2013
	0.28 ± 0.13 2.41 ± 0.25 1.85 ± 0.25		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	2.22		wet wt.	Sinop	Bat and Sezgin 2015
	3.48 ± 0.01 4.50 ± 0.13 3.25 ± 0.12 4.61 ± 0.36 3.88 ± 0.55 4.80 ± 0.08 4.64 ± 0.13 4.58 ± 0.17		dry wt.	Sinop	Gündoğdu *et al*. 2016
	2.11 ± 0.25 2.23 ± 0.40 1.51 ± 0.24		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

17. Cobalt (Co)

Figure 7 shows the overall mean concentrations of Co in fish species from the Turkish Black Sea coasts. Co is a naturally occurring element found in water, sediment, rock and living organisms. It has both beneficial and hazard effects on human health. At low amounts of Co, it is part of vitamin B12 which is essential for human, but at high amounts it may harm the heart and lungs (ATSDR 2004b).

The highest content of Co was found in *M. b. ponticus* (0.42 mg/ kg wet wt.) and *S. sarda* (0.40 mg/ kg wet wt.) from Samsun, Ordu, Trabzon, Rize (Mendil *et al*. 2010b). This corresponds with the results of Akaydın (2014), who found concentrations of 0.32 mg/ kg wet wt. in *M. cephalus* from Giresun and Rize (Table 7).

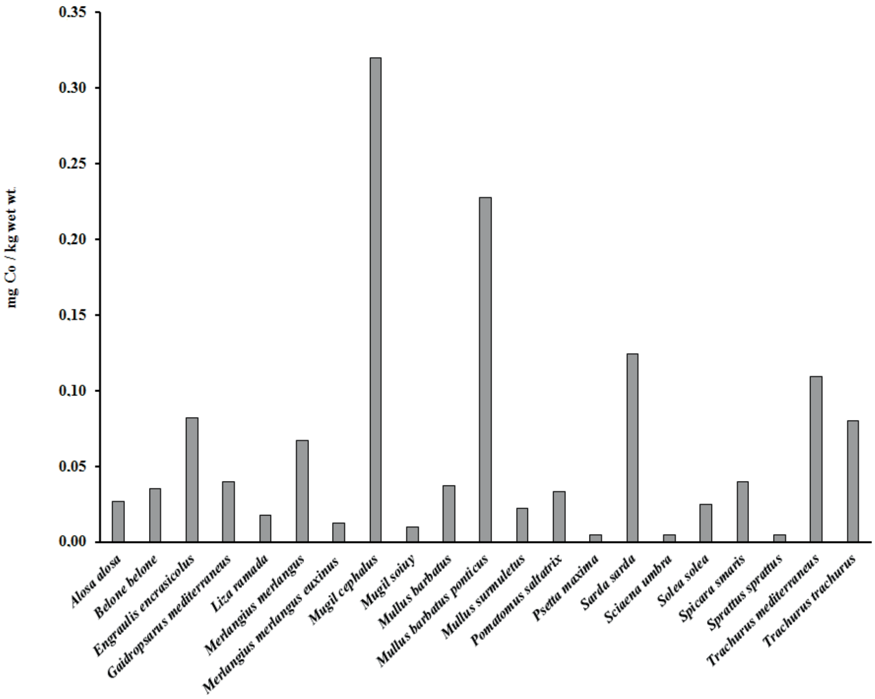

Figure 7. Overall mean concentrations of Co in the edible tissues of fish species from the Turkish Black Sea coasts

Table 7. Cobalt (Co) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	0.03 ± 0.00 0.02 ± 0.00		wet wt.	Trabzon, Rize	Akaydın 2014
	0.03 ± 0.00		wet wt.	Samsun	Türkmen and Dura 2016
Belone belone	0.08 ± 0.05 0.02 ± 0.00 0.02 ± 0.00		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.02 ± 0.00 0.03 ± 0.01 0.04 ± 0.00		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Engraulis encrasicolus	0.4		wet wt.	Amasra	Topçuoğlu *et al*. 2002
	0.07 ± 0.03 0.06 ± 0.01 0.08 ± 0.01		wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al*. 2008b
	0.30 ± 0.08		dry wt.	Black Sea	Alkan *et al*. 2013
	0.03 ± 0.01 0.04 ± 0.00 0.03 ± 0.01		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.04 ± 0.00 0.03 ± 0.02 0.05 ± 0.00		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gaidropsarus mediterraneus	0.04 ± 0.01		wet wt.	Sinop	Ateş *et al*. 2015
Liza ramada	0.07 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius merlangus	<0.05		wet wt.	Perşembe, Rize	Topçuoğlu *et al*. 2002

	0.07 ± 0.02 0.06 ± 0.02 0.05 ± 0.02		wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	0.25 ± 0.03		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.04 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.04 ± 0.00 0.03 ± 0.00 0.03 ± 0.00		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.03	0,02-0,05	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.29		wet wt.	Sinop	Bat and Arıcı 2016a
	0.02 ± 0.00 0.03 ± 0.00 0.02 ± 0.00		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	0.05	0,01-0,09	dry wt.	Trabzon	Alkan *et al*. 2012
Mugil cephalus	0.32 ± 0.48 0.32 ± 0.30		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	<0.01 ± 0.00		wet wt.	Sinop	Ateş *et al*. 2015
Mullus barbatus	0.11 ± 0.03 0.07 ± 0.02		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	0.05 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.03 ± 0.01 0.01 ± 0.00 0.06 ± 0.04		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.11	0,10-0,11	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	<0.01 ± 0.00 0.02 ± 0.00		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

	0.02 ± 0.00				
Mullus barbatus ponticus	0.42 ± 0.04		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.14	0,05-0,23	dry wt.	Trabzon	Alkan *et al*. 2012
Mullus surmuletus	0.09 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Pomatomus saltatrix	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.04 ± 0.00 0.03 ± 0.00 0.05 ± 0.00		wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	0.04 ± 0.01 0.03 ± 0.00 0.04 ± 0.00		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Sarda sarda	<0.5		wet wt.	Sinop	Bat *et al*. 2006
	0.40 ± 0.04		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
	0.04 ± 0.00 0.04 ± 0.00 0.03 ± 0.01		wet wt. wet wt. wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.06 ± 0.001 0.03 ± 0.00 0.04 ± 0.00		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Sciaena umbra	0.02 ± 0.01		dry wt.	Black Sea	Ergül and Aksan 2013
Solea solea	0.10 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
Spicara smaris	0.04 ± 0.01		wet wt.	Trabzon	Türkmen *et al*. 2008b
Sprattus sprattus	0.02 ± 0.01		dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus mediterraneus	0.15 ± 0.01		wet wt.	Sinop, Bartın	Türkmen *et al*. 2008

	0.17 ± 0.01			
	0.03 ± 0.01	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus trachurus	0.38 ± 0.04	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.04 ± 0.02 0.02 ± 0.00 0.02 ± 0.00	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.04 ± 0.00 0.05 ± 0.00 0.01 ± 0.00	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

18. Chromium (Cr)

Cr (III) is an essential nutrient metal, necessary for metabolism of carbohydrates (Authman *et al*. 2015), but Cr (VI) compounds are toxins and known human carcinogens and found in rocks, animals, plants, and soil and can be in liquid, solid, or gas form (Martin and Griswold 2009). Cr enter the aquatic environment through effluents discharged from leather tanneries, textiles, electroplating, metal finishing, mining, dyeing and printing industries, ceramic, photographic and pharmaceutical industries etc. (Ahmed *et al*. 2013). Its soluble forms are used in wood preservatives (Martin and Griswold 2009). Without treatment of these effluents they can lead to existence of Cr (VI) in the surrounding aquatic ecosystem, where it is mostly found at potentially detrimental amounts to fish (Li *et al*. 2011) and its' compounds are very persistent in sediments in water (Martin and Griswold 2009).

It is noted that skin contact with Cr can cause skin ulcers and long term exposure to Cr can cause damage to liver, kidney circulatory and nerve tissues (Martin and Griswold 2009).

The highest Cr content was found in *T. trachurus* (1.74 mg/ kg wet wt.) caught in the Black Sea (Tüzen 2009). Other samples of fish species in the obtained data (Table 8) showed generally low levels of Cr content. Figure 8 shows the overall mean concentrations of Cr in fish species from the Turkish Black Sea coasts.

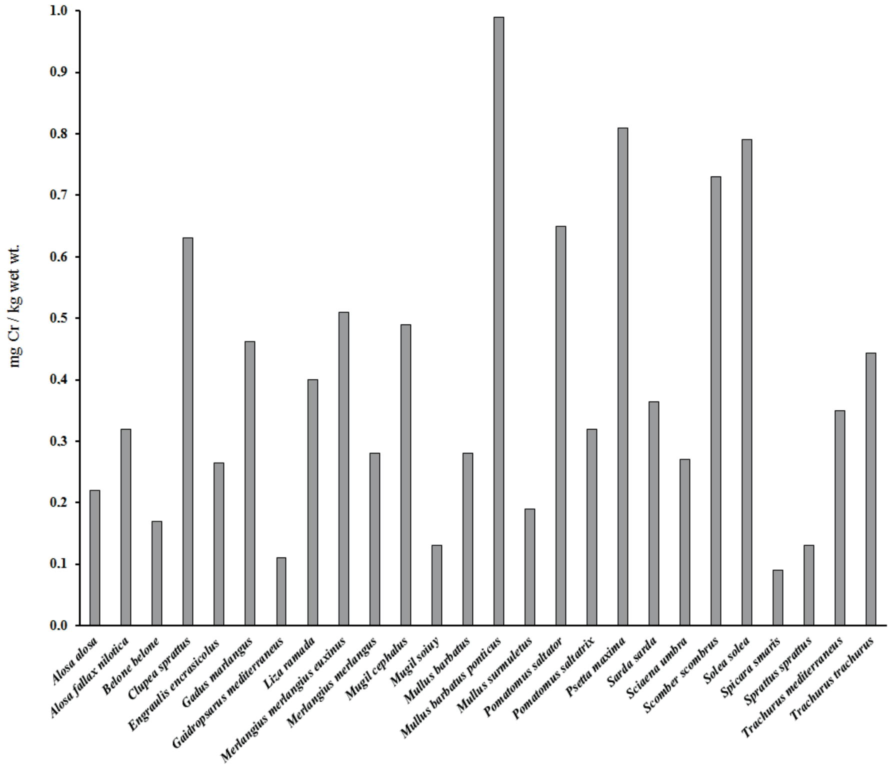

Figure 8. Overall mean concentrations of Cr in the edible tissues of fish species from the Turkish Black Sea coasts

Table 8. Chromium (Cr) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	0.29 ± 0.04 0.27 ± 0.07		wet wt.	Trabzon, Rize	Akaydın 2014
	0.11 ± 0.01		wet wt.	Samsun	Türkmen and Dura 2016
Alosa fallax nilotica	0.32		wet wt.	Sinop	Bat and Sezgin 2015
Belone belone	0.05 ± 0.01 0.25 ± 0.04		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014

	0.19 ± 0.11			
	0.02 ± 0.005 0.43 ± 0.05 0.08 ± 0.06	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Clupea sprattus	0.63 ± 0.04	wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	1.82 ± 0.15	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.17 ± 0.05 0.15 ± 0.03 0.09 ± 0.02	wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al*. 2008b
	0.074 ± 0.020	dry wt.	Black Sea	Turan *et al*. 2009
	1.12 ± 0.11	wet wt.	Black Sea	Tüzen 2009
	0.67 ± 0.05	dry wt.	Black Sea	Alkan *et al*. 2013
	0.17 ± 0.04 0.12 ± 0.02 0.17 ± 0.02	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.65	wet wt.	Sinop	Bat and Sezgin 2015
	0.15 ± 0.03 0.16 ± 0.03 0.12 ± 0.05	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura, 2016
Gadus marlangus	1.85 ± 0.17	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
Gaidropsarus mediterraneus	0.11 ± 0.03	wet wt.	Sinop	Ateş *et al*. 2015
Liza ramada	1.60 ± 1.28	dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius merlangus	0.13 ± 0.03 0.19 ± 0.05 0.13 ± 0.04	wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	0.144 ± 0.050	dry wt.	Black Sea	Turan *et al*. 2009

	0.86 ± 0.07		wet wt.	Black Sea	Tüzen 2009
	0.82 ± 0.08		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.92 ± 0.40	0.63-1.62	wet wt.	Bartın	Fındık and Çiçek 2011
	1.50 ± 1.07		dry wt.	Black Sea	Ergül and Aksan 2013
	0.04 ± 0.01 0.28 ± 0.06 0.04 ± 0.01		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.62	0.49-0.72	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.04 ± 0.01 0.18 ± 0.05 0.03 ± 0.01		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	0.995	0.35-1.64	dry wt.	Trabzon	Alkan *et al*. 2012
	0.51		wet wt.	Sinop	Bat and Sezgin 2015
Mugil cephalus	1.30 ± 0.11		wet wt.	Black Sea	Tüzen 2009
	0.07 ± 0.01 0.09 ± 0.03		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	0.13 ± 0.04		wet wt.	Sinop	Ateş *et al*. 2015
Mullus barbatus	0.17 ± 0.02 0.15 ± 0.06		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	1.055 ± 0.289		dry wt.	Black Sea	Turan *et al*. 2009
	1.35 ± 0.12		wet wt.	Black Sea	Tüzen 2009
	0.14 ± 0.16	0.02-0.65	wet wt.	Bartın	Fındık and Çiçek 2011
	0.33 ± 0.04		dry wt.	Black Sea	Ergül and Aksan 2013
	0.09 ± 0.01 0.35 ± 0.09 0.11 ± 0.02		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014

	0.41		wet wt.	Sinop	Bat and Sezgin 2015
	0.56	0.50-0.65	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.21 ± 0.05 0.40 ± 0.07 0.03 ± 0.01		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Mullus barbatus ponticus	0.99 ± 0.1		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.74	0.43-1.04	dry wt.	Trabzon	Alkan *et al*. 2012
Mullus surmuletus	0.74 ± 0.47		dry wt.	Black Sea	Ergül and Aksan 2013
Pomatomus saltator	0.82 ± 0.07		wet wt.	Black Sea	Tüzen 2009
	0.48		wet wt.	Sinop	Bat and Sezgin 2015
Pomatomus saltatrix	0.61 ± 0.15		dry wt.	Black Sea	Ergül and Aksan 2013
	0.39 ± 0.02 0.28 ± 0.04 0.51 ± 0.03		wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	0.18 ± 0.05 0.36 ± 0.10 0.37 ± 0.13		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	1.20 ± 0.10		wet wt.	Black Sea	Tüzen 2009
	0.94 ± 0.50		dry wt.	Black Sea	Ergül and Aksan 2013
	0.99		wet wt.	Sinop	Bat and Sezgin 2015
Sarda sarda	1.92 ± 0.18		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.68 ± 0.05		wet wt.	Black Sea	Tüzen 2009
	0.64 ± 0.06		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	1.34 ± 0.45		dry wt.	Black Sea	Ergül and Aksan 2013
	0.23 ± 0.09 0.24 ± 0.04		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014

	0.10 ± 0.345			
	0.23 ± 0.02 0.36 ± 0.04 0.34 ± 0.03	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Sciaena umbra	0.25 ± 0.06	dry wt.	Marmara and Black Sea	Acar *et al*. 2010
	1.89 ± 1.64	dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	0.73 ± 0.05	wet wt.	Black Sea	Tüzen 2009
Solea solea	1.44 ± 0.67	dry wt.	Black Sea	Ergül and Aksan 2013
	1.22	wet wt.	Sinop	Bat and Sezgin 2015
Spicara smaris	0.09 ± 0.04	wet wt.	Trabzon	Türkmen *et al*. 2008b
Sprattus sprattus	0.52 ± 0.02	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus mediterraneus	0.38 ± 0.14 0.50 ± 0.16	wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	0.68 ± 0.05	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus trachurus	1.43 ± 0.12	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	1.74 ± 0.14	wet wt.	Black Sea	Tüzen 2009
	0.95 ± 0.1	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	0.09 ± 0.03 0.43 ± 0.14 0.19 ± 0.04	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.44	wet wt.	Sinop	Bat and Sezgin 2015
	0.26 ± 0.02 0.28 ± 0.05 0.07 ± 0.03	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

19. Manganese (Mn)

Mn is a trace element and eating a small amount from food or water is needed to good health and is a naturally occurring metal that is found in many types of rocks. Exposure to high amounts can cause damage to the brain. It is noted that nervous system and reproductive effects have been observed in animals after high oral doses of Mn (ATSDR 2008).

The highest Mn value (25.16 mg/ kg wet wt.) was found in *Mugil* sp. from Sinop (Bat *et al*. 2006). These levels are very similar to those found in *P. maxima* (24.22 mg/ kg wet wt.) by Bat *et al*. (2006) for the same localities (Table 9). Figure 9 shows the overall mean concentrations of Mn in fish species from the Turkish Black Sea coasts.

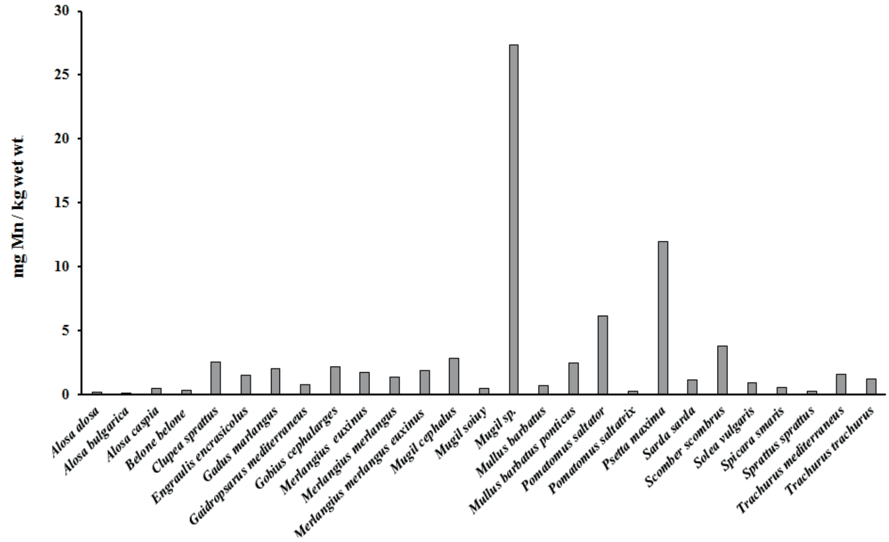

Figure 9. Overall mean concentrations of Mn in the edible tissues of fish species from the Turkish Black Sea coasts

Table 9. Manganese (Mn) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	0.19 ± 0.04 0.25 ± 0.04		wet wt.	Trabzon, Rize	Akaydın 2014
	0.17 ± 0.02		wet wt.	Samsun	Türkmen and Dura 2016

Alosa bulgarica	0.31	0.18-0.44	dry wt.	Sinop	Bat 1992
	0.18 ± 0.032		dry wt.	Sinop	Öztürk and Bat 1994
Alosa caspia	1.57 ± 0.24 1.56 ± 0.14		dry wt.	Samsun	Tüzen 2003
	2.50		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Belone belone	0.10 ± 0.02 0.15 ± 0.02 0.19 ± 0.04		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.08 ± 0.006 1.26 ± 0.28 0.19 ± 0.05		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	0.95 ± 0.15		dry wt.	Sinop	Bat *et al*. 1998
Clupea sprattus	2.82 ± 0.24 2.74 ± 0.44		dry wt.	Samsun	Tüzen 2003
	6.32 ± 0.35		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	0.58 ± 0.02		dry wt.	Sinop	Bat *et al*. 1996
	2.23		wet wt.	Amasra	Topçuoğlu *et al*. 2002
	1.96 ± 0.12 1.98 ± 0.32		dry wt.	Samsun	Tüzen 2003
	9.21 ± 0.83		dry wt.	Black Sea	Tüzen *et al*. 2004
	5.61		dry wt.	Black Sea	Uluozlu *et al*. 2007
	0.76 ± 0.13 0.70 ± 0.12 2.82 ± 1.12		wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al*. 2008b
	1.390 ± 0.326		dry wt.	Black Sea	Turan *et al*. 2009
	9.10 ± 0.66		wet wt.	Black Sea	Tüzen 2009

	3.93		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	2 ± 0 4.2 ± 0.9		dry wt.	Samsun	Aygun and Abanoz 2011
	0.60 ± 0.15		dry wt.	Black Sea	Alkan *et al*. 2013
	0.68 ± 0.18 0.57 ± 0.10 0.63 ± 0.05		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.51 ± 0.07 0.77 ± 0.08 0.30 ± 0.04		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	8.12 ± 0.75		dry wt.	Black Sea	Tüzen *et al*. 2004
Gaidropsarus mediterraneus	0.77 ± 0.10		wet wt.	Sinop	Ateş *et al*. 2015
Gobius cephalarges	8.56		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Merlangius euxinus	6.92		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Merlangius merlangus	3.56 2.22		wet wt.	Perşembe, Rize	Topçuoğlu *et al*. 2002
	0.57 ± 0.16 0.69 ± 0.21 0.42 ± 0.04		wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	0.079 ± 0.024		dry wt.	Black Sea	Turan *et al*. 2009
	7.63 ± 0.45		wet wt.	Black Sea	Tüzen 2009
	3.6 ± 0.4		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	2.13 ± 0.30	1.85-2.60	wet wt.	Bartın	Fındık and Çiçek 2011
	0.43 ± 0.13 0.30 ± 0.04 0.18 ± 0.08		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.92	0.64-1.28	dry wt.	Samsun, Ordu	Alkan *et al*. 2016

	0.70		wet wt.	Sinop	Bat and Arıcı 2016a
	0.14 ± 0.01 0.08 ± 0.01 0.15 ± 0.04		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	0.166		wet wt.	Sinop	Bat *et al*. 2006
	4.3 ± 0.7 3		dry wt.	Samsun	Aygun and Abanoz 2011
Mugil cephalus	8.18 ± 0.52		wet wt.	Black Sea	Tüzen 2009
	0.06 ± 0.01 0.16 ± 0.09		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	0.51 ± 0.15		wet wt.	Sinop	Ateş *et al*. 2015
Mugil sp.	25.16		wet wt.	Sinop	Bat *et al*. 2006
Mullus barbatus	0.33 ± 0.02		dry wt.	Sinop	Bat *et al*. 1996
	0.23		wet wt.	Sinop	Bat *et al*. 2006
	6.54		dry wt.	Black Sea	Uluozlu *et al*. 2007
	0.38 ± 0.02 0.48 ± 0.08		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	0.005 ± 0.018		dry wt.	Black Sea	Turan *et al*. 2009
	2.76 ± 0.17		wet wt.	Black Sea	Tüzen 2009
	6.96		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.77 ± 0.47	0.31-1.53	wet wt.	Bartın	Fındık and Çiçek 2011
	0.24 ± 0.04 0.43 ± 0.08 0.32 ± 0.10		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	1.05	0.79-1.38	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.19 ± 0.04		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

	0.32 ± 0.06 0.11 ± 0.007			
	0.75 0.66 1.78 1.74	wet wt.	İğneada, Sinop, Samsun, Trabzon	Bat and Arıcı 2016c
Mullus barbatus ponticus	2.5 ± 0.3	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
Pomatomus saltator	0.96 ± 0.16	dry wt.	Sinop	Bat *et al*. 1998
	12.92	wet wt.	Sinop	Bat *et al*. 2006
	1.28	dry wt.	Black Sea	Uluozlu *et al*. 2007
	6.90 ± 0.40	wet wt.	Black Sea	Tüzen 2009
Pomatomus saltatrix	5.14	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.13 ± 0.03 0.15 ± 0.02 0.12 ± 0.03	wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	0.15 ± 0.04 0.07 ± 0.01 0.06 ± 0.006	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	24.22	wet wt.	Sinop	Bat *et al*. 2006
	3.67 ± 0.22	wet wt.	Black Sea	Tüzen 2009
	3.26	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sarda sarda	1.06 ± 0.27 1.33 ± 0.42	dry wt.	Samsun	Tüzen 2003
	8.14 ± 0.81	dry wt.	Black Sea	Tüzen *et al*. 2004
	1.72	wet wt.	Sinop	Bat *et al*. 2006
	2.68 ± 0.22	dry wt.	Black Sea	Uluozlu *et al*. 2007
	4.72 ± 0.24	wet wt.	Black Sea	Tüzen 2009
	2.0 ± 0.2	dry wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b

	3.53 ± 0.48	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.23 ± 0.05 0.16 ± 0.03 0.60 ± 0.22	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.13 ± 0.02 0.34 ± 0.15 0.27 ± 0.13	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Scomber scombrus	5.15 ± 0.34	wet wt.	Black Sea	Tüzen 2009
Solea vulgaris	0.72	wet wt.	Sinop	Bat *et al*. 2006
Spicara smaris	0.39 ± 0.05	wet wt.	Trabzon	Türkmen *et al*. 2008b
	2.60	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sprattus sprattus	0.95 ± 0.09	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus mediterraneus	2.58 ± 0.74 1.92 ± 0.10	wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	0.56 ± 0.03	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus trachurus	0.47 ± 0.06	dry wt.	Sinop	Bat *et al*. 1996
	3.76 ± 0.45 3.50 ± 0.58	dry wt.	Samsun	Tüzen, 2003
	1.29 ± 0.11	dry wt.	Black Sea	Tüzen *et al*. 2004
	7.40	dry wt.	Black Sea	Uluozlu *et al*. 2007
	7.21 ± 0.55	wet wt.	Black Sea	Tüzen 2009
	1.3 ± 0.1	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	10.72	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.44 ± 0.14 0.27 ± 0.03 0.23 ± 0.06	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014

0.35 ± 0.18 0.22 ± 0.07 0.27 ± 0.05	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

20. Nickel (Ni)

Ni which is a very abundant natural element (ATSDR 2005a), is an essential element at low concentrations for many organisms, and it is toxic at higher concentrations (Authman *et al*. 2015). Ni is also found on the sea bed (ATSDR 2005a). Ni discharged in industrial waste water comes to an end in sediment where it mightily attaches to particles containing Fe or Mn (ATSDR 2005a). Exposure to Ni may lead to various adverse health effects, such as nickel allergy, contact dermatitis, and organ system-toxicity (Authman *et al*. 2015). However, Ni does not appear to accumulate in fish (ATSDR 2005a).

Ni may have a negative impact on human health if its levels exceed allowable limits in the edible muscles of fish. The highest content of Ni was found in S. sarda (5.91 ± 0.21 mg/ kg wet wt.) caught in Giresun (Akaydın 2014). Similarly, the high contents of Ni were found in *P. maxima* (4.504 mg/ kg wet wt.) captured in Sinop (Bat *et al*. 2006), in *S. sarda* (4.46 ± 1.06 mg/ kg wet wt.) caught in Rize (Akaydın 2014). Ni concentrations in the edible muscles of fish species from the Turkish Black Sea coasts were shown in Table 10. However, Figure 10 shows the overall mean concentrations of Ni in fish species from the Turkish Black Sea coasts.

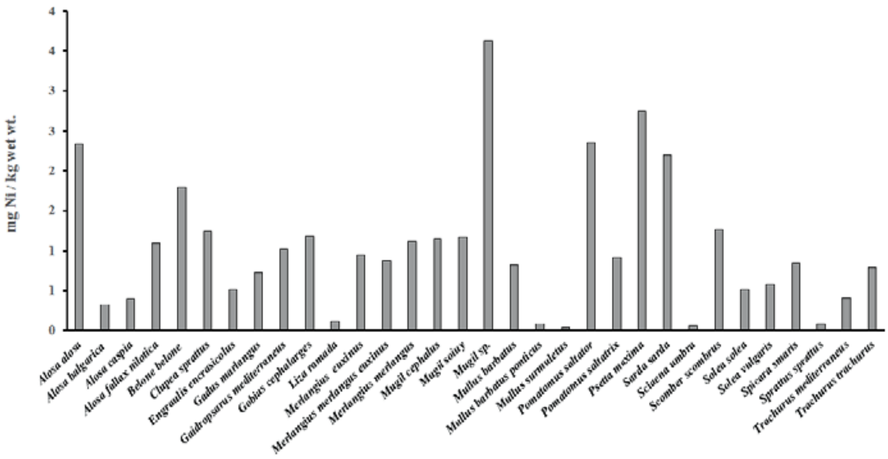

Figure 10. Overall mean concentrations of Ni in the edible tissues of fish species from the Turkish Black Sea coasts

Table 10. Nickel (Ni) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	1.57 ± 0.01 1.70 ± 0.09		wet wt.	Trabzon, Rize	Akaydın 2014
	3.74 ± 0.08		wet wt.	Samsun	Türkmen and Dura 2016
Alosa bulgarica	1.79	0.84-2.73	dry wt.	Sinop	Bat 1992
	0.84 ± 0.202		dry wt.	Sinop	Öztürk and Bat 1994
Alosa caspia	1.60		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
	1.22 ± 0.14		dry wt.	Sinop	Bat *et al.* 1998
Belone belone	1.72 ± 0.06 1.88 ± 0.10 1.96 ± 0.15		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	3.53 ± 0.25 0.42 ± 0.18 2.72 ± 0.68		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Clupea sprattus	1.25 ± 0.10		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	1.51 ± 0.22		dry wt.	Sinop	Bat *et al.* 1996
	<0.01		wet wt.	Amasra	Topçuoğlu *et al.* 2002
	9.36 ± 0.81		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al.* 2004
	2.63		dry wt.	Black Sea	Uluozlu *et al.* 2007
	1.51 ± 0.26 0.63 ± 0.19 0.51 ± 0.12		wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al.* 2008b
	0.348 ± 0.106		dry wt.	Black Sea	Turan *et al.* 2009
	1.93 ± 0.15		wet wt.	Black Sea	Tüzen 2009

	3.12	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.27 ± 0.07	dry wt.	Black Sea	Alkan *et al*. 2013
	1.04 ± 0.35 0.48 ± 0.12 0.54 ± 0.15	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.47 ± 0.02 0.70 ± 0.09 0.49 ± 0.07 0.72 ± 0.06 0.66 ± 0.06 0.76 ± 0.00 0.78 ± 0.05 0.91 ± 0.00	dry wt.	Sinop	Gündoğdu *et al*. 2016
	0.14 ± 0.05 0.13 ± 0.04 0.33 ± 0.19	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	2.90 ± 0.18	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
Gaidropsarus mediterraneus	1.02 ± 0.31	wet wt.	Sinop	Ateş *et al*. 2015
Gobius cephalarges	4.75	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Liza ramada	0.46 ± 0.37	dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius euxinus	3.78	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Merlangius merlangus	<0.01	wet wt.	Perşembe, Rize	Topçuoğlu *et al*. 2002
	0.83 ± 0.21 1.95 ± 0.66 0.67 ± 0.16	wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	1.363 ± 0.50	dry wt.	Black Sea	Turan *et al*. 2009

	1.14 ± 0.10		wet wt.	Black Sea	Tüzen 2009
	1.96 ± 0.66	1.25-2.87	wet wt.	Bartın	Fındık and Çiçek 2011
	0.31 ± 0.29		dry wt.	Black Sea	Ergül and Aksan 2013
	0.09 ± 0.02 1.80 ± 0.04 2.44 ± 0.49		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.61	0.41-0.82	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	3.05 ± 0.32 0.80 ± 0.17 2.52 ± 0.17		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura, 2016
Merlangius merlangus euxinus	0.077		wet wt.	Sinop	Bat *et al*. 2006
	0.36	0.01-0.71	dry wt.	Trabzon	Alkan *et al*. 2012
Mugil cephalus	2.74 ± 0.17		wet wt.	Black Sea	Tüzen 2009
	0.64 ± 0.36 0.09 ± 0.04		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	1.18 ± 0.36		wet wt.	Sinop	Ateş *et al*. 2015
Mugil sp.	3.345		wet wt.	Sinop	Bat *et al*. 2006
Mullus barbatus	2.26 ± 0.59		dry wt.	Sinop	Bat *et al*. 1996
	0.152		wet wt.	Sinop	Bat *et al*. 2006
	4.34		dry wt.	Black Sea	Uluozlu *et al*. 2007
	1.24 ± 0.21 1.05 ± 0.29		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	0.658 ± 0.333		dry wt.	Black Sea	Turan *et al*. 2009
	1.55 ± 0.12		wet wt.	Black Sea	Tüzen 2009
	2.47		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.63 ± 0.85	0.09-2.84	wet wt.	Bartın	Fındık and Çiçek 2011

	0.05 ± 0.05		dry wt.	Black Sea	Ergül and Aksan 2013
	2.54 ± 0.03 1.73 ± 0.02 1.78 ± 0.08		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.46	0.43-0.48	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	0.39 ± 0.01 0.54 ± 0.10 0.44 ± 0.02 0.59 ± 0.07 0.44 ± 0.00 0.42 ± 0.05 0.51 ± 0.05 0.45 ± 0.02		dry wt.	Sinop	Gündoğdu *et al*. 2016
	2.21 ± 0.44 0.21 ± 0.04 2.85 ± 0.06		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	0.47 0.61 1.17 1.35		wet wt.	İğneada, Sinop, Samsun, Trabzon	Bat and Arıcı 2016c
Mullus barbatus ponticus	0.35	0.02-0.67	dry wt.	Trabzon	Alkan *et al*. 2012
Mullus surmuletus	0.17 ± 0.02		dry wt.	Black Sea	Ergül and Aksan 2013
Pomatomus saltator	1.20 ± 0.09		dry wt.	Sinop	Bat *et al*. 1998
	3.785		wet wt.	Sinop	Bat *et al*. 2006
	3.89		dry wt.	Black Sea	Uluozlu *et al*. 2007
	1.87 ± 0.15		wet wt.	Black Sea	Tüzen 2009
Pomatomus saltatrix	1.91		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.13 ± 0.06		dry wt.	Black Sea	Ergül and Aksan 2013

	0.27 ± 0.06 1.68 ± 0.030 0.41 ± 0.14	wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	2.45 ± 0.36 1.61 ± 0.74 0.40 ± 0.05	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	4.504	wet wt.	Sinop	Bat *et al*. 2006
	3.60 ± 0.21	wet wt.	Black Sea	Tüzen 2009
	3.22	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.08 ± 0.08	dry wt.	Black Sea	Ergül and Aksan 2013
Sarda sarda	5.30 ± 0.39	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	0.307	wet wt.	Sinop	Bat *et al*. 2006
	2.70 ± 0.18	wet wt.	Black Sea	Tüzen 2009
	3.04 ± 0.24	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	0.43 ± 0.03	dry wt.	Black Sea	Ergül and Aksan 2013
	5.91 ± 0.21 2.94 ± 0.92 4.46 ± 1.06	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	1.24 ± 0.09 2.89 ± 0.73 2.52 ± 0.17	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Sciaena umbra	0.25 ± 0.15	dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	2.11 ± 0.15	wet wt.	Black Sea	Tüzen 2009
Solea solea	0.30 ± 0.06	dry wt.	Black Sea	Ergül and Aksan 2013
Solea vulgaris	0.45	wet wt.	Sinop	Bat *et al*. 2006
Spicara smaris	0.25 ± 0.07	wet wt.	Trabzon	Türkmen *et al*. 2008b

	5.77	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sprattus sprattus	0.30 ± 0.12	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus mediterraneus	0.51 ± 0.11 0.62 ± 0.02	wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	0.53 ± 0.16	dry wt.	Black Sea	Alkan *et al*. 2013
Trachurus trachurus	1.57 ± 0.26	dry wt.	Sinop	Bat *et al*. 1996
	6.73 ± 0.52	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	3.93	dry wt.	Black Sea	Uluozlu *et al*. 2007
	1.50 ± 0.13	wet wt.	Black Sea	Tüzen 2009
	4.68	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	1.41 ± 0.01 1.77 ± 0.03 1.78 ± 0.10	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.49 ± 0.01 0.36 ± 0.02 0.67 ± 0.06 0.40 ± 0.06 0.30 ± 0.02 0.29 ± 0.03 0.64 ± 0.12 0.45 ± 0.04	dry wt.	Sinop	Gündoğdu *et al*. 2016
	0.22 ± 0.05 0.34 ± 0.18 2.92 ± 0.35	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

21. Zinc (Zn)

Zn is the second most abundant metal after Fe (ATSDR 2005b), and is an essential element and micronutrient in aquatic organisms, found almost in every cell and being involved in nucleic acid synthesis and occurs in many enzymes (Authman *et al*. 2015). Zn and its compounds are widely used in industry to make paint, rubber, dyes, wood preservatives, ointments (ATSDR 2005b), and in commerce and in medicine (Authman *et al*. 2015). It may occur in aquatic ecosystem as a free cation as soluble Zn complexes, or can be adsorbed on suspended matter. Recently, Authman *et al*. (2015) reviewed that Zn wastes can have a straight toxicity to fish at increased waterborne levels, and fisheries can be affected by either Zn alone or more often allied to Cu and other metals.

As it can be seen from Table 11, High Zn concentrations were found in *P. saltator* (93.4 ± 5.8 mg/ kg wet wt.), *S. scombrus* (88.2 ± 4.6 mg/ kg wet wt.) and *M. cephalus* (86.2 ± 7.5 mg/ kg wet wt.) captured in the Turkish Black Sea coasts (Tüzen 2009). Figure 11 shows the overall mean concentrations of Zn in fish species from the Turkish Black Sea coasts.

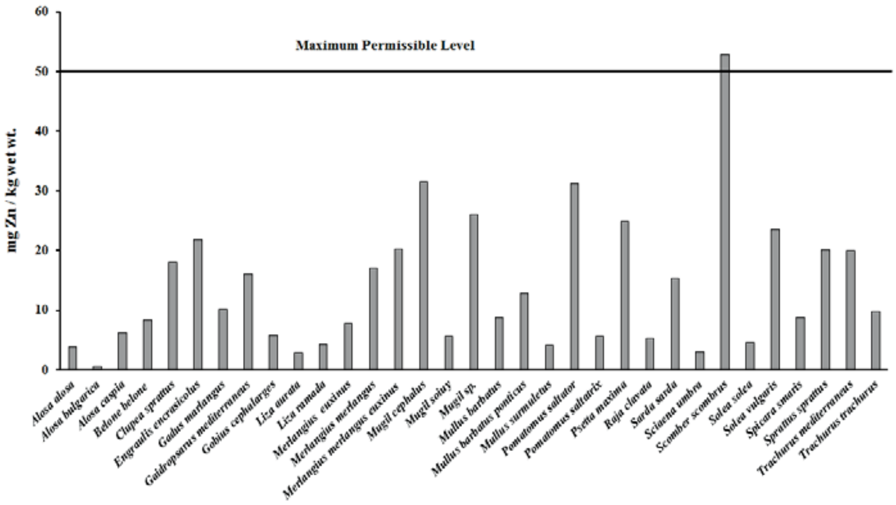

Figure 11. Overall mean concentrations of Zn in the edible tissues of fish species from the Turkish Black Sea coasts

Table 11. Zinc (Zn) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	3.65 ± 0.55 4.28 ± 0.78		wet wt.	Trabzon, Rize	Akaydın 2014
	3.62 ± 0.15		wet wt.	Samsun	Türkmen and Dura 2016
Alosa bulgarica	3.07	1.65-4.48	dry wt.	Sinop	Bat 1992
	1.65 ± 0.17		dry wt.	Sinop	Öztürk and Bat 1994
Alosa caspia	20.41 ± 1.75 22.94 ± 1.60		dry wt.	Samsun	Tüzen 2003
	30.87		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010
Belone belone	7.76 ± 1.37		dry wt.	Sinop	Bat *et al.* 1998
	5.75 ± 0.60 8.01 ± 0.60 6.58 ± 0.76		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	7.46 ± 1.09 19.5 ± 0.46 9.59 ± 1.13		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Clupea sprattus	9.50 ± 0.60 10.36 ± 1.29		dry wt.	Samsun	Tüzen 2003
	49.1 ± 3.7		wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	3.55 ± 0.68		dry wt.	Sinop	Bat *et al.* 1996
	35.7		wet wt.	Amasra	Topçuoğlu *et al.* 2002
	17.38 ± 2.01 18.85 ± 1.72		dry wt.	Samsun	Tüzen 2003
	112.71 ± 10.8		dry wt.	Black Sea	Tüzen *et al.* 2004

40.20	dry wt.	Black Sea	Uluozlu *et al*. 2007
10.8 ± 1.29 10.6 ± 0.88 45.6 ± 22.1	wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al*. 2008b
25.416 ± 3.664	dry wt.	Black Sea	Turan *et al*. 2009
38.8 ± 3.2	wet wt.	Black Sea	Tüzen 2009
26.25	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
129.3 ± 15 221 ± 10.5	dry wt.	Samsun	Aygun and Abanoz 2011
8.23 ± 2.94	dry wt.	Black Sea	Alkan *et al*. 2013
17.56 ± 2.13 15.04 ± 1.02 11.14 ± 0.48	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
9.5 ± 1.43 8.6 ± 1.29	wet wt.	Sinop	Bat *et al*. 2014
9.7 ± 1.46 12.9 ± 1.94		Samsun	
12.7 ± 1.91 11.7 ± 1.76		Fatsa	
13.0 ± 1.95 11.7 ± 1.76		Batumi	
40.28 ± 0.67 44.82 ± 3.04 40.01 ± 1.91 31.96 ± 0.76 36.07 ± 1.05	dry wt.	Sinop	Gündoğdu *et al*. 2016

	42.23 ± 1.17 40.79 ± 1.13 35.65 ± 1.62				
	17.6 ± 1.00 11.4 ± 1.71 11.5 ± 0.67		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	40.54 ± 3.88		dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
Gaidropsarus mediterraneus	16.1 ± 3.59		wet wt.	Sinop	Ateş *et al*. 2015
Gobius cephalarges	23.30		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Liza aurata	2.9		wet wt.	Sinop	Bat *et al*. 2015
Liza ramada	17.2 ± 1.0		dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius euxinus	31.34		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Merlangius merlangus	43.1 30.2		wet wt.	Perşembe, Rize	Topçuoğlu *et al*. 2002
	3.3		wet wt.	Black Sea	Dalman *et al*. 2006
	8.62 ± 0.54 12.9 ± 4.14 5.72 ± 0.37		wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	6.029 ± 0.545		dry wt.	Black Sea	Turan *et al*. 2009
	65.4 ± 4.2		wet wt.	Black Sea	Tüzen 2009
	27.7		wet wt.	Black Sea	Durali *et al*. 2010
	20.6 ± 2.1		wet wt.	Samsun, Ordu, Trabzon, **Rize**	Mendil *et al*. 2010b
	77.99 ± 46.91	37.96-152.67	wet wt.	Bartın	Fındık and Çiçek 2011
	18.0 ± 1.4		dry wt.	Black Sea	Ergül and Aksan 2013
	3.77 ± 0.22 5.65 ± 0.58 4.08 ± 0.36		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014

	3.4		wet wt.	Sinop	Bat *et al*. 2015
	21.5	18.78-24.83	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	23		wet wt.	Sinop	Bat and Arıcı 2016a
	5.04 ± 0.58 3.47 ± 0.27 3.99 ± 0.50		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	15.32		dry wt.	Black Sea	Boran *et al*. 2000
	9.46		wet wt.	Sinop	Bat *et al*. 2006
	86.07	8.86-163.28	dry wt.	Sinop	Türk Çulha *et al*. 2007
	58 ± 3.5 28.3 ± 1		dry wt.	Samsun	Aygun and Abanoz 2011
	43.35	18.64-68.06	dry wt.	Trabzon	Alkan *et al*. 2012
Mugil cephalus	86.2 ± 7.5		wet wt.	Black Sea	Tüzen 2009
	4.18 ± 0.41 3.99 ± 0.99		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	5.63 ± 1.69		wet wt.	Sinop	Ateş *et al*. 2015
Mugil sp.	24.04		wet wt.	Sinop	Bat *et al*. 2006
Mullus barbatus	2.42 ± 0.27		dry wt.	Sinop	Bat *et al*. 1996
	9.90		wet wt.	Sinop	Bat *et al*. 2006
	4.3		wet wt.	Black Sea	Dalman *et al*. 2006
	32.36	1.42-63.29	dry wt.	Sinop	Türk Çulha *et al*. 2007
	106.00		dry wt.	Black Sea	Uluozlu *et al*. 2007
	8.26 ± 0.77 10.5 ± 2.03		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	7.573 ± 0.389		dry wt.	Black Sea	Turan *et al*. 2009
	75.5 ± 5.3		wet wt.	Black Sea	Tüzen 2009

	17.8		wet wt.	Black Sea	Durali *et al*. 2010
	23.71		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	16.03 ± 14.05	3.48-40.72	wet wt.	Bartın	Fındık and Çiçek 2011
	14.6 ± 1.3		dry wt.	Black Sea	Ergül and Aksan 2013
	6.02 ± 0.45 7.15 ± 0.64 5.00 ± 0.31		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	3.2		wet wt.	Sinop	Bat *et al*. 2015
	19.7	18.89-20.99	dry wt.	Samsun, Ordu	Alkan *et al*. 2016
	13.00 ± 0.07 11.93 ± 0.77 10.64 ± 0.45 19.53 ± 1.77 12.97 ± 0.86 12.45 ± 0.34 13.81 ± 0.57 13.79 ± 0.02		dry wt.	Sinop	Gündoğdu *et al*. 2016
	4.95 ± 0.60 9.49 ± 0.38 5.71 ± 0.88		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	5.60 6.10 8.90 9.40		wet wt.	İğneada, Sinop, Samsun, Trabzon	Bat and Arıcı 2016c
Mullus barbatus ponticus	17.8 ± 1.8		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	31.7	19.89-43.50	dry wt.	Trabzon	Alkan *et al*. 2012
Mullus surmuletus	16.5 ± 1.0		dry wt.	Black Sea	Ergül and Aksan 2013
Pomatomus saltator	9.40 ± 1.48		dry wt.	Sinop	Bat *et al*. 1998

	15.39		wet wt.	Sinop	Bat *et al*. 2006
	35.40		dry wt.	Black Sea	Uluozlu *et al*. 2007
	93.4 ± 5.8		wet wt.	Black Sea	Tüzen 2009
Pomatomus saltatrix	25.51		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	15.3 ± 1.0		dry wt.	Black Sea	Ergül and Aksan 2013
	5.75 ± 0.77 4.44 ± 0.65 6.76 ± 0.39		wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	6.83 ± 0.28 5.66 ± 0.56 6.02 ± 0.86		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	32.93		wet wt.	Sinop	Bat *et al*. 2006
	45.2 ± 2.7		wet wt.	Black Sea	Tüzen 2009
	24.83		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	21.9 ± 0.6		dry wt.	Black Sea	Ergül and Aksan 2013
Raja clavata	21.24	6.60-35.87	dry wt.	Sinop	Türk Çulha *et al*. 2007
Sarda sarda	11.20 ± 1.44 13.72 ± 1.32		dry wt.	Samsun	Tüzen 2003
	25.76 ± 2.01		dry wt.	Black Sea	Tüzen *et al*. 2004
	12.66		wet wt.	Sinop	Bat *et al*. 2006
	48.7 ± 3.7		dry wt.	Black Sea	Uluozlu *et al*. 2007
	64.9 ± 5.2		wet wt.	Black Sea	Tüzen 2009
	21		wet wt.	Black Sea	Mendil *et al*. 2010a
	21.0 ± 2.1		dry wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	19.55 ± 1.20		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	15.16	12.75-17.56	wet wt.	Sinop	Bat *et al*. 2012

	12.3 ± 0.3		dry wt.	Black Sea	Ergül and Aksan 2013
	12.97 ± 3.68 11.73 ± 1.97 12.47 ± 2.53		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	32.1 ± 10.2 7.29 ± 2.51 5.26 ± 1.07		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Sciaena umbra	11.6 ± 1.64		dry wt.	Marmara and Black Sea	Acar *et al*. 2010
	12.7 ± 0.4		dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	88.2 ± 4.6		wet wt.	Black Sea	Tüzen 2009
Solea solea	18.4 ± 0.6		dry wt.	Black Sea	Ergül and Aksan 2013
Solea vulgaris	18.03		wet wt.	Sinop	Bat *et al*. 2006
Spicara smaris	31.99	6.23-57.74	dry wt.	Sinop	Türk Çulha *et al*. 2007
	12.2 ± 2.63		wet wt.	Trabzon	Türkmen *et al*. 2008b
	24.35		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sprattus sprattus	0.87 ± 0.07		dry wt.	Black Sea	Alkan *et al*. 2013
	13.40 25.40		wet wt.	Samsun, Sinop	Bat and Arıcı 2016b
	22.50 38.90		wet wt.	Samsun, Sinop	
Trachurus mediterraneus	42.6 ± 9.14 8.15 ± 1.81		wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	18.13 ± 0.95		dry wt.	Black Sea	Alkan *et al*. 2013
	24.7		wet wt.	Sinop	Bat *et al*. 2015
Trachurus trachurus	3.28 ± 0.66		dry wt.	Sinop	Bat *et al*. 1996
	12.05 ± 2.30 11.41 ± 1.15		dry wt.	Samsun	Tüzen 2003
	53.4 ± 4.3		dry wt.	Black Sea	Tüzen *et al*. 2004

37.40	dry wt.	Black Sea	Uluozlu *et al*. 2007
52.7 ± 4.9	wet wt.	Black Sea	Tüzen 2009
25.7	wet wt.	Black Sea	Durali *et al*. 2010
25.7 ± 2.6	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
27.70	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
3.75 ± 0.73 6.38 ± 0.95 5.57 ± 1.04	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
24.52 ± 0.17 21.09 ± 2.18 19.83 ± 0.48 24.17 ± 0.39 20.45 ± 1.44 25.10 ± 0.71 19.98 ± 1.67 27.39 ± 0.97	dry wt.	Sinop	Gündoğdu *et al*. 2016
6.90 ± 0.41 11.5 ± 1.97 5.70 ± 0.83	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

22. Iron (Fe)

Fe is the fourth most common element in the Earth's crust. It plays a major act in biology, forming complexes with molecular oxygen in haemoglobin and myoglobin which are common oxygen transport proteins in vertebrates. It is a prevalent component of industrial and mining effluents that are frequently discharged into marine environments (Authman *et al*. 2015). Ferrous Fe^{2+} is found to be more toxic to fish than the ferric Fe^{3+} form (Decker and Menendez 1974) and the toxicity of Fe is augmented with increasing acidity (Vuorinen *et al*. 1999). In general, Fe concentrations in fish species from the Black Sea of Turkey were the most abundant element compared with the other ten elements. Fe concentrations in the edible muscles of fish species from the Turkish Black Sea coasts were shown in Table 12. Figure 12 shows the overall mean concentrations of Fe in fish species from the Turkish Black Sea coasts.

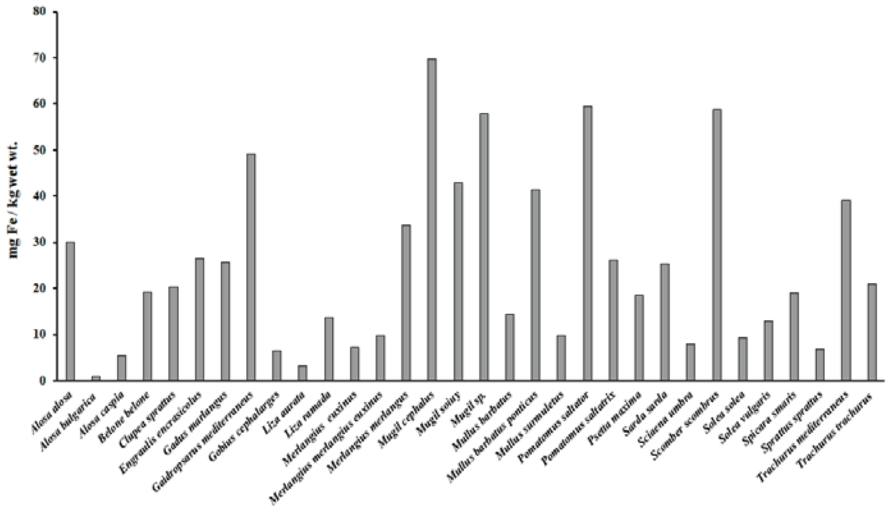

Figure 12. Overall mean concentrations of Fe in the edible tissues of fish species from the Turkish Black Sea coasts

Table 12. Iron (Fe) concentrations in the edible muscles of fish species from the Turkish Black Sea coasts

Species	Mean ± SD	Min-Max	Method	Locations	References
Alosa alosa	38.6 ± 4.39 35.0 ± 4.11		wet wt.	Trabzon, Rize	Akaydın 2014
	16.6 ± 9.29		wet wt.	Samsun	Türkmen and Dura 2016
Alosa bulgarica	5.38	1.61-9.14	dry wt.	Sinop	Bat 1992
	1.61 ± 0.30		dry wt.	Sinop	Öztürk and Bat 1994
Alosa caspia	16.08 ± 1.15 15.50 ± 2.10		dry wt.	Samsun	Tüzen 2003
	33.78		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al.* 2010

	18.6 ± 5.75 39.0 ± 4.07 30.4 ± 7.84	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
Belone belone	13.1 ± 1.80 7.50 ± 1.68 20.2 ± 4.67	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	25 ± 4.1	dry wt.	Sinop	Bat *et al*. 1998
Clupea sprattus	25.48 ± 3.18 24.12 ± 2.06	dry wt.	Samsun	Tüzen 2003
	48.2 ± 4.3	wet wt.	Black Sea	Tüzen 2009
Engraulis encrasicolus	4.87 ± 1.15	dry wt.	Sinop	Bat *et al*. 1996
	44	wet wt.	Amasra	Topçuoğlu *et al*. 2002
	10.45 ± 1.63 10.32 ± 1.05	dry wt.	Samsun	Tüzen 2003
	80.56 ± 7.9	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	95.60	dry wt.	Black Sea	Uluozlu *et al*. 2007
	44.4 ± 9.23 35.7 ± 9.81 35.9 ± 12.1	wet wt.	Trabzon, Sinop, Bartın	Türkmen *et al*. 2008b
	18.008 ± 2.697	dry wt.	Black Sea	Turan *et al*. 2009
	75.7 ± 6.5	wet wt.	Black Sea	Tüzen 2009
	26.06	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	34 ± 2.5 51.5 ± 5.3	wet wt.	Samsun	Aygun and Abanoz 2011
	53.6 ± 0.45 52.9 ± 0.42	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014

	53.1 ± 0.59			
	22.18 ± 1.16 23.90 ± 3.77 18.69 ± 0.03 23.20 ± 0.54 19.22 ± 0.52 18.33 ± 0.59 17.27 ± 2.09 17.86 ± 0.11	dry wt.	Sinop	Gündoğdu *et al*. 2016
	54.1 ± 0.12 52.5 ± 0.74 54.0 ± 0.14	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Gadus marlangus	102.51 ± 9.8	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
Gaidropsarus mediterraneus	49.2 ± 10.5	wet wt.	Sinop	Ateş *et al*. 2015
Gobius cephalarges	26.17	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Liza aurata	3.2	wet wt.	Sinop	Bat *et al*. 2015
Liza ramada	55.0 ± 5.0	dry wt.	Black Sea	Ergül and Aksan 2013
Merlangius euxinus	28.84	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Merlangius merlangus	57 46	wet wt.	Perşembe, Rize	Topçuoğlu *et al*. 2002
	2.5	wet wt.	Black Sea	Dalman *et al*. 2006
	48.4 ± 12.6 81.9 ± 18.3 34.0 ± 2.24	wet wt.	Trabzon, Sinop, Bartın	Tepe *et al*. 2008
	4.488 ± 0.441	dry wt.	Black Sea	Turan *et al*. 2009
	98.1 ± 7.7	wet wt.	Black Sea	Tüzen 2009
	27.7 ± 2.8	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b

	83.01 ± 38.14	59.97-150.74	wet wt.	Bartın	Fındık and Çiçek 2011
	84.2 ± 12		dry wt.	Black Sea	Ergül and Aksan 2013
	32.1 ± 6.89 45.6 ± 4.52 8.16 ± 2.32		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	0.87		wet wt.	Sinop	Bat *et al*. 2015
	11.00		wet wt.	Sinop	Bat and Arıcı 2016a
	17.7 ± 5.40 8.34 ± 1.88 16.4 ± 1.78		wet wt. wet wt. wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Merlangius merlangus euxinus	14.14		dry wt.	Black Sea	Boran *et al*. 2000
	16.52		wet wt.	Sinop	Bat *et al*. 2006
	9.9 ± 2.1 7 ± 4.6		wet wt.	Samsun	Aygun and Abanoz 2011
Mugil cephalus	125 ± 10		wet wt.	Black Sea	Tüzen 2009
	42.9 ± 4.26 41.1 ± 4.34		wet wt.	Giresun, Rize	Akaydın 2014
Mugil soiuy	43.0 ± 12.9		wet wt.	Sinop	Ateş *et al*. 2015
Mugil sp.	6.34		wet wt.	Sinop	Bat *et al*. 2006
Mullus barbatus	4.18 ± 0.81		dry wt.	Sinop	Bat *et al*. 1996
	21.33		wet wt.	Sinop	Bat *et al*. 2006
	4.5		wet wt.	Black Sea	Dalman *et al*. 2006
	163.00		dry wt.	Black Sea	Uluozlu *et al*. 2007
	27.7 ± 5.63 21.8 ± 2.01		wet wt.	Trabzon, Sinop	Tepe *et al*. 2008
	21.272 ± 1.476		dry wt.	Black Sea	Turan *et al*. 2009

	53.2 ± 2.8		wet wt.	Black Sea	Tüzen 2009
	29.17		dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	21.20 ± 12.99	7.90-39.88	wet wt.	Bartın	Fındık and Çiçek 2011
	20.2 ± 0.7		dry wt.	Black Sea	Ergül and Aksan 2013
	44.7 ± 3.08 49.5 ± 8.70 30.5 ± 8.46		wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	2.3		wet wt.	Sinop	Bat *et al*. 2015
	17.80 ± 2.28 12.87 ± 2.13 16.41 ± 2.59 20.81 ± 2.62 19.09 ± 2.79 20.31 ± 0.02 18.86 ± 3.52 19.10 ± 1.45		dry wt.	Sinop	Gündoğdu *et al*. 2016
	24.9 ± 6.83 2.11 ± 0.41 10.4 ± 3.89		wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
	3.30 2.80 7.20 6.30		wet wt.	İğneada, Sinop, Samsun, Trabzon	Bat and Arıcı 2016c
Mullus barbatus ponticus	41.4 ± 4.1		wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
Mullus surmuletus	39.4 ± 9.8		dry wt.	Black Sea	Ergül and Aksan 2013
Pomatomus saltator	21 ± 3.7		dry wt.	Sinop	Bat *et al*. 1998
	62.19		wet wt.	Sinop	Bat *et al*. 2006
	68.60		dry wt.	Black Sea	Uluozlu *et al*. 2007

	110 ± 8	wet wt.	Black Sea	Tüzen 2009
Pomatomus saltatrix	23.81	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	17.2 ± 2.4	dry wt.	Black Sea	Ergül and Aksan 2013
	43.4 ± 5.28 31.4 ± 6.56 48.0 ± 5.43	wet wt.	Rize, Giresun, Trabzon	Akaydın 2014
	30.6 ± 7.42 20.7 ± 5.37 24.7 ± 6.79	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016
Psetta maxima	39.84	wet wt.	Sinop	Bat *et al*. 2006
	36.2 ± 2.4	wet wt.	Black Sea	Tüzen 2009
	21.72	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	17.3 ± 2.8	dry wt.	Black Sea	Ergül and Aksan 2013
Sarda sarda	9.52 ± 0.81 10.14 ± 1.11	dry wt.	Samsun	Tüzen 2003
	52.51 ± 4.92	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	12.18	wet wt.	Sinop	Bat *et al*. 2006
	73.5 ± 6.3	dry wt.	Black Sea	Uluozlu *et al*. 2007
	68.5 ± 5.4	wet wt.	Black Sea	Tüzen 2009
	25.5 ± 2.3	dry wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	25.96 ± 2.73	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	41.0 ± 3.9	dry wt.	Black Sea	Ergül and Aksan 2013
	40.7 ± 10.42 47.4 ± 3.83 37.8 ± 7.53	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	39.6 ± 4.35	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

	37.2 ± 8.95 43.1 ± 1.34			
Sciaena umbra	40.1 ± 8.7	dry wt.	Marmara and Black Sea	Acar *et al*. 2010
	23.2 ± 0.5	dry wt.	Black Sea	Ergül and Aksan 2013
Scomber scombrus	87.3 ± 5.2	wet wt.	Black Sea	Tüzen 2009
Solea solea	37.1 ± 1.5	dry wt.	Black Sea	Ergül and Aksan 2013
Solea vulgaris	21.02	wet wt.	Sinop	Bat *et al*. 2006
Spicara smaris	32.2 ± 8.00	wet wt.	Trabzon	Türkmen *et al*. 2008b
	23.89	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
Sprattus sprattus	5.15 3.87 7.22 11.20	wet wt.	Samsun, Sinop	Bat and Arıcı 2016b
Trachurus mediterraneus	57.2 ± 17.9 57.6 ± 3.63	wet wt.	Sinop, Bartın	Türkmen *et al*. 2008
	2.2	wet wt.	Sinop	Bat *et al*. 2015
Trachurus trachurus	4.28 ± 0.95	dry wt.	Sinop	Bat *et al*. 1996
	32.40 ± 2.70 31.26 ± 1.73	dry wt.	Samsun	Tüzen 2003
	68.24 ± 5.72	dry wt.	Black Sea and River Yeşilırmak	Tüzen *et al*. 2004
	74.30	dry wt.	Black Sea	Uluozlu *et al*. 2007
	145 ± 12	wet wt.	Black Sea	Tüzen 2009
	36.4 ± 3.5	wet wt.	Samsun, Ordu, Trabzon, Rize	Mendil *et al*. 2010b
	21.17	dry wt.	Samsun, Sinop, Terme, Fatsa, Ordu	Nisbet *et al*. 2010
	39.4 ± 6.09 45.7 ± 5.20 40.9 ± 5.02	wet wt.	Giresun, Trabzon, Rize	Akaydın 2014
	19.65 ± 0.20	dry wt.	Sinop	Gündoğdu *et al*. 2016

	21.13 ± 2.86 24.34 ± 0.32 31.28 ± 2.84 23.85 ± 2.20 30.73 ± 1.59 30.71 ± 1.01 30.72 ± 0.82			
	2.09 ± 0.12 2.88 ± 2.02 39.5 ± 6.70	wet wt.	Samsun, Sinop, Kocaeli	Türkmen and Dura 2016

It can be clearly seen that heavy metal levels in edible fish tissues are varied. The indicated variability of metal concentration in the same species depends on their habitats. *Alosa* spp., *Belone belone, Engraulis* spp., *Mugil* spp., *Pomatomus* spp. *Sarda sarda, Trachurus* spp. are pelagic species and migrate frequently. They are mainly feed upon plankton or crustaceans or small fish. However, *Merlangius* spp. are benthopelagic. The studied species occupy different layers of the water column. *Mullus* spp., *Psetta maxima, Solea* spp. live in association with sediment and has been found to be a carnivorous species, feeding on crustaceans, molluscs, sand grain, and detritus. These species spawn in different seasons and they have very different ecological traits. According to many studies, metals tend to accumulate in sediment. It is surprising that some flatfish and bottom feeders, and are associated with sediment species, did not show the highest level of metals compare to pelagic species. These patterns confirm that the differences in metal concentration in various fish species could considerably be attributed to the differences in feed habits. It may be suggested that feeding modes play basic and significant role in the control of heavy metal accumulation.

It should be also kept in mind that if there is any significant difference on the weights and lengths of the fish as a result of sampling period, metal levels in fish muscles may be different. This is very important because differences in weights may bring differences in the concentrations of heavy metals in body tissues. For example, if a fish A is heavier than fish B and both fish have taken the same amount of a pollutant, then fish A would have lower concentration of the pollutant due to biological dilution.

23. Health Risk Assessment

Considering the consumption structure in the Black Sea, fish with high economic value and large consumption rates were selected for the studies (Tables 2-12). The risk to human health as a result of consuming these species was evaluated by calculating Estimated Daily Intake (EDI). The mean heavy metal concentrations in muscle were used to evaluate the human health risk assessment from fish consumption. The EDI and EWI of heavy metals are shown in Table 13.

Table 13. Estimated Weekly Intakes (EWI) and Estimated Daily Intakes (EDI) of heavy metals in edible tissues of fish species from Turkish coastal waters of the Black Sea

Metals	PTWI[a]	PTWI[b]	PTDI[c]	EWI[d]	EDI[e]
Hg	0.004	0.28	0.04	0.0056	0.0008
Cd	0.007	0.49	0.07	0.0112	0.0016
Pb	0.025	1.75	0.25	0.053	0.007
As	0.015	1.05	0.15	0.044	0.006
Cu	3.5	245	35	0.1568	0.0224
Co	-	f	f	0.00784	0.00112
Cr (III) Cr (VI)	0.0233	1.631	0.233	0.0448	0.0064
Mn	2-5	140-350	20-50	0.1904	0.0272
Ni	0.035	2.45	0.35	0.1232	0.0176
Zn	7	490	70	1.68	0.24
Fe	5.6	392	56	2.688	0.384

[a]PTWI (Provisional Tolerable Weekly Intake) in mg/week/kg body weight
[b]PTWI for 70 kg adult person (mg/week/70 kg body wt.)
[c]PTDI (Permissible Tolerable Daily Intake) (mg/day/70 kg body wt.)
[d]EWI (Estimated Weekly Intake) (mg/week/ 70 kg body wt.)
[e]EDI (Estimated Daily Intake) (mg/day/ kg body wt.)
[f]There is no PTWI set for Co

Estimated hazard quotient (HQ) of Hg, Cd, Pb, As, Cu, Co, Cr, Mn, Ni, Zn and Fe suggest that these metals in the edible tissues of studied fish species (Tables 2-12) do not hazard any apparent threat to people, where the total HQ= 0.459) of all the considered metals were below the value of 1 (Figure 13).

Recently, the consumption of the Black Sea fishes has become popular among the Turkish people, and the intake of heavy metals, through fish consumption is of high concern for human health risk. To evaluate the health risk to the Turkish people through consumption of the Black Sea fishes, the daily intake of the heavy metals was estimated on the basis of the concentrations (wet wt. basis) of the heavy metals in the edible tissues of fish and daily fish consumption. Thus, the presence of the heavy metals in the muscle of the Black Sea fishes may not cause any serious health risk to the consumers.

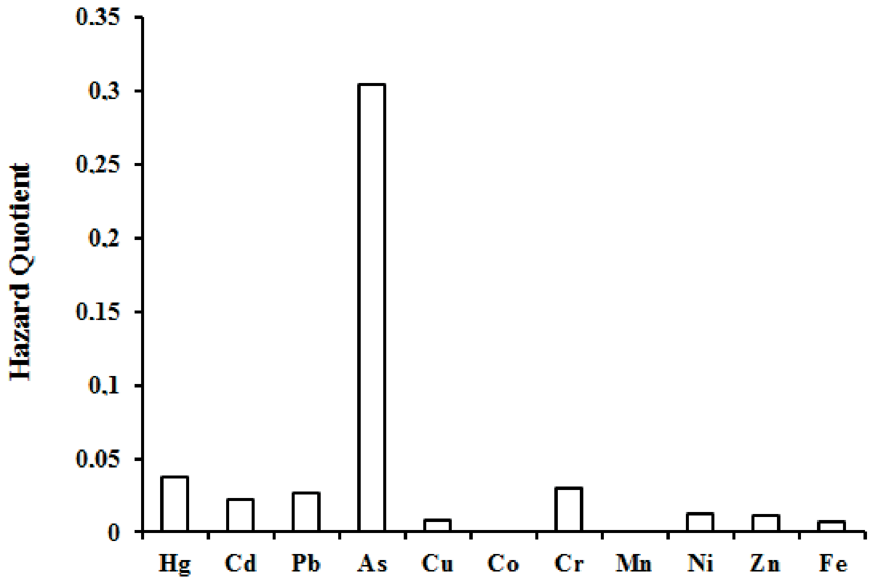

Figure 13. Total hazard quotient of Hg, Cd, Pb, As, Cu, Co, Cr, Mn, Ni, Zn and Fe via consumption of edible tissues of fish species from Turkish coastal waters of the Black Sea

24. Conclusion

It should be put into words that the changeability of the available results from various studies is explained taking into account that the regulation of heavy metals in fish and inductive reaction changes significantly, depending on factors related to variability of the metal, residence time in the medium, time of exposure, concentrations; physiology, metabolism, morphology and age of the fish; and the physical and chemical characteristics of the water. There are also inter-individual responses of fish, even stimulate that responses maybe because of the adaptive capacity of individuals to contaminated marine environments.

The results of metals concentrations in the fish samples did not exceed the permissible limits set for metals. The daily intakes (EDI) of the metals were estimated taking into account the average of metal in all fish samples and the average consumption of fish per day for adults. These results are normally significantly lower than those in the recommended values of FAO/WHO and EU.

Estimated hazarded quotients of all the considered metals were below the value of 1, therefore the metals in fish samples do not pose any apparent threat to the population and these fishes in the Black Sea coasts of Turkey were healthy for consumption.

To protect people from toxic effect of fish consumption and to make sure of healthy foods, a continuous monitoring of the hazard quotients for food fish in natural conditions is very desirable (Gladyshev *et al*. 2009).

References

Acar, O., O.M. Kalfa, Ö. Yalçınkaya, and A.R. Türker. 2010. Calcium, magnesium, iron, zinc, cadmium, lead, copper and chromium determinations in Brown Meagre (*Sciaena umbra*) bone stone by flame and electrothermal Atomic Absorption Spectrometry. Gazi University Journal of Science, 23(1): 41-48.

Agency for Toxic Substances and Disease Registry (ATSDR). 1999. Toxicological profile for mercury. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 2004a. Toxicological profile for copper. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 2004b. Toxicological profile for cobalt. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 2005a. Toxicological Profile for Nickel (Update). Atlanta, GA: U.S. Department of Public Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 2005b. Toxicological Profile for Zinc (Update). Atlanta, GA: U.S. Department of Public Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 2007. Toxicological Profile for lead (Update). Atlanta, GA: U.S. Department of Public Health and Human Services, Public Health Service.

Agency for Toxic Substances and Disease Registry (ATSDR). 2008. Toxicological Profile for manganese (Draft for Public Comment). Atlanta, GA: U.S. Department of Public Health and Human Services, Public Health Service.

Akaydın, A. 2014. Assessment of heavy metal bioaccumulation in economically important fish species caught in the marine waters of the Eastern Black Sea. Giresun University Institute of Natural Sciences Department of Biology, Masters Thesis, 70 p.

Alkan, N., M. Aktaş, and K. Gedik. 2012. Comparison of metal accumulation in fish species from the Southeastern Black Sea. Bull. Environ. Contam. Toxicol., 88(6): 807-812.

Alkan, N., A. Alkan, K. Gedik, and A. Fisher. 2013. Assessment of metal concentrations in commercially important fish species in Black Sea. Toxicol. Ind. Health, 32 (3): 447-456.

Alkan, N. and M. Boran. 2014. Antropogenic, agricultural, oil pollution and marine litter in the southern Black Sea. In E. Düzgüneş, B. Öztürk, M. Zengin [eds.], Turkish Fisheries in the Black Sea. Published by Turkish Marine Research Foundation (TUDAV), Publication number: 40, ISBN: 987-975-8825-32-5 Istanbul, Turkey, p. 53-70.

Altas, L. and H. Büyükgüngör. 2007. Heavy metal pollution in the Black Sea shore and offshore of Turkey. Environmental Geology, 52(3): 469-476.

Appenroth, K.J. 2010. Definition of "Heavy Metals" and their role in biological systems. In I. Sherameti, and A. Varma [eds.], Soil Heavy Metals, Soil Biology, 19: 19-29.

Ateş, A., M. Türkmen, M. and Y. Tepe. 2015. Assessment of heavy metals in fourteen marine fish species of four Turkish Seas. Indian Journal of Geo-Marine Sciences, 519-525.

Authman, M.M.N., M.S. Zaki, E.A. Khallaf, and H.H. Abbas. 2015. Use of fish as bio-indicator of the effects of heavy metals pollution. J. Aquac. Res. Development, 6: 328.

Aygun, S.F. and F.G. Abanoz. 2011. Determination of heavy metal in anchovy (*Engraulis encrasicolus* L 1758) and whiting (*Merlangius merlangus euxinus* Nordman, 1840) fish in the Middle Black Sea. Kafkas Univ. Journal of the Faculty of Veterinary Science, 17(A): 145-152.

Bakan, G. and H. Büyükgüngör. 2000. The Black Sea. Marine Pollution Bulletin, 41(1-6): 24-43.

Balkis, N., A. Aksu, and H. Hicsönmez. 2012a. Metal levels in biota from the Southern Black Sea, Turkey. J Black Sea/Mediterranean Environment, 18(2): 134-143.

Bat, L. 1992. A study on trace element levels in some organisms collected from upper-infralittoral of Sinop peninsula, (in Turkish). OMÜ. Institute of Natural Sciences, Department of Fisheries Masters Thesis, Sinop, 108 p.

Bat, L., M. Öztürk, and M. Öztürk. 1996. Heavy metal amounts in some commercial teleost fish from the Black Sea. O.M.U. Faculty of Science-Arts, Journal of Science, 7(1): 117-135.

Bat, L., M. Öztürk, and M. Öztürk. 1998. Heavy metal concentrations in some fish and crab from the Black Sea of Turkey, (Biology), Octber 23-25 1997 Manisa, Celal Bayar University Journal of the Faculty of Science and Literature, 1: 148-155.

Bat, L. and A. Gündoğdu. 2003. Heavy metal amounts in zooplankton and some commercial teleost fish and water samples at different depths from iner harbour of Sinop, Black Sea. (O.M.Ü. Project Research Fund Number S.078), 27 pp. (in Turkish).

Bat, L., A. Gündoğdu, Ö. Yardım, T. Zoral, and S. Çulha. 2006. Heavy metal amounts in zooplankton and some commercial teleost fish from inner harbour of Sinop, Black Sea. (in Turkish). SUMDER (Journal of Fisheries Engineering), 25: 22-27.

Bat, L., O. Gökkurt, M. Sezgin, F. Üstün, and F. Sahin. 2009. Evaluation of the Black Sea land based sources of pollution the coastal region of Turkey. The Open Marine Biology Journal, 3: 112-124.

Bat, L., M. Sezgin, F. Ustun, and F. Sahin. 2012. Heavy metal concentrations in ten species of fishes caught in Sinop coastal waters of the Black Sea, Turkey. Turkish Journal of Fisheries and Aquatic Sciences, 12: 371-376.

Bat, L., M. Sezgin, O. Gökkurt Baki, F. Üstün and F. Şahin. 2013. Determination of heavy metals in some commercial fish from the Black Sea coast of Turkey. Walailak Journal, 10(6): 581-589.

Bat, L. 2014. Heavy metal pollution in the Black Sea. In E. Düzgüneş, B. Öztürk, M. Zengin [eds.], Turkish Fisheries in the Black Sea. Turkish Marine Research Foundation (TUDAV), Publication number: 40, Istanbul, Turkey, p. 71-107.

Bat, L., Y. Kaya, and H.C. Öztekin. 2014. Heavy metal levels in the Black Sea anchovy (*Engraulis encrasicolus*) as biomonitor and potential risk of human health. Turkish Journal of Fisheries and Aquatic Sciences, 14: 845-851.

Bat, L. and M. Sezgin. 2015. Heavy metal levels in some commercial fish from Sinop coast of the Black Sea, Turkey, pp. 645-656. Proceedings of the Twelfth International Conference on the Mediıerranean Coastal Environment MEDCOAST 2015, 06-10 October, Varna, Bulgaria.

Bat, L., H.C. Öztekin, and F. Üstün. 2015. Heavy metal levels in four commercial fishes caught in Sinop coasts of the Black Sea, Turkey. Turkish Journal of Fisheries and Aquatic Sciences, 15: 399-405.

Bat, L. and E. Arici. 2016a. Heavy metal levels in tissues of *Merlangius merlangus* (Linnaeus, 1758) from the Black Sea coast of Turkey and potential risks to human health. International Journal of Marine Science, 6(10): 1-8.

Bat, L. and E. Arici. 2016b. Heavy metal levels in the Black Sea Sprat (*Sprattus sprattus*). METU Turkish Marine Sciences Conference, 31 May-3 June, Ankara, Turkey.

Bat, L. and E. Arıcı. 2016c. Contamınation of heavy metals in *Mullus barbatus* Linnaeus, 1758 from the southern of the Black Sea coasts and potential risks to people health. Rapp. Comm. int. Mer Médit., 41: 248.

Bat, L., E. Arıcı, M. Sezgin and F. Şahin. 2017. Heavy metal levels in commercial fishes caught in the southern Black Sea coast. International Journal of Environment and Geoinformatics, 4 (2): 94-102.

Bellinger, E.G. and B.R. Benham. 1978. The levels of metals in dock-yard sediments with particular reference to the contributions from ship-bottom paints. Environ. Pollut., 15: 71-81.

Boran, M., H. Karaçam, S. Çelikkale, S. Köse, and S. Kutlu. 2000. Levels of heavy metals in blue whiting caught from the eastern Black Sea area of Turkey. Toxicological and Environmental Chemistry, 75: 67-73.

Büyükgüngör, H., G. Bakan, and F. Akbal. 2014. Land-Based pollution monitoring and assessment of Black Sea region of Turkey. In E. Düzgüneş, B. Öztürk, M. Zengin [eds.], Turkish Fisheries in the Black Sea. Turkish Marine Research Foundation (TUDAV), Publication number: 40, Istanbul, Turkey, p. 108-131.

Clark, R.B. 1986. Marine Pollution. Clarendon Press, Oxford.

Cohen, J.T., D.C. Bellinger, W.E. Connor, P.M. Kris-Etherton, R.S. Lawrence, D.A. Savitz, B.A. Shaywitz, S.M. Teutsch, and G.M. Gray. 2005. A quantitative risk-benefit analysis of changes in population fish consumption. American Journal of Preventive Medicine, 29 (4): 325-334.

Commission Regulation (EC). 2001. No 466/2001 of 8 March 2001 Setting maximum levels for certain contaminants in foodstuffs.

Commission Regulation (EC). 2006. Official Journal of the European Union. Setting maximum levels for certain contaminants in food stuffs. Commission Regulation (EC) No 1881/2006, 364: 5-24.

Commission Regulation (EC). 2013. No 1275/2013 of 6 December 2013 amending Annex I to Directive 2002/32/EC of the European Parliament and of the Council as regards maximum levels for arsenic, cadmium, lead, nitrites, volatile mustard oil and harmful botanical impurities, L 328/86.

Commission Regulation (EC). 2015. Official Journal of the European Union. Amending Regulation (EC) No 1881/2006 as regards maximum levels of lead in certain foodstuffs. *Commission Regulation* (EC) No 1005/2015, 161: 9-13.

Commission Regulation (EU). 2014. No 488/2014 of 12 May 2014 amending Regulation (EC) No 1881/2006 as regards maximum levels of cadmium in foodstuffs, L 138/75.

Council of Europe. 2001. Council of Europe's policy statements concerning materials and articles intended to come into contact with foodstuffs. Policy Statement concerning materials and alloys. Technical Document. Guidelines on metals and alloys used as food contact materials. (09.03.2001), Strasbourg. pp. 67.

Dalman, O., A. Demirak, and A. Balci. 2006. Determination of heavy metals (Cd, Pb) and trace elements (Cu, Zn) in sediments and fish of the Southeastern Aegean Sea (Turkey) by Atomic Absorption Spectrometry. Food Chemistry, 95: 157-162.

Das, Y.K., A. Aksoy, R. Baskaya, H.A. Duyar, D. Guvenc, and V. Boz. 2009. Heavy metal levels of some marine organisms collected in Samsun and Sinop coasts of Black Sea, in Turkey. Journal of Animal and Veterinary Advances, 8(3): 496-499.

Decker, C. and R. Menendez. 1974. Acute toxicity of iron and aluminium to brook trout. Proc. W. Virg. Acad. Sci., 46: 159-167.

Depledge, M.H., J.M. Weeks, and P. Bjerregard. 1994. Heavy metals. In P. Calow [ed.], Handbook of Ecotoxicology. Oxford Blackwell Sci. Publ., London 2(5): 79-105.

Domingo, J.L., A. Bocio, G. Falcó, and J.M. Llobet. 2007. Benefits and risks of fish consumption Part I. A quantitative analysis of the intake of omega-3 fatty acids and chemical contaminants. Toxicology, 230: 219-226.

EFSA NDA Panel (EFSA Panel on Dietetic Products, Nutrition and Allergies). 2014. Scientific Opinion on health benefits of seafood (fish and shellfish) consumption in relation to health risks associated with exposure to methylmercury. EFSA Journal, 12 (7): 761-780.

EFSA Panel on Contaminants in the Food Chain (CONTAM). 2010. Scientific Opinion on Lead in Food. EFSA Journal, 8(4): 1570. 151 pp., Available online: www.efsa.europa.eu

EFSA. 2012a. Cadmium dietary exposure in the European population. EFSA Journal, 10 (1): 2551, 37 pp.

EFSA Panel on Contaminants in the Food Chain (CONTAM). 2012b. Scientific Opinion on the risk for public health related to the presence of mercury and methylmercury in food. EFSA Journal, 10 (12): 2985, 241 pp.

EFSA. 2012c. Lead dietary exposure in the European population. EFSA Journal, 10(7): 2831, 59 pp.

EFSA Scientific Committee. 2015. Statement on the benefits of fish/seafood consumption compared to the risks of methylmercury in fish/seafood. EFSA Journal, 13(1): 3982, 36 pp.

Ergül, H.A. and S. Aksan. 2013. Evaluation of non-essential element and micronutirent concentrations in seafood from the Marmara and Black Seas. J. Black Sea/Mediterranean Environment, 19(3): 312-331.

FAO/WHO. 2010. Summary report of the seventy-third meeting of JECFA. Joint FAO/WHO Expert Committee on Food Additives. Geneva.

FAO/WHO. 2011. Joint FAO/WHO food standards programme codex committee on contaminants in foods, Fifth Session, working document for information and use in discussions related to contaminants and toxins in the GSCTFF, The Hague, The Netherlands, 90 p.

Fındık, Ö. and E. Çiçek. 2011. Metal concentrations in two bioindicator fish species, *Merlangius merlangus*, *Mullus barbatus*, captured from the west Black Sea coasts (Bartin) of Turkey. Bull. Environ. Contam. Toxicol., 87: 399-403.

Förstner, U. and G.T.W. Wittmann. 1983. Metal Pollution in the Aquatic Environment. Second Revised Edition. Springer-Verlag, Berlin.

GAIN (Global Agriculture Information Network) Report. 2002. Russian Federation Sanitary/ Phytosanitary/ Food Safety Russian Sanitary Rules and Norms. GAIN Report #RS2010. SanPiN-96. USDA Foreign Agricultural Service. Gossanepidnadzor Department of the Ministry of Public Health Care of Russia.

GAIN (Global Agriculture Information Network) Report. 2006. China, Peoples Republic of FAIRS Product Specific Maximum Levels of Contaminants in Foods. GAIN Report Number: CH6064. USDA Foreign Agricultural Service. Issued by the Ministry of Hygienic.

Georgian Food Safety Rules. 2001. Fish, other river/sea products and products made from them. SanPiN-2.3.2.560-96. The Minister's Decree 16/08/2001 N301/n for Health, Labour and Social Affairs.

Gladyshev, M.I., N.N. Sushchik, O.V. Anishchenko, O.N. Makhutova, G.S. Kalachova and I.V. Gribovskaya. 2009. Benefit-risk ratio of food fish intake as the source of essential fatty acids vs. heavy metals: A case study of Siberian grayling from the Yenisei River. Food Chemistry, 115: 545-550.

Gündoğdu, A., S. Türk Çulha, F. Koçbaş and M. Çulha. 2016. Heavy metal accummulation in muscles and total bodies of *Mullus barbatus, Trachurus trachurus* and *Engraulis encrasicolus* captured from the coast of Sinop, Black Sea. Pakistan J. Zool., 48(1): 25-34.

Järup, L. 2003. Hazards of heavy metal contamination. British Medical Bulletin 68: 167-182.

Korotaev, G., T. Oguz, A. Nikiforov, and C. Koblinsky. 2003. Seasonal, interannual, and mesoscale variability of the Black Sea upper layer circulation derived from altimeter data. J. Geoph. Res., 108(C4): 3122.

Köse, H.Ö., A. Taner, and B. Erkan. 2013. International cooperation for saving the Black Sea and the coordinated parallel audit by SAIs of the region. Yönetim ve Ekonomi, 20(1): 105-117.

Kovalev, A.V., V.A. Skryabin, Yu A. Zagorodnyaya, F. Bingel, A.E. Kıdeyş, U. Niermann, and Z. Uysal. 1999. The Black Sea zooplankton: Composition, spatial/temporal distribution and history of investigations. Tr. J. Zoology, 23: 195-209.

MAFF (The Ministry of Agriculture, Forestry and Fisheries). 1995. Monitoring and surveillance of non-radioactive contaminants in the aquatic environment and activities regulating the disposal wastes at sea, of 1993. Directorate of Fisheries Research, Lowestoft, Aquatic Environment Monitoring Report, No.44.

Mance, G. 1987. Pollution threat of heavy metals in aquatic environments. Pollution Monitoring Series. Elsevier App. Sci., London.

Martin, S.E. and W. Griswold. 2009. Human Health Effects of Heavy Metals. Environmental Science and Technology Briefs for Citizens Center for Hazardous Substance Research 15: 6 pages.

Mee, L. 1992. The Black Sea in crisis: A need for concerted international action. Ambio 21(4): 278-286.

Mee, L.D. 2005. How to Save the Black Sea. Your Guide to the Black Sea Strategic Action Plan. 31 pp.

Mendil, D., Z. Demirci, M. Tuzen, and M. Soylak. 2010a. Seasonal investigation of trace element contents in commercially valuable fish species from the Black Sea, Turkey. Food and Chemical Toxicology, 48: 865-870.

Mendil, D., Ö.F. Ünal, M. Tüzen, and M. Soylak. 2010b. Determination of trace metals in different fish species and sediments from the River Yeşilırmak in Tokat, Turkey. Food and Chemical Toxicology, 48: 1383-1392.

National Academy of Science. 1989. Recommended Dietary Allowances, 10th Edition, National Academy Press, Washington, D.C., p. 298.

Nieboer, E. and D.H.S. Richardson. 1980. The replacement of the nondescript term “heavy metals” by a biologically and chemically significant classification of metal ions. Environ Poll Series B- Chem. Phys., 1: 3-26.

Nisbet, C., G. Terzi, O. Pilger, and N. Sarac. 2010. Determination of heavy metal levels in fish sample collected from the Middle Black Sea. Kafkas Univ. Vet. Fak. Der., 16(1): 119-125.

Official Journal of the European Union. 2008. Directives Directive 2008/56/Ec of The European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). L 164: 19-40.

Oguz, T., V.S. Latun, M.A. Latif, V.V. Vladimirov, H.I. Sur, A.A. Makarov, E. Ozsoy, B.B. Kotovshchikov, V. Eremeev, and U. Unluata. 1993. Circulation in the surface and intermediate layers of the Black Sea. Deep Sea Res. Part I, 40: 1597-1612.

Oguz, T., S. Tugrul, A.E. Kideys, V. Ediger, and N. Kubilay. 2009. Chapter 33. Physical and biochemical characteristics of the Black Sea. Available online at: http://www.ims.metu.edu.tr/cv/oguz/PDFs/oguz_sea14_ch33.pdf (accessed 5 April 2013)

Öztürk, M, and L. Bat. 1994. Heavy metal levels in some edible organisms from Sinop coast of the Black Sea, (in Turkish). Journ. of the Fac. of Science. E. U. Series B, (16/1): 177-186.

Paradas, W.C. and G.M. Amado Filho. 2007. Are metals of antifouling paints transferred to marine biota? Brazillian Journal of Oceanography, 55(1): 51-56.

Sioen, I., S. De Henauw, F. Verdonck, N. Van Thuynec and J. Van Camp. 2007. Development of a nutrient database and distributions for use in a probabilistic risk-benefit analysis of human seafood consumption. Journal of Food Composition and Analysis, 20: 662-670.

Štirn, J. 1981. Manual of methods in aquatic environment research. Part 8. Ecological assessment of pollution effects. (Guidelines for the FAO (GFCM)/UNEP Joint Coordinated Project on Pollution in the Mediterranean). FAO Fish. Tech. Pap. 209: 70 p.

Svobodová, Z., R. Lloyd, J. Máchová, and B. Vykusová. 1993. Water quality and fish health. EIFAC Technical Paper. No. 54. Rome, FAO. 59 p.

Tepe, Y., M. Turkmen, and A. Turkmen. 2008. Assessment of heavy metals in two commercial fish species of four Turkish Seas. Environ Monit Assess., 146: 277-284.

Terry, P., P. Lichtenstein, M. Feychting, A. Ahlbom, and A. Wolk. 2001. Fatty fish consumption and risk of prostate cancer. The Lancet, 357(2): 1764-1766.

TFC. 2002. Turkish Food Codex, Notice on the maximum levels of certain contaminants in food. Official gazette: 23/09/2002- Issue: 24885 Notice No: 2002/63.

TFC. 2008. Notice on the maximum limits of contaminants in foods (in Turkish). Official gazette: 17.05.2008- Issue: 26879, Notice No: 2008/26.

TFC. 2009. Official Gazette of Republic of Turkey. Notifications changes to the maximum levels for certain contaminants in foodstuffs (in Turkish). (Notification No: 2009/22), Issue: 27143.

The Earth Report-3. 1992. An A-Z guide to environmental issues. In E. Goldsmith, and N. Hildyard [eds.], Mitchell Beazley Publishers, London, 175 p.

Topcuoglu, S., C. Kirbasoglu, and N. Gungor. 2002. Heavy metals in organisms and sediments from Turkish Coast of the Black Sea, 1997-1998. Environment International, 27: 521-526.

TUIK, Turkish Fishery Statistics. 2016. http://www.tuik.gov.tr/

Turan, C., M. Dural, A. Oksuz, and B. Ozturk. 2009. Levels of heavy metals in some commercial fish species captured from the Black Sea and Mediterranean coast of Turkey. Bull Environ. Contam. Toxicol., 82: 601-604.

Turk Culha, S., L. Bat, M. Culha, A. Efendioglu, M. Andac, and B. Bati. 2007. Heavy metals levels in some fishes and molluscs from Sinop peninsula of the southern Black Sea, Turkey. Rapp. Comm. int. Mer Medit., 38.

Türkmen, A., Y. Tepe, and M. Türkmen. 2008. Metal levels in tissues of the European Anchovy, *Engraulis encrasicolus* L., 1758, and Picarel, *Spicara smaris* L., 1758, from Black, Marmara and Aegean Seas. Bull Environ Contam Toxicol., 80: 521-525.

Türkmen, M. and N. Dura. 2016. Assessment of heavy metal concentrations in fish from south western Black Sea. Indian Journal of Geo Marine Sciences, 45(11): 1552-1559.

Tuzen, M. 2003. Determination of heavy metals in fish samples of the Middle Black Sea (Turkey) by graphite furnace atomic absorption spectrometry. Food Chemistry, 80: 119-123.

Tüzen, M., D. Mendil, H. Sarı, M. Suiçmez, and E. Hasdemir. 2004. Investigation of trace metal levels in fish species from the Black Sea and the River Yeşilırmak, Turkey by Atomic Absorptıon Spectrometry. Fresenius Environmental Bulletin, 13(5): 472-474.

Tuzen, M. 2009. Toxic and essential trace elemental contents in fish species from the Black Sea, Turkey. Food and Chemical Toxicology, 47: 1785-1790.

Uluozlu, O.D., M. Tuzen, D. Mendil, and M. Soylak. 2007. Trace metal content in nine species of fish from the Black and Aegean Seas, Turkey. Food Chemistry, 104(2): 835-840.

Ünsal, M., M. Doğan, U. Ataç, S. Yemencioğlu, Ş. Akdoğan, Y. Kayıkçı, and M. Aktas. 1992. Determination of heavy metals in the marine organisms of economical importance in the central and eastern Black Sea, (in Turkish). Report on 1991. Ministry of Agriculture and Rural Affairs Trabzon Fisheries Research Institute. Project No: DEBAG- 18/G; pp. 64.

Ünsal. M., Y. Bekiroglu, Ş. Akdoğan, U. Ataç, Y. Kayıkçı, N. Alemdağ, M. Aktaş, and C. Yıldırım. 1993. Determination of heavy metals in some economically important marine organisms in southwestern Black Sea, (in Turkish). TUBİTAK Project No: DEBAG-80/G pp.78.

Ünsal, M., Y. Bekiroğlu, Ş. (Akdoğan) Beşiktepe, Y. Kayıkçı, Y. Alemdağ, M. Aktaş, and C. Yıldırım. 1995. Determination of the land-based sources of heavy pollution in the middle and eastern Black Sea Coast, (in Turkish). Ministry of Agriculture and Rural Affairs Trabzon Fisheries Research Institute. Project No: DEBAG–121/G; pp. 59.

Vuorinen, P.J., M. Keinänen, S. Peuranen, and C. Tigerstedt. 1999. Effects of iron, aluminium, dissolved humic material and acidity on grayling (*Thymallus thymallus*) in laboratory exposures, and a comparison of sensitivity with brown trout (*Salmo trutta*). Boreal Environment Research, 3: 405-419.

WHO. 1989. Evaluation of certain food additives and contaminants. Report of the Thirty-Third of the Joint FAO/WHO Expert Committee on Food Additives. Technical Report Series No. 776. Geneva.

WHO. 1996. Trace elements in human nutrition and health. ISBN 92 4 156173 4 (NLM Classification: QU 130), Geneva.

WHO. 2004. Evaluation of certain food additives and contaminants. Report of the Sixty-First of the Joint FAO/WHO Expert Committee on Food Additives. Technical Report Series No. 922. Geneva.

Young, D.R., G.V. Alexander, and D. Mc Dermott-Ehrlich. 1979. Vessel-related contamination of Southern California Harbours by copper and other metals. Mar. Pollut. Bull., 10: 50-56.

Zaitsev, Yu. and V. Mamaev. 1997. Marine Biological Diversity in the Black Sea: A Study of Change and Decline. GEF Black Sea Environmental Programme. United Nations Publications, New York, 208 pp.

EVALUATION OF MONOAROMATIC HYDROCARBON POLLUTION IN SEDIMENTS OFFSHORE TURKISH BLACK SEA COAST

Selma ÜNLÜ and Bedri ALPAR

Istanbul University, Institute of Marine Sciences and Management, 34134 Vefa, Istanbul, Turkey
su@istanbul.edu.tr

1. Introduction

Monoaromatic hydrocarbons constitute an important fraction of volatile organic compounds in the aquatic environment. The volatile mono aromatic hydrocarbons, a collective name for benzene, toluene, ethylbenzene, and *o*-xylene, *(m+p)*-xylenes (light aromatic BTEX compounds) are also major constituents of re-refined petroleum products and other common environmental contaminants. They are highly volatile and are quickly lost through evaporative processes. The BTEX compounds are among the most abundantly produced chemicals, and majority of them released into the environment enter the atmosphere directly (Buczynska *et al.* 2009). In addition to some natural sources (*e.g.* superior plant wax, algae and plankton), they are generated by incomplete combustion of organic matter from mobile (vehicle exhaust) and stationary (wood, coal and waste burning, heating, oil refining) sources (Hinwood *et al.* 2006). They are included in the US Environmental Protection Agency (EPA) purgeable priority pollutants list (USEPA 1989, 1993).

2. Study Area

The major environmental problems of the Black Sea, a marine basin virtually dead below a depth of about 100-150 m where high concentrations of hydrogen sulphide and sulphate-reducing bacteria are present (Murray *et al.* 1991), are markedly differrent from those in other seas. Having excess nutrient loads via the rivers (320-350 km^3 per year) and directly from land-based sources of domestic, industrial and agricultural sources and having anoxic conditions accounting for 87% of it, the Black Sea is now the largest natural anoxic water basin in the world and ranked among the most threatened inland seas of the world.

Oil pollution is another problem of the Black Sea especially at places close to well-known sources. The highest levels of petroleum hydrocarbons (>0.18 mg l^{-1}) detected in the surface waters of the Black Sea are located in three distinct areas. They are offshere the Georgian oil terminals, Danube River, and Turkish coast from Bulgarian border to the Zonguldak industrial area (BSERP 2007). Even the region along the northern exit of the Strait of Istanbul (Bosphorus) is not an industrial region but it is placed on the main shipping routes. Oil contamination in sediments, however, is considerably less (5.5 – 60 μg g^{-1}) than those found in surface waters. High-speed Black Sea currents and clean Mediterranean water within the two-layer water exchange should be preventing most of the deposition in sediment. To the east, petroleum hydrocarbon contamination in sediments becomes more crucial mainly due to major land-based sources and maritime transport of petroleum carrying tankers (Ünlü *et al.* 2009).

Land-based pollution sources (mainly rivers, domestic and industrial discharges and dumping) account for more than 70% of the sediment pollution in the Black Sea. The large river systems drain 87% of its catchments and provide the 60% of the freshwater input. The water input and sediment load of the Turkish rivers are estimated annually at 41 km^3 and 28 million tons, respectively (Hay 1994). Oil waste discharged annually into the Black Sea is estimated >110,000 tons; half-transported by the Danube River (>53,900 tons) and the rest from land-based sources of its coastal states. Moreover, all maritime activities, including petroleum transport and operational discharges of vessels, contribute to the environmental pollution (Palshin 1998).

The sedimentogenesis situation in the basin is greatly influenced by the runoff fluctuations of Black Sea Rivers, which display a wide range of seasonal variations with a maximum in spring, and by the characteristic features of the watershed. Most of the sediment is carried by the rivers around the periphery and the total annual sediment load into the basin is at least 145 million ton, 20% of which enters into the Anatolian shelf region (Hay 1994). These coasts are mostly polluted with oil particularly close to seaports and river mouths (*e.g.,* Sakarya, Filyos, Kızılırmak Yeşilırmak, Filyos and Bartın).

If compared to the others, Turkey's Black Sea region is not heavily industrialized. Various types of small-scale industries, *e.g.* textile, food, forest products, metal, etc., are scattered in and around the settlement areas usually occupying nearly the whole of the space between the sea and the backside mountains. Some of the larger industrial establishments are located between Ereğli and Zonguldak, the coastal cities of affected from interdependent processes of modern economic development, i.e. industrialization, urbanization and immigration (Ünlü and Alpar 2010).

Iron and steel complexes composed from many separate plants, hard-core production, coke plant, ore processing, mine quarries, mining machine industries and thermal power plants are responsible for the major coastal "hot spots". These areas still suffer from the impacts of air and water pollution from industries mostly due to the difficulties involved in enforcing environmental laws on the existing facilities (Özhan 1996).

Oil waste discharged into the Black Sea because of unlawful disposal of ships' wastes and accidents, as well as through land-based sources is estimated to be 110,840 tons annually; nearly half of it is transported by the Danube River (53,300 tons) and the rest from land-based sources of the Black Sea coastal states (BSERP 2007). Even though oil levels are not very high in the open Black Sea, unacceptable levels can be detected near polluted harbours and some river mouths. However, there is no sufficient measurement data including the content and potential sources of the aromatic fuel oil components in the aquatic environment of the Turkish Black Sea coast of Turkey.

The Turkish coast of the Black Sea is not a heavily industrialized region excluding some well-known hot spot areas. During the last decades, however, the Black Sea has been subjected to strong environmental impacts that may lead to serious changes in the ecology. The main scopes of the present study are to define the archieval database of monoaromatic hydrocarbon (BTEX) compounds in sediments offshore the Turkish coast of this inland sea, to understand their distribution characteristics according to other parameters such as depth and texture, and to identifiy their possible major sources.

3. Materials and Methods

3.1. Sampling procedure

The surface samples were collected in September 2005 from 48 stations along the Turkish Black Sea shelf areas. The sampling depths were between 9 and 113 m (Figure 1). The topmost 3 cm parts of the grab samples were removed carefully using clean stainless steel spatula. The samples were boxed on a dry ice bed immediately after sampling and transported to the laboratory as soon as possible for analyses.

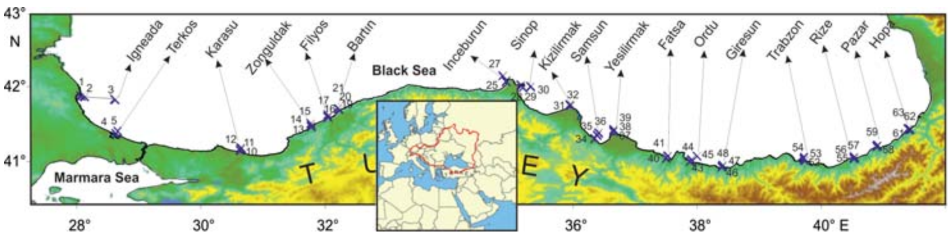

Figure 1. Map showing the sampling stations along the Black Sea shelf of Turkey. Inset shows drainage area of the Black Sea basin

3.2. Sample prepration for chemical analysis

Approximately 10 g of wet sediment was placed in precombusted jar for chemical drying with anhydrous sodium sulfate until it is dry, free-flowing, and homogeneous, then automatic Soxhlet-extracted with dichloromethane (100 ml) for 8h with activated copper. Two grams of anhydrous sodium sulfate were added to remove water. The combined extracts were dried with anhydrous sodium sulphate, and the volume was reduced to 2 ml by rotary evaporation. Aromatic fraction is obtained by adsorption chromatography, using alumina: silica (1:2 volume) column chromatography

(UNESCO 1982). Standard response curves of fluorescence intensity versus concentration are generated for 1) seven different crude oils (from Libya, Saudi Arabia, Egypt, Syria, Cas-pian basin, Iran and Iraq) representing their usage and transportation in the Black Sea region (Ünlü and Güven 2001), and 2) chrysene (Merck), the standard aromatic hydrocarbon. As the geological source of the seven different crude oils used and transported in the Black Sea region is the Thetis Ocean, a huge paleogeographical sea dominant in the periods of Jurassic and Cretaceous, in this study, a com-bined name of Thetis-Oil is given for the seven crude oils (Ünlü *et al.* 2009, Alpar and Ünlü 2010).

3.3. Chemicals and reagents

Standard solutions containing benzene (99.99%), toluene (99.5%), ethyl benzene (99.97%), *m*-xylene (99.8%), *p*-xylene (99.9%) and *o*-xylene (99.3%) were purchased from Merck (Darmstadt, Germany). For qualitative and quantitative recognition of the BTEX compounds in samples, standard curves have been generated for different concentration ranges using benzene, toluene, ethyl benzene, *m-*, *p-* and *o-*xylene standards in hexane. Detection limits and recoveries were obtained from analysis of three replicates standard solutions at concentrations of 1.5, 3.12, 6.25, 12.5, 25, 50 µg L^{-1}, respectively.

3.4. Analyses

3.4.1. Volatil aromatic hydrocarbons (BTEX compounds)

The qualitative and quantitative identification of BTEX compounds were conducted by Finnigan Thermo trace DSQ gas chromatography/mass spectrometry (GC/MS) using a modified EPA Method 5021 for the detailed molecular characterization of gasoline-derived contamination. This method describes an automated headspace analysis for soils and other solid matrices.

The concentrations in the sediment samples were determined at MERLAB Central Research Laboratory of Istanbul University using a static headspace autosampler (Thermo Finnigan model HS 2000) equipped with 10 ml glass vials. HS-GC–MS reference procedure set was in accordance with the description of Esteve-Turrillas *et al.* (2007). For qualitative and quantitative identification of the BTEX compounds in the sediment samples, standard curves have been generated for different concentration ranges using benzene, toluene, ethyl benzene, *m-*, *p-* and *o*-xylene standards in hexane. One gram of sediment sample was weighted in glass vial. The sample heated in headspace autosampler at 90°C for 10 min with shaking (headspace syringe temperature: 100°C). The initial oven temperature was 40°C (held for 10 min), then increased up to 200°C (rate 20°C min^{-1}) and held at this temperature for two minutes. Electron impact ionization was used at 70eV and helium flow is 1 ml min^{-1}. Transfer line temperature was held at 250°C. The detector temperature was set to

230°C. In order to obtain the reference data by chromatography a Hewlett Packard HP 5MS (Palo Alto, CA, USA) column was used (30m x 0.32mm i.d., film thickness: 0.25µm).

3.4.2. Analytical Quality Assurance

The vendor software Xcalibur from Thermo (Waltham, MA, USA) and TurboQuant Analyst 6.0 software (Thermo Nicolet Corp. Madison, USA) was employed for measurements and calibration. The mass spectra were obtained at a mass-to charge ratio (*m/z*) scan range from 75 to 200. The specific ions generated at *m/z* 77 and 78 for benzene, *m/z* 91 and 92 for toluene and *m/z* 91 and 106 for ethylbenzene and xylenes. The recoveries of compounds were found to be between 70 and 130%. The repeatability (n=3) varied between 14.9 % (benzene), 7.0 % (toluene), 3.1 % (ethylbenzene) and 13.7 % (xylene). %. The limit of detection (LOD) was between 0.25-0.5 µg kg^{-1} dw for each component.

3.4.3. Other analyses in the sediment samples

Particle grain size (PGS) analysis was applied to samples using the method described in standard operating procedures SOP-8908 at GERG. Granulometric fractions influence the chemical composition in sediment significantly and considered as a normalization parameter. Organic carbon content of samples were measured by Thermo Finnigan FLASH EA 1112 model CHN analyzer at the MERLAB Central Research Laboratory of Istanbul University, after removing the inorganic carbonate fractions, and were replicated within runs and over time with a confidence interval of 0.1%. TOC data was also measured by means of the Walkley-Black method (Loring and Rantala 1992). The analytical precision of analysis was better than ±4% at 95% significance level from five replicates.

3.4.4. Statistical Analyses

Pearson's correlation coefficients calculated the strength of relationships between the monoaromatic hydrocarbon concentrations, and principal component analysis (PCA) quantified spatial/temporal variability of BTEX sources for Turkish Black Sea coast sediment samples (n=48). The first few components explain the inherent variances to largest possible extent (Varmuza and Filzmoser 2008). In the present study, PCA was conducted with varimax rotation. The first three eigenvalues retained were greater than one; as 3.86, 1.95 and 1.49 (n=48).

4. Results and Discussion

4.1. Textural characteristics of sediment

The southern shelves of the Black Sea extend northwards until a shelf break at about 100-130 m water depth. The sediment samples collected above 100 m stay within the oxygenated surface layer of the Black Sea, which is only 50-100 m thick (Table 1). The samples are mainly composed of various size-grained sediments, mainly mud (Figure 2). The depth seems not to be the sole restraint parameter on the grain size distribution, possibly due to rapidly changing morphology incised by canyons and the chaotic physical processes in the water column especially above the sea surface.

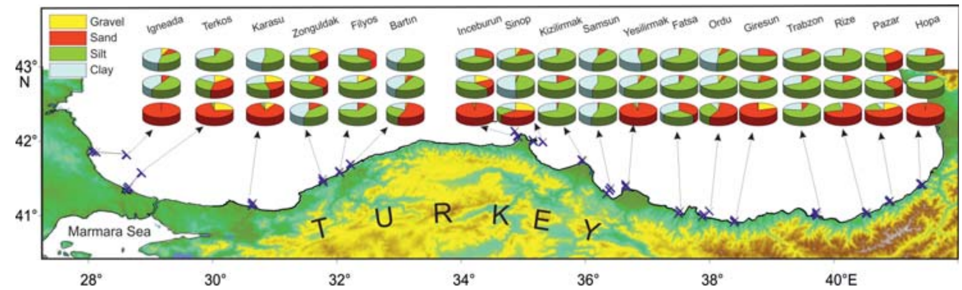

Figure 2. Distribution of textural characteristics of sediments offshore Turkish Black Sea coast

4.2. TOC and TPH Distributions

The TOC content in sediments ranges from 0.5 to 3.2% with an average of 1.54±0.67% (n=48) (Table 1). The highest values of TOC content were recorded offshore the harbours of Zonguldak and Ordu (3.2%), due to coal production and port activities.

The levels of total hydrocarbon, which are calculated using the equation given by Ünlü *et al.* (2009), are scattered in a wide range from 6 to 1546 $\mu g\ g^{-1}$ (dry weight) (Table 1). The high values (>100 $\mu g\ g^{-1}$ dw) confirm chronic oil pollution, especially those measured near the Zonguldak port (1546 $\mu g\ g^{-1}$ dw), Inceburun peninsula (1292 $\mu g\ g^{-1}$ dw), Sinop port (915 $\mu g\ g^{-1}$ dw) and Trabzon port (330 $\mu g\ g^{-1}$ dw). According to Readman *et al.* (2002) the concentrations higher than 100 $\mu g\ g^{-1}$ dw are mainly related with port activities or riverine (terrestrial) inputs.

Table 1. The depth (Dep in m), mud (%), sediment water content (Swc in %), total organic carbon (TOC in %), total petroleum hydrocarbon (TPH in μg g^{-1} dw) and concentrations of light aromatic BTEX fractions and total BTEX (μg kg^{-1} dw) in the sediment samples given in Figure 1.

Region	St.	Dep	Mud	Swc	TOC	TPH	B	T	EB	*(m+p)*-X	*o*-X	Total
	1	23	0.1	14.4	0.5	10	BC	BC	BC	BC	BC	BC
	2	50	92.5	57.8	1.5	80	0.3±0,1	0.7±0,1	BC	BC	BC	1.0
Igneada	3	100	84.3	47.4	2.4	102	BC	BC	BC	BC	BC	BC
	4	21	3.1	16.5	1.2	143	BC	BC	BC	BC	BC	BC
Terkos	5	53	46.7	37.4	2.4	43	BC	BC	BC	BC	BC	BC
	10	21	4.1	27.7	1.1	8.2	0.7±0,1	16.4±1,9	3.3±0,5	43.8±3,9	13.2±1,2	77.4
	11	50	54.2	38.0	1.5	29	BC	BC	BC	BC	BC	BC
Karasu	12	98	100	59.3	2.7	46	0.4±0,1	1.5±0,6	BC	0.6	BC	2.5
	13	23	87.3	25.7	3.2	1546	6.2±0,1	9.3±3,1	5.1±2,8	21.7±7,3	2.3±3,2	44.5
	14	51	64.0	38.2	2.1	390	4.2±0,7	9.0±1,4	0.8±0,1	16.6±3,1	1.4±0,0	32.0
Zonguldak	15	103	59.3	43.5	1.4	25	BC	BC	BC	BC	BC	BC
	16	21	91.3	21.3	1.0	513	BC	BC	BC	BC	BC	BC
Filyos R.	17	50	85.5	36.0	2.1	207	0.2±0,1	0.5±0,1	BC	BC	BC	0.7
	19	21	44.0	29.5	0.7	9	2.6±1,8	3.3±2,5	BC	BC	BC	5.9
	20	54	92.5	40.5	1.2	294	0.5±0,1	0.7±0,2	BC	1.3±0,2	BC	2.6
Bartın	21	103	100	45.1	1.3	286	0.3±0,0	1.9±0,5	BC	BC	BC	2.2
	25	21	1.9	20.1	0.8	1292	BC	0.3±0,0	BC	BC	BC	0.3
Inceburun	27	101	69.6	46.9	1.5	164	2.0±0,3	6.1±1,0	0.7±0,1	3.9±0,6	0.9±0,0	13.6
	28	21	36.2	32.7	1.0	915	BC	0.3±0,1	BC	BC	BC	0.3
	29	49	97.6	53.8	1.6	59	1.3±0,2	2.5±0,6	BC	BC	BC	3.8
Sinop	30	97	81.0	43.9	1.6	100	0.3±0,0	0.9±0,1	BC	BC	BC	1.2
	31	25	98.4	32.1	0.7	28	0.3±0,0	0.9±0,2	BC	BC	BC	1.1
Kızılırmak	32	38	85.9	37.1	0.8	62	0.2±0,0	0.7±0,2	BC	BC	BC	0.9
	34	13	98.6	8.9	2.0	119	4.4±0,3	147±16,8	22±4,0	148.2±23,9	18.5±1,6	340
	35	51	100	46.1	0.9	34	0.1±0,0	0.3±0,0	BC	BC	BC	0.4
Samsun	36	103	91.4	50.4	1.7	77	0.2±0,0	1.4±0,4	BC	1.0±0,1	BC	2.6
	37	12	4.8	17.9	0.8	32	BC	BC	BC	BC	BC	BC
	38	51	92.7	34.7	1.3	43	BC	0.4±0,2	BC	BC	BC	0.4
Yesilırmak	39	103	96.5	47.9	1.3	122	BC	14.3±2,7	2.9±0,3	36.5±10,5	13.0±2,5	67
	40	21	63.7	43.1	0.7	100	BC	BC	BC	BC	BC	BC
Fatsa	41	51	95.5	44.3	1.6	63	0.2±0,0	0.7±0,1	BC	BC	BC	0.8
	43	9	42.6	23.7	0.7	96	BC	14.5±1,2	2.4±0,6	19.5±8,4	10.0±1,9	46.4
	44	53	92.9	45.2	3.2	64	0.3±0,1	0.2±0,0	BC	BC	BC	0.6
Ordu	45	100	90.1	55.5	1.9	123	0.7±0,0	16.3±1,3	3.5±0,7	32.3±3,9	15.8±1,1	69
	46	21	0.7	20.8	0.7	94	BC	12.6±0,4	2.5±0,6	23.2±1,8	10.7±2,4	49.0
	47	53	84.9	48.1	1.7	64	BC	13.1±1,2	1.9±0,8	17.7±4,4	8.3±1,0	41.0
Giresun	48	98	75.1	44.8	2.1	88	BC	BC	BC	BC	BC	BC
	52	10	93.6	38.4	0.9	330	2.2±0,2	8.2±2,1	0.7±0,1	4.5±1,2	0.8±0,1	16.4
	53	52	90.0	50.6	1.7	40	BC	BC	BC	BC	BC	BC
Trabzon	54	93	87.1	40.8	1.4	57	BC	13.4±3,5	3.3±0,9	34.7±12,6	13.8±3,8	65.1
	55	21	28.9	28.8	1.1	269	BC	15.4±2,1	2.4±0,8	19.2±11,9	9.2±5,1	46.2
	56	53	87.6	53.2	2.1	201	BC	0.5±0,1	BC	BC	BC	0.5
Rize	57	113	97.4	48.6	1.9	12	BC	BC	BC	BC	BC	BC
	58	21	25.3	11.5	1.4	12	BC	14.7±1,9	1.8±1,0	11.5±1,2	6.0±1,6	34.0
Pazar	59	52	59.6	45.8	2.4	88	BC	BC	BC	BC	BC	BC
	61	22	1.5	17.5	1.3	7	BC	BC	BC	BC	BC	BC
	62	52	88.1	47.4	2.6	132	BC	15.4±1,1	BC	7.8±0,6	6.1±0,8	29.3
Hopa	63	101	79.4	47.4	2.3	86	0.7±0,1	0.6±0,1	BC	BC	BC	1.3
Min		9.0	0.1	9.0	0.5	7.0	0.1	0.2	0.7	0.6	0.8	BC
Max		113	100	59	3.2	1546	6.0	147	22	148	18	340
Mean		53	67.6	38	1.5	185	1.3	10.1	3.8	24.7	8.7	20.8

BC: not calculated due to concentrations below the detection limits. B: Benzene, T: Toluene, E: Etylbenzene, *(m+p)*-X: *(meta+para)*-Xylene, *o*-X: *ortho*-Xylene.

4.3. BTEX compounds in sediment samples

Distributions of concentrations of volatile gasoline-related compounds were different in the sites sampled and they varied between concentrations below the detection limits and 340 μg kg^{-1} dw along the southern Black Sea shelf (Figure 3). The distribution of BTEX concentrations may depend on various factors such as petroleum hydrocarbon distribution, distance to the hot points, water depth, sediment texture, land-based pollutant sources and the variability of biodegradation processes. The total BTEX concentrations, in general, were much higher in the Eastern Black Sea (EBS) region than the western Black Sea (WBS) region and the maximum value was (340 μg kg^{-1}) at station 34 near-shore sediments in Samsun. Median concentrations of BTEX compounds in the EBS region and the WBS region were 32.4 and 8.3 μg kg^{-1}, respectively (Table 1).

4.4. Statistical relationships between parameters

The regression analysis revealed the relationships between the concentration of individual BTEX compounds, percentage of grain size, sediment water content, TOC and total petroleum hydrocarbon levels (Table 2). The TOC concentrations increase slightly with the increasing depth and finer grain size. The finer grained sediments (i.e. silt and clay) have much ability to carry and store pollutants than coarse-grained sandy sediments. Therefore, the samples with low TOC values are mostly made up of coarse-grained sediments (r^2=0.48, $p<0.01$). The samples taken from higher depths (93-113 m) contain higher TOC contents (1.8-2.7%), with a correlation of r^2=0.43 ($p<0.01$). Clay is better correlated with TOC for shallow depths than 25 m ($r^{2=}$0.55, $p<0.05$). The organic matter sedimentation rates are highest in anoxic systems. Therefore, in addition to seaport areas, most of carbon preservation in sediment occurs in anoxic systems.

The correlation matrix exhibits moderate to high similarities between the BTEX compounds ($0.47>r^2>0.99$; $p<0.01$), except weak correlation between benzene and *o*-Xylene. There is a moderate correlation between the levels of TPH and benzene (0.45, $p<0.01$), while no meaningful correlations have been detected with other light aromatic hydrocarbon compounds.

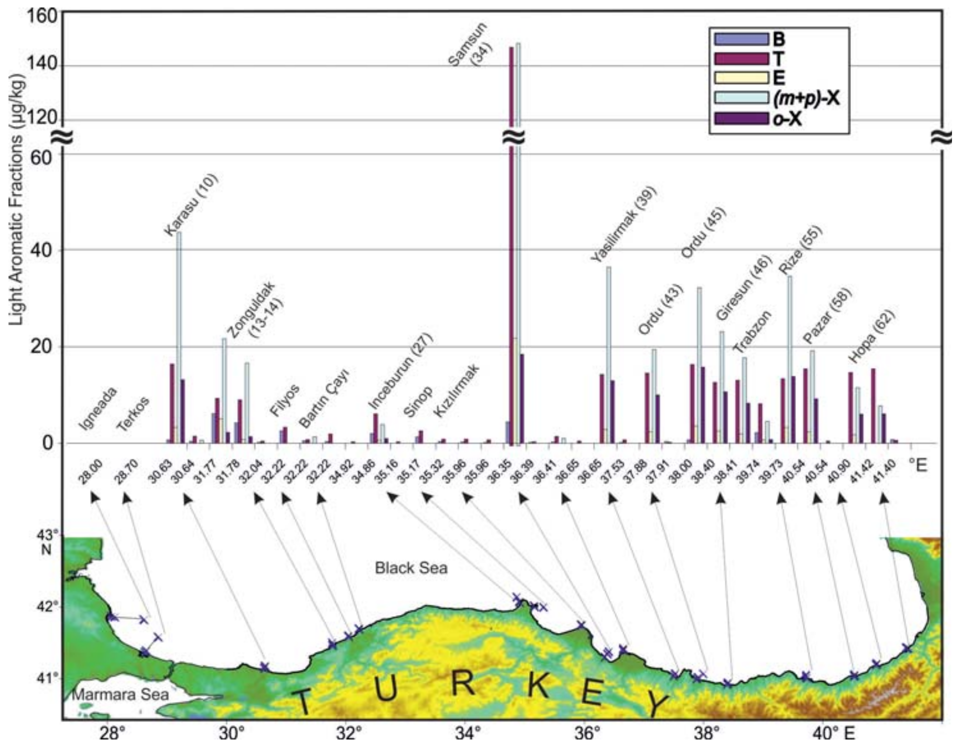

Figure 3. Contributions of BTEX levels of sediments offshore Turkish Black Sea coast.

4.5. Source identification of the BTEX compounds in sediment samples

PCA technique reveals if relevant relationships exist between the cases. Three principal components were retrieved for the Black Sea shelf sediments. Including the loadings of different BTEX congeners, TPH, and some physicochemical parameters in sediment samples and considering all of the stations from Western and Eastern Black Sea, the variance loading of the first three factors is 42.9, 21.7 and 16.6% of the total variability respectively (accumulative variance 81.2%, n=48). If we separate the stations into two clusters, as the western (n=23, stations 1-32) and the eastern Black Sea (n=25, stations 34-63), the main two factors used to identify the source categories and the loadings are shown in Figures 4a and b.

Factor 1. Accounting for 46.4 and 48.4% of total variance in the western and eastern Black Sea region, respectively, this factor exhibits higher loadings for light aromatic fractions and TPH, influenced from anthropogenic inputs either from point or non-point sources.

Table 2. Pearson-coefficient correlation matrix (r) between concentrations of BTEX compounds, TPH, and some physicochemical parameters in sediment samples (n = 48).

	Depth	Gravel	Sand	Silt	Clay	swc	TOC	TPH	B	T	E	*(m+p)*-X	*o*-X
Gravel	-.158												
Sand	-.516**	.260											
Silt	.376**	-.452**	-.899**										
Clay	.570**	-.342*	-.852**	.603**									
swc	.719**	-.252	-.683**	.590**	.646**								
TOC	.426**	-.029	-.457**	.381**	.389**	.426**							
TPH	-.247	.026	.082	-.115	-.017	-.231	.108						
B	-.173	-.176	-.144	.083	.247	-.174	.295*	.447**					
T	-.195	-.090	-.085	.053	.134	-.342*	.089	-.022	.468**				
E	-.192	-.085	-.073	.015	.161	-.362*	.115	.079	.536**	.975**			
(m+p)-X	-.154	-.071	-.043	-.013	.132	-.325*	.073	.006	.468**	.957**	.976**		
o-X	-.062	-.010	.072	-.103	.003	-.202	-.046	-.091	.156	.660**	.701**	.806**	
∑BTEX	-.172	-.079	-.055	.009	.131	-.334*	.079	.001	.476**	.979**	.985**	.995**	.780**

*Correlation is significant at the 0.05 level (2-tailed). **Correlation is significant at the 0.01 level (2-tailed).

Factor 2. This factor showed the similar distribution pattern in both regions (with 22.6 and 22.1% of total variance). It controls different weathering degrees of light aromatic fractions and TPH. This includes rapid aerobic/anaerobic biochemical degradation under the control of nitrate or sulfate as the terminal electron acceptor, or desorption in the water column during the mixing, transportation and deposition of organic matter from point and non-point sources. The depth of the station, sediment texture and TOC control this factor. Mud and TOC, however, is only correlated for shallow depths (<25 m).

Factor 3. The third factor is responsible for 15.6% of the total variance in the western Black Sea, slightly higher than the eastern coasts (12.0%). This factor predominantly composed by TPH pollution solely, coming from point sources. They were observed at the western (4, 16, 17, 20, 21, 25, 28 and 30) and eastern (40 and 56) stations. These stations are close to the coast, except the station 30. Their TPH levels were greater than 100 μg g^{-1}, implying occurrence of oil spill or leakage pollution caused by vessels, possible discharges from municipal and industrial wastewater or occasional surficial runoff.

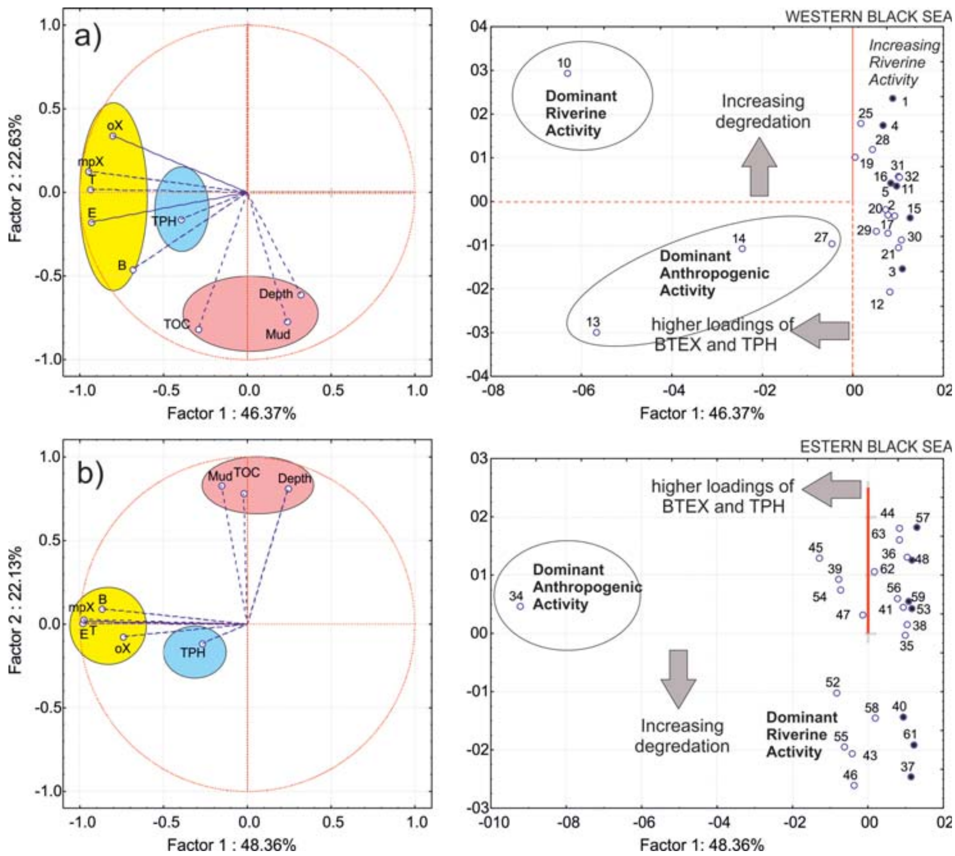

Figure 4. The projection of the variables and cases on the factor plain 1x2 for a) western and b) eastern basins of the Black Sea.

5. Conclusion

The exceptional geography, characteristic hydrographic features and intricate oceanographic conditions make the Black Sea region a unique but sensitive ecosystem. It is more vulnerable to various environmental problems facing humankind. Hydrocarbon (crude oil, diesel and gasoline oil etc) pollution in sediment is not a common phenomenon along the Turkish coast, but usually determined by various reasons. In addition to increasing ship transportation, for example, various land-based sources, such as commercial ports, fuel storage terminals, and anthropogenic inputs from industrial point sources or diffuse emissions are the most serious impacts of pollution on the Black Sea environment.

The highest concentrations of total BTEX were observed at the stations offshore the Zonguldak Industrial Zone, the Samsun Port and the river mouths, especially the Karasu River. If compared to the non-polluted stations, the concentrations close to such point sources were higher up to 4-8 times in the Eastern Black Sea, and 11-65 times in the Western Black Sea. There was not meaningful correlations between the levels of TPH and light aromatic hydrocarbon compounds, except a moderate one with benzene. In terms of the component scores and loadings, the main factors responsible for the incorporation, distribution and fate of the hydrocarbon pollution in the Turkish Black Sea coastal sediments are the high loading of anthropogenic / riverine inputs, the differences in the rate of weathering of light aromatic fractions and TPH and finally individual TPH pollution usually coming from point sources.

It is imperative that planned and continuous monitoring of pollutants be carried out at the polluted areas specified in this study and other vulnerable regions. Such kind of systematic programs will provide a basis for environmental impact assessment and control.

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References

Alpar, B. and S. Ünlü. 2010. Volatile aromatic compounds (BTEX) in sediments offshore Zonguldak Industrial Region, Black Sea, Turkey. Asian J. Chem., 22: 3531-3540.

BSERP. 2007. Black Sea Transboundary Diagnostic Analysis, Black Sea Ecosystem Recovery Project, Blck Sea Commision, GEF, UNDP, UNOPS. RER/01/G33/A/1G/31, Programme Coordinating Unit, Istanbul, Turkey.

Buczynska, A.J, A. Krata, M. Stranger, A.F.L. Godoi, V. Kontozova-Deutsch, L. Bencs, *et al.* 2009. Atmospheric BTEX-concentrations in an area with intensive street traffic. Atmos. Environ., 43: 311-318.

Esteve-Turrillas, F.A., S. Armenta, S. Garrigues, A. Pastor, and M. de la Guardia. 2007. Headspace-mass spectrometry determination of benzene, toluene and the mixture of ethylbenzene and xylene isomers in soil samples using chemometrics. Anal. Chim. Act., 587: 89-96.

Hay, B.J. 1994. Sediment and water discharge rates of Turkish Black Sea rivers before and after hydropower dam construction. Environ. Geol., 23: 276-283.

Hinwood, A.L., H.N. Berko, D. Farrar, I.E. Galbally, and I.A. Weeks. 2006. Volatile organic compounds in selected micro-environments. Chemosphere, 63: 421-429.

Loring, D.H. and R.T.T. Rantala. 1992. Manual for the geo-chemical analyses of marine sediments and suspended particulate matter. Earth-Sci. Rev., 32: 235-283.

Murray, J.W., Z. Top,. E. Özsoy. 1991. Hydrographic properties and ventilation of the Black Sea. Deep-Sea Res., 38 (2A): 663-690.

Özhan, E. 1996. Coastal Zone Management in Turkey. Ocean Coast. Manage., 30: 153-176.

Palshin, G. 1998. Black Sea in Crisis. In Proceedings from the 23rd Session of the International Seminars on Planetary Emergencies, ICSC-World Laboratory Rep. No. 23, Erice, Sicily, August 19-24.

Readman, J.W., G. Fillmann, I. Tolosa, J., Bartocci, J.-P. Villeneuve, C. Catinni, and L.D. Mee. 2002. Petroleum and PAH contamination of the Black Sea. Mar. Pollut. Bull., 44: 48-62.

UNESCO. 1982. The determination of petroleum hydrocarbons in sediments. Manuals and Guides, Intergovernmental Oceanographic Commission. 11: 1-35.

Ünlü, S. and K.C. Güven. 2001. Role of reference materials used in measurement of oil pollution and a correlation equation to determine oil in seawater. Bull. Environ. Contam. Toxicol., 67: 1-5.

Ünlü, S., B. Alpar, and Ş. Aydın. 2009. Spectrofluorometric characterization of aromatic hydrocarbon contamination in the sediment from the Zonguldak Industrial Region, Black Sea, Turkey. Fresenius Environ. Bull., 18: 474-480.

USEPA. 1989. Method 503.1 Volatile Aromatics. Environmental Monitoring and Support Laboratory, Cincinnati, USA.

USEPA. 1993. Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons. EPA/600/R-93/089, Washington, DC.

Varmuza, K. and P. Filzmoser. 2008. Introduction to Multivariate Statistical Analysis in Chemometrics. CRC Press, Taylor and Francis Group, Boca Raton, FL.

PREPAREDNESS AND RESPONSE TO OIL POLLUTION IN THE BLACK SEA

Fatma TELLİ KARAKOÇ [1], Dilek EDİGER [2], Ersan BAŞAR [1], and Çolpan POLAT BEKEN [3]

[1]Marine Sciences Faculty, Karadeniz Technical University, Çamburnu, Sürmene, Trabzon, Turkey
[2]Istanbul University, Institute of Marine Sciences and Management, Vefa, İstanbul, Turkey
[3]TUBİTAK Marmara Research Centre, Environment and Clean Technology Institute Gebze, Kocaeli, Turkey
fatma.tellikarakoc@ktu.edu.tr

1. Introduction

1.1. Geography and Maritime Traffic

Turkey is semi-surrounded by 4 seas which are the Black Sea in the north, The Sea of Marmara in the north-west, The Aegean Sea in the west and the Mediterranean Sea in the south. The Mediterranean Sea is connected to the Marmara Sea and the Black Sea via Çanakkale Strait (Dardanelles) and Istanbul Strait (Bosphorus) respectively. This system is called "Turkish Straits Systems". These consecutive straits opening from the Mediterranean Sea to the Black Sea, are extremely vital for the migration of marine organisms and maritime facilities.

The Black Sea is a landlocked sea with limited exchange with the world ocean. The climate and water properties of the Black Sea are listed in Table 1 (AMM 2008a). The physico-chemical properties of the Black Sea is unique. Black Sea is the largest and the most stable anoxic marine basin in the world (Jannasch and Truper 1974 in Baykara 2011). The presence of hydrogen sulphide (H_2S) containing water in the deep water of the Black Sea was first discovered in the 19th century. The anoxic conditions exist for nearly 7300 years, caused by the density stratification following the significant influx of the Mediterranean water though the Bosphorus nearly 9000 years ago (Deuser 1974 in Baykara, 2011). The hydrogen sulphide layer lies some 100 to 200 m below the surface. There are also seasonal and annual fluctuations in the level at which hydrogen sulphide is first encountered. Seasonal atmospheric variations produce considerable variations in circulation (Oguz *et al.* 1995). Fresh water discharge from large rivers contributes to buoyancy-driven component of the basin-wide circulation system. Eddies, meanders, filaments, offshore jets of the Rim Current often introduces strong shelf-deep basin exchanges and two-way transports of biota and chemicals between near-shore and offshore regions (BSC 2008). Strong salinity gradient and a permanent halocline which limits vertical supply of oxygen and nutrients from the deeper layers (Tuğrul *et al*. 2014).

Table 1. The average values of the physical characteristics of the Black Sea

Parameters	The Black Sea (min-max)
Water temperature (°C)	5-22
Salinity (‰)	17-19,5
Tide height (cm)	32
Air temperature (°C)	4-23
Rain (mm/day)	0,6-3
Humidity (%)	70-85

Table 2. Ship incidents in the Eastern Black Sea Turkish Economic Zone (Atlantis 2016)

Years	Turkish Search and Rescue Area Number of incidents*		Black Sea
2010	194		
2011	132		
2012	135		11
2013	106		7
2014	96		8
	Total	68	
2015	Very serious incidents	7	6
	Serious incident	4	

*: Capsize, conflict, man overboard, loss, machine failure, explosion, drift, living, touch, side-lying, medical evacuation, fire

Around 90% of the world trade is carried by the international shipping industry. Maritime trade bring benefits for consumers across the world. Turkey has a geopolitical and strategically important location between two continents and Turkish Straits are the only way between Black Sea and Mediterranean Sea connection. Turkish Straits System is the busiest natural channels with national and international maritime traffic and their loads are mainly dangerous goods, like crude oil and its products and any types of chemicals. There are over 43.000 ships passing from Turkish Straits Systems to the Black Sea (DGCS 2016) (Figure 1).

During the last few decades, the pollution of the world's oceans has become a matter of increasing international concern. Nevertheless, a significant amount of pollution is caused by shipping and maritime activities generally. The best known cause of oil pollution is that arises from tanker accidents (IMO 1998). Although this may contribute to comparatively a small percentage of the total oil entering the sea in a year, the consequences of an accident can be disastrous to the immediate area, particularly if the ship involved is a large one and the accident occurs close to the coasts. Russian and

Middle East Asia petroleum transport ways are flow through all around the Turkish coasts. This dense tanker traffic has serious accidental oil pollution risks for the Turkish coasts (Table 2).

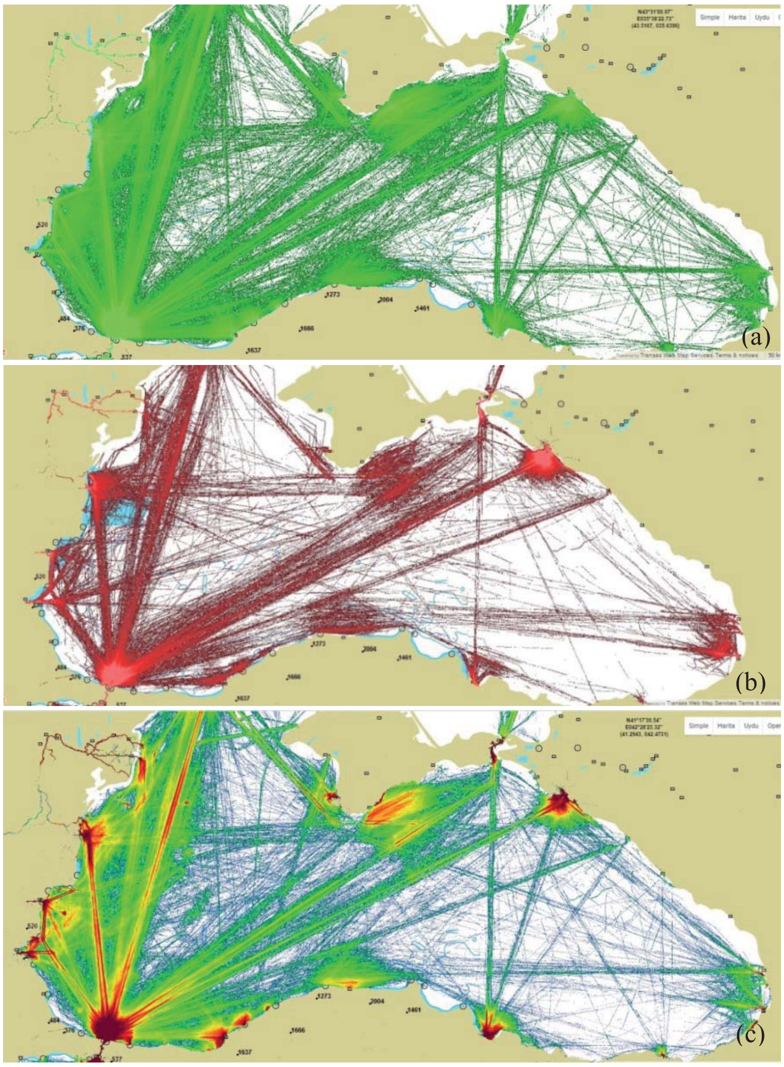


Figure 1. Intensity of a) total ship traffic, b) bulk carrier ship traffic c) tanker traffic in the Black Sea (MVT 2013)

2. Pollution Response Authorities and Their Roles in Turkey

An increasing marine transportation triggered marine incidents risks. These incidents take into account as a signal for the protection of the sea by national and international regulations (OPRC, MARPOL *etc*.). In that respect, the Black Sea is defined as "special areas" by MARPOL at 1983 for their oceanographic and ecological condition (IMO 2016).

2.1. Organization of Pollution Response in the Turkish Coasts

In the national level, responsible ministries (Ministry of Transport Maritime Affairs and Communication (TM-TMAC) and Ministry of Environment and Urbanization (TM-EU) in Turkey has regulated national legislation for the protection of the seas from oil and other harmful substances pollution. In addition to the Turkish Environment Law, another law related with oil and other harmful substances is called in English "Marine Environment Pollution From Oil And Other Harmful Substances And Compensation For Losses In Emergency Response Situations" and it is adopted in 2005 (Law-5312, 2005). According to this law, TM-TMAC was identified and prepared infrastructure necessities for Turkish coastal areas while TM-EU prepared laws and regulations according to the level of responsibilities starting from coastal facilities to national levels even at international level. Coastal facilities' contingency plans were prepared by themselves and were approved by Ministry of Environment and Urbanization. Regional and national contingency plans were prepared by Ministry of Environment and Urbanization. The role of the other ministries, regional governments, cleaning facilities, NGO's, experts (according to specific subjects such as plant, animals, oil response etc) were identified and integrated in the contingency plans (AMM 2010, AMP 2011).

Law and regulations were adopted according to the national necessities and regional and international responsibilities. With this law, the duties of the related public enterprises and private organizations are regulated. Preparedness activities are carried out and coordinated by TM-TMAC. Emergency response facilities are based on tiered base approached. Tier-1 consists of small scale pollution from coastal facilities and ships. Tier 2 is activated in the middle scale pollution events. Tier 3 is activated in large scale pollution and is covered national capabilities (AMP 2011). With the application of this law.

1. Prepared the regional and national emergency action plan: 16 cities are located in the Black Sea coast and the emergency response plan was prepared for each city. These plans were called as a "Regional Emergency Response Plan". According to the incident location, one of the related cities' Governors will be the "General Coordinator" for incident.

2. Determined the best place for the local and national emergency response centre/ stock piles: 8 different locations were selected as a stockpiles from Hopa to İğneada at the Black Sea coast.

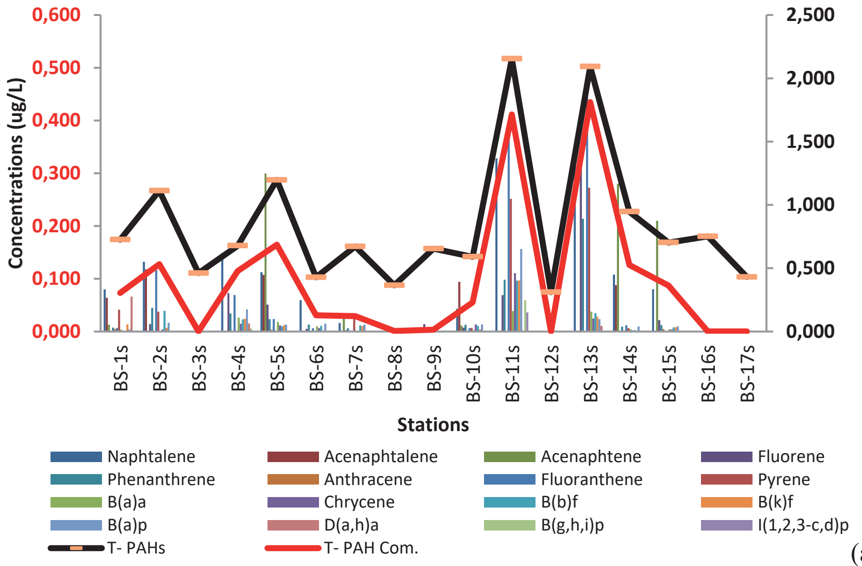
3. Installed the GIS based decision support system (YAKAMOS) for decision makers to give most reliable action during intervention of the marine pollution.

4. The Black Sea coast is analysed according to the Natural Protected Areas (Coastal Natural Gardens (*5*), Coastal Natural Protected Areas (*4*), Coastal special protected environments (*1*), Coastal natural and cultural areas (*14*), important bird areas (*10*), important turtle areas (*no*), important monk seal areas (*no*), important plant areas (*5*) and important Sea meadow banks (no), Important economic activity areas (Marine fishing areas (*more than 13*), Fishing closed areas (*5 areas*), Fishermen ports and fishermen shelters (*142*), Tourist facilities and tourism areas, Beaches (*296*), Industrial facilities (*3*), Shipyards (*13*), Load and passengers ports (27 port authorities) and Marinas (*no*) and Human settlement areas (*16 cities*), and this information is integrated in the YAKAMOS.

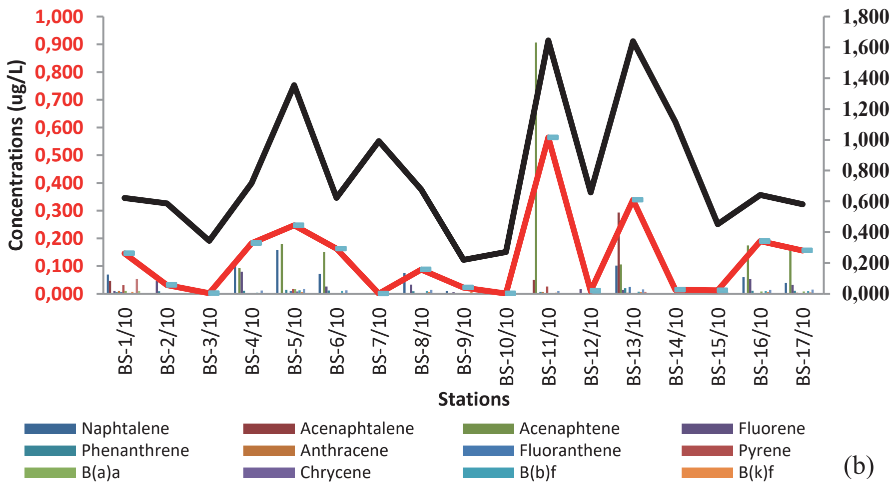
5. Installed semi-online Oil spill model in the YAKAMOS.

6. Accidental risk, environmental sensitivities and place of refugees (PoRs) are analysed and identified according to many related parameters such as, maritime traffic, previous accidents locations, importance of the coastline (according to the article 4), bathymetry, distance from land, output of the spill model, etc.

7. Determined background concentrations according to the "polluters pay for the petroleum hydrocarbons (Dissolved dispersed petroleum hydrocarbons, polycyclic aromatic hydrocarbons (16 compounds)), BTEX, salinity, temperature, dissolved oxygen along the Black Sea waters. Sampling stations were selected 1 miles off the coast and in each 50 nautical miles intervals and from surface and 10m depth to define background concentrations of the areas (Figure 2).



(a)



(b)

Figure 2. The concentrations of PAHs and its compounds in the Black Sea a) surface water; b) 10 m depth. **Black line**: Total PAHs; **Red line**: Total PAHs compounds (AMM 2008a)

3. Oil Pollution Monitoring Practice and Existing Systems

Oil Spill simulations are an excellent way to exercise and train personnel in their emergency roles and to test contingency plans and procedures. Valuable lessons can be learned from such exercises and these can be used to improve plans. Important relationships with external organizations and contractors are made during larger scale or multi-agency simulations (IPIECA 2000). The representatives of the organizations and institutions, who serve in Black Sea contingency plans, were trained and to see how these plans are applied and if they were get ready for emergency situations. According to the law and related regulations, related governments (at least ones a year) and coastal facilities (at least two times in a year) do practical emergency response exercises. Two national/regional emergency response exercises and one theoretical exercise (Karadeniz Ereğlisi, Samsun and Trabzon) were done in between 2008-2015. According to the preparedness for the international emergency situations, one international exercise (Karadeniz Ereğlisi (SULH 2007) was done in 2007 and Turkey participated in the exercises done in Romania and Georgia in 2009 and 2011, respectively (http://www.didgm.gov.tr/).

Aerial surveillance at sea and satellite-based remote sensing monitoring systems are also used for preparedness of incidental oil spills at sea. Aerial surveillance is useful for determining the overall extent of shoreline pollution. Aerial surveillance is to detect oil spills and thus prevent violations of the existing regulations on prevention of pollution from ships. During the initial phase of a response, aerial surveillance can help response of the personnel to assess the location and extent of oil contamination and verify predictions of movement and fate of oil at sea.

4. Amount of Oil Pollution

4.1. Maritime Accidents

During the last few decades, the pollution of the world's oceans has become a matter of increasing international concern. Nevertheless, a significant amount of pollution is caused by shipping and maritime activities generally. The best known cause of oil pollution is that arising from tanker accidents (IMO 1998). Although this may contribute a comparatively small percentage of the total oil entering the sea in a year, the consequences of an accident can be disastrous to the immediate area, particularly if the ship involved is a large one and the accident occurs close to the coast such as, the Torrey Canyon (1967), the Amoco Cadiz (1978) and the Exxon Valdez (1989), Prestige (1979), Independanta (1999) (IMO 1998, MTMAC 2013).

Serious marine pollutions related with maritime accidents forced countries to take precaution for the protection of the environment and diminished the incidents. Every serious accident forced the authorities to adopt a new regulation for preventing accidents for protecting marine environment. "MARPOL 1973/75 International Convention for the Prevention of Pollution from ships" has entered into force after Torrey Canyon (1967) incident and Prestige (2002) incident triggered to prepare a regulation for a ship in need of assistance. After international regulations and sanctions, the number of the incidents have been dramatically decreased since 1970 (ITOPF, 2015) (Figure 3). The total recorded amount of oil spilled was approximately 7,000 tons in 2015. The decreasing trends were also noticed in Turkish Search and Rescue Area (Figure 4).

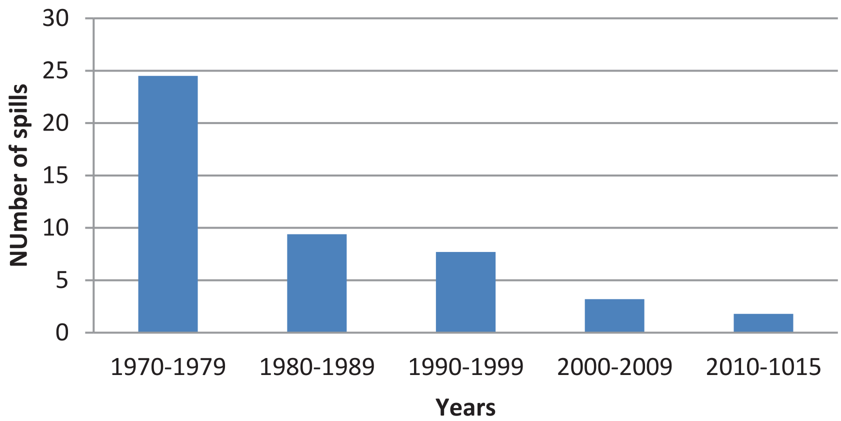


Figure 3. Number of spills in the world (ITOPF 2015)

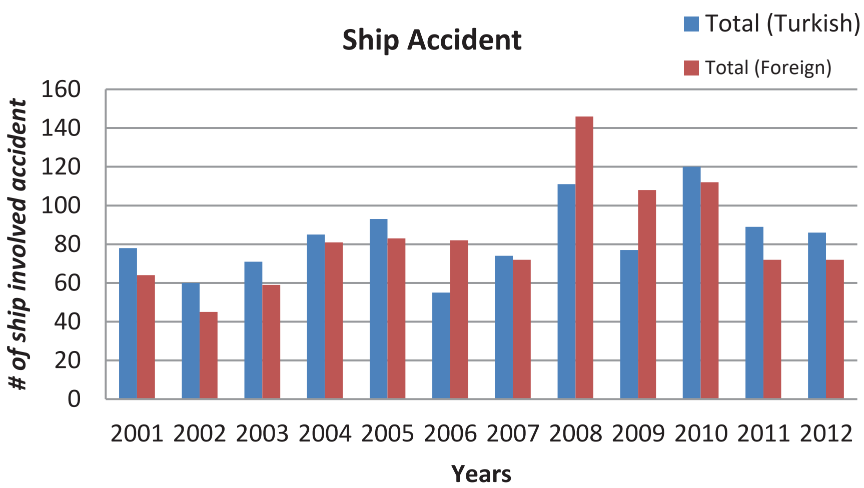


Figure 4. Ships involved accident since 2001-2012 in the Turkish Search and Rescue Zone (MTMAC 2013)

4.2. Pollution Risks from Vessels

There is no refinery in the Turkish coast of the Black Sea however, a lot of natural gas, crude oil and oil product tankers, pipelines, ports, offshore platforms and other coastal facilities have potential of oil pollution sources. Harbours and different sized tankers, which have large petroleum handling capacities, have expected higher environmental pollution risk according to their loading capacities. According to the risk analysis, in general, Black Sea coastal areas are under pollution risk, but some parts such as Zonguldak and Bosphorus exit through the Black Sea region have higher risks (Figure 5). Figure 6 demonstrated that the density of the maritime traffic, especially tankers in Bosphorus entrance, have always very high accidental risk for the Sea of Marmara and the Black Sea environments.

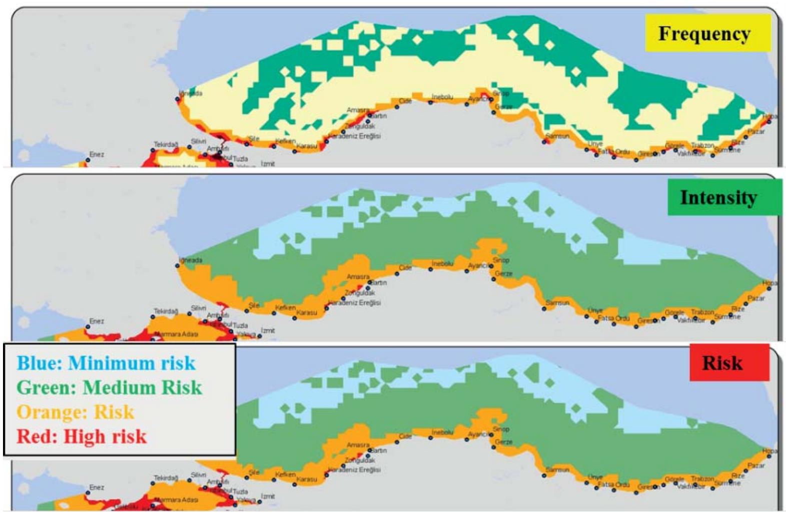


Figure 5. Frequency (upper) Intensity (medium) and risk (lower) map of the Black Sea (AMM 2008b)

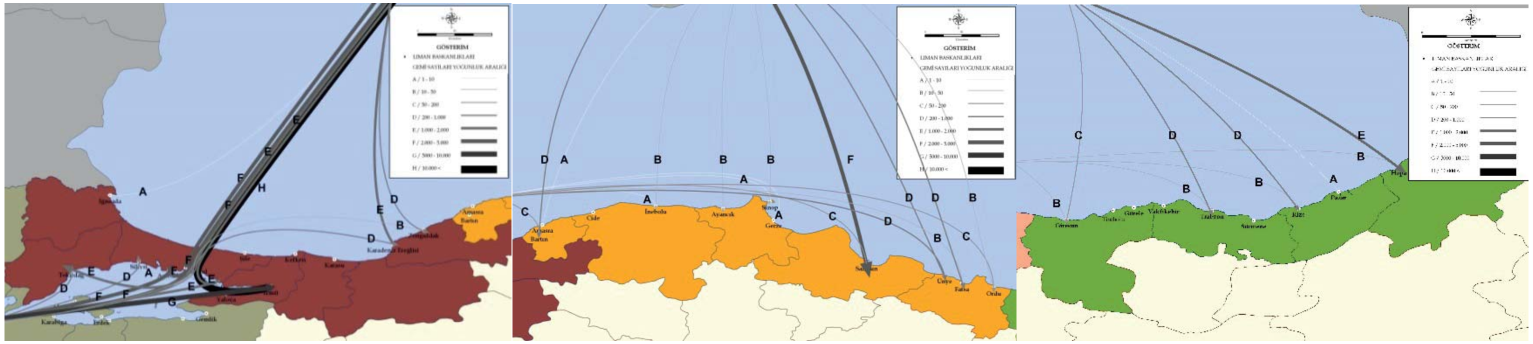


Figure 6. Maritime traffic pressure of the Black Sea (AMM 2010)

4.3. Penalties for Oil Discharges

In Turkey, Environment Law (No.2872) has been changed for the revision of the administrative penalty fee in 2006. According to this revision, environmental damage based on oil pollution for loading facilities is punished with penalty fee according to ship gross tonnage (for ≤1000gross tonnage, 81,78 TL/tonnage; for 1000>- 5000≤ gross tonnage 102,18 TL/tonnage; for >5000 gross tones 104,14 TL/tonnage). Petroleum products and wastes such as sludge, bilges slope, and etc. has also been punished with penalty fees. There is another article in the law related with the response of their pollution and recoveries. At that time, the penalty fee is reduced at a ratio of 1/3. There is another law related with the accidental oil pollution and clean-up environment and compensation of the losses are controlled by law 2872 (Law-b 2016).

5. Impact on the Environment

In general, oil spills can affect marine organisms either externally or internally. Digestion or inhalation of the oil by the organism could be an example for the internal exposure and external exposure which affect skin, carapax, stem, leaf and eye. Oil can also smother some small species of fish, invertebrates, birds or mammals and coat their skin, feathers, fur or gills stopping the maintenance of their body temperatures. Marine organisms, some of which are relatively immobile such as bivalves and mollusks and are filter-feeders, may not be able to avoid exposures to oil. In addition, they don't possess the same suite of enzymes to breakdown contaminants as fish or other vertebrates. The type of oil spilled behave in a different way in the environment, and the effects of marine organisms vary with different types of oil. In general, oil is classified as a "light oil" such as fuel oil, and "heavy oil" such as crude oil. Light oil is easily evaporated and more toxic, although heavy oil look black and sticky. They can persist in the environment for months or even years if not removed. Heavy oils can be very persistent, less acutely toxic and have some chronic effects like cancer and mutation (NOAA 2016).

Knowing background pollutant levels in the sea are very crucial for reimbursement of losses by insurance company after incidents. The concentrations of hazardous substances are measured for the determination of the background concentrations. Dissolved dispersed petroleum hydrocarbons, potential carcinogen/mutagen PAHs and other PAHs compounds concentration were measured lower than 2µg/L in the surface and 10m depth sea water of the Black Sea (Figure 2).

6. Principles of the Oil Pollution Response Activities

Turkey has many laws and regulations related with pollution control, diminishing wastes and penalties according to the "polluter pays" opinion. Protection of the seas from petroleum pollution has been taken into account since 2005 by adopting the law called "Law No: 5312, Fundamentals of Emergency Responses and Loss

Compensation in Marine Environment Pollution Caused by Petroleum and Other Harmful Substances". According to this law, Coastal facilities Contingency plans were prepared by themselves and were approved by Ministry of Environment and Urbanization. Regional and national contingency plans were prepared by Ministry of Environment and Urbanization. The role of the other ministries, regional governments, cleaning facilities, NGO's, experts (according to specific subjects such as plant, animals, oil response etc.) were identified and integrated in the contingency plans (Figure 7). At the national level, for this purpose, the preparedness of the infrastructure such as stock piles and emergency response centres and decision support system installation are under the responsibility of TM-TMAC. However, preparation of the laws and regulations are TM-EU's responsibilities. In Turkey, emergency response is planned in three tiers: the first tier is *coastal facilities contingency plan*, second tier is *city based regional contingency plan* and tier third is *national contingency plan*. City based contingency plans were prepared for 16 coastal cities at the Black Sea coast. Contingency plan consists of the Coordination and the Operations Units and their responsibilities in the plans are identified (AMP 2011). In a situation, where the accident is on a national scale, the National Contingency Plan is activated, and general coordination is carried out by the Ministry of Environment and Forestry. If an incident is local then the closest city Governor acts as a general coordinator. Many related guidelines based on national and local contingency plans are prepared. Such as;

- Defined marine and shoreline response system and general shoreline cleaning methods,
- Determined the rudiments regarding the acceptance of vessels into the places of refuge, in accordance with national and international regulations,
- Defined use of dispersants in emergency response situations,
- Defined the transportation and elimination of the waste materials during/after accidents,
- Terminated response operations and determined rehabilitation operations,
- Determined the compensation demands, and a comparative analysis between the international agreements and national regulations within the framework of the contingency plan.
- Identified and documented an emergency response situation, communication among the teams and informing the public.

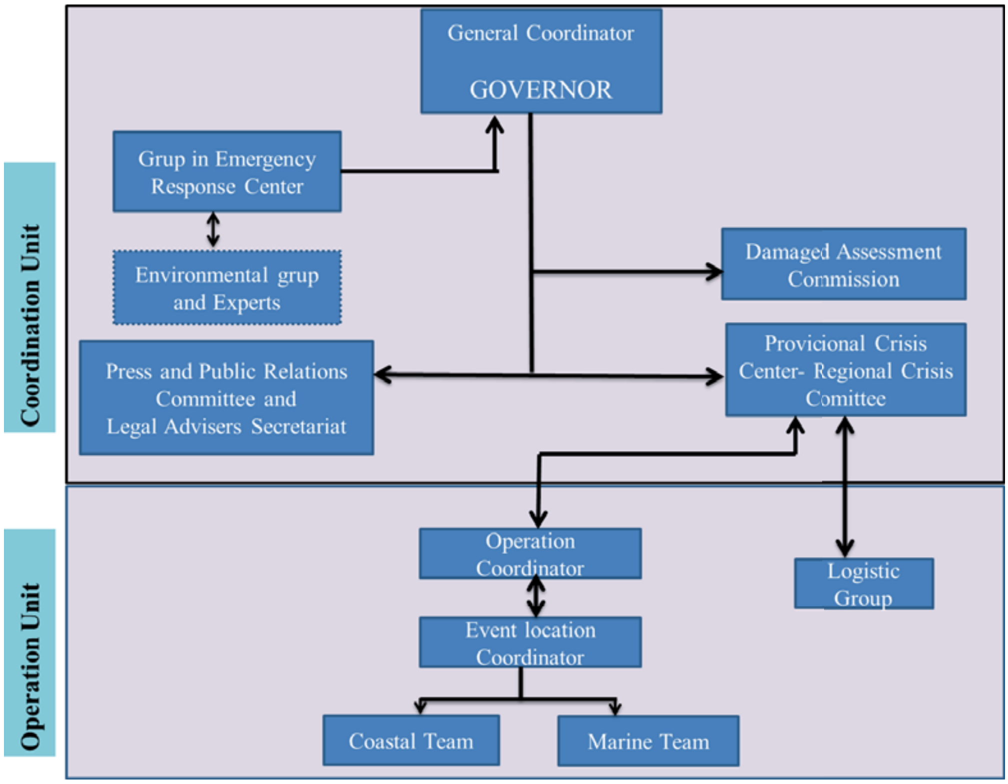


Figure 7. Black Sea Regional Contingency Plan (AMP 2011)

References

AMM 2008a. Constitution of the Emergency Response Centres and Determination of the Present Situation of the Turkish International Waters for the Feasibility Works, Project No.506 G 217. 72 pages. Interim Report-2. March 2008.

AMM 2008b. Constitution of the Emergency Response Centres and Determination of the Present Situation of the Turkish International Waters for the Feasibility Works, Project No.506 G 217. 72 pages. Interim Report-4. August 2008.

AMM 2010. Constitution of the Emergency Response Centres and Determination of the Present Situation of the Turkish International Waters for the Feasibility Works, Project No.506 G 217. 149 pages. Final Report November 2010.

AMP, 2011. The National Emergency Plan to Combat Pollution of the marine environment by oil and other harmful substances in case of emergency situations Final Report. 285 pages. September 2011, Ankara.

Baykara, S.Z. 2011. Black Sea and hydrogen sulphide, p. 151-175. In A.L. Ryann and N.J. Perkins [eds.], The Black Sea: Dynamics, Ecology and Conservation. Nova Science Publishers, Inc.C. Chapter 5.

BSC, 2008. State of the Environment of the Black Sea (2001 - 2006/7), pp. 448. In T. Oguz [Chief Ed], Publications of the Commission on the Protection of the Black Sea Against Pollution (BSC) 2008-3, Istanbul, Turkey.

IMO, 1998. Focus on IMO. MARPOL 25 years. 33 pages.

IMO, 2016. http://www.imo.org/en/OurWork/Environment/SpecialAreas UnderMARPOL/Pages/Default.Aspx.

IPIECA, 2000. A Guide to Contingency Planning for Oil Spills on Water. 2nd edition, Vol. 2, London. 29p.

Law, 2005. Law on Marine Environment pollution from Oil and Other Harmful substances and Emergency Response and Damages Compensation. Official Newspaper No.5312, 03 March 2005, Issue.25752 (in Turkish).

Law-b, 2016. 2872 Environment Law and Its Last Version for the Environmental Fines https://www.csb.gov.tr/db/ced/webicerik/webicerik969.docx (in Turkish)

MTMAC, 2013. Transportation accident statistics. Accident free roads, safe transportation. Ministry of Transportation, Maritime Affairs and Communications, Accident Investigation Board. 58 page. Ankara, Turkey, (In Turkish).

MVT, 2013. http://www.marinevesseltraffic.com/2013/06/mediterranean-sea-marine-traffic.html.

NOAA, 2016. http://response.restoration.noaa.gov.

Oguz, T., P. Malanotte-Rizzoli, and D. Aubrey. 1995. Wind and thermohaline circulation of the Black Sea driven by yearly mean climatological forcing. Journal of Geophysical Research, 100: 6846-6865.

Tuğrul, S., J.W. Murray, G.E. Friederich, and I. Salihoğlu. 2014. Spatial and temporal variability in the chemical properties of the oxic and suboxic layers of the Black Sea. Journal of Marine Systems, 135: 29-43

ITOPF, 2015.(http://www.itopf.com/knowledge-resources/data-statistics/statistics/)

http://www.didgm.gov.tr/, 2016. Ministry of Transport, maritime affairs and communication.

DGCS, 2016. Directorate General of Coastal Safety https://www.kiyiemniyeti.gov.tr/Default.aspx?pid=212

Atlantis, 2016. https://atlantis.udhb.gov.tr/istatistik/istatistikdiger.aspx, 2016: Ministry of Transport, maritime affairs and communication.

Abbreviations
TM-TMAC: Turkish Ministry of Transport, Marine Affairs and Communications
TM-EU: Ministry of Environment and Urbanization
M of TMC: Ministry of Transport, Maritime Affairs and Communications
PM-DEMA: Prime Ministry-Disaster and Emergency Management Authority
Com-TAF: Turkish Army Force, General Commander
M of FA: Ministry of Foreign Affairs
M of I-CGC: Ministry of Interior Turkish Coast guard command
M of TMC-DGCS: Ministry of Transport, Maritime Affairs and Communications, Directorate General of Coastal Safety G of ERC
DAC: Damage assessment commission
PCC: Provincial crisis centre
PPRC: Press and Public Relations Committee
LAS: Legal Advisers Secretariat
EG&E: Environment Group and Experts
GERC: Group in the Emergency Response Centre
RCC: Regional Crisis Committee
YAKAMOS: Help Search Rescue Emergency Response Automation System
DGCS: Directorate General of Coastal Safety

FISHERIES IMPACTS ON COASTAL ECOSYSTEMS

Ertuğ DÜZGÜNEŞ and Hacer SAĞLAM

KTU Faculty of Marine Sciences 61530 Camburnu, Trabzon, Turkey
ertug@ktu.edu.tr

1. Introduction

Historically, fisheries has one of the earliest interactions between humankind and the aquatic environment. All individual attempts may have certain impacts on the ecosystems which was not perceivable at certain levels where recruitment is higher than the removals from exploited the populations. As the human population has increased, the impact of fisheries became more important and irreversible at or beyond the threshold levels of recruitment of the aquatic living resources. In line with the technological progresses in fishing gear manufacture, vessel construction, onboard hauling devices, navigation instruments and fish finders, the efficiency of fisheries has been increased against the fish populations in the near history. As a result, some of the species became extinct, many of them are under the threat of extinction but most importantly, productivity of the ecosystems has reduced causing serious habitat, economic and social losses. On the other hand, imperfect understanding of ecosystem structure and functioning, as well as the inherent difficulty of distinguishing between natural and human-induced changes which are not always perfectly predictable and/or reversible, had been the reason of very serious alterations in the ecosystem functioning.

Impacts of fisheries on the ecosystems have been intensively reviewed by several scientists since 1990's (Dayton *et al.* 1995, Goni 1998, Agardy 2000, Kaiser *et al.* 2003, Gislason 2003). In fact, fishery is responsible to reduce abundance and spawning potential, and to modify population parameters, age, size structure and sex ratio of the targeted species. On the other hand, it affects genetics and species composition of the species sharing the same ecosystem (FAO 2003).

When fisheries could not be efficiently controlled, fishing mortality has an increasing trend in most of the fisheries causing overfishing and destruction of conventional food webs by changing the relationships between the trophic levels.

Overfishing is one of the most important common impacts almost for all species in the aquatic resources of the globe. It is responsible to chance the stability of the populations by reducing mature individuals which supports recruitment causing to lower the number of spawners and recruits. The impact of overfishing is more efficient on the species having long life span rather than the short lived species.

In global scale most of the fishing activities have been focused on the high valued predators, big sized fish species. Then, fisheries came to end of reduction of the species located on the higher trophic levels modifying flow of energy in the food web of the ecosystem.

On the other hand, destructive fishing methods applied for a given species can be harmful to those others living on the bottom; i.e. demersal species, sea grasses, algal beds and coral reefs. This is one of the universal threats for the case of using towed gears (bottom trawls, beam trawls and dredge) in fisheries.

Use of unselective fishing gears and methods could be a threat on immature individuals of targeted fish and other protected species sharing the same habitat. If there is lack of any management measures for a given species living in the coastal areas, there would be very serious impacts till the extinction of that species from the ecosystem.

Another failure is the lack of information about the catch, landings, by catch and fishing effort for any of the fisheries. Useful management measures need sufficient data both in good quality and quantity. Any deficiencies may cause very serious destructions which may need very long years to restore the ecosystem; in many cases these impacts could be irreversible. On the other hand, illegal fisheries is one of the major challenge in the world fisheries. It can be done either by the licensed or the pirate fishing vessels. In order to combat with illegal fishing, all countries pays special attention under the decision of FAO, European Union, regional fishery organizations collaborating with INTERPOL, national intelligence services, International Maritime Organization and other global or regional environmental conservation organizations (Greenpeace, Sea Shepherd Conservation Society, Sea Turtle Conservancy). The main objective is to reduce illegal, unregulated and unreported fisheries.

Aquaculture is one of the main sources of food supply for the fisheries industry and direct human consumption. If large- scale mariculture farms were poorly managed, mariculture can damage coastal wetlands and nearshore ecosystems where often used as nursery areas for many species, and may contaminate the ecosystem with food residues, waste, antibiotics, hormones, diseases and alien species. On the other hand market prefers mostly carnivorous species which they need a big portion of fish meal in their diet. The recent situation is "feeding the fish with fish" which enforce fishermen to catch more undersized and cheaper fish to support fish meal and oil industry. Producer companies should change their attention more towards the polyculture and herbivorous/omnivorous species.

2. Impacts of Fisheries in the Black Sea Coastal Ecosystem

Majority of aquatic living organisms in the marine and inland water ecosystems prefer coastal zones for their ecological and biological demands such as homing, feeding, spawning and protection. On the other hand near shore ecosystems are the locations for intensive sediment transportation, nutrient cycles and support food web. Therefore, these areas are productive and the main fishing grounds in the world (Gücü 1995, Çelikkale *et al*. 1999).

3. Fishing

There is an increasing global trend in demand for seafood together with the awareness towards environmental impacts and alterations in good environmental state of the habitats. Therefore, national fisheries management policies should focus on "sustainable development" and "environmental management" issues altogether. In Turkey, fishery activities are classified as the whole processes from the resource to the dish; ecosystem, fishing, aquaculture, fattening, enhancement, processing and marketing under the enforcement of Fisheries Law (No 1380) and more EU Common Fisheries Policy due to agreement between Turkish Government and EU Commission (TKB 2008, EU 2008, FAO 2008).

Fishing is carried out in the coastal zone as daily activities in Turkey in marine and inland waters. Majority of the catch are coming from the capture fisheries but the rate of aquaculture has been in rapid increase in recent years; *i.e* share of aquaculture has risen from 20% in 2006 to 35.8 % in 2015. Export value of aquaculture is 2.4 times higher than the marine capture fisheries. So the main impact comes from fishing activities. There are very well known worldwide impacts of fisheries on the coastal ecosystems; in some regions ecosystems may tolerate it, but in many other locations the impacts cannot be reversible. The Black Sea is a very fragile ecosystem and the southern-most coastal zone is different and very sensitive compared to the other coasts in riparian countries. Continental shelf is very narrow at the central and eastern Black Sea (from Sinop to Georgian border) but wider at the western part where trawling is permitted in 3 miles off the coastal line. Purse seining is free along all coastlines in the depths over 24 m. and mainly carried out in the central and eastern Black Sea.

The direct impact of fishing comes from the fishing gear and method used to catch certain fish communities. Trawls and purse seine nets are the most common fishing gears in industrial fisheries. In line with the developments in vessel construction, fishing gear manufacture, navigation and fish finder industry, fishing efficiency of the gears by means of quality and quantity is over the recruitment potential of the fish stocks at present. Therefore, almost all fish stocks are under threat of overfishing in the Black Sea which is the reason of extinction or endangerment for many species. As precautionary measures, some of the species (*i.e*, sturgeon, marine mammals) are under full protection or their fishing is limited by season, size and gear restrictions for the sustainable management of these stocks for demersal species as shrimp, red mullet, sole, place, turbot, rays and skates. Main impact comes from their physical contact to the bottom by collecting all living organisms and non-living materials on its path proportional to the mouth wide of the net and swept distance/time of the haul (Lokkeborg 2005). Especially the destruction of the sea grasses (*Posidonia* sp.) and other sea weeds is one of the main threats in the ecosystems. Bottom, mid-water or pelagic trawls are responsible to catch untargeted and endangered species such as sea turtles, marine mammals and other fish species which are under protection. On the other hand, due to insufficient selectivity, blocking effect and being far from optimum mesh size and shape, trawl nets have considerable high impact on the immature fish both targeted and untargeted species. This is a very common case in Turkish fisheries carried out in the western and central Black Sea. Selectivity of the trawl nets must be in harmony by determining optimum mesh size and shapes (from diamond to square) in the cod end for the fish under the size of maturity. Various studies showed that trawling practices in Turkey has high by-catch rates as a result of smaller size and diamond shapes of meshes. Kasapoglu and Duzgunes (2015) reported that by catch rates in commercial trawl operations were 62% by weight and 50% by number, while 62% by weight and 80% by number based on the experimental trawling surveys (Table 1).

Table 1. By-catch rates of various fishing gears in the Black Sea coastal waters of Turkey (%)

Fishing gear	Weight basis	Number basis
Bottom gill nets	30	34
Trammel nets	58	43
Anchovy purse seine	37	13
Bonito purse seine	11	63
Bottom trawl	62	50
Hydraulic dredge	19	23
Experimental bottom gill net	12	10
Experimental bottom trawl	62	80

The biggest share in marine capture fisheries comes from pelagic fishes such as anchovy, horse mackerel, sardines, pickerel, blue fish and bonito by purse seining operations. By catch rates are high in purse seine nets due to their unselective nature. It also catches marine mammals, dogfish, and various demersal and benthic fish, Crustacea, mollusks and sea weeds due to operations carried out up to the depths of 24 m from the coast line with the nets more than 160 m in depth and over 1400 m in length (Çelikkale *et al.* 1999). This is the most important contradiction why purse seiners permitted to operate their vessels in shallower coastal waters instead of hauling fish in the water column. The main reason is to catch migrating fish, especially blue fish and horse mackerel while they are feeding in the near shore areas. In recent years, the main target species for purse seine fisheries have been overfished and recruitment in the stock is at the low levels due to high fishing effort than the abundance of the existing stocks. There is growth and recruitment overfishing since the end of the 1980s while environmental pressures has started to increase as new sources of threats such as introduction of invasive species (*Mnemiopsis leidyi*, *Beroe ovata*), climate change, industrial pollution and domestic wastes discharged without sufficient purification, manmade constructions (landfills, coastal road from Samsun to Georgian border, dams, small reservoirs and hydroelectric power plants almost on all of the rivers). Under these pressures, overfishing has reached the greatest impact level in the Black Sea. On the other hand, anchovy fisheries in the Abkhazian waters especially carried out by the big purse seine vessels is another impact under the permission of the local authorities as to catch smaller fish for fish meal and oil industry and export some big sized part of the catch to export Turkish markets. Under these circumstances, special anchovy management plan(s) and international agreement is very crucial. At present, anchovy schools disappear at the half of the traditional anchovy season and some part of the vessels prefer to go to Georgia to catch migrated anchovy stocks in the Georgian coasts after the shortened fishing season in Turkey.

Rapa whelk, the most dangerous invasive alien species in the Black Sea, had become one of the alternative economic species for the fishermen as an export material to the Asian countries since 1985. In recent years exportation has started in other riparian countries. In Rapa fisheries, harvesting method is important. Historically, it was started to be collected by diving (with pipes). This method is the most ecological friendly one by its limited harvest mainly focusing on the bigger individuals and without any damage on the bottom habitat. This advantage was lost due to several mortal accidents due to using divers without any license and experience. Another impact of such method is the loss of bony fishes living on rocky areas. Divers were able to stay for a longer time under the water by the opportunity given by this method, and sacrificed major rock fishes with high market value such as meagre (*Sciaena umbra),* bogue *(Boops boops*) and sea bream (*Sparus aurata*) as well as flat fishes (turbot, plaice and sole) by using spears and harpoons. At present, all these species are under the threat of extinction or endangerment. Later, dredges were introduced to the Rapa fisheries and their numbers rapidly increased to cover the needs of processing industry. The major impact of the dredge fishery is the destruction of the bottom habitat, especially in the eastern Black Sea where trawling is not permitted. At present dredges were allowed to catch *Rapana* during the fishing season in the day time, out of the 500 m distance to the coast. Dredges also have high bycatch rates after the meshes were blocked with bigger individuals such as turbot, sole, whiting, red mullet, seahorse, sea weeds, other shellfish and mollusks (Düzgüneş *et al*. 1997).

Gill nets are the most environmental friendly method in coastal fisheries in the literature. But it is not so in practice. Due to ineffective control mechanism, mesh sizes are under the standards in many cases and fishermen can change the rigging of the net providing less selectivity with the official mesh size, coming to the point to catch more but mostly undersized fish both targeted and/or untargeted. This is a very big problem in the western Black Sea in turbot bottom gill net fisheries. Dolphins are the main bycatch in this type of fisheries. There are some research studies and experimental trials using pingers to reduce dolphin bycatch in these nets but none of them could be successfully transferred to the practice. Artisanal fisheries has no restriction by means of fishing season in the coastal areas. Their major impact is to catch fish in their reproduction period which is very important reason to reduce spawning stock biomass mainly for the local stocks in an unsustainable manner.

Ghost fishing is another problem in coastal fisheries due to lost, dumped or abandoned or detached fishing gears or nets from the fishing vessels or mariculture farms, which continue to catch or trap fish and other marine living organisms. Literally hundreds of kilometers of nets and lines get lost every year and due to the nature of the materials used to produce these types of gear, they can and will keep fishing for multiple decades, possibly even for several centuries. The issue of "ghost fishing" was first brought to the attention of world at the 16th Session of the FAO Committee on Fisheries in April 1985. Later, Scientific Committee of GFCM, advised member countries to take all necessary measures to stop ghost fishing in 2012. It is estimated that 1000-2000 km of nets per year are lost in the Turkish seas. According to the latest surveys, ghost fishing is the case in Turkish seas. Some of the surveys were carried out in İzmir Bay (Ayaz *et al.* 2004), İskenderun Bay at Karataş and Yumurtalık (Taşlıel 2008) and İstanbul (Yıldız, 2010), giving some data on the amount of lost bottom gill nets as 200-280 km in İzmir Bay, 624 km nets for shrimp, sole and others in İskenderun Bay and 230 km nets for turbot, bonito and striped mullet, 2700 m longlines and 14 fish traps in Istanbul. There are no specific surveys in the Black Sea but it is estimated that bottom nets for turbot is the main reason for ghost fishing in the western Black Sea coasts due to left or lost nets.

The impact of fishing is very obvious if we compare the fishery statistics for 1968 and 2015. Just before the implementation of Fisheries Law enacted in 1971, there was 46 major species having significant production with the periods' fishing vessels up to 10 m summing up 82245 t in the cities located on the Black Sea coast. For instance Trabzon was the leader (29000 t) and followed by Ordu (19700 t) and Rize (12600 t). Some of the registered species in 1968, their production and locations were given as leer fish (*Licia amia*), 2 tons in Kırklareli; hake (*Merluccius merluccius*), 6 tons in Rize and Giresun; sea bream (*Sparus aurata*), 15 tons in Rize, Samsun and Sinop; sole and plaice (*Solea solea* and *Platichthys flesus*), 130 tons in Giresun, Kastamonu, Ordu, Rize, Samsun, Sinop and Trabzon), and those at lower catches are Comber (*Serranus cabrilla*), swordfish (*Xiphias gladius*) in Trabzon and Samsun; turbot (*Psetta maxima*), gurnard (*Chelidonichthys lucerna*), bogue (*Boops boops*), chub mackerel, saddled seabream (*Oblada melanura*), Blue fin tuna (*Thunnus thynnus*), common dentex (*Dentex dentex*), striped mullet (*Mullus surmelatus*) and pink dentex (Dentex gibbosus). Unfortunately there are only 20 fish species in the last fishery statistics (2015) and only 7-8 species has been exploited commercially. Most of the fish living on rocks and pebbles were extinct/endangered and commercial ones are even overfished (TUIK 2016).

In order to reduce the impact of fishing on the ecosystem, priority should be given to the assessment of the stock abundances of the exploited fish stocks. As a second step, fishing effort must be proportionally adjusted with the size of the stocks. This is one of the big problem of fisheries in Turkey. On the other hand, determination of minimum allowable catch size and fishing season for all species, promoting more selective fishing methods and gears, fighting against illegal, unregulated and unreported (IUU) fisheries, and creating more efficient monitoring, control and surveillance (MSC) services are the essential measures and tools for the Turkish fisheries for restoration phase. There is a strong need to take serious measures against their destructive impacts as to implement marine protected areas on sensitive ecosystems mainly to protect spawning, nursery and on growing areas on the coastal waters to support ecosystem by conserving habitat and immature individuals from the destructive impact of these fishing methods. On the other hand in case of purse seining, use of midwater trawls can be supported. Instead of dredge fishery for *Rapana*, the use of pots and traps should be encouraged by supporting fishers changing the fishing methods. Existing fisheries management policy needs to be radically changed as fully adopted to the universal standards as imposed by FAO and GFCM.

4. Aquaculture

Due to reaching the limits of exploited stocks in the seas, and water pollution and other climatic impacts on the stocks, researchers, administrators and investors have believed that only aquaculture may cover the increasing demands from the markets (Muir and Beveridge 1994). But there is an important risk to increase aquaculture production due to selection of mainly carnivorous species, coming to a point “feeding fish with fish”. So as long as there is increase in aquaculture capacities in Turkey, either in the Black Sea or in other seas, it will affect the Black Sea fisheries to cover the need of trash fish (unprocessed anchovy, horse mackerel and sprat) for fattening Bluefin tuna in the Mediterranean and providing fish meal and oil for fish farms and exportation to foreign fish feed and oil companies. This is one of the big threats on the Black Sea anchovy stock fisheries due to high revenues but it has high impact on the immature stocks in Turkish and Georgian coastal fisheries. Wastes, faces, antibiotics and feed additives used for colorization and supporting faster growth may have also a certain level of impact on the marine ecosystem. But the main impact in the Black Sea comes from the carnivorous fish species which escaped from the cages due to physical damages by storms or failures during farming processes as changing of the nets, transfer of fish from one cage to another or other cases by the enemies or competitors in the same area. Food and prey competition, genetic modification and high predation are the main risks in the Black Sea.

Mariculture in cages is progressing in our region. If there are failures on site selection, currents and wave strengths, together with the capacity determination, there might be enrichment in organic materials, moreover may cause eutrophication and hyper nitrification and affect benthic communities. Destruction of the natural aesthetics, conflicting with transportation, and tourism activities, introduction of antibiotics and chemicals used for fish diseases and parasites, and interactions between natural stocks and cultured species are the main conflicting interests in a region. Therefore polyculture with filter feeders such as mussels and oysters is very important to reduce organic matter impact (Okumuş 1997).

Major inputs from aquaculture to the marine ecosystems are:

- Water inlets (warm water discharge, coastal currents),
- Feed and faces (carbon, nitrogen, phosphorous),
- Microorganisms (unnatural pathogens),
- Antibiotics and other chemicals used for treatment (Oxytetracycline, Romet 30, Tribrissen, Ivermectin, Terramycin),
- Chemicals (used for ecto-parasites and fungi, *i.e.* Malachite green, formalin),
- Species for aquaculture (Use of the fingerlings from natural stocks, non-native species from other habitats to the habitat).

The inputs which have such impacts in the ecosystems are as follows: habitat modification, changes in the food web, new diseases, eutrophication, more oxygen consumption to get rid of organic load, increase in suspended matter, chemical accumulation in the sediment, changes in the benthic fauna and flora, toxic algae blooms, effects on marine mammals, diseases coming from culture environment and effects of carnivorous species escaped from the culture site on the natural fish stocks.

Some measures can be taken in order to reduce these impacts during implementation and operational phase; by good planning and proper site selection, alternating use of water resources, reduction in use of chemicals, effective use of carrying capacity, effective input use, alternate space use in rotation, sufficient distance between farms, allocating sites far from the coasts and bays, pre-treatment of discharge water for the farms on land, applying polyculture, not allowing young fish collection from the sea and promoting culture of natural species living in the same habitat (Çelikkale *et al.* 1999).

5. Processing industry

Processing industry need fish both from nature and aquaculture. Majority of the products have been exported after processing various ways; frozen, filleted, canned, etc. Of course there might be fewer impacts as discharge of organic wastes, washing and cleaning materials from the plant. So all possible impacts should be taken into consideration and necessary measures should be taken in order to get rid of these risks of possible impacts during the planning and construction stage of the plants. So, detergents, hardly soluble processing wastes, smell and solid wastes are possible sources of impact risks depending on several factors; size and the shape of the processed species, processing period and technology, processed quantity, washing temperature, cleaning and sanitation process, degraded products, melting water and molten ice, internal organs, bones, skin, sauce, brine, fish oil and other oils, broken can boxes (Saleem 2008).

6. Enhancement

If it is not carefully planned, enhancement of the poor or new areas with fish from aquaculture or from other locations may have also impact on the ecosystem causing changes on the existing gene pool, affect migration patterns of current species, creates food competition by pushing local species out of the ecosystem and reduce biodiversity.

7. Conclusion

Fisheries management is a scientific approach to create a balance with nature and user groups to provide food and employment. Sustainable fisheries may only be implemented by research and participation of the fishermen and other stakeholders. If existing management policies have not been modified or fully changed, future of the Black Sea fisheries has never been better than before. Immediate actions are needed for the better management of the Black Sea fishery resources.

References

Agardy, T. 2000. Effects of fisheries on marine ecosystems: a conservationist's perspective. ICES Journal of Marine Science, 57: 761-765.

Ayaz, A., V. Unal, and U. Ozekinci. 2004. A research on ghost fishing in Izmir Bay. Journal of Fisheries & Aquatic Sciences, 21(1-2): 35-38.

Çelikkale, M.S., E. Duzgunes, and İ. Okumuş. 1999. Fisheries Sector in Turkey: Its potential, current status, problems and solution recommendations, (in Turkish). 414 p. İTO Issue No: 1992-2, İstanbul.

Dayton, P.K., S.F. Thrush, M.T. Agardy, and R.J. Hofman. 1995. Environmental effects of marine fishing. Aquatic Conservation: Marine and Freshwater Ecosystems, 5:205-232.

Düzgüneş, E., C. Şahin, N.S. Başçınar, and H. Emiral. 1997. Fisheries of rapa whelk and its impact on the coastal ecosystem. p. 485-489. In E. Özhan [ed.], Abstracts Book of National Conference on Turkey's Coastal and Marine Areas, June 24-27, Ankara.

EU, 2008. Destructive Fishing Methods. http://ec.europa.eu/fisheries/cfp/ management_resources/ environment/destructive_en.htm.

FAO, 2003. The ecosystem approach to marine capture fisheries. FAO Technical Guidelines for Responsible Fisheries, No. 4(Suppl.2): 112 pp.

FAO, 2008. Precautionary approach in fisheries management. http://www.fao.org/focus/e/fisheries.htm

Folke, C. and N. Kautsky. l989. The role of ecosystems for a sustainable development of aquaculture. Armbio, 18(4): 234-243.

Garcia, S.M., A. Zerbi, C. Aliaume, T. Do Chi, and G. Lasserre. 2003. The ecosystem approach to fisheries: issues, terminology, principles, institutional foundations, implementation and outlook. 71 p. FAO Fisheries Technical Paper. No. 443. Rome, FAO.

Gislason, H. 2003. The effect of fishing on non-target species and ecosystem structure and function. pp. 255-274. In M. Sinclair and G. Valdimarsson [eds.], Responsible fisheries in the marine ecosystem, Rome, Italy, and Wallingford, UK.

Goni, R. 1998. Ecosystem effects of marine fisheries: an overview. Ocean and Coastal Management, 40: 37-64.

Gowen, R.J. and Bradbury, N.B. l987. The Ecological Impact of Salmonid Farming in Coastal Waters: A Review. Oceanogr. Mar. Ann. Rev. 25: 563-575.

Gowen, R.J., J. Brown, N.B. Bradhury, and D.S. McLusky. 1988. Investigations into Benthic Enrichment, Hypernutrification and Eutrophication Associated with Mariculture in Scottish Waters, 289 p. Report to the Highlands and Islands Development Board.

Gücü., A.C. 1995. Role played by fishing on the Black Sea ecosystem, sensitive to change; Black Sea, Baltic Sea and North Sea, E. Özsoy and A. Mikaelyen [eds.], NATO ASI Series 2, Environmental, 27: 149-162.

Hovgard, H. and H. Lassen. 2000. Manuel on estimation of selectivity for gillnet and longline gears in abundance surveys, 84 p. FAO Fish. Tech. Pap. No: 397. Rome.

Kaiser, M.J., J.S. Collie, S.J. Hall, S. Jennings, and I.R. Poiner. 2003. Impacts of fishing gear on marine benthic habitats, pp. 197-216. In M. Sinclair and G. Valdimarsson [eds.], Responsible fisheries in the marine ecosystem, Rome, Italy, and Wallingford, UK. FAO and CABI Publishing.

Kasapoğlu N. and E. Duzgunes. 2015. Illegal, Unregulated and Unreported (IUU) fisheries in the Black Sea. Marine and coastal development by the frame of sustainable use. Trabzon, Turkey, September 18-20, 1(1): 87.

Lokkeborg, S. 2005. Impacts of Trawling and scallop dredging on benthic habitats and communities, 58 p. FAO Fish. Tech. Pap. No: 472. Rome.

Muir, J.F. and M.C.M. Beveridge. 1994. Resources, planning and management in coastal aquaculture. Proceedings of fisheries and Ocean Industrial Development. Research Center of Ocean Industrial Development, Pusan, Kore, 209-234.

Okumuş, I. 1997. Environmental impacts of aquaculture in marine cages first national conference on the coastal zone management in Turkey, 97. E.Özhan [ed.]. Pro; 24-27 June. Proc. Ankara.

Saleem, 2008. Environmental impacts from meat and fish processing. http://saleemindia.blogspot.com/2008/02/environmental-impacts-from-meat-and.html.

Stirling, H.P. and I. Okumuş. 1995. Growth and production of mussels (*Mytilus edulis* L.) suspended at salmon cages and shellfish farm in two Scottish Sea. Aquaculture, 134: 193-210.

Taşlıel, A.S. 2008. Determinatıon of amount of lost fishing gear on Karataş and Yumurtalık (Iskenderun Bay) during a fishing season, Masters Thesis, Çukurova University, Institute of Natural Sciences.

TKB, 2008. Fisheries Act No 1380. http://www.kkgm.gov.tr

TUIK 2016. Fishery Statistics. Turkish Statistical Association. Ankara.

Yıldız, T. 2010. Determination of the amount of lost fishing gears causing ghost fisheries on İstanbul coasts, Masters Thesis, Istanbul University, Institute of Natural Sciences.

MODELING AS A MANAGEMENT TOOL

Bettina A. FACH, Barış SALİHOĞLU, Sinan ARKIN, Ekin AKOĞLU and Ceren GÜRASLAN

Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
bfach@ims.metu.edu.tr

1. What is modeling and why is it useful for ecosystem management?

When talking about modeling of marine systems, the term "modeling" stands for the theoretical description of the system in question, using sets of differential equations which describe the ecosystem dynamics (Fennel and Neumann 2006). Marine ecosystems are rather complex systems that may be simplified by assuming flux of material from nutrients to phytoplankton, to zooplankton, to fish and then recycling back to nutrients. Phytoplankton communities consist of a variety of microscopic single-cell plants which are mostly the primary producers. Primary producers build up organic compounds directly from carbon dioxide and various nutrients are dissolved in the water.

Models are only simplified forms of the real world and hence include certain levels of uncertainties in reproducing the natural dynamics. It can therefore be debated if anything can be learned from such models. However, there are inherent benefits to the use of modeling which Fennel and Neumann (2004) summarize as follows:

- to develop and enhance understanding,
- to quantify description of processes,
- to synthesize and consolidate our knowledge,
- to establish interaction of theory and observations,
- to develop predictive potential,
- to simulate scenarios of past and future developments.

Models can be used to test and develop hypotheses. Also, nature itself cannot be manipulated but the models can, thus they can be used to do sensitivity analyses of ecosystem processes. "What-if" scenarios can be tested using the models. Because models include a wide spectrum of processes and they can show us the gaps in our knowledge of the ecosystem dynamics and thereby can illuminate the aspects of further study. Hard-to-measure quantities can be estimated using models (*e.g.* removal of phytoplankton biomass by grazers). With the advent of computers, models can now be used to make predictions considering different climate change scenarios. Also models emerge as tools that can provide knowledge and even options for policy making towards better management of the oceans.

Oceans provide habitat to an enormous and largely undiscovered biodiversity and supply a critical fraction of food and other resources consumed by the world population. Human activities including different types of pollution, nutrient loading, overfishing, transportation of non-indigenous species, and resource exploitation, are adding to the pressure on the oceans. These growing pressures and accompanying changes will have unforeseeable consequences for marine life, ocean health, and human wellbeing. The changes induced by these pressures can impact the ecosystem structure and function as well as its ability to deliver key services. In recent decades, international collaborative research has led to an improved understanding of the influence of human activities on the marine systems. To enhance our understanding of fundamental processes and to be able to assess the interconnected ocean ecosystem-environment-human system, we need modeling tools (Schulz *et al.* 2015).

2. Current modeling needs towards ecosystem based management

2.1. Importance of considering the whole ecosystem for ecosystem management

There are strong interactions and feedbacks among climate, upper-ocean biogeochemistry, and the LTL components of marine food webs. Ecosystem approaches are now considered necessary because of the connection between the climate, environmental change and associated stressors which can affect the ecosystem as a whole or can only impact certain levels of the ecosystem which can cascade through different levels. Only the ecosystem models that include all the levels of the ecosystem (end-to-end) can capture most of the interactions occurring in the sea and permit to assess both primary and secondary effects of climate, environmental variability and management changes. These end-to-end models can support the worldwide movement toward ecosystem-based management, and assess complexity of the interacting factors that control ecosystem dynamics. Today, there is a big demand for quantitative tools to support ecosystem based management initiatives and thus development of these models is in advancement.

2.2. Ecological Indicators produced by models

Models by themselves proved to be efficient tools for investigating and experimenting with structure and function of marine ecosystems and predicting the societal benefits associated with them. In addition, they also come very handy in quantifying their well-being (homeostasis). Utilising the flows in the food web and the biomasses of its compartments as simulated by the ecological models, one could compute synthetic ecological indicators that would provide information about the maturity *sensu*

Odum (1971) of the ecosystem in question, as well as the impact of anthropogenic and climatic stressors such as overfishing and global warming on that ecosystem. By this way, an invaluable opportunity is opened up for comparing different ecosystems as well as different conditions of a single ecosystem over the course of its history.

The most widely-adopted ecological indicators that provide us information about the impact of fisheries exploitation on the ecosystem are the mean trophic level of the catch (mTLc; *e.g.* Pauly *et al.* 1998), marine trophic index (MTI; Pauly and Watson 2005), primary production required for the catch (PPRc; Pauly and Christensen 1995) and fishing in balance (FiB) index. Hitherto, these indicators have been widely used for assessing the impact of fisheries in various ecosystems. However, when recovery of ecosystems is considered, a second dimension of indicators that give us information about the health of the ecosystem comes into play. The most common ones are Finn's Cycling Index (FCI; Finn 1976), Ascendancy and Capacity (Ulanowicz 1986).

Sustainability of the ecosystem services, the link between ecosystem function and human demands, has gained much importance together with the recent management approaches (*e.g.* EAF, MSFD). Socio-economic indicators simulated by the models such as jobs, wages, (ex-vessel) revenue, cost, profit and discounting rate help to deliver scientific advice to policymakers for specific conditions.

3. Policy oriented models in the Black Sea

3.1. Hydrodynamics

Marine hydrodynamic models are examples of General Circulation Models (GCMs) that use principles of geophysical fluid dynamics and thermodynamics to estimate the physical properties of the oceans. They constitute one of the most advanced tools used in physical oceanography as unlike observational tools, which are often sparsely distributed, they can have extensive spatio-temporal coverage. When combined with data assimilation they can be used to fill in the gaps in historical observational data or provide accurate forecasts for the near-term future. The quantities predicted by hydrodynamic models include the three spatial current components, temperature, salinity and turbulent mixing. Surface boundary conditions including the transfer of heat, momentum and water between the air and the ocean are provided by coupling the ocean GCM to an atmospheric GCM. This coupling could be one-way, where the atmospheric parameters and variables generated by an a-priori atmospheric GCM simulation are used in the ocean GCM as input, or the coupling could be two-way, whereby the two models are simulated simultaneously with feedback between the atmosphere and the ocean. Freshwater fluxes from rivers can also be included in the ocean GCMs as lateral boundary conditions. If the computational domain includes open boundaries, the lateral boundary conditions must be provided by another model.

A critical consideration in the use of GCMs is their spatial resolution. Higher resolutions (*i.e.* closer grid points) lead to more accurate predictions and the ability to generate dynamical features at small spatial scales such as mesoscale eddies and frontal structures. However high resolution setups are computationally expensive and require parallel computational methods to generate simulations in reasonable times. Since their inception, a large number of open-source GCMs have been developed differing in the way they represent the ocean domain (*i.e.* the grid structure), the way in which different physical processes are represented, the numerical methods used and the approximations employed. Some of the commonly used models include the Princeton Ocean Model (POM), Modular Ocean Model (MOM), The Regional Ocean Modelling System (ROMS), Nucleus for European Modelling of the Ocean (NEMO), and General Estuarine Transport Model (GETM).

Ocean GCMs form an integral part of end-to-end coupled ecosystem models (see Section 3.f.), where they provide the velocity fields required to predict the transport of plankton and nutrients as well as the temperature fields, which control the rates of most biological reactions including growth and decomposition.

Within the FP-7 project MEECE, POM was set up for the Black Sea where model domain encompassed the entire Black Sea (41°S-46°N, 28°E-41.5°E) but excluded the Azov Sea. It consisted of a (0.1° x 0.0625°) resolution, Arakawa C horizontal grid and a 26 level, sigma-coordinate vertical grid. Both the Kerch Strait and the Bosphorus, as well as the 8 major rivers around the Black Sea (Danube, Dniester, Dnieper, Inguri, Rioni, Yesilirmak, Kizilirmak and Sakarya) provided freshwater and nutrient input into the model domain. The model was forced with the ERA-40 atmospheric products of The European Centre for Medium-Range Weather Forecasts (ECMWF). The model was later parallelized through the implementation of the parallel version of POM (sbPOM) and imparted with improved representation of mesoscale processes within another FP-7 project, Operational Ecology (OPEC). Figure 1 shows an example of the temperature, salinity and velocity fields generated by the model.

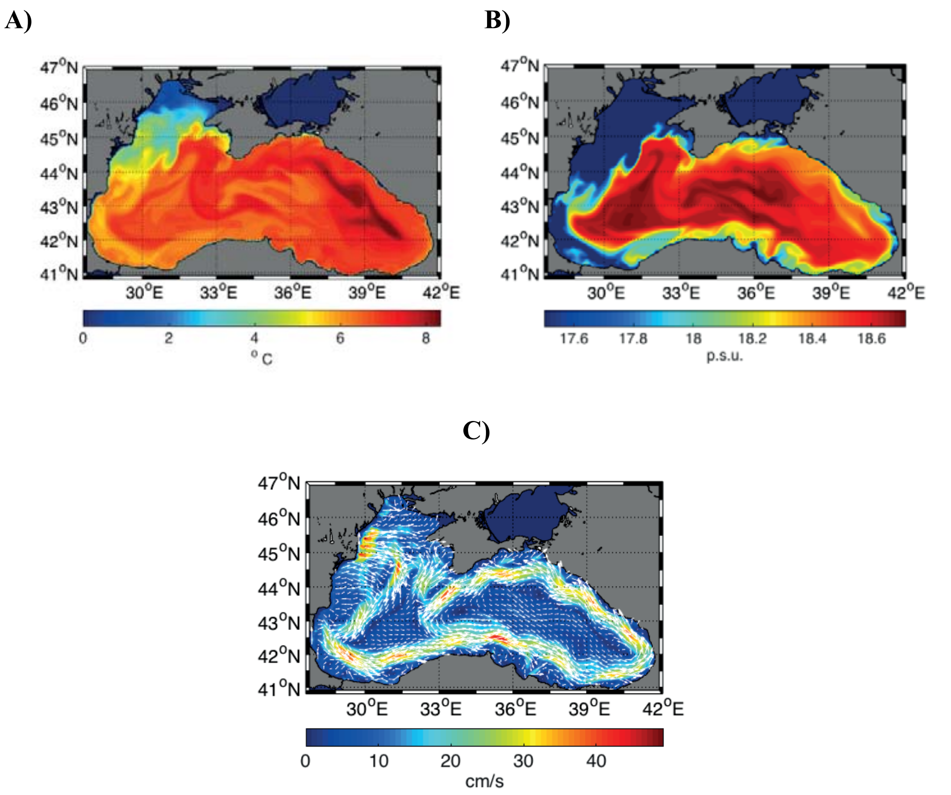


Figure 1. Surface (A) temperature, (B) salinity, and (C) velocity fields generated by the Black Sea model (sbPOM) for 15 February 2010

3.2. Lower Trophic Level Models

Plankton form the foundation of marine ecosystems and the functions they perform play important roles in the global biogeochemical cycles. Lower Trophic Level (LTL) models are aimed at predicting the interaction between the ocean environment (physics, inorganic nutrients, light, *etc.*) and plankton communities as well as the food web dynamics between plankton groups. Plankton are often represented as Functional Types (FTs) which are groups of species that perform similar functions within the ecosystem. LTL models tend to have four major components, inorganic nutrients required or generated by organisms, a group of autotrophic FTs (phytoplankton) that use solar radiation and inorganic nutrients to produce organic matter, a group of heterotrophic FTs (zooplankton) that predate on autotrophic organisms, organic matter in either dissolved or particulate form which is produced by organisms either through excretion or through the death of the organisms, and bacterial communities which remineralize organic matter to produce inorganic nutrients. LTL models are often simulated coupled to a physical model (either an Ocean GCM or a 1D water column model) which provide the LTL with the physical parameters such as solar radiation and temperature required to parametrize biological rates and which also perform the transport of biological components through currents and vertical turbulent mixing.

A number of generic, open-source LTLs have been developed and applied to many marine regions around the world. These include the European Regional Seas Ecosystem Model (ERSEM) and its variant Biogeochemical Flux Model (BFM), Pelagic Interaction Scheme for Carbon and Ecosystem Studies (PISCES), and Ecological Regional Ocean Model (ERGOM). However, many of these models are unsuitable for use in the Black Sea as they lack representation of processes that are pertinent to the Black Sea, particularly the redox layer processes.

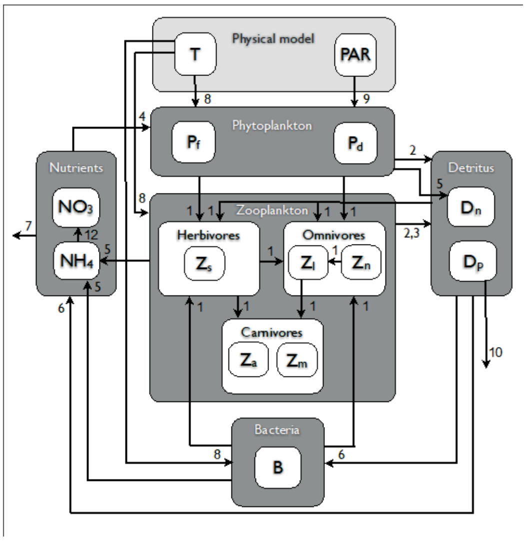


Figure 2. Schematic of the initial BIMS-Eco model setup used during EU FP-7 MEECE project. Modified from Cannaby *et al.* (2013)

BIMS-Eco is a Black Sea LTL model that started its development during the FP-6 project, MyOcean, and continued to be improved through the EU FP-7 projects, MEECE, OPEC and Policy-oriented marine Environmental Research for the Southern European Seas (PERSEUS). The pelagic ecosystem model used is based on the 1D model by Oguz *et al.* (2001b). The model domain extends to 150 m depth. It originally had 23 z-levels with a 2 m resolution near the surface and 20 m near the lower boundary. The model had 12 state variables (Figure 2) that include two phytoplankton groups, small and large phytoplankton (Ps, Pl; smaller and larger than 10 μm representing flagellate and diatoms), micro- and mesozooplankton (< 0.2 mm Zs and > 0.2-2 mm Zl), bacterioplankton (B), labile pelagic detritus (Pn), DON (Dn), nitrate (N), ammonium (A), as well as the opportunistic heterotrophic dinoflagellate *Noctilua scintillans* (Zn) and the gelatinous carnivores *Aurelia aurita* (Za) and *Mnemiopsis leidyi* (Zm).

The simple version of BIM-Eco (Figure 2) was used to assess possible changes in the productivity of the Black Sea under a hind cast scenario, a simulation run for the time frame 1980-2000, depending on the nutrient loads of the rivers flowing into the Black Sea. As an example of what can be assessed with such a model, Figure 3 shows the change in annual primary production under the assumption of a 50% increase (a) and a 50% decrease (b) in nitrate loads from all rivers emptying into the Black Sea during the time 1980-2000. It shows that eutrophication has a strong impact on the level of primary production in the Black Sea in this simulation, which is particularly pronounced in the deep basin and eastern regions of the basin (Figure 3). Increasing river input has a stronger impact than decreasing the river input and both simulations show reduced sensitivity to increased riverine nutrient loading near the major river mouths on the north-western shelf, particularly near the Danube delta, and at the southern coast where the Sakarya, Yesilirmak and Kizilirmak rivers enter. Net primary production is increased up to 60% over much of the Black Sea inner basin when nutrient loads are doubled while it decreases by 40% when the load is cut in half.

A) **B)**

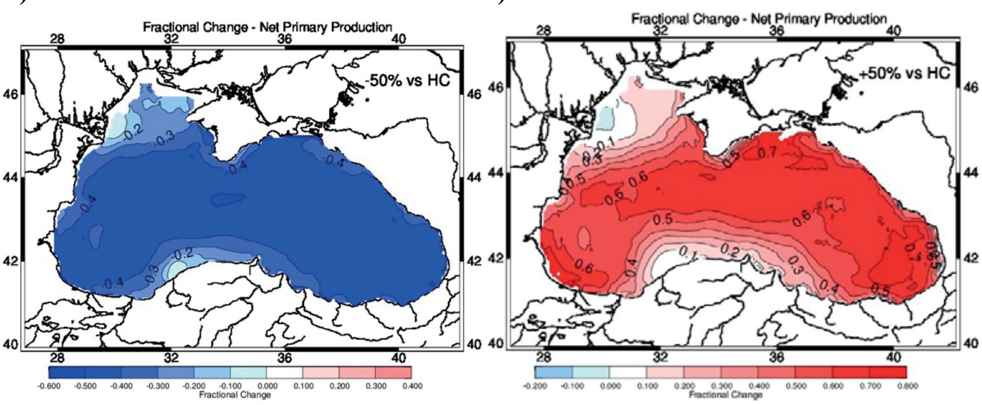


Figure 3. Fractional change in annual primary production relative to the reference simulation (1980-2000) caused by decreasing (A), and increasing (B) riverine nutrient loads by 50%

The BIMS-Eco model has since been developed much further to include four phytoplankton groups, diatoms (P_d), non-toxic dinoflagellates (P_f), coccolithophores (P_c), and the small phytoplankton group (P_s) representing picophytoplankton and nanophytoplankton (e.g. autotrophic flagellates) (Figure 4). Coccolithophores were introduced as a separate group due to their special feature of calcification ($CaCO_3$ formation). Consumers comprise four zooplankton functional/species groups, bacterioplankton (B) decomposes particulate organic nitrogen and phosphorus to produce inorganic nutrients ammonium (NH_4) and phosphate (PO_4). It also includes parametrization of the redox layer processes including chemotrophic oxidation of hydrogen sulfide and anaerobic oxidation of ammonium (Figure 4).

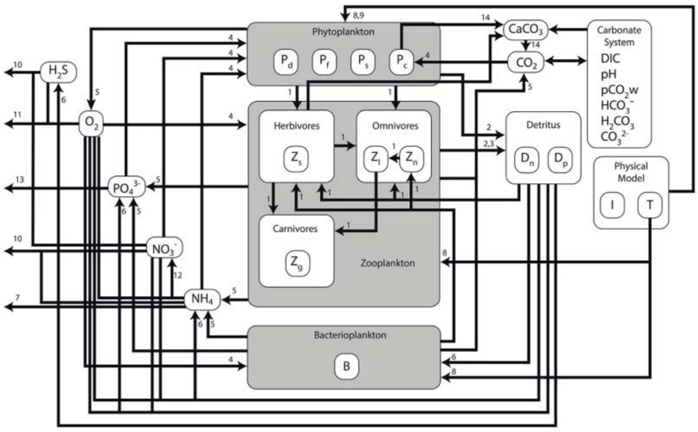


Figure 4. Schematic of the improved BIMS-Eco model setup and trophic interactions. The model now includes four phytoplankton groups, three zooplankton groups, two detritus groups, bacterioplankton and nutrients (NO_3, NH_4, PO_4) and a detailed representation of the carbonate cycle. Modified from Salihoglu *et al.* (2017)

The improved BIMS-Eco model has been applied to model the change of net primary production between the years 2000-2014 in respect to a forecast simulation for the immediate future (2015-2020) without any changes in river nutrient input. Model simulation shows a net decrease in primary production when the entire basin is considered, much of which is predicted to be along the western coast of the Black Sea, the central basin and also along the north-eastern coast (Figure 5). At the same time, future net primary production increases in the northern part of the north-western shelf and to a rather small extent in the western central gyre. Lowest overall reduction occurs in the western gyre of the basin, (Figure 5). This observed decrease in net primary production is in agreement with other modelling studies using future climate change scenarios such as the comparison study of four different global models that predict lower net primary production rates for future climate scenarios (Bopp *et al.* 2001, Boyd and Doney 2002, Steinacher *et al.* 2010, Bopp *et al.* 2013, Marinov *et al.* 2013, Cabré *et al.* 2015, Laufkotter *et al.* 2015, 2016). The main mechanism that has been suggested to explain such a decrease is increased stratification which effectively reduces nutrient supply to the surface layer causing decreased phytoplankton growth and therefore reduced net primary production (Bopp *et al.* 2001, Steinacher *et al.* 2010). In addition, increased grazing pressure caused by warmer water temperatures may be a factor reducing net primary production (Laufkötter *et al.* 2015).

A) **B)**

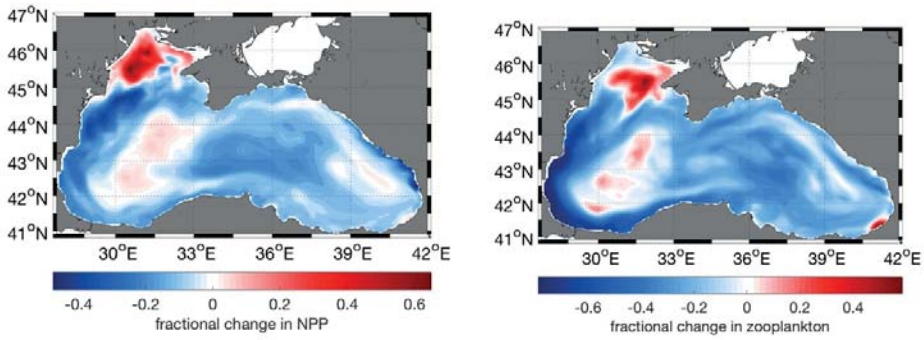


Figure 5. Fractional change of A) Net Primary Productivity and B) Zooplanton biomass between the present time (2010-2015) and future (2015-2020) periods.

3.3. Higher Trophic Level Models

One example of higher trophic level models is the Ecopath with Ecosim (EwE) ecological/ecosystem modelling software that is freely available (http://ecopath.org). It consists of three components which are namely *Ecopath* – a static, mass-balanced snapshot of the system; *Ecosim* – a time dynamic simulation module for policy exploration; and *Ecospace* – a spatial and temporal dynamic module primarily designed for exploring impact and placement of protected areas.

In an effort to model the Black Sea higher trophic level dynamics during above mentioned EU-FP7 projects a Black Sea Ecopath with Ecosim higher trophic level model was set up centred around a few functional groups of species in general; top predators, pelagic piscivorous fish, demersal fish, small pelagic fish, gelatinous zooplankton, trophic zooplankton and primary producers. However, they were broken down into major species as representatives of the functional groups. The rationale behind the model is to focus on investigating the dynamics of anchovy stock; *i.e.* its recruitment and spawning, by representing the ontogenetic structure of the anchovy in detail in the model. However, with the inclusion of the full representation of the food web in the model (Figure 6), it enables us to derive ecological indicators that could be used to assess the structure and function of the Black Sea ecosystem over the years. The model simulation starts from 1960s, a period during which the Black Sea ecosystem is considered to be in a quasi-pristine state, and originally extends to 2020 so that it provides short term predictions for the likely changes expected to occur in the Black Sea. However, long-term forecast predictions were also carried out for the period 2080-2099.

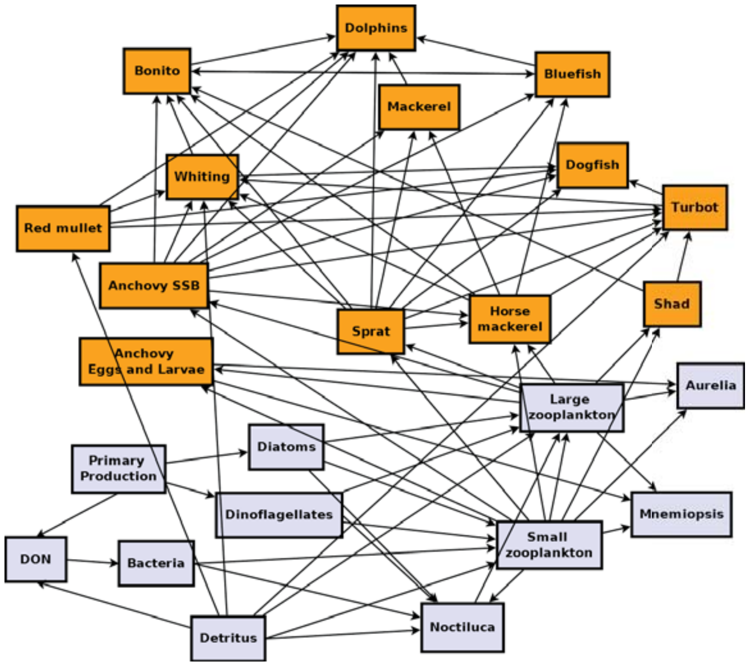


Figure 6. Schematic view of the Black Sea Ecopath with Ecosim model. Arches show flows between groups. Nodes are the state variables

The mass-balance Ecopath model of the Black Sea was based on Akoglu *et al.* (2015) and further developed by disaggregating the functional groups of small pelagic fish, pelagic piscivorous fish and demersal fish, which were aggregated guilds of multiple species in the earlier study, into individual species. Further, new state variables were introduced; *i.e.* two nutrient compartments; ammonium (NH_4) and nitrate (NO_3). The model was extended to include 22 functional groups, which comprised of 12 fish groups; Black Sea anchovy (*Engraulis encrasicolus ponticus*; Alexandrov 1927), Black Sea sprat (*Sprattus sprattus phalaericus*; Risso 1827), Pontic shad (*Alosa kessleri pontica*; Eichwald 1838), Black Sea horse mackerel (*Trachurus mediterraneaus ponticus*; Aleev 1956), bonito (*Sarda sarda*; Bloch 1973), bluefish (*Pomatomus saltator*; Linnaeus 1776), Atlantic mackerel (*Scomber scombrus*; Linnaeus 1758), turbot (*Psetta maeotica*; Pallas

1814), spiny dogfish (*Squalus acanthias*; Linnaeus 1758) and red mullet (*Mullus barbatus ponticus*; Essipov 1927), one jellyfish group representing *Mnemiopsis leidyi* (Agassiz 1865), *Aurelia aurit*a (Linnaeus 1758), *Pleurobrachia* spp. and *Beroe ovata* (Mayer 1912); two phytoplankton groups representing the large and small phytoplankton (Phy1 and Phy2) and two zooplankton groups; one representing mesozooplankton (Zoo2) and one representing microzooplankton (Zoo1), one bacteria group and one dolphin group to represent the Black Sea marine mammals, which are composed of short-beaked common dolphin (*Delpinus delphis*; Linnaeus 1758), bottlenose dolphin (*Tursiops truncates;* Montagu 1821) and harbor porpoise (*Phocoena phocoena*; Linnaeus 1758). Two fishing types were identified; trawlers and purse seiners to represent the fishery impact on the ecosystem. The mass-balance model was set up and balanced for the quasi-pristine conditions of the early 1960s. The diet composition matrix of the model was largely based on data available by stomach content analysis and compiled from FishBase (Froese and Pauly 2011).

This model was utilized to investigate future progressions of the Black Sea ecosystem under predicted IPCC medium emission climate scenario (Fig. 2) within the scope of EC FP 7 MEECE project as well as understanding mechanisms behind the observed changes in the Black Sea ecosystem during the course of second half of the 20th century.

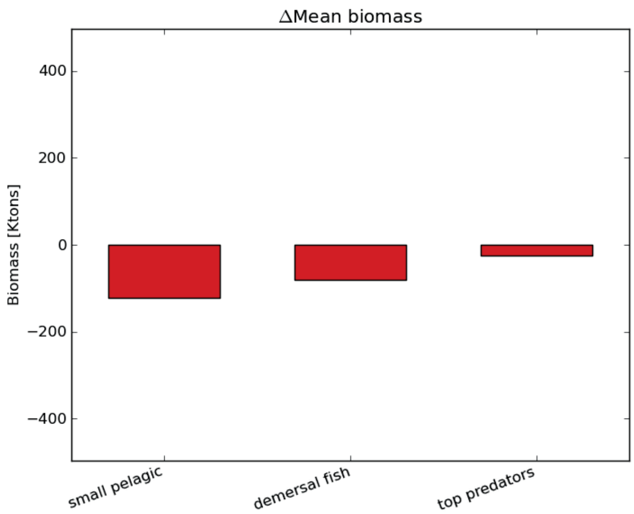


Figure 7. Change in fish biomass between 1980-2000 (present day) and 2080-2100 when forced with IPCC medium-emissions Scenario (A1B)

The decrease observed in the fish stocks (Figure 7) is due to the predicted reduction in basin-wide primary production for A1B scenario and the impact of high fisheries exploitation levels. The decrease in the top predators puts forward the future consequences of their contemporary unmanaged exploitation levels by the Black Sea fisheries along with resource limitation caused by decreased small pelagic fish stocks.

3.4. Individual based models (IBM's)

Individual based models are mathematical models that simulate populations or communities by following individual organisms and their properties. Individual based modelling today is an important modelling tool in oceanography and ecology and has been applied increasingly there in the last 20 years. The strength of this modelling approach is that it allows for a high degree of complexity of individuals and of interactions among individuals (DeAngelis and Grimm 2014). The way these models work is that each individual is assigned a set of properties and even behaviours. These may include physiological traits such as growth rates, reproduction rates and energy budgets of individuals or behaviour such as dispersal, migration or habitat selection and are useful when modelling individuals or populations of different marine species, from zooplankton to fish. The possibility to include variation between individuals of the same population and variations of individuals during their life cycle; local interactions among individuals; adaptive behaviour; and interactions with their abiotic environment makes them a powerful tool to address the management of populations and can be readily used in an ecosystem based approach to resource management.

Different types of individual based models have been applied in the Black Sea in recent years. Fach (2014) used flow trajectories from satellite derived geostrophic flow in a Lagrangian scheme, generating an individual based model for larval dispersal of anchovy. To evaluate the spatial scales over which larvae may be dispersed under realistically varying spatial and temporal oceanographic conditions, the model was run for three years (2001-2003) resolving interannual variability in transport within the entire region. The IBM model includes a number of biological parameters such as pelagic larval duration (PLD), temperature dependent growth parameters and adult spawning strategies (season and frequency). Results showed for the first time the high potential of larval dispersal within the Black Sea, reaching distances of up to 1000 km away from their spawning site within a month. This larval dispersal is strongly controlled at the basin scale by the Rim Current circulation and its two cyclonic basin-wide gyres while it is locally controlled by mesoscale eddies (Figure 9). Variability in the dispersal of larvae is considerable when comparing different years and seasons (Fach 2014).

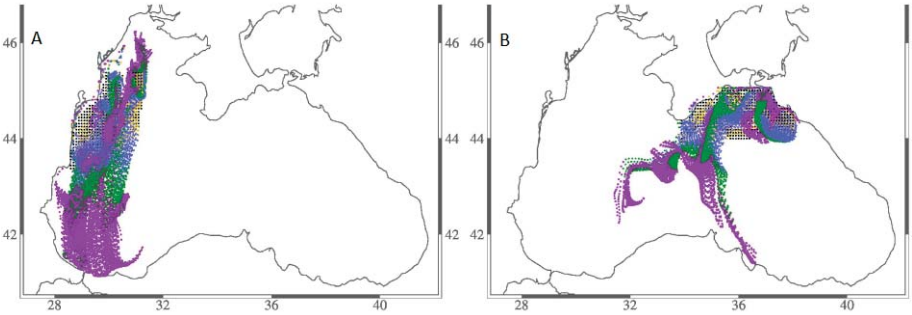


Figure 8. Trajectories of anchovy larvae released in August 2002 on A) the lower north-western shelf B) off Kerch Strait. Daily locations are recorded for 36 days of simulation. Larval stages are color-coded as: eggs in black, yolk sac larva orange, early larva (< 10 mm) blue, larva (< 20 mm) green, late larva magenta

The IBM of anchovy was later extended to include adult anchovy swimming behaviour and has since then been used to elucidate the interannual variation in Black Sea anchovy migration routes given inter-annual and seasonal variability of the oceanic currents and sea surface distribution in the same three divergent years (2001-2003) (Guraslan 2016). The goal of this research was to understand the environmental factors influencing successful anchovy migration, as well as determine from which regions in the Black Sea anchovy can successfully migrate to the overwintering areas located at the eastern Anatolian coast. Model results showed that years with increased mesoscale variability in flow dynamics facilitate successful migration of drifters representing migrating anchovy schools from nursery areas located on the north-western shelf to the overwintering area (Guraslan *et al.* in review) and the resulting migration pathways (Figure 9) differ from traditionally accepted migration pathways of earlier studies in the 1980's-1990's (Ivanov and Beverton 1985, Chashchin 1996). Results further suggest that overwintering anchovy that are supplying the Turkish anchovy fisheries along the Eastern Anatolian coast do not usually originate from the north-western shelf, but rather originate from nursery grounds in the eastern Black Sea basin (Guraslan *et al.* in review). It was shown that variability in migration success between years and seasons are due to the intensity and timing of cooling events during fall, as well as the strength of currents and therefore is important for fisheries management purposes.

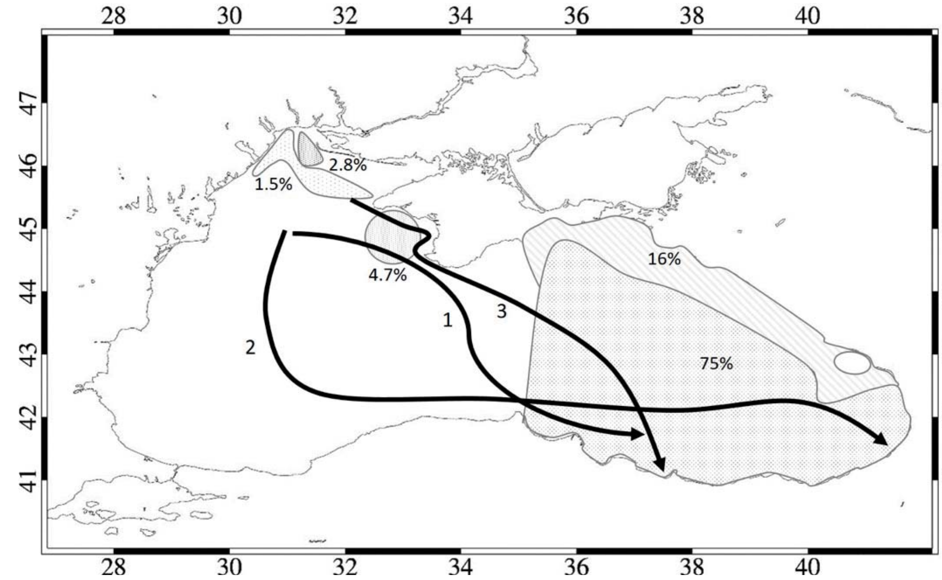


Figure 9. Conceptual figure of the regions from where anchovy can reach the overwintering area when swimming along temperature gradients (shaded areas) and migration pathways (black lines) identified for Black Sea anchovy released from the northwestern shelf. Modified from Guraslan *et al.* (in review)

It is well known that larval dispersal by ocean currents and connectivity between different oceanic regions are crucial factors when designing Marine Protected Areas (MPA) (Cowen *et al.* 2006, Moffit *et al.* 2009, Lester *et al.* 2009). It also plays a major role in assuring population persistence in an MPA network (Moffitt *et al.* 2011). Therefore, the above described modelling approach is very valuable when designing networks of Marine Protected Areas in the Black Sea. To that effect simulations were undertaken with virtual fish larvae of different length PLD's and at different spawning times to assess the feasibility of proposed marine protected areas along the Turkish coast of the Black Sea (Özturk *et al.* 2017). The simulations showed that the Şile and Doğanyurt sites are good locations for establishing MPAs, and because they are well-connected, can also play an important role in maintaining a Black Sea MPA network.

3.5. End-to-end Models

End-to-end models, *i.e.* two-way and online coupled models that include the full explicit representations of almost all the processes within the ecosystem without closures or simplifications on the level of biogeochemical cycles, are in their infancy; however, they have proved to be efficient tools for investigating ecosystem structure and function in the most realistic sense (Fulton 2010, Rose *et al.* 2010, Salihoglu *et al.* 2013). They are also useful for enabling the most accurate derivation/calculation of ecological indicators to assess the ecosystem structure and function because they do not include the extreme simplifications and abstractions such as excluding organisms above a certain trophic level or defining time series of productivity forcing functions; instead they opt to represent the ecosystem to its fullest extent possible. This does not mean that these models incorporate every process or group in an ecosystem, but means that they do not sacrifice the major processes and groups within an ecosystem via oversimplification. A recent study (Dişa 2016) shows how fisheries can affect the biogeochemical cycles in the Saragossa Sea. This study also shows how the biomasses of different fish species are affected by changes in the biogeochemistry. These types of studies are needed to understand how fisheries affect the carbon cycle and export, one of the most important ecosystem services. Also, how changes in climate and environmental factors will be reflected on the fish species can be assessed with end-to-end models.

4. Forecasting and Prediction Tool for the Black Sea

The general framework of such a tool should include an atmospheric model that produces atmospheric forcing functions (surface fluxes of momentum, heat and mass); a watershed model that forecasts the discharge rates and nutrient fluxes into the sea from the entire Black Sea catchment area; and a coupled physical-ecological-biogeochemical ocean model of the Black Sea. This tool can build on available expertise in the Black Sea. For example, an implementation of watershed model, SWAT for the entire Black Sea catchment was developed within the EnviroGrids project (Building Capacity for the Black Sea Basin Observation and Assessment System Supporting Sustainable Development). The MONERIS (Modelling Nutrient Emissions in River System) model for nutrient emissions to be used for regional, national and international studies of water quality in catchment areas and was used as a modelling tool in the FP5 daNUbs (Danube Nutrients Black Sea) Project. As detailed above there are several ocean hydrodynamics models and ecosystem models that have been developed for the Black Sea. These models should run as ensembles in the Black Sea to better demonstrate the skills of models and reduce the model uncertainty.

One of the main bottle necks in developing such an integrated forecasting tool is the lack of data. Although there are many databases, these databases would only be extremely useful for the model framework if the scattered structure was removed and the data is merged under one database for the Black Sea. The modelling system needs data both to force the models (such as river input) but also to evaluate the results. Forcing fields should be provided close to near real time to achieve most realistic model forecasts. There are two major weaknesses in the available databases: i) most data is coastal whereas the Black Sea basin functions as a whole. It follows that the national monitoring systems really should be extended to include open ocean observations. ii) although there is ample amount of reported physical and chemistry data, ecological data (even at the level of chl) is limited.

References

Akoglu, E., S. Libralato, B. Salihoglu, T. Oguz, and C. Solidoro. 2015. EwE-F 1.0: an implementation of Ecopath with Ecosim in Fortran 95/2003 for coupling and integration with other models. Geoscientific Model Development, 8: 2687-2699.

Bopp, L., P. Monfray, O. Aumont, J. Dufresne, H. Le Treut, G. Madec, L. Terray, and J. Orr. 2001. Potential impact of climate change on marine export production. Global Biogeochem. Cy. 15: 81-100.

Bopp, L., L. Resplandy, J.C. Orr, S.C. Doney, J.P. Dunne, M. Gehlen, P. Halloran, C. Heinze, T. Ilyina, R. Séférian, J. Tjiputra, and M. Vichi. 2013. Multiple stressors of ocean ecosystems in the 21st century: projections with CMIP5 models. Biogeosciences, 10: 6225-6245.

Boyd, P.W. and S.C. Doney. 2002. Modelling regional responses by marine pelagic ecosystems to global climate change. Geophys. Res. Lett., 29: 1-4.

Cabré, A., I. Marinov, and S. Leung. 2015. Consistent global responses of marine ecosystems to future climate change across the IPCC AR5 earth system models. Climate Dynamics, 45(5-6): 1253-1280.

Chashchin, A.K. 1996. The Black Sea populations of anchovy. Scientia Marina, 60(2): 219-225.

Cowen, R.K., C.B. Paris, and A. Srinivasan. 2006. Scaling of connectivity in marine populations. Science, 311: 522-527.

DeAngelis, D.L. and V. Grimm. 2014. Individual-based models in ecology after four decades. F1000Prime Rep., 6(39): 6.

Disa, D. 2016. MSc. Thesis. Middle East Technical University, Institute of Marine Sciences.

Fach, B.A. 2014. Modeling the influence of hydrodynamic processes on anchovy distribution and connectivity in the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 353-365.

Fennel, W. and T. Neumann. 2004. Introduction to the modelling of marine ecosystems, 297 p. (Elsevier Oceanography Series; 72), Amsterdam.

Finn, J.T. 1976. Measures of ecosystem structure and function derived from analysis of flows. Journal of theoretical Biology, 56(2): 363-380.

Froese, R. and D. Pauly. 2011. Editors. FishBase. World Wide Web electronic publication.www.fishbase.org.

Fulton, E.A. 2010. Approaches to end-to-end ecosystem models. Journal of Marine Systems, 81(1): 171-183.

Guraslan, C. 2016. Modeling the impact of climate variability on anchovy overwintering migration in the Black Sea. Dissertation. Erdemli (Mersin). Middle East Technical University.

Guraslan, C., B.A. Fach, and T. Oguz (in review) Understanding the impact of environmental variability on anchovy overwintering migration in the Black Sea and its implications for a dynamic fishing industry managed under the Common Fisheries Policy. Frontiers of Marine Science

Ivanov, L. and R.J.H. Beverton 1985. The Fisheries Resources of the Mediterranean. pt. 2: Black Sea. FAO.

Laufkötter, C., M. Vogt, N. Gruber, M. Aita-Noguchi, O. Aumont, L. Bopp, E. Buitenhuis, S. Doney, J. Dunne, T. Hashioka, and J. Hauck. 2015. Drivers and uncertainties of future global marine primary production in marine ecosystem models. Biogeosciences, 12: 6955-6984.

Laufkötter, C., M. Vogt, N. Gruber, *et al.* 2016. Projected decreases in future marine export production: the role of the carbon flux through the upper ocean ecosystem. Biogeosciences, 13(13): 4023-4047.

Lester, S., B. Halpern, K. Grorud-Colvert, J. Lubchenco, B. Ruttenberg, S. Gaines, S. Airamé, and R.R. Warner 2009. Biological effects within no-take marine reserves: a global synthesis. Mar. Ecol. Prog. Ser., 384: 33-46.

Marinov, I., S.C. Doney, I.D. Lima, K. Lindsay, J.K. Moore, and N. Mahowald. 2013. North-South asymmetry in the modelled phytoplankton community response to climate change over the 21st century. Global Biogeochem., Cy. 27: 1274-1290.

Moffitt, E.A., L.W. Botsford, D.M. Kaplan, and M.R. O'Farrell. 2009. Marine reserve networks for species that move within a home range. Ecological Applications, 19: 1835-1847.

Moffitt, E.A., J.W. White, and L.W. Botsford. 2011. The utility and limitations of size and spacing guidelines for designing Marine Protected Area networks. Biol. Conserv., 144: 306-318.

Odum, E.P. 1971. Fundamentals of Ecology, 574 p. Third Edition. Philadelphia: Saunders.

Oguz, T., P. Malanotte-Rizzoli, H.W. Ducklow. 2001. Simulations of phytoplankton seasonal cycle with multi-level and multi-layer physical-ecosystem models: The Black Sea example. Ecol. Model. 144: 295-314.

Öztürk, B., Fach, B.A., C. Keskin, S. Arkın, B. Topaloglu, and A.A. Öztürk 2017. Prospects for Marine Protected Areas in the Turkish Black Sea, p. 247-262. In P.D. Goriup [ed.], Management of Marine Protected Areas: A Network Perspective. UK, Wiley Blackwell.

Pauly, D. and V. Christensen. 1995. Primary production required to sustain global fisheries. Nature, 374(6519): 255.

Pauly, D., V. Christensen, J. Dalsgaard, R. Froese, and F. Torres. 1998. Fishing down marine food webs. Science, 279(5352): 860-863.

Pauly, D. and R. Watson. 2005. Background and interpretation of the 'Marine Trophic Index'as a measure of biodiversity. Philosophical Transactions of the Royal Society of London B: Biological Sciences, 360(1454): 415-423.

Rose, K.A., J.I. Allen, Y. Artioli, M. Barange, J. Blackford, F. Carlotti, R. Cropp, U. Daewel, K. Edwards, K. Flynn, and S.L. Hill. 2010. End-to-end models for the analysis of marine ecosystems: challenges, issues, and next steps. Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science, 115-130.

Salihoglu, B., S. Neuer, S. Painting, R. Murtugudde, E.E. Hofmann, J.H. Steele, R.R. Hood, L. Legendre, M.W. Lomas, J.D. Wiggert, and S. Ito. 2013. Bridging marine ecosystem and biogeochemistry research: lessons and recommendations from comparative studies. Journal of Marine Systems, 109: 161-175.

Schulz, M., H. Goose, E. Hofmann, P.-Y. Le Traon, S. Lozier, B. Salihoglu, and I.S. Pinto. 2015. 5th EMB Forum Consensus Statement: Ocean-Climate Nexus-The critical role of ocean science in responding to climate change. European Marine Board, Ostend, Belgium. 4 pp.

Steinacher, M., F. Joos, T.L. Frölicher, L. Bopp, P. Cadule, V. Cocco, S.C. Doney, M. Gehlen, K. Lindsay, J.K. Moore, B. Schneider, and J. Segschneider. 2010. Projected 21st century decrease in marine productivity: a multi-model analysis. Biogeosciences, 7: 979-1005.

Ulanowicz, R.E. 1986. Growth and Development: Ecosystems Phenomenology, 203 p. New York, Springer-Verlag.

MARINE LITTER POLLUTION IN THE BLACK SEA: ASSESSMENT OF THE CURRENT SITUATION IN LIGHT OF THE MARINE STRATEGY FRAMEWORK DIRECTIVE

Levent BAT, Ayşah ÖZTEKİN and Elif ARICI

Sinop University, Faculty of Fisheries, Department of Hydrobiology, Sinop, Turkey
leventbat@gmail.com

1. Introduction

Anthropogenic litter on the ocean surface, beaches and seafloor has significantly increased in recent decades and the Black Sea has been described as one of the most affected areas.

Marine litter can be defined as (UNEP 2005):

"Any persistent, manufactured or processed solid material disposed of or abandoned in the marine and coastal environment."

Marine litter may consist of 'plastics, wood, metals, glass, rubber, clothing, paper *etc*.' and is a globally recognized environmental issue of increasing concern. Marine litter has been encountered in all the world's oceans, from the poles to the equator, from continental coastlines to small distant islands. It takes place not only close to intensively populated coasts, but also in far out from any obvious sources (Pawar *et al.* 2016).

Various programs and organizations such as IMO, UNEP, IOC-UNESCO, FAO and lately the EU MSFD (Descriptor 10) accepted marine litter as a global threatening issue from environmental, economic, human health and safety, and aesthetic aspect (Moncheva *et al.* 2016). Marine litter can effect marine wildlife, degrade ocean environments, reduce navigation safety, cause economic loss to shipping, fishing, and coastal communities, and pose a threat to people health. These negative forces have been supported by documents around the world. To support the economy and protect human health, many human-created persistent objects from fishing nets to medical equipment to food packaging play key roles (NOAA 2008).

UNEP (2005) indicated that the total input of marine litter into the oceans, worldwide, was at nearly 6.4 million tonnes per year and with regard to other calculations, some 8 million items of marine litter have been estimated to enter oceans and seas every day, about 5 million of which are thrown overboard or lost from ships according to "Marine Litter (ML) analytical overview". Estimates are suggesting that more than 13,000 pieces of plastic litter are floating on every square kilometre of ocean surface.

In these days, plastics dominate in marine litter as one of the most widely used substances over the world. Plastics are broadly integrated into today's lifestyle and make a major contribution to virtually all product areas. The typical characteristics that depict them so useful are primarily based on the fact that they are both flexible and durable (Hammer *et al.* 2012). Over the last 60 years, plastic production has increased enormously from 1.7 to 288 million tonnes (Plastics Europe 2013).

One of the most omnipresent and durable recent changes to the surface of our planet is the accumulation and fragmentation of plastics (Barnes *et al.* 2009). The durability and increasing usage of plastics create a major waste management problem (Thompson *et al.* 2009a). Substantial quantities of plastic have accumulated in natural environment and in landfills (Thompson *et al.* 2009b). Plastic litter constitutes 60% - 80% of all marine litter (Gregory and Ryan 1997). Most common used materials are plastic films, such as carrier bags, which are easily carried by the wind, as well as discarded fishing equipment and food and beverage packaging (Barnes *et al.* 2009).

Excessive polymeric materials that go into the marine environment depend on degradation that is induced by a combination of factors, including thermal oxidation, photo-oxidative degradation, biodegradation and hydrolysis (Hammer *et al.* 2012). Microplastics have been defined as synthetic polymer particles, being less than 5 mm (Arthur *et al.* 2009). They either go into the marine environment as preproduction pellets (preliminary microplastics) or show up the weathering and breakdown of bigger pieces already introduced as marine litter in the oceans (subsidiary microplastics) through the combined action of mechanical, biological, photic and thermal abrasion, leading to their fragmentation into increasingly small pieces (Andrady 2011, Cole *et al.* 2011, CIESM 2014). In recent studies, the presence of microplastics was reported from all over the worlds' beaches, sea floor and sea water and even freshwater (Retama *et al.* 2016, Isobe *et al.* 2017, Tsang *et al.* 2017, Wang *et al.* 2017) and also from Turkey (Güven *et al.* 2017, Aytan *et al.* 2016).

2. Sources of marine litter

Unexpected or planned human behaviours and activities are the sources of marine litter. Distribution of the majority of sea and ocean-based sources of marine litter derive from merchant shipping, ferries and cruise liners; fishing vessels; military fleets and research vessels; pleasure craft; offshore oil and gas platforms and drilling rigs; and aquaculture installations. Ocean currents, tidal cycles, regional-scale topography, including sea-bed topography and wind are strongly affected marine litter dispersion and deposition. Land-based sources of marine litter arise from coastal or inland areas including beaches, piers, harbours, marinas, docks and riverbanks. Urban disposal areas (waste dumps) located on the coast, water bodies such as rivers, lakes and ponds that are used as illegal dump sites, riverine transport of waste from landfills and other inland sources, discharges of untreated municipal sewage and storm water, industrial facilities, medical waste, and coastal tourism involving recreational visitors and beach-goers, are the primary sources of land-based marine litter. Natural storm-related events (such as hurricanes, tsunamis, tornadoes and floods) can bring a great quantity of materials which are washed from coastal areas that can end in the marine habitat. Therefore, high winds, large waves and storm surges produce result in land-based items to be introduced into the marine environment (UNEP 2009).

Globally, land-based sources are evaluated to account for some four-fifth of marine litter, with the rest of one-fifth coming from marine sources (Truowborst 2011). For instance, in the North Sea and Australia, it has been estimated that up to 70 per cent of the marine litter that enters the sea ends up on the seabed. Half of the remains are found on beaches and half floating on the water surface (UNEP 2005).

3. Impacts of marine litter

A report of UNEP 2009 summarizes marine litter as "*an environmental, economic, health and aesthetic problem*".

In environmental aspect, marine litter can impact species directly, such as through entanglement or smothering of species, or indirectly, such as through changes to habitat (NOAA 2008). The primary kinds of direct damage to wildlife are entanglement and ingestion (UNEP 2005). Some entanglement can occur by accident or when an animal is attracted to the debris as part of normal behaviour or out of curiosity. Starvation or malnutrition can happen via ingestion of marine litter.

In recent studies, it was reported that microplastics was found many marine species from zooplankton to invertebrates, fish, sea birds and marine mammals (Sun *et al.* 2017, Rosas-Luis 2016, Bråte *et al.* 2016, Poon *et al.* 2016, Wójcik-Fudalewska *et al.* 2016, Ryan *et al.* 2016) and recently Güven *et al.* 2017 reported microplastic occurrence in the gastrointestinal tract of fish in Turkish territorial waters of the Mediterranean Sea. Microplastics are consumed through filter-feeding at the base of the food web (Cole *et al.* 2013) and transfer of the trophic level (Setala *et al.* 2014, Farrell and Nelson 2013) has been reported in experimental studies. Resulting from ingestion, concerns have also been raised about plastic litter transferring toxic pollutants into marine food chains. Highest concentrations of PCBs, DDT, and a range of other persistent organic pollutants (POPs) were found in nurdles and microplastics. While some of these compounds are added to plastics during manufacture, others are adsorbed by and accumulated in plastic litter from the environment. More than 260 species (including invertebrates, turtles, fish, seabirds and mammals) have been reported to ingest or become entangled in plastic debris, resulting in impaired movement and feeding, reduced reproductive output, lacerations, ulcers and death (Laist 1997, Derraik 2002, Gregory 2009, Thompson *et al.* 2009).

Other threats to wildlife and the environment from marine litter include the smothering of the seabed, the transport of invasive alien species which occurs when organisms cling to drifting litter and thus hitch-hike into ecosystems where they do not belong and the disturbance of habitats from mechanical beach clean-up operations and also marine litter is believed to be a source of accumulation of toxic substances in the marine environment (UNEP 2005, Truowborst 2011).

Economic impacts includes direct cost and loss of income due to marine litter affecting a range of maritime sectors including impacts on tourism (loss of visual amenity and obstruction to beach use), losses in catch revenues, loss of fishing gear, damaged vessels (downtime and damage due to entanglements), and human injuries, costs for clean-up, animal rescue operations, recovery and disposal, damage to cooling water intakes in power stations (UNEP 2005, 2009, NOAA 2008, CIESM 2014).

Social impacts of marine litter are loss of aesthetics and / or visual amenity, loss of indigenous values, antagonism against perceived polluters, perceived or actual risks to health and safety and threat to navigation (UNEP 2009, CIESM 2014).

Marine litter related damages to public safety can be defined as navigational hazards (loss of power or steerage at sea is potentially life threatening), hazards to swimmers and divers (entanglements), cuts, abrasion and stick (puncture) injuries, leaching of poisonous chemicals and explosive risk (UNEP 2005, 2009).

4. Marine Strategy Framework Directive and Guidance for Marine Litter Monitoring

The European Commission enhanced the Marine Strategy Framework Directive (MSFD) to protect and provide a sustainable use of marine ecosystems. The MSFD establishes a framework within which Member States shall take action to achieve or maintain Good Environmental Status (GES) of their marine waters by 2020. The management of human activities is referred explicitly, recognizing that the "environmental status" also includes the effects of human activities. The characteristics are to be stated relying on the list of 11 qualitative descriptors in Annex I and by reference to Commission Decision 2010/477/EU on "*Criteria and methodological standards on good environmental status of marine waters*", which proffers 56 indicators for the 11 descriptors (Table 1). This approach focus on the usage of consistent criteria and methodologies across the European Union (EU) and at an impressive harmonization between different regions of the extent to which GES is being achieved (Galgani *et al.* 2013).

Table 1. 11 descriptors listed in Annex I of the MSFD for determining GES

Descriptor 1	Biodiversity is maintained
Descriptor 2	Non-indigenous species do not adversely alter the ecosystem
Descriptor 3	The population of commercial fish species is healthy
Descriptor 4	Elements of food webs ensure long-term abundance and reproduction
Descriptor 5	Eutrophication is minimised
Descriptor 6	The sea floor integrity ensures functioning of the ecosystem
Descriptor 7	Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
Descriptor 8	Concentrations of contaminants give no effects
Descriptor 9	Contaminants in seafood are below safe levels
Descriptor 10	**Marine litter does not cause harm**
Descriptor 11	Introduction of energy (including underwater noise) does not adversely affect the ecosystem

GES is based on eleven descriptors as listed in Annex I and Marine litter (Descriptor 10) has been defined as "*Properties and quantities of marine litter do not cause harm to the coastal and marine environment*". Galgani *et al.* (2013) pointed out that Commission Decision 2010/477/EU identify the following criteria and associated four indicators for Descriptor 10.

Criteria 10.1 Characteristics of litter in the marine and coastal environment;

(i) trends in the amount of litter washed ashore and/or deposited on coastlines, including analysis of its composition, spatial distribution and, where possible, source (10.1.1)

(ii) trends in the amount of litter in the water column (including floating at the surface) and deposited on the sea-floor, including analysis of its composition, spatial distribution and, where possible, source (10.1.2)

(iii) trends in the amount, distribution and, where possible, composition of microparticles (in particular microplastics) (10.1.3)

In 2010, following the Commission Decision on criteria and methodological standards on GES of marine waters, the Marine Directors requested the Directorate-General for the Environment (DG ENV) to establish an Technical Subgroup on Marine Litter (TSG-ML) under the Working Group on GES (WG GES), to address these gaps and further develop Descriptor 10. The TSG-ML is led by DG ENV and chaired by IFREMER, the EC Joint Research Centre and the German Environment Agency. The group consists of Member State (MS) delegates and invited experts from relevant organizations. (MSFD GES Technical Subgroup on Marine Litter, 2013)

During 2011, the TSG-ML focused on providing advice through the report "Marine Litter – Technical Recommendations for the implementation of MSFD requirements", which defined the options and tools available for the monitoring of marine litter in different environmental areas and a review of the existing monitoring programmes or surveys that generated data in Europe. Member states have then requested a follow-up through an additional mandate of the TSG-ML. Thus, Final Report "Guidance on Monitoring of Marine Litter in European Seas" occurred, which was the output of the work of the TSG-ML between 2012 and 2013. The aim of such Guidance is to assure member states with suggestions and knowledge needed to initiate the monitoring of the MSFD Descriptor 10. Specific protocols and considerations were described to collect, report and assess data on marine litter, in particular beach litter, floating litter, seafloor litter, litter in biota and microlitter (MSFD GES Technical Subgroup on Marine Litter 2013).

5. Marine Litter Pollution in the Black Sea

As it can be seen in Figure 1, geographical area of the marine litter problem extends over all the catchment area of the Black Sea drainage basin; two secondary seas (the Sea of Azov and Marmara Sea); two straits connecting the Black Sea with these secondary seas (the Strait of Kerch and Istanbul (Bosphorus) Strait); all rivers (along with their tributaries), flowing into the sea; coastal territories bordering to these coastal areas; and all land drained by the rivers and their confluents (BSC 2009). BSC (2009) emphasized that air masses changing the region add to the problem of marine litter accumulation and dissemination. In addition to all these factors, the Black Sea has a very dynamic current system allowing cross-border transportation of waste materials (Topcu and Ozturk 2010), which in turn makes this enclosed sea very sensitive to marine litter (Topcu *et al.* 2013).

Figure 1. The Black Sea

Total population of the Black Sea in the catchment area exceeds 160-170 million, and daily activities of all these people in some way or other affect the Black Sea environment and, probably, contribute to marine litter problem which is originated almost completely (but not only) from the problem of solid waste pollution (BSC 2009). The marine litter problem is closely related to main major problems of public health, conservation of the environment, and sustainable development in the Black Sea region. Marine litter originates from various land- and sea-based sources as a result of manifold human activities and, apparently, causes multivectorial adversarial effect on the population, wild life, abiotic nature and some economic sectors (BSC 2009, UNEP 2009).

The large rivers flow into the Black Sea namely, Danube, Dnieper, Bug, Dniester, Don, Kuban, Rioni etc. transport noticeable loads of pollutants (Topcu *et al.* 2013) and a recent study estimated that 4.2 tonnes of plastic come to the Black Sea by way of the Danube per day (1533 tonnes every year) (see Lechner *et al.* 2014, Aytan *et al.* 2016). Additionally, widespread distribution of illegal, unreported and unregulated (IUU) fishing in the Black and Azov Seas can be considered as a peculiar source of marine litter. That is really true regarding numerous illegal nets and nets which were discarded or abandoned creating the so-called "*ghost fishing*" (BSC 2009).

At the Black Sea region of Turkey, most of the municipal and industrial solid wastes, mixed with hospital and hazardous wastes are dumped on the nearest lowlands and river valleys or into the sea. The impact of riverside and seashore dumping of solid wastes adds importantly to problems arising from sewage and industry on the Black Sea coast. Appropriate integrated solid waste management systems are needed here as well; however, more difficult topography, weaker administrative structures, and the lower incomes of the inhabitants can make this more difficult to implement than it may be in Istanbul (Berkun *et al.* 2005).

There are international and regional conventions and agreements which are related to prevention and mitigation of the Black Sea marine litter problem. These treaties include the Convention on the Protection of the Black Sea Against Pollution (the Bucharest Convention), the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), the Convention for the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (the London Convention), the Convention on the Transboundary Movements of Hazardous Wastes and Their Disposal (the Basel Convention), and some other instruments which have indirect relation to the control of ML problem [United Nations Convention on Biological Diversity (CBD), Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), Convention on the Conservation of Migratory Species of wild Animals (CMS, Bonn Convention) and Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOMBAMS)].

UNEP (2009) notified that some governmental and private institutions or organizations in Bulgaria, Romania, Russia, Turkey and Ukraine conducted marine litter research handling different approaches and methods during the last decade. However, international collaboratively and national studies on marine litter in the Black Sea region are still scarce. One of them is MISIS project. The survey in the North- Western Black Sea - in front of Romania, Bulgaria and Turkey, at 6 polygons has been conducted under DG ENV Project (MISIS Joint Cruise Scientific Report, 2014). A full report which drew attention on marine litter in the Black Sea was published by the Black Sea Commission "Marine litter in the Black Sea Region" (BSC 2007) and "Marine Litter in the Black Sea Region: A Review of the Problem" (BSC 2009) and then the UNEP Reports (UNEP 2009) evaluated existing data, policies, activities, and institutional arrangements and proposed several actions to deal with the problem (Begun *et al*. 2012).

In these reports which are reviews about marine litter pollution in the Black Sea Region, mentioned that the first attempt to estimate approximate level of ML pollution in the Black Sea marine environment had been performed in August 2002 within "Azovka-2002" in which the main goal of the project was to collect data on abundance and distribution of Black Sea cetaceans (dolphins and porpoises) by means of aerial surveys in Ukraine and Russia. Concomitant information on ML was gained in addition only, thanks to that opportunity. According to results of the researches, there was an overwhelming predominance of plastics (80-98 percent) in the litter in comparison with glass (2–20 percent) on the remote beaches. Other data in the report were large quantities of petroleum tar balls found washed ashore in 2003 in western Crimea and it was stated that the concentration of this contaminant was estimated as high as 11,600 kg per km^2 of beach. Similar cetacean and marine litter vessel-based surveys had been fulfilled in Kerch Strait of Ukrainian and Russian part (Afalina Project-2003). Rather different aerial marine litter surveys have been conducted in the Russian Black and Azov Seas in 2003-2005 along unpopulated (but visited by unorganized tourists) parts of the Russian Black Sea and Azov Sea coasts. Such marine litter deposits are known to be present on the sandy north eastern coast of the Kerch Strait and also in the Anapa and Novorossiysk areas. In Bulgaria, five public beaches in Bourgas, Pomorie and Sozopol were monitored during March-July 2001 and 1,087, 3,409 and 6,710 litter items were collected, respectively (BSC 2009, UNEP 2009).

Various non-governmental organizations focus on the importance of marine litter pollution with their research and social responsibility projects on marine litter [Turkish Marine Environment Protection Association (TURMEPA), Turkish Marine Research Foundation (TUDAV), etc.]. One of them is MARLISCO (Marine Litter in Europe Seas: Social Awareness and Co-Responsibility) project which TUDAV draws attention to the issue with a variety of activities and social responsibility projects. MARLISCO's goal was to raise public awareness, facilitate dialogue and promote co-responsibility among the different actors towards a joint vision for the sustainable management of marine litter across all European seas. MARLISCO activities took place in the four European Regional Seas: North-Eastern Atlantic, Baltic, Mediterranean and Black Sea, by a consortium with members located in 15 coastal countries and one of the project's partners is TUDAV. Many activities were carried out in the Black Sea under this project which resulted in 2015. Besides, TURMEPA has continued the International Coastal Clean-up Campaign (ICC) since 2002.

Scientific studies on this issue have gained speed in recent years but it is still inadequate. In this review the scientific literatures on marine litter were examined in the Black Sea and classified according to the main focus of each research: (i) beach litter, (ii) seafloor litter, (iii) floating litter, (iv) litter in biota and (v) microplastics.

(i) In studies conducted in the Black Sea's coasts show that litter densities seem to be quite high and marine litter have pressure on coastal areas, at both popular and unpopular beaches (Fig. 2). Results showed that plastic were the dominant litter type and the effect of plastics on biota and environment is unignorable. But the biggest handicap in these studies is the lack of a common methodology and the diversed evaluation of data and monitoring strategies.

Figure 2. Marine litter in the Black Sea (Sinop coasts)

Guneroglu (2010) surveyed 15 streams in Trabzon and Rize cities to estimate litter load on the Black Sea coastal areas. Composition and distribution of sampled marine litter were investigated and plastic had the highest ratio of 56% among all litter type. In this study it was reported that coastal marine litter in the Black Sea was mainly caused by transportation and deposition of anthropogenic waste resulting from river outflows and measures and regulations remain inadequate to protect the coastal regions against pollution in the region.

Eruz *et al.* (2010) researched solid waste pollution in Trabzon of the south-eastern Black Sea. Daily solid waste production was found to be as 1.115 kg/person in the Trabzon city centre, 0.73 kg/person in Sürmene and 0.79 kg/person in Of districts, and %3.5 of the total wastes produced per person were materials that do not decompose in nature for a long time and may be carried to seas by way of river carriage. According to this ratio, the amount of wastes that can be carried to shores daily is 368 kg in Sürmene and 712 kg in of. When areal distribution of wastes in coasts was examined, it was seen that total waste quantity identified in Sürmene shores was 1.373 kg and it was 1.086 kg in of shores. It was found in the study that plastics formed %49, textile %28, metal %12, styrofoam %5, glass %5 and paper %1 of the wastes.

Beach litter abundance and origin were investigated on 10 beaches in the Turkish Western Black Sea coast by Topcu *et al.* (2013). Their results showed that litter density was 0.88±0.95 items m^{-2} and it was mainly composed of unidentifiable small size (2-7 cm) plastic pieces and beverage-related litter such as bottles and bottle caps. The litter found on the beaches was mainly plastic whereas materials such as glass, paper and wood had very small shares. At the same time foreign origin litter including 25 different countries, 23% of which are in the Black Sea region was found in the research area.

Terzi and Seyhan (2013a) conducted surveys to determine the composition and density of marine litter on the eastern Black Sea coasts. They found litter density between 0.05-0.55 items/m^2 and 0.001-0.015 kg/m^2 and the most abundant litter item was found to be plastic. The most common usage categories were foams and beverage related items.

Visne and Bat (2016) investigated seasonal marine litter pollution in Sinop Sarikum Lagoon Coast of the Western Black Sea and they used the monitoring protocol proposed by MSFD GES TSG-ML. Seasonal litter density was found as a mean of 1,033-2,352 pieces/m^2 and 0,019-0,041 kg/m^2 and the most common type of litter was plastic (95.61%). Foreign origin litter was found in region and encountered foreign origin litter ratio was found to be 2.38% of all litter items and they mainly originate from neighbouring countries to the Black Sea.

(ii) There are relatively more scientific literature about the seafloor litter. And all these studies mentioned that there was a large quantity of marine litter in sea bed and the most available marine litter type was plastic like beach litter.

A number of underwater surveys for marine litter were undertaken at different sites within the boundaries of Istanbul city. Most pieces of litter were composed of glass (31%), plastic (25%) and metal (21%). The seabed and local communities of benthic organisms are covered by solid wastes. Some representatives of marine fauna including cephalopods and crustaceans were found to have been entangled in the discarded and abandoned nets (‘ghost’ fishing) (BSC, 2009; UNEP, 2009).

Topcu and Ozturk (2010) investigated the abundance and composition of solid wastes in the southwestern Black Sea by trawling. They found solid waste concentration ranging from 128–1320 items km^{-2} and 8–217 kg km^{-2}. The most abundant material type was plastic and at the same time they found foreign origin litter in the study area. They reported that marine litter concentrations were higher than that in the Mediterranean Sea.

Anton *et al.* (2012) determined the situation of marine litter collected during demersal surveys in the Romanian Black Sea area. Marine litter was found in approx. 40% of the total hauls performed. The total amount of marine litter was found to be as

554.53 kg. They reported that metal and oil wastes, namely rubber came from vessels and waste fishing gears originate from fishery activities at the Romanian coast and also came from the fishing gears abandoned by Turkish, Bulgarian and Romanian vessels.

Terzi and Seyhan (2013b) researched the composition and density of marine litter on the Eastern Black Sea trawl areas of Turkey. Mean amount of litter items per unit area was found to be as 222.6±105.11 item/km^2 and 34.32±41.93 kg/km^2. The most abundant material type was plastic and the most encountered usage category was unidentified pieces. They reported that the large part of undefined litter items were the pieces of plastics and nylon.

Ioakeimidis *et al.* (2014) investigated abundance, spatial distribution and qualitative composition of benthic marine litter, in five study areas from the Eastern Mediterranean and Black Seas (Saronikos, Patras and Echinades Gulfs; Limassol Gulf; Constanta Bay). They performed surveys using the monitoring protocol proposed by MSFD GES TSG-ML. Average marine litter densities were found as follows: Saronikos Gulf, 1211 ± 594 items/km^2; Gulf of Patras, 641 ± 579 items/km^2; Echinades Gulf, 416 ± 379 items/km^2; Constanta Bay, 291 ± 237 items/km^2 and Limassol Gulf, 24 ± 28 items/km^2. Plastics were predominant in all the study areas. They reported that Constanta Bay has by far the greatest influence as it is situated in the vicinity of the Danube River delta but their data from the five study areas did not reflect the importance of Danube River as a source of marine litter.

Moncheva *et al.* (2016) reported the results of a pilot assessment of bottom ML in the Black Sea during the MISIS Project Joint Black Sea Cruise along 3 transects in the NW Black Sea. Their methodology was in compliance to MSFD GES TSG-ML Monitoring Guidance. They used trawling in the coastal bed (depth of ~ 40 m) and a ROV (Remote Operating Vehicle) in order to test its applicability to detect and quantify ML. Average density of marine debris was found to be as 6359 items/km^2 (SE = 2015). They reported that the number of items decreased from north to south with maximum in front of the Romanian coast. In coastal areas, the abundance of ML was generally much higher than that on the continental shelf. The most frequent and abundant debris type was plastics (~68 %). And they mentioned that fishing and tourism related activities obviously contributed significantly to littering of the seafloor.

(iii) The first essay to assess approximate levels of floating ML in the Black Sea was performed in August 2002 by Birkun and Krivokhizhin (2005), when aerial marine litter surveys were accomplished in the Azov Sea, Kerch Strait and north-eastern shelf area of the Black Sea. The notional consistency of marine litter in the Kerch Strait come out to be almost as high as in the southern Azov Sea and twice as high as in the Black Sea waters off the northern Caucasus and the eastern Crimea. Consequently, quantitative values of floating plastic marine litter were determined as 6.6 and 65.7 pieces/km^2 in the

Ukrainian Black Sea coasts and Kerch Strait (Birkun and Krivokhizhin 2005, BSC 2009, UNEP 2009).

In a recently published paper which was provided through EU 7th FP CoCoNET, a ship-based visual survey was carried out in the North-Western part of the Black Sea, providing the first preliminary data on the characteristics of floating debris in Romanian waters. Study results show that high litter densities were found in the study area (mean 30.9±7.4 items km^{-2}) and most of the objects we sighted consisted of plastic items (89.1%) of all sighted man-made items (Suaria *et al.* 2015).

(iv) Investigations about the impact of marine litter on living organisms have not been made in the Black Sea yet. But illegal, unreported and unregulated (IUU) fishing in the Black and Azov Seas is also considered as an important source of ML due to discarded and abandoned nets (ghost fishing) (BSC 2009, Moncheva *et al.* 2016). In some regions, the high concentrations of fixed and floating IUU fishing gear has resulted in the reduction of habitat space, the presentation of obstacles on migration routes and an increase in incidental mortality (by-catch) of cetaceans, fishes and crustaceans. Several sources reported that ghost fishing has a serious detrimental impact on marine species especially in studies on cetaceans (Radu and Anton 2014, Tonay *et al.* 2012).

Particularly, in the spring of 1991, a total of 194 dead dolphins and harbour porpoises (*Phocoena phocoena*) along with 18,424 turbots (*Psetta maeotica*), 143 sturgeons (*Acipenser* spp.), 401 spiny dogfishes (*Squalus acanthias*) and 1,359 rays (*Raja clavata* and *Dasyatis pastinaca*) were found entangled in 6,416 bottom-set gillnets nearly 640 km long in Ukrainian waters (Birkun 2002). Tonay *et al.* (2012) found eight net entanglement cetacean individuals on the Turkish Western Black Sea coast.

(v) The researches about microplastics are quite scarce. Recently, Aytan *et al.* (2016) reported the first evaluation of neustonic microplastics in the Black Sea waters. They reported that the relatively high microplastic concentrations suggest that Black Sea is a hotspot for microplastic pollution and there is an urgency to understand their origins, transportation and effects on marine life. They found a considerable amount of microplastic [$1.2x10^3$ ($\pm 1.1x10^3$) particle m^{-3} and $0.6x10^3$ ($\pm 0.55x10^3$) particle m^{-3}] in the South Eastern Black Sea surface waters.

6. Conclusion

Marine litter can cause significant problems for the marine and coastal environment at global and regional level. These are environmental, economic, health, safety and social problems and originate mostly from land-based and sea-based activities. Experts published significant data on permanent sources of marine litter. Solid waste management is one of the principal ecological problems in the Black Sea region (Celik 2002). It was documented that, at the southern coast of the Black Sea, many municipal and industrial solid wastes, combined with hospital and dangerous wastes, are being drained off close to lowlands and river valleys, directly on the seashore or even at sea (Berkun *et al.* 2005, UNEP 2009).

Researches on marine litter in the Black Sea region are still scarce especially on microlitter and effects on biota but this issue has gained momentum all over the world in recent years and need further examination for the Black Sea. The current lack of comparable data makes it impossible to estimate future trends in marine litter or to save the Black Sea ecosystem.

The studies in the Black Sea demonstrate that the region is affected by the marine litter pollution. However, the biggest handicap in these studies is the lack of a common methodology. Developing regional and national marine litter monitoring and assessment schemes on the base of common research approach, methodology, evaluation criteria and reporting are necessary in the Black Sea. In this regard, Guidance on Monitoring of Marine Litter in European Seas closes most open parts in terms of creating a common methodology.

Sustainable integrated management of marine litter issues in the Black Sea region harmonize and implement necessary environmental policies, strategies and measures. It should be achieved that the management of marine litter in the Black Sea is implemented in accordance with valid international standards and approaches as well as those of relevant regional organizations and as suitable in harmony with programmes and measures applied in other seas. Standardised methods exist for the sampling of macro- and meso- marine litter on beaches, at sea or on the seafloor and for ingested litter (Galgani *et al.* 2013).

The problem of marine litter can be efficaciously dealt with only by ensuring an inclusive approach that is local in scale and global in scope, directed at source prevention, and establishes an educated community that can be empowered to action (NOAA 2008).

Solutions to the Black Sea's marine litter problems require that uniform strict rules be approved by each country of the Black Sea coasts. Turkey is a growing country where industrial and urban development largely occur in coastal areas through increased input of wastes imposing a further stress on the Turkish coasts of the Black Sea. The application of the agreements requires that each country concerned, which has a coast to the Black Sea creates an environmental policy.

References

Anton, E., G. Radu, G. Ţiganov, M. Cristea, and M. Nenciu. 2013. The Situation of marine litter collected during demersal surveys in 2012 in the Romanian Black Sea area. Cercetări Marine, 43:350-357.

Arthur, C., J. Baker, and H. Bamford. 2009. Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. Sept 9-11, 2008. NOAA Technical Memorandum NOS-OR&R-30.

Aytan, Ü., A. Valente, Y. Senturk, R. Usta, F.B. Esensoy Sahin, R.E. Mazlum, and E. Agirbas. 2016. First evaluation of neustonic microplastics in Black Sea waters. Marine Environmental Research, 119: 22-30.

Barnes, D.K., F. Galgani, R.C. Thompson, and M. Barlaz. 2009. Accumulation and fragmentation of plastic debris in global environments. Philosophical Transactions of the Royal Society B: Biological Sciences, 364(1526): 1995-1998.

Begun, T., M. Muresan, T. Zaharia, K. Dencheva, M. Sezgin, L. Bat, and V. Velikova. 2012. Conservation and Protection of the Black Sea Biodiversity. Review of the existing and planned protected areas in the Black Sea (Bulgaria, Romania, Turkey) with a special focus on possible deficiencies regarding law enforcement and implementation of management plans. EC DG Env. MISIS Project Deliverables. www.misisproject.eu

Berkun, M., E. Aras, and S. Nemlioglu. 2005. Disposal of solid waste in Istanbul and along the Black Sea coast of Turkey. Waste Management, 25: 847-855.

Birkun, A.J. and S. Krivokhizhin. 2006. Estimated levels of marine litter pollution in the Ukrainian Black Sea and coastal environment. Black Sea Ecosystem 2005 and Beyond (Abstracts of the 1st Biannual Sci. Conf. BSC, Istanbul, Turkey, 8-10 May). Istanbul, 220 pp.

Bråte, I.L.N., D.P. Eidsvoll, C.C. Steindal, and K.V. Thomas. 2016. Plastic ingestion by Atlantic cod (*Gadus morhua*) from the Norwegian coast. Marine Pollution Bulletin, 112: 105-110.

BSC. 2009. Marine litter in the Black Sea Region: A Review of the Problem. Black Sea Commission Publications 2007-1, Istanbul, Turkey, 148 pp.

Celik, F. 2002. A case study: Interstate highway in the Black Sea coast, (in Turkish). Proc. 4th Conf. on Turkish Coast and Coastal Areas (Izmir, Turkey, 5-8 November), 2: 847-856.

CIESM. 2014. Marine Litter in the Mediterranean and Black Seas. CIESM Workshop Monograph n° 46 [F. Briand, ed.], 180 p., CIESM Publisher, Monaco.

Cole, M., P. Lindeque, C. Halsband, and T.S. Galloway. 2011. Microplastics as contaminants in the marine environment: A review. Marine Pollution Bulletin, 62: 2588-2597.

Cole, M., P. Lindeque, E. Fileman, C. Halsband, R.M. Goodhead, J. Moger, and T. Galloway. 2013. Microplastic ingestion by zooplankton. Environmental Science & Technology, 47: 6646-6655.

Derraik, J.G.B. 2002. The pollution of the marine environment by plastic debris: a review. Marine Pollution Bulletin, 44: 842-852.

Di Beneditto, A.P.M. and R.M.A. Ramos. 2014. Marine debris ingestion by coastal dolphins: what drives differences between sympatric species? Marine Pollution Bulletin, 83(1):298-301.

Erüz, C., Y. Liman, B. Çakır, and K. Özşeker. 2010. Solid waste pollution on eastern Black Sea coast, (in Turkish). In L. Balas [ed.], Coastal and Marine Areas of Turkey VIII. National Congress 27 April-1 May, Trabzon, Turkey.

Farrell, P. and K. Nelson. 2013. Trophic level transfer of microplastic: *Mytilus edulis* (L.) to *Carcinus maenas* (L.). Environmental Pollution, 177: 1-3.

Galgani, F., G. Hanke, S. Werner, and L. De Vrees. 2013. Marine litter within the European Marine Strategy Framework Directive. ICES Journal of Marine Science, 70(6): 1055-1064.

Gregory, M.R. and P.G. Ryan. 1997. Pelagic plastics and other seaborne persistent synthetic debris: a review of Southern Hemisphere perspectives. pp. 49-66. In J.M. Coe, D.B. Rogers [eds.], Marine Debris - Sources, Impacts and Solutions. Springer-Verlag, New York.

Güneroğlu, A. 2010. Marine litter transportation and composition in the coastal southern Black Sea region. Scientific Research and Essays, 5(3): 296-303.

Güven, O., K. Gokdag, B. Jovanovic, and A.E. Kıdeys. 2017. Microplastic litter composition of the Turkish territorial waters of the Mediterranean Sea, and its occurrence in the gastrointestinal tract of fish. Environmental Pollution (in press).

Hammer, J., M.H.S. Kraak, and J.R. Parsons. 2012. Plastics in the marine environment: The dark side of a modern gift. Reviews of Environmental Contamination and Toxicology, 220.

Hidalgo-Ruz, V., L. Gutow, R.C. Thompson, and M. Thiel. 2012. Microplastics in the Marine Environment: A review of the methods used for identification and quantification. Environmental Science & Technology, 46: 3060-3075.

Ioakeimidis, C., C. Zeri, H. Kaberi, M. Galatchi, K. Antoniadis, N. Streftaris, F. Galgani, E. Papathanassiou, and G. Papatheodorou. 2014. A comparative study of marine litter on the seafloor of coastal areas in the Eastern Mediterranean and Black Seas. Marine Pollution Bulletin, 89: 1-2.

Isobe, A., K. Uchiyama-Matsumoto, K. Uchida, and T. Tokai. 2017. Microplastics in the Southern Ocean. Marine Pollution Bulletin, 114(1): 623-626.

Laist, D.W 1997. Impacts of marine debris: entanglement of marine life in marine debris including a comprehensive list of species with entanglement and ingestion records, pp. 99-140. In J.M. Coe and D.B. Rogers [eds.], Marine Debris. Sources, Impacts, Solutions. Springer-Verlag New York, Inc.

MISIS Joint Cruise Scientific Report, 2014. In S. Moncheva and L. Boicenco [eds.], State of Environment Report of the Western Black Sea based on Joint MISIS cruise (SoE-WBS). 401 pp.

Moncheva, S., K. Stefanova, A. Krastev, A. Apostolov, L. Bat, M. Sezgin, F. Sahin, and F. Timofte. 2016. Marine litter quantification in the Black Sea: a pilot assessment. Turkish Journal of Fisheries and Aquatic Sciences, doi:10.4194/1303-2712-v16_1_22

Moore, C.J. 2008. Synthetic polymers in the marine environment: A rapidly increasing, long-term threat. Environmental Research, 108: 131-139.

MSFD Technical Subgroup on Marine Litter. 2013. Guidance on Monitoring of Marine Litter in European Seas. Luxembourg, Publications Office of the European Union. 124 pp.

National Oceanographic and Atmosphere Administration (NOAA). 2008 Proceedings of the International Research Workshop on the Occurrence, Effects and Fate of Microplastic Marine Debris. Silver Spring.

Official Journal of the European Union. 25.06.2008. Directives Directive 2008/56/Ec Of The European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (Marine Strategy Framework Directive). L 164, 19-40.

Official Journal of the European Union. 2.9.2010. Commission Decision of 1 September 2010 on criteria and methodological standards on good environmental status of marine waters. 2010/477/EU, L 232: 14-24.

Pawar, P.R., S.S. Shirgaonkar, and R.B. Patil. 2016. Plastic marine debris: Sources, distribution and impacts on coastal and ocean biodiversity. PENCIL Publication of Biological Sciences, 3(1): 40-54.

Plastics Europe. 2013. An analysis of European latest plastics production, demand and waste data. 38 pp. Retrieved from http://www.plasticseurope.org

Poon, F.E., J.F. Provencher, M.L. Mallory, B.M. Braune, and P.A. Smith. 2016. Levels of ingested debris vary across species in Canadian Arctic seabirds. Marine Pollution Bulletin (in press). http://dx.doi.org/10.1016/j.marpolbul.2016.11.051

Retama, I., M.P. Jonathan, V.C. Shruti, S. Velumani, S.K. Sarkar, P.D. Roy, and P.F. Rodríguez-Espinosa. 2016. Microplastics in tourist beaches of Huatulco Bay, Pacific coast of southern Mexico. Marine Pollution Bulletin, 113(1–2): 530-535.

Rosas-Luis, R. 2016. Description of plastic remains found in the stomach contents of the jumbo squid *Dosidicus gigas* landed in Ecuador during 2014. Marine Pollution Bulletin, 113(1–2):302–305.

Setälä, O., V. Fleming-Lehtinen, and M. Lehtiniemi. 2014. Ingestion and transfer of microplastics in the planktonic food web. Environmental Pollution, 185: 77-83.

Suaria, G., M.C. Melinte-Dobrinescu, G. Ion, and S. Aliani. 2015. First observations on the abundance and composition of floating debris in the North-Western Black Sea, Marine Environmental Research, 107: 45-49.

Sun, X., O. Li, M. Zhu, J. Liang, S. Zheng, and Y. Zhao. 2017. Ingestion of microplastics by natural zooplankton groups in the northern South China Sea. Marine Pollution Bulletin, 115(1-2): 217-224.

Terzi, Y. and K. Seyhan. 2013a. Seasonal changes in the marine litter in the Eastern Black Sea Region of Turkey. INOC-IIUM- International Conference on Oceanography and Sustainabe Marine Production: A Challenge of Managing Marine Resources under Climate Change, ICOSMaP, Kuantan- Malaysia.

Terzi, Y. and K. Seyhan. 2013b. Preliminary investigation of benthic marine litter on eastern Black Sea. The First International Fisheries Symposium in Northern Cyprus, 24-27 Mart.

Thompson, R.C., S.H. Swan, C.J. Moore, and F.S. vom Saal. 2009a. Our plastic age. Philosophical Transactions of the Royal Society B, 364: 1973-1976.

Thompson R.C., C.J. Moore, F.S. vom Saal and S.H. Swan. 2009b. Plastics, the environment and human health: current consensus and future trends. Philosophical Transactions of the Royal Society B, 364: 2153-2166.

Topcu, E.N. and B. Ozturk. 2010. Abundance and composition of solid waste materials on the western part of the Turkish Black Sea seabed. Aquatic Ecosystem Health & Management, 13(3): 301-306.

Topcu, E.N., A.M. Tonay, A. Dede, A.A. Ozturk, and B. Ozturk. 2013. Origin and abundance of marine litter along sandy beaches of the Turkish Western Black Sea Coast. Marine Environmental Research, 85: 21-28.

Trouwborst, A. 2011. Managing marine litter: exploring the evolving role of international and European law in confronting a persistent environmental problem. Merkourios International and European Environmental Law, 27(73): 4-18.

Tsang, Y.Y., C.W. Mak, C. Liebicha, S.W. Lamb, E.T-P. Sze, and K.M. Chan. 2017. Microplastic pollution in the marine waters and sediments of Hong Kong. Marine Pollution Bulletin, 115 (1-2): 20-28.

UNEP. 2005. Marine Litter, An Analytical Overview. United Nations Environment Programme, Nairobi. 58 pp.

UNEP. 2009. Marine Litter: A Global Challenge. United Nations Environment Programme, Nairobi. 232 pp.

Vişne, A. and L. Bat. 2016. Marine litter pollution in Sinop Sarıkum Lagoon coast of the Black Sea, (in Turkish). Turkish Marine Science Conference. Ankara, Turkey. 399 pp.

Wang, W., A.W. Ndungu, Z. Li, and J. Wang. 2017. Microplastics pollution in inland freshwaters of China: A case study in urban surface waters of Wuhan, China. Science of The Total Environmen., 575: 1369-1374.

Wójcik-Fudalewska, D., M. Normant-Saremba, and P. Anastácio. 2016. Occurrence of plastic debris in the stomach of the invasive crab *Eriocheir sinensis.* Marine Pollution Bulletin, 113(1–2): 306-311.

COASTAL WETLANDS AND PROTECTION

Beyhan TAŞ

Ordu University, Faculty of Arts and Sciences, Department of Biology,
Cumhuriyet Campus, Altınordu, Ordu, Turkey
beyhantass@gmail.com

1. Introduction

Wetlands are defined as "all natural or artificial, continuous or temporary, calm or running, fresh, brackish or saline water, marsh and turbary which cover depths of less than six meters during the falling tide of the seas and which are important as the habitats of living organisms, mainly waterfowls" (Regulation on the Protection of Wetlands 2014). Although wetlands cover 3% of the Earth, they are ecologically very important and quite complicated natural systems. They form the richest and the most productive ecosystems of the world with the biological diversity, natural functions and economic values they have. In wetland ecosystem, all living and non-living factors are in a continuous interaction. Wetlands, which make up a significant part of our biological resources, are of significance importance in terms of feeding, wintering and incubating activities of waterfowls. Wetlands are very important aquatic ecosystems which influence the climate, agriculture, topography, hydrology, water quality, vegetation, biological efficiency and socio-economic structure of the area they are in. There is a density of living organisms in wetlands and organic matter production, biodiversity and natural life are very rich in these areas. Wetlands, which are among the most important genetic reservations of the world, host 40% of all the species in the world and 12% of all the animal species. Wetlands also store rain by soaking up extra water in excessive rainfall, keep the required level of water for agricultural practices and prevent floods and erosion. They decrease nitrate and phosphate contamination and prevent eutrophication because of their high biological activities. Wetlands also control erosion and prevent soil loss in riparian areas (Taş 2006, Anonymous 2016).

Ramsar Convention is the only international convention that aims to take wetland ecosystem under a global protection. The primary aim of the convention is stated as "wetlands constitute a great resource economically, scientifically and recreationally and they cannot be brought back when they are lost". Turkey became a party to Ramsar Convention, signed in Ramsar (Iran) in 1971, officially as of 17 May 1994. Within this context, Turkey undertook to protect, develop and use itswetlands wisely. Turkey is a rich country in terms of wetlandsand they are very important nationally and internationally. The reason for this is the fact that the two most important of four bird migration routes in the Western Palearctic Region pass over Turkey. Turkey is the focal point of bird migrations between the continents of Europe, Asia and Africa. Other main reasons are our wetlands' different ecological characteristics, hosting various species or species under threat or being significant in terms of waterfowls or fish. For these reasons, wetlands in Turkey and their significance are known and closely monitored by the world.

There are 135 internationally important wetlands in Turkey, 14 of which are Ramsar sites (total area: 184 487 ha). In addition to these, 20 national (total area: 278 072 ha) and 5 locally (total area: 1 262 ha) important wetlands have also been registered. 27 wetlands have been approved as conservation areas. Registration processes of other wetlands are still continuing (URL1). This study is about the Black Sea coastal wetlands, their characteristics and conservation.

2. Overview of the Coastal Wetlands

Turkish coastal length of the Black Sea, which has a total coastal length of 4 340 km, is 1 400 km. There are 80 major coastal wetlands in the Black and Azov Seas region encompassing freshwater, brackish and saline ecosystems (Marushevsky 2003). Black Sea, which is located on the north of Turkey, starts from the borders of Georgia in the east and continues to Bulgaria in the west. It also gives its name to the area which is in the east of Sakarya Plain. The Black Sea Region is divided into three sections: Eastern, Central and Western Black Sea regions. The Black Sea coast from the east of Sakarya Plain to the Bulgarian border is within Marmara region. The Black Sea coasts of Turkey have a total of six internationally/nationally important wetlands, one of which is a Ramsar site (Figure 1, Table 1).

2.1. Yeşilırmak Delta

Samsun, which is in the Central Black Sea region of the Black Sea coastline, is between the deltas where Yeşilırmak and Kızılırmak rivers flow into the Black Sea. Yeşilırmak and Kızılırmak deltas are called "Samsun deltas". The fact that these two deltas are neighbors with similar formation characteristics and similar problems has been influential in their being discussed together. In terms of surface area, Yeşilırmak Delta is the second biggest delta of Turkey after Çukurova delta while Kızılırmak delta is the third biggest (Uzun 2006). On the delta plain formed by the alluvions carried for centuries by Kızılırmak and Yeşilırmak rivers, Bafra and Çarşamba plains which are the plains with highest agricultural potential in our country have formed. The Black Sea climatic characteristics are seen in the coastal areas of Samsun. The city has a climate which is not too hot in summers and warm in winters, with rainfall in every season. There is an irregular rainfall regime in the city. Thus, the city is faced with drought and flood risks at times (Anonymous 2013a).

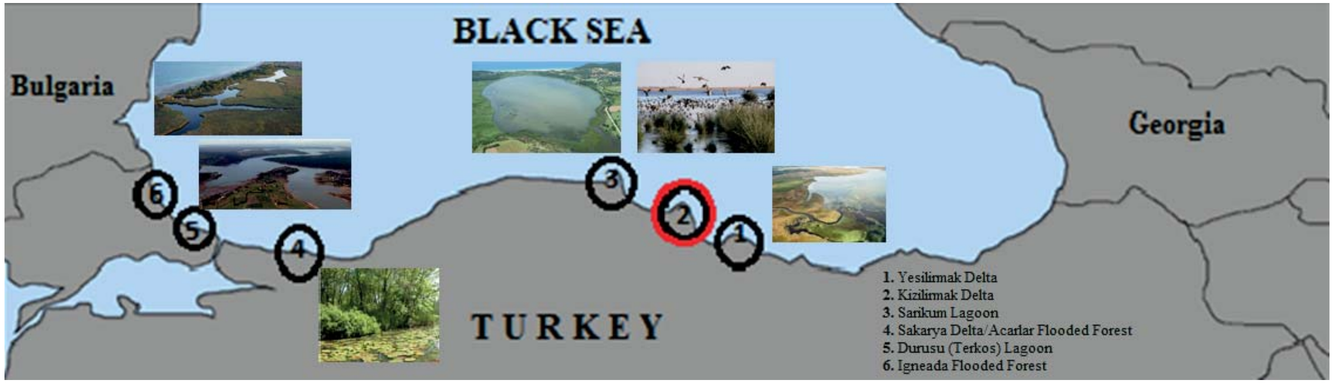


Figure 1. The Black Sea costal wetlands of Turkey (numbers correspond with the numbers in the text and Table 1)

Table 1. Overwiew of the Black Sea costal wetlands of Turkey

No	Site name	Province/District	Latitude-Longitude	Area (ha)	Conservation status
1	Yeşilırmak Delta	Samsun/Çarşamba	41°18'N-36°55'E	16 043	WCA
2	Kızılırmak Delta	Samsun/Bafra	41°36'N-36°05'E	21 700	Ramsar Site, NA, WCA
3	Lagoon Sarıkum	Sinop	42°01'N-34°55'E	785	NA, NPA
4	Sakarya Delta-Acarlar Lake and Flooded Forest	Sakarya	41°07'N-30°26'E 41°08'N-30°27'E	2 800	NA, WCA
5	Lagoon Durusu (Terkos)	Istanbul, Kırklareli	41°25'N-28°21'E	5 850	NA, NPA
6	Igneada Lakes and Flooded Forest	Kırklareli/Igneada	41°49'N-27°57'E	3 155	NP

NA: Natural Assets, NP: Natural Parks, NPA: Nature Protection Area, WCA: Wildlife Conservation Area

Yeşilırmak River is within number 14 Yeşilırmak Basin. The River Yeşilırmak, which is 468 km long, originates from Köse Mountains of Sivas (2 801 m), reaches Çarşamba plain and flows into the Black Sea at Cape Cıva. Yeşilırmak Delta is one of the biggest deltas on the Black Sea coastline. Yeşilırmak Delta consists of the River Yeşilırmak, Akçay, Miliç, Terme and Kocaman creeks and Abdal and Büyüklü streams. Çarşamba Plain, which is one of the important delta plains of Turkey, is in this delta. The wetland type of the delta which is at sea level is K (coastal freshwater lagoons), 3 (irrigated land), 4 (seaonally flooded agricultural land). Electric energy is generated at Kılıckaya, Almus, Ataköy, Hasan Uğurlu and Suat Uğurlu dams built on the river Yeşilırmak. The biggest lakes of the delta are on the northeast of Yeşilırmak Delta, behind the dune area at the coastline. These lakes are lagoons that occur as a result of an old cove being closed with sandbars. The width of sandbars that seperate lagoons from the sea is more than 500 m. Lakes are connected to the sea through a narrow canal opened from these waterfronts. The water levels of lakes which have a depth of 1.5-2 m in the central areas decrease to 20-30 cm in seasons when rainfall decreases and evaporization increases (Uncu 1995). Main freshwater lagoons of the delta are: Akgöl Lagoon (65.5 ha, 11 067.6 m), Simenlik Lagoon (119.8 ha, 20 077.1 m), Kargalı Lagoon (78.4 ha, 5 349.8 m), Dumanlı Lagoon (27.8 ha, 11 822.6 m), and Akarcık Lagoon (28.2 ha, 5 034.5 m). On the eastern area of the delta, there is Simenlik-Akgöl wetland complex, which has partly kept its natural features, sand dunes and a wide afforestation area behind these. 200 hectares of 1 900 hectare surface area of Simenlik Lake–Akgöl is an open water area, while the rest is reed bed and marsh. The greatest human activity in this wetland is reed cutting with annually 500 tons and they are exported to Europe. Very important amount of fish farming occurs in Simenlik Lake–Akgöl complex. These activities are important socio-economic values for the people of the area.

Yeşilırmak delta has significant floristic and faunistic values. Studies conducted in Lake Simenit (Simenlik) (Ersanlı and Gönülol 2006) and Akgöl (Ersanlı *et al*. 2006) examined the phytoplankton community of the lakes and results of the studies showed that the lakes had eutrophic character. Lakes region is rich in terms of birds and fish. 25 fish species of 10 families have been found in lagoons in Yeşilırmak and Kızılırmak deltas (Uğurlu *et al*. 2008). 5 species (*Abramis brama, Carassius auratus gibelio, Liza saliens, Mugil cephalus, Tinca tinca*) have been identified in the fish fauna of Lake Simenit in Yeşilırmak Delta (Uğurlu (Helli) and Polat 2003).

Site qualifies as an IBA (Important Bird Area) for its breeding population of *Ardeola ralloides* and wintering populations of *Netta rufina* and *Melanitta fusca*. Breeding birds of the area include *Nycticorax nycticorax*, *Egretta garzetta* and *Plegadis falcinellus*. *Bubulcus ibis* is frequently observed and believed to breed. Moderate numbers of waterfowl (including up to 7 750 *Anas platyrhynchos,* 3 000 *A. crecca,* 5 400 *Aythya ferina* and 1 600 *A. acuta*) can be seen in winter, although most of the ducks are forced to spend the day at sea as a result of human disturbance in the wetlands. At night, the birds feed in the delta (Demircan 2003). There are 10 001-20 000 individual birds at Yeşilırmak Delta, which is one of the important stopover points of waterfowls.

Wetland conservation areas of Yeşilırmak Delta, which is internationally important with its 16 043 ha area, were specified in 2008 and the area was registered as Wildlife Conservation Area. Terme Gölardı Simenlik Lake Wildlife Development Area is 3 355 ha.

Too many agricultural activities in the area, construction of dams on big rivers and thus sending enough water to the basins below during dry seasons, making use of the rivers in the region for the irrigation of agricultural areas and drainage water from agricultural areas reaching lagoons cause eutrophication. Wide marshes around lakes forge ahead shallow lagoons. Substances carried from drainage canals such as clay and silt cause lake to fill up slowly and take the form of marsh. This situation damages the ecological balance of lakes and coastal wetlands. Damages caused in water balance threaten first fishing and the living organisms in lakes. Climatic changes cause a quick change in wetlands. Yeşilırmak Delta is getting smaller due to deficit in delta sediment budget as a result of human interventions, rises at sea level and dams on Yeşilırmak trapping alluvions.

Rises at sea level cause coastal line and coastal profile to change landwards. This phenomenon is more evident especially at low coasts. According to Bruun formula (Uzun 2005), which gives more correct results in areas where the bedrock consists of soft, sandy, national stores, when 1 cm rise occurs in sea level and the shore is eroded about 100 cm landwards (Uzun 2006). Today, sea level rises due to the increase in global warming and the sea is predicted to rise 50 cm on average until the end of 21st century (IPCC 2001). According to Bruun rule, Samsun deltas will retreat about 50 m due to this rise and since the total coastal length is 200 km, an area of 10 000 decares will be occupied by the sea. The rise in sea level will also cause widening and deepening of neigbouring lagoons, flooding of pasture areas and the transformation of agricultural areas into pasture areas as a result of the rise in groundwater. Physical and chemical properties of lakes will also change (Uzun 2006).

Sediment trap of dams constructed on Yeşilırmak cause the delta to be undernourished and to get smaller because of coastal erosion. Süzen and Özhan (2000) examined the coastline change in Yeşilırmak Delta with remote sensing method, and found that, the delta has advanced about 3 kms and got 2 617 km^2 wider before the construction of Hasan Uğurlu and Suat Uğurlu dams. Kuleli (2010) examined coastal changes at Yeşilırmak river-mouth within the last 20 years through satellite images and DSAS software. As a result of the study, it was found that Yeşilırmak river-mouth coastline moved 620 m landwards with an erosion rate of -31 m/year. In order to protect Yeşilırmak Delta and the important wetlands we have, precautions should be taken to prevent global temperature increases before it is too late. International studies about this issue should be supported. Scientific projects should be developed to prevent coastal erosion. Other precautions that should be taken are preventing water pollution, using natural resources in wetlands wisely and maintaining their sustainability, preparing and applying delta management plan.

2.2. Kızılırmak Delta

Kızılırmak Delta is the biggest and the most important wetland of the Black Sea coast which has protected its natural characteristics. At the same time, it is the only Ramsar site on the Black Sea coast. It was included in Ramsar sites with features of Cultural and Natural Asset; Permanent Wildlife Reserve in 15.04.1998 with site number 942. Wetland type of the delta, which has an area of 21 700 ha at the sea level, according to Ramsar classification system is F (estuarins waters), K (coastal freshwater lagoons), 3 (irrigated land). Kızılırmak Delta Ramsar site meets 8 of 9 criteria for wetlands of international importance.

The River Kızılırmak, which constitutes the delta, is within number 15 Kızılırmak Basin. Kızılırmak is the longest river of Turkey with its 1 355 km length. It originates from Imranlı (Sivas) (altitude: 2 000 m) on the north of Central Anatolia and reaches the Black Sea from Bafra (Samsun). Its main tributaries are Delice Stream, Devrez and Gökırmak. Alluvions carried by Kızılırmak for many years have formed Bafra plain, which is a very fertile delta plain. Delta site is under the Black Sea climate regime. The rainfall area of Kızılırmak River in Bafra town is 75 120 km^2 and the rainfall level is 38 m. The annual average flow coming from the rainfall area is 5 808 hm^3 and the annual average flow rate is 184.2 m^3/s. The average flow rate in August, which is the driest month of the year, is 106.5 m^3/s (Anonymous 2013b). Kesikköprü, Hirfanlı, Altınkaya and Derbent dams are within Kızılırmak Basin. Derbent Dam in the lower basin was made for the purposes of irrigation, energy and overflow control. This dam lake has a great importance in the irrigation of Bafra Plain (Taş and Gönülol 2007a).

Kızılırmak Delta has a special place among the wetlands of our country because it includes various habitats such as rivers, brackish water lakes, fresh water lakes, wetland meadows, longos, agricultural areas, coastal dunes and sea. Surface areas and perimeters of lagoons which are accepted to be within wetlands close to the coastal area of the delta are as follows: Uzun Lagoon: 312.2 ha, 28 631 m; Tatlı Lagoon: 68.6 ha, 3 541.5 m; Gıcı Lagoon: 128 ha, 4 983.5 m; Balık Lagoon: 842.6 ha, 25 890.2 m; Altınlı Lagoon: 32.1 ha, 3 988.7 m; Paralı Lagoon: 8.6 ha, 1 540.3 m; Liman Lagoon: 258.1 ha, 15 599.5 m; Cernek Lagoon: 1 174.6 ha, 53 193.4 m; Mülk Lagoon: 31.7 ha, 6 370.3 m; Karaboğaz Lagoon: 186.1 ha, 31 990 m.

The Kızılırmak Delta is the largest and most intact wetland on the Turkish Black Sea coast. The entire delta covers 56 000 ha, 70% of which is now used intensively. The remaining 16 110 ha of natural habitat comprises the eastern part of the delta (13 400 ha), where six lakes (Balık, Uzun, Cernek, Liman, Gıcı and Tatlı) are situated, and the western part (2 710 ha), which includes Lake Karaboğaz and Lake Mülk. Of the 16 110 ha of natural habitat, 2 600 ha are open water, 5 600 ha marsh vegetation, 2 100 ha dunes and sand, 4 500 ha farmland and 1 310 ha woodland (Demircan 2003). The site includes dunes, beaches, shallow lakes, seasonal marshes, and wooded areas. Dominant vegetation includes vast reedbeds and seasonally flooded forest. Numerous species of waterbirds breed at the site, several of which are globally threatened. Over 92 000 waterbirds of various species winter at the site. Human activities include cattle grazing, reed cutting, fishing, and agriculture (URL2).

Lagoons called "Bafra Fish Lakes" which are in the east part of Kızılırmak delta are seperated from the Black Sea with sandbars. The maximum depth of shallow lakes and lakes at the sea level are around 3 m. Level of water has been reported to go below the level of sea water after the dry period (Dijksen and Kasparek 1985). Closing of lagoon outlets with coastal dune sets and seasonal increase in the level of water affect low agricultural areas and meadows in the area. In order to solve this problem, canals were opened to the sea from Karaboğaz, Liman, Cernek, Uzungöl and Balık lagoons. These canals are cleaned from time to time and the levels of lake are kept at minimum (Uzun 2006).

Lakes are surrounded with wide marshes. Typical vegetation at the coastal areas of lakes and at marshes includes reeds, bamboos and soft rush. *Phragmites/Typha/Scirpus* vegetation is widespread in shallow lakes. At some sites, aquatic Nymphaeaceae vegetation is present. There is maqui-like vegetation in some parts of dunes. There are longos of *Alnus/Fraxinus* in Galeriç Forest in the east of the delta (east of Uzungöl).

A great number of scientific studies have been conducted about the flora and fauna richness in Kızılırmak Delta which has a wide biodiversity. It is accepted as one of the rare regions in the world with a diversity of living orhanisms such as phytoplankton (Taş *et al*. 2002, Baytut *et al*. 2006, Gönülol *et al*. 2009, Taş and Gönülol 2007b, Soylu and Gönülol 2010 a,b), zooplankton (Emir 1990, Demirkalp *et al*. 2004, Bekleyen and Taş 2006, Saygı *et al*. 2011, Ustaoğlu *et al*. 2012, Gündüz *et al*. 2013), fish (Demirkalp 2007, Uğurlu *et al*. 2008), bird (Magnin and Yarar 1997, Yeniyurt *et al*. 2008, Barış *et al*. 2010, Erciyas *et al*. 2010, Erciyas-Yavuz *et al*. 2015) etc.

There is a wide population of birds in the delta (100 001-300 000 individuals). While there are a total of 465 bird species in Turkey, there are 341 bird species in Kızılırmak Delta. It is the area with the greatest number of bird species in Turkey. About 40% of Western Palearctic bird species are in this region (Yeniyurt *et al.* 2008, Barış *et al*. 2010). Cernek Bird Ringing Station is located on the Cernek Lake shore in Kızılırmak Delta (Barış *et al.* 2005). Bird ringing studies are conducted here by Ondokuz Mayıs University Ornithology Research Center. A great number of participants from domestic universities and universities abroad, from CSOs and volunteers have contributed to these studies. There are also bird watching stations at the site. At these stations, a great number of scientists and nature lovers can watch birds. The site is also suitable for outdoor nature education. Nature education project studies supported by TÜBİTAK are conducted in the site.

Besides waterfowls, wetlands are important habitats for inland water fish such as chondrostei. There are fish species in the delta which are under threat of extinction globally. Some of these fish are *Acipenser gueldenstaedtii, A. stellatus, A. sturio, Huso huso* (Yeniyurt *et al.* 2008). *Aphanius danfordii* species living in the site is another endemic fish species in our country. Fish species in Lake Cernek which has the biggest wetland in the delta are: *Carassius carassius*, *Chalcalburnus chalcoides*, *Cyprinus carpio*, *Leuciscus cephalus*, *Liza ramada*, *Mugil cephalus*, *M. soiuy*, *Neogobius fluviatilis*, *Proterorhinus marmoratus*, *Sander lucioperca*, *Scardinius erythrophthalmus*, *Vimba vimba* (Demirkalp 2007, Uğurlu *et al.* 2008). Fish which have economic value are caught at the end of hunting season and brought to the market under the control of aquaculture cooperative. Kızılırmak Delta is among the 122 Important Plant Sites of our country with 400 plant species it includes (Korkmaz and Sağlam 2010). There are 9 species under the threat of extinction in the site (Özhatay *et al*. 2005). Kızılırmak Delta wetland ecosystem makes great contributions to the local and national economy besides its ecological importance (Can and Taş 2012). Wide wetlands of the delta are very important in terms of aquacultural production, reed production and water buffalo breeding. Reed/bamboo at wetlands and lake shores (*Phragmites australis*, *Scirpus lacustris, Typha angustifolia*) are cut and dried in specific seasons under the control of the cooperative and they are exported.

One of the areas which have the greatest water buffalo population in our country is around Lake Cernek which is in Kızılırmak Delta. Recently, projects have been conducted to increase the number of water buffalos. Water buffalo milk is a perfect nutritional source. A great number of products such as yoghurt, cheese, cream, ice cream and various deserts are made from water buffalo milk. Water buffalos are important not only for meat and diary but also for wetland ecosystems. Meadow vegetation is one of the important parts of the wetland ecosystem for lake sedimentation and for the lives of living organisms such as birds and fish. The presence of water buffalos in the delta is important also for controlling the plant propogation of a great number of wetland plants, for reeds to renew themselves and for nesting of bird species in reeds and marshes (forming sheltered areas).

There is advancement in the trophic levels of delta wetlands and lake ecosystems which are ecologically and economically very important. Wetlands are faced with serious problems such as insufficient nutrition of deltas since dams trap water, domestic wastewaters and nutrient rich waters from agricultural areas reaching wetlands, getting water from wetland for agriculture, sedimentation, and water loss with evaporization as a result of global warming.It has been reported in studies conducted in delta lakes that especially phytoplankton (Taş *et al*. 2002, Demirkalp *et al*. 2004, Taş and Gönülol 2007b) and zooplankton (Demirkalp *et al*. 2004, Bekleyen and Taş 2008) composition of Lake Cernek includes widespread and plenty species in eutrophic waters and the lake has been reported to be a lagoon with a tendency of hyperthrophy and a potential of high eutrophication.

Kızılırmak Delta is protected with the status of Ramsar Site, Natural Protected Area, Wildlife Development Site and Important Bird Area. As a result of the studies conducted, "Kızılırmak Delta Bird Sanctuary" has entered the UNESCO World Heritage temporary list this year. However, the delta is under the threat of human activities. 4 000 ha area which covers lake Cernek and its surroundings was declared to be Wildlife Conservation Site in 1979 and hunting was completely banned here. However, there is illegal hunting since it is not sufficiently inspected. In 1994, all of the wetlands in the eastern part of the delta were declared as 1st degree natural protected site and they were taken under protection. In 1996, the delta was evaluated with all of its wetlands and environmental plan was prepared and put into force. Management plans of Kızılırmak Delta were made in 2008. With the enforcement of plans, fast increasing illegal housing in the coastal area of the delta and in Galeriç forest were averted. It is pleasing that the buildings in the area are being torn down. Forestation in the area will be able to prevent coastal erosion and dune movements.

Chemical drugs and fertilizers used in intense agricultural activities especially in Bafra Plain reach wetlands and lagoons with groundwater and drainage canals. These waters from agriculture and domestic wastewaters cause eutrophication in wetlands. This in turn causes damage in ecological balance of the wetland ecosystems, changes in trophic level, decreases in diversity of species and wetland habitat loss due to increasing sedimentation. Pollution and over hunting pressure in delta lagoons and wetlands have decreased aquaculture production. With the effect of global warming, rainfall decreases in the region as evaporation increases. This can be seen from the increase in *Salicornia* species plants which are halophytes in wetland meadows and pastures. Other threats on the delta are activities such as trying to turn wetlands into agricultural areas by drying them, burning reed fields to widen pasture areas, taking sand-pebbles from coastal dunes illegally and in an uncontrolled way. Altınkaya (1987) and Derbent (1991) dam lakes constructed on river Kızılırmak have caused the amount of sediment coming to the delta to decrease. The delta began to get smaller since the sediment budget had a deficit. The primary reasons for the deficit in delta budget were too many dams on Kızılırmak, sand pits and concrete worksites taking materials in the river bed and sand taken from sand pits on the coast (Zeybek *et al*. 2012). In a study by Kuleli (2010), it was found that the coastal line of Kızılırmak river bed moved landward 660 m with an erosion of -33 m/years in the last 20 years. The retreat in Kızılırmak riverbed forced the authorities to take urgent precautions and thus a series of wave breaker and dike were built. However, more advanced scientific projects are required to prevent coastal erosion such as big interception sets (Uzun 2006). Environmental effects of facilities planned for energy need should certainly be taken into consideration.

2.3. Lagoon Sarıkum

Sinop Peninsula is a natural port on the Black Sea coast in the northernmost point of Turkey in the Western Black Sea region. The peninsula is an “Important Natural Site” with Inceburun and Sarıkum Lake and the forestland around. Sarıkum Lagoon and its surrounding is within the borders of Sarıkum village in the west of the peninsula on the 19th km of Sinop-Ayancık highway, on the north of the road. The average depth of this lagoon, which is at sea level, is about 1 m. The lagoon is a coastal set lake which was formed as a result of an old gulf and the streams flowing to this gulf closed with coastal dunes. The lagoon is fed by Keçi Stream, Sarıkum Stream and Dereönü Stream. It is connected to the sea with a canal of 300 m long from the North. Thus, the lagoon has brackish water. There are two other very small lakes between the lake and the sea. The area of the lake changes depending on the rising and falling water. The perimeter of Sarıkum Lagoon, which has an area of 102 ha, is 6 635.2 m. The lagoon has a total area of 184 ha with the marshes around it. The edges of the lake, which have ana eutrophic character, are surrounded by *Juncus* sp. and *Phragmites australis.* The wetland type of the area is coastal freshwater lagoons (K). The area has typical Black Sea climatic characteristics. On the west and south of Sarıkum lake, there are quaternary reservoirs (yellow sand) which give the vicinity its name (Sarıkum=yellow sand). Sarıkum area, which was completely covered with forests 100 years ago, led up to a desert appearance combined with wind erosion as a result of deforestation (Yılmaz 2005).

Sarıkum Lake and its vicinity is a wetland ecosystem that meets international wetland criteria with its characteristics such as animal and plant species in and around the area, the variations in the habitats of these animals and plants, providing food and stopover for crowded bird groups as a result of being on the migration routes. Because of its habitat richness that results from the sea, the coast, dunes, the lake, the desert and the forest being all close within very short distances, the area was declared as “Sarıkum Natural Reserve” in 1987. At the same time, it is a first and second degree protected area. Of the 785 ha area, 102 ha covers the lake, 82 ha covers the marsh, 385 ha covers the forest and 216 ha covers the open area (Yılmaz *et al*. 2013). With all these characteristics, Sarıkum Nature Conservation Area is assessed within ecotourism context.

Although Sinop Peninsula and Sarıkum cover a small area, they contain various vegetation types. There are endemic types especially in dune plants. Eleven of these are rare plants that should be protected according to “Red Data Book”. There is an extensive, seasonally flooded forest of *Fraxinus angustifolia* to the south of the lake extending several kilometres inland. On drier ground, extensive *Quercus* and *Carpinus* forests surround the lake, whilst part of the dunes have been forested with *Pinus* (Demircan 2003). The area is an important bird area since it is on the migration routes of birds. The individual number of birds stopping over Sarikum Lagoon is between 3 001 and 10 000. Bird watching and numbering studies are conducted in the area. A small village and arable fields lie within the boundaries of the IBA (Demircan 2003). Several commercial fish species (such as carp, zander, eel and gray mullet) occur, but the Nature Reserve regulations ban fishing.

Sarıkum Lagoon is one of the most well protected areas among the existing wetlands in Turkey. In 1987, 785 ha area was declared a "Natural Reserve" and in 1991 a total of 826 ha was declared as "1st and 2nd degree Protected Area". The area is also an "Important Bird Area" and "Wildlife Development Area". The dune movement around the lake was stopped by taking under control and the lake surface stopped being a threat for residential and agricultural areas. Today these dune topography remains are seen in areas up to 60 m heights from the sea level (Yılmaz 2005). "Biodiversity and Natural Resources Management Project", which is conducted to transfer the existing ecological structure of the area to future generations, is very important. Thus, the existing values of the area will be protected and sustained with a contributing approach.

Various studies have been conducted at Sarıkum Lake and conservation area. Ertan *et al*. (1989) examined the migratory and permament birds in the lake. Öztürk (1994) examined the macro and micro algae in the lake while Sıvacı *et al*. (2008) examined the benthic algae. Byfield (1994) examined the flora in Sarıkum dunes. Akbulut *et al*. (2002) and Yardım *et al.* (2008) examined the macrobenthic invertebtrate fauna of the lake and reported that the species were characteristic species of euthropic lakes. Öztürk and Özer (2007, 2008 a,b, 2010) and Öztürk (2013) conducted various studies in the lake about fish parasites. Yılmaz (2005) and Yılmaz *et al*. (2013) gave detailed information about Sarıkum Lake and conservation area ecosystem. Öztürk (2015) published a study about the development strategies of Sarıkum Nature Protection Area and the analysis showed the following: the rich biological diversity and the existence of endemic species were the reserve's most significant strength.

The most important factors that threaten Lake Sarıkum are physical and human activities. One of these is wind erosion. Particularly winds from the west carry coastal dunes to the lake. Due to alluvion carried by rivers, the water level of the lake decreases and the lake area decreases while marsh and peatland increase from the east. Agricultural pollution caused by agricultural activities from surrounding lands and the pollution caused by visitors and people coming for picnic are also threats for the area. There are also illegal hunting practices in the area despite protection precautions in the area. There is still no management model including the villagers within the conservation area. The principle of "sustainable development within balance of protection-use" which is globally accepted should be used in the area. For the protection and sustainability of the physical structure and ecological character of especially the lake area, a management plan should be made which includes the people of Sarıkum village besides total protection, ecological exposure and buffer zones.

2.4. Sakarya Delta-Acarlar Longos

Sakarya Delta is on the northeast of Marmara Region, within Çatalca-Kocaeli section. Sakarya Delta was formed with sediments carried by River Sakarya (510 km), one of the three biggest rivers of Turkey that flow into the Black Sea. Okçular, Kaynarca and Kancalar streams are other important streams. The delta includes various ecosystems such as longos, freshwater lakes, rivers, sea coasts and coastal dunes. There are wetlands such as Akgöl, Acarlar Longos, Küçükboğaz Lake and Anagöl at the Black Sea coast. Biodiversity is rich in coastal wetlands and dune ecosystems. Acarlar Longos is one of the 135 internationally important wetlands of Turkey. Wetland type of the area is Xf (freshwater, tree-dominated wetlands) according to Ramsar classification. Oceanic climatic characteristics are seen in the area. The specific value of the area is “Longos”.

Acarlar Lake and Longos Forest, which are within the borders of Karasu and Kaynarca towns of Sakarya, are approximately 6 km west to the river mouth of Sakarya River that flows into the Black Sea. The coordinates of Acarlar Lake is 41°07'-41°08'N 30°26'-30°27'E. It is a wetland located parallel to the Black Sea, it is 2 km to the sea on the North and it has a length of 12 km and a depth that varies between 1 and 1.5 km. Acarlar Lake is a lagoon that was geologically formed by seperating from the Black Sea. The depth of the lake reaches 5-6 m especially in winter months during the rainy season and decreases to 1 m in summer months when rainfall decreases. Kaynarca, Kancalar, Eğridere, Kemer and Yakınağaza streams feed the wetland. The wetland decharges to River Sakarya with Okçu Stream and to the Black Sea from there. The total area is 2 800 ha (Anonymous 2016). Acarlar Longos is one of the three longos areas in Turkey. It is the second greatest longos of Turkey after Igneada. The area is covered with intense ash trees.

Acarlar Longos is very rich in terms of flora and fauna since all the characteristics of forest and wetland ecosystems intertwine. 247 plant species have been found in the area. 12 plant species are endemic. 6 amphibians, 13 reptiles, 169 birds and 29 mammals are found to inhabit Acarlar Longos. *Cyprinus carpio, Silurus glanis, Blicca bjoerkna, Esox lucius, Leuciscus cephalus, Tinca tinca* fish inhabit the area (Anonymous 2016). Uzun *et al*. (2008), Gönençgil (2008), Arslangündoğdu (2009), Tunca *et al*. (2014) have conducted various studies in the area.

2 517 ha area was taken under protection as “Wildlife Development Area” in 2006. The whole area of Lake Acarlar (2 800 ha) was declared as “1st degree Natural Protected Area” and taken under total protection in 1998. Acarlar Longos and Sakarya Delta which includes longos forests are candidate areas for Ramsar sites. Acarlar Longos Management Plan and Acarlar Longos Wetland Conservation Areas borders were approved and accepted as a whole by National Wetland Comission on 02 April 2009 (Anonymous 2016). “Culture and Nature Tourism Plan” was prepared in 2014 and studies have been conducted since then to develop nature tourism.

The area has important problems and threats. Acarlar Longos includes connected systems due to river and longos water regimes. However, an anthropogenic transformation occurs in the area because of the deterioritaion of the connection between these systems and the water regime and the expansion of agricultural areas to the detriment of longos. This transformation causes disintegration of habitats and isolation. High agricultural pressure in the area, irrigation water taken from the lake, dewatering of the lake, not being aware of the importance of longos ecosystem, continuation of illegal hunting and tree cutting in the area due to insufficient control and pollution resulting from agricultural activities are main threats.

2.5. Lagoon Durusu (Terkos)

Durusu Lagoon (Terkos Lake) is located in the North of Trakya Peninsula, in Çatalca region on the Black Sea coast. Lagoon Durusu is located in the north-west of Istanbul (40-50 km). It has a total area of 5 850 ha and it is between 40°19'N and 41°12'N latitudes and 28°29'E and 28°32'E longtitudes. Wetland type is K (caostal freshwater lagoons). Terkos (Durusu) Lagoon, which is a coastal leeve lake, has a water area of 39 km^2 and catchment area of 736.2 km^2. Its average depth is 3.4 m and its height from the sea level is 2.75 m. All surface flow and streams in the plain flow into the lake. The most important one is Istıranca Stream coming from the west. Thus, despite its being close to the Black Sea, the lake has become a fresh water lake in time. The lagoon is connected to the Black Sea with Boğazdere Canal (Baylan and Karadeniz 2006). Terkos Lake and wetland is one of the areas that meets Ramsar international wetland criteria with its flora, fauna and endemic species richness. Terkos Lake is the second most important fresh water reserve around İstanbul with its water potential. It meets an important part of city drinking water. Fishing and crawfish hunting is common in the lake while agriculture is common around the lake. The lake is used for various activities recreationally.

Terkos Lake is seperated from the Black Sea with sand dunes which have a width between 250 m and 5 km with an average width of 2 km. Terkos dunes, which are on the north of the area between Terkos Lake and the Black Sea, start from 25 km west of Bosphorus and expand to an area of 30 km along the Black Sea coast. There is a transition climate between Mediterrenean and the Black Sea climates and continental climate characteristics around Lake Terkos (Baylan and Karadeniz 2006).

The site comprises a freshwater lagoon, coastal sand dunes, and reed-beds. The lake is one of the main water sources for Istanbul but is being filled by sand that blows in from the coast. The combined inflow of four streams formed Lake Terkos behind a natural embankment at mean sea level. The water drains from a catchment of semi-natural vegetation composed of coppiced forest and heathland; the lakebed has a slightly acidic sand/clay and soft limestone/calcareous soil. The lake is separated from the sea by a 5 km long and 2 km wide dune (Demircan 2003). The area is defined as important plant site, nature conservation area and wildlife protection area with international treaties (Özhatay *et al*. 2003).

Existing wetlands have a great importance for wildlife and water quality in the area. The area is very rich in terms of flora and fauna. 17 of 73 endemic plant species in Turkey are within the borders of Terkos plain (Özhatay *et al*. 2003). *Ardeola ralloides;* large numbers of *Phalacrocorax carbo, Botaurus stellaris, Ardea purpurea, Nycticorax nycticorax* and *Egretta garzetta* breed at Lake Terkos. The site lies on a major migration route, and is especially important for storks and raptors (Demircan 2003).

Various studies have been conducted at Terkos Lake and its vicinity on different subjects by various researchers (Altınsaçlı and Yılmam 1995, Güher 2002, Maktav *et al*. 2002, Güher *et al*. 2004, Güner 2006, Kurun *et al*. 2010, Demirtaş 2011, Demirtaş and Şenel 2012, Kosal Sahin 2012, Yılmaz and Güleçal 2012, Bayram *et al*. 2013, Kurt 2015). Güher *et al*. (2004) reported that the lake had eutrophic character in terms of some physical characteristics and that population intensity of *Brachionus* and *Keratella* zooplankton species were important eutrophic indicators in Lake Terkos. Yılmaz and Güleçal (2012) reported that the phytoplankton group in the lake and the streams around the lake included oligotrophic, mesotrophic and eutrophic species and the trophic structure of the lake will turn into mesotrophic character from oligotrophic character in the near future.

Terkos Lake can lose its characteristics in the following years. The Project of third airport constructed at 2.5 km distance to Terkos Lake which is an important wetland and one of the most important drinking water reserves of Istanbul and the Project "Canal Istanbul" which is planned to pass from the west of the area will have serious effects on the area. Wetlands are under pressure because of such studies that change the water regime and pollution sources. Settlement cannot be prevented in the basin. Illegal land and water hunting is another pressure in the area. Besides being an important freshwater basin for Istanbul, Terkos Lake is one of the areas with the richest flora in Turkey with its fresh water and dune ecosystems and with its endemic species richness it can serve to environment and plant analysis of ecological tourism. Thus, settlement should be stopped in water basins and forests. Soil, air and water pollution measure mechanisms should be developed. Baylan and Karadeniz (2006) concluded that the most suitable tool and factor in protecting and developing natural and cultural environment of the area is "lake management" within the context of ecosystem management approach. All Terkos Lake users and managers should adapt ecossytem management, water resources integrated management and lake management principles on a national and local scale.

2.6. Igneada Lakes and Flooded Forests

Igneada Flooded Forest (Longos Forests) are located in Trakya section of Marmara Region at Yıldız Mountains. They are located at 41°49'N, 27°57'E coordinates in Kırklareli. The area from the sea level to 15 m altitude is 3 155 ha. The wetland type of the area according to Ramsar classification is Xf (freshwater, tree-dominated wetlands) and J (coastal brackish/saline lagoons). It had various status such as Nature Conservation Area and Natural Protected Area, Wildlife Protection Site and the areas protected sepreately from each other were integrated and the area was declared as National Park in 2007. It is the 39th National Park of Turkey. Igneada Longos Forests are the widest longos forest ecosystem of Turkey and they are the greatest alluvial longos forests in Europe.

Flooded forests are one of the most fragile and rare ecocystems in the world. All over the world, there are a limited number of these areas and there are very significant at local, national, regional and global levels. In the Bern Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention), they were defined as habitats under threat. Igneada Longos Forests are the largest longos forests in Turkey and the second largest longos forests in Europe. Igneada longos forests are a special area with their deciduous forest ecosystems, fresh water and saline water lakes, wetlands, rivers, low and high coastal areas, coastal dunes and sea ecosystems. Igneada has a rich biodiversity. It is one of the 122 Important Plant Areas and 184 Important Bird Areas of Turkey. This area is a valuable site because of being both a core-site within WWF (World Wildlife Fund) Global 200 eco-region and a potential Natura 2000 site. Seasonally flooded forest, fresh water lakes, marshes and sandy shores contain rich animal and plant species. They host 194 bird species, 310 insect species, 46 mammal species, 28 fish species, 11 reptile species and 6 amphibian species. According to the flora report prepared as part of GEF-II (Global Environment Facility) project which is carried out by the Ministry of Forestry, 21 of 592 plant species in İğneada are rare species, and also 4 of those are endemic species (Bozkaya 2013). Igneada Flooded Forests were formed as a result of the accumulation of alluvion carried by the rivers coming from forests of Istranca (Yıldız) Mountanious area to Black Sea coasts. Black Sea climatic characteristics are seen in this area which includes wetlands.

There are five lakes in the area. Lake Erikli is a lagoon that was formed with Efendi Stream filling in the sea in time. The North and west of the lake are surrounded with forested area. Igneada is on the south while the Black Sea coast line is on the east. The lake empties its extra water directly to the Black Sea. Erikli Lagoon has an area of 43 ha. 36.5 ha of this area is surrounded with reeds (*Phragmites australis*). The deepest part is about 1.80 m. Mert Lagoon (Kocagöl) is on a wide plain on the South of Igneada. It is a coastal leeve lake formed at where Deringeçit Stream flows into the sea. There is a dune band at the east of this lake which gets wide and narrow from time to time. The lake meets the Black Sea when the waters rise. The surrounding of the lake is completely reeds and marsh. Longos forests start where reeds end. The deepest place of the lake which has a water surface of 222 ha is 1.5 m. Reed and marsh areas of the lake are 178 ha. Saka Lagoon is on the South of Mert Lagoon. It was formed with Bulanık Stream filling in the sea in time. The lake has an area of 55 ha with its reed and forest areas. This area is flooded in spring and autumn. The area is still a virgin area due to transportation problems. This lake, which is surrounded by longos forests, has a dune band in front. This dune band is very important especially in terms of endemic species. Hamam Lake (19 ha) and Pedina Lake (10 ha) are on alluvial plains in the forest. Hamam Lake is 2 km away from the Black Sea and 20 m higher than the sea level. Its deepest place is 2.6 m. The lake which is fed by many streams from the forest empties its extra water into Bulanık Stream with a canal. Pedina Lake is in 5 km west of Hamam Lake. Its deepest place is 2.1 m. The lake is fed by small streams coming from the forest and empties its extra water into Bulanık Stream with a canal (Anonymous 2015). 1.5% (526 ha) of the national park consists of wetland ecosystem. The plains which include Erikli, Mert and Saka wetlands are alluvial ground level plains. The slope of these plains filled by rivers is very small. At times when there is a lot of rainfall, floods occur here and lakes form frequently. Longos forests which are in 3 areas as Mert Lake Longos (509 ha), Erikli Lake Longos (803 ha) and Saka Lake Longos (537 ha) start from the wetland coasts and advance inland for kilometers (Bozkaya 2013). *Fraxinus angustifolia* subsp. *oxycarpa* is the dominant species in longos.

Conservation status of the area are as follows: 5 399 ha area was declared as "Wildlife Protection Area" in 1978. Saka Lake Longos was declared as "Nature Protection Area" (1 345 ha) in 1988. Saka Lake Longos (1991), Erikli Lake and vicinity (1991), Mert Lake and vicinity (1994) have a status of "1st degree Natural Protected Area"; the area between Erikli Lake and the sea (1994) has a status of "2nd degree Natural Protected Area" and the area on the north of Mert Lake (1994) has a status of "3rd degree Natural Protected Area". The area which included longos forests (3 155 ha) was declared as "National Park" in 2007 (Bozkaya 2013).

The area which includes the most important nationally and internationally protected longos forest forms qualified and different habitats for a great number of living organisms with its different ecosystems. One of these is the coastal dunes. Its width reaches 50-60 m and its length reaches 10 km at some places. The coastal dunes and the longos forests of Igneada constitute the most sensitive ecosystem in the study area. Most of the known endemic plants (*Silene sangaria*, *Crepis macropus*, *Centaurea kilaea*) in Igneada and its vicinity are found in the coastal dunes and also the presence of species though not endemics, of national and international concern such as *Pancratimum maritimum* (Özyavuz and Yazgan 2010). Coastal lagunes are very important in terms of anadromous and catadrome fish species which migrate for breeding, protection and feeding. Eight fish species living in the streams and lakes of the area are in the category of "endangered species" of Bern list. The area hosts a great number of domestic and foreign bird species because it is on west Palearctic bird migration routes. Recent studies found 227 bird species in the area (Kaya 2015). Igneada lakes and longos forests have a very rich potential in terms of hunting tourism because it hosts a great number of fish species, in terms of botanic tourism because of its biodiversity and in terms of recreational activities such as bird watching, nature photographs and water sports (Çakır and Çakır 2012). However, the area is faced with a great number of problems as in other wetland ecosystems. Igneada lakes and longos forests, which are unique natural areas since they host integrated different ecosystems, are under various threats and dangers. The ecological integrity of the area is not fully protected. The streams which consitute the area are not in the conservation system. The reeds in Mert Lake are cut irregularly and the breeding areas of birds decrease. Mert and Erikli lagoons get shallow because of the materials carried by rivers (Özyavuz 2011). Domestic waste waters contaminate the wetland, illegal sand taking from the coasts, illegal wood cutting from longos forests and illegal hunting occurs in the area. Dams are planned on streams which feed the longos forests in order to meet the drinking water need of Istanbul. This Project means the destruction of longos forests and the ecosystem in these areas. One of the places for nuclear power plants declared in 2006 is Igneada. This is a potential threat for national park area. In addition, the highway project planned to connect Turkey and Bulgaria and port projects are other important threats for the area.

3. Conclusion

Recommendations to protect wetlands are as follows (Goradze 2008): *Surveying and finding the value of wetland sites of non-protected status for their suitability as Ramsar sites, considering landscape and biological diversity values and wetland functions or ecosystem-services. *Making an assessment of the ecological impacts of human activities on the wetlands system. *For identified areas providing mitigation measures to reduce the ecological impacts of human activities including appropriate restoration, regulation, management, education, inventory and monitoring activities. *Identifying and promoting alternative and environmentally friendly means of income for local people. *Ensuring consideration of the wetland eco-systems in the spatial-territorial planning and development projects on the coast. *Improving public awareness on ecological importance and ecological values and services of the coastal wetlands; improving educational facilities for local people. *Providing means to train students in modern environmental management and in land-use planning. *Developing a database for the synthesis and collation of biodiversity monitoring and inventory information. *Creating modern eco-tourism facilities.

References

Akbulut, M., M. Öztürk, and M. Öztürk. 2002. The benthic macroinvertebrate fauna of Sarıkum Lake and spring waters (Sinop). Turkish J. Mar. Sci., 8: 103-119.

Altınsaçlı, S. and S. Yılmam. 1995. The Ostracoda (Crustacea) fauna of Lake Terkos (Lake Durusu), (in Turkish). Turk. J. Zool., 19: 207-212.

Anonymous, 2013a. Drought Management Action Plan (2013-2017), (in Turkish). Governor of Samsun.

Anonymous, 2013b. Environmental Status Report (2012), (in Turkish). Governor of Samsun.

Anonymous, 2015. Environmental Status Report (2014), (in Turkish). Governor of Kırklareli.

Anonymous, 2016. The wetland management plan of Acarlar Lake longos forest (2016-2020), (in Turkish). Ministry of Forestry and Water Affairs, General Directorate of Nature Conservation and National Parks, Ankara.

Arslangündoğdu, Z. 2009. Waterbird counting in December at the damp zones in the Sakarya River Basin, (in Turkish). J. Fac. For. Istanbul U., 59: 1-14.

Barış, Y.S., K. Erciyas, A. Gürsoy, C. Özsemir, and J.K. Nowakowski. 2005. Cernek: A new bird ringing station in Turkey. Ring, 27: 113-120.

Barış, Y.S., Ö. Sağlam, K. Erciyas, N. Yavuz, and C. Özsemir. 2010. An important natural heritage: Kızılırmak Delta Birds, 169 pp. Erol Offset Printing Packaging Publishing Industry & Trade Limited Company, Society of Natural and Wildlife Conservation (SNWC) Published No: 1, Samsun, Turkey.

Baylan, E. and N. Karadeniz 2006. Research on conservation and development of natural and cultural environment; case study Terkos Lake, Istanbul, (in Turkish). Journal of Agricultural Sciences (JAS) 12(2): 151-161.

Bayram, B., D.Z. Seker, U. Acar, Y. Yuksel, H. Guner, A. Arı, and I. Cetin. 2013. An integrated approach to temporal monitoring of the shoreline and basin of Terkos Lake. J. Coast. Res., 29(6): 1427-1435.

Baytut, O., A. Gonulol, N. Arslan, and E. Ersanli. 2006. The phytoplankton of Karabogaz Lake in Samsun, Turkey. J. Freshwater Ecol., 21: 359-361.

Bekleyen, A. and B. Taş. 2008. Zooplankton fauna of Cernek Lake (Samsun), (in Turkish). Ekoloji, 17(67): 24-30.

Bozkaya, A.G. 2013. Temporal assessment of Igneada conservation area with remote sensing and geographic information systems and modeling the future, (in Turkish). MSc Thesis, Istanbul Technical Univ. Istanbul.

Byfield, A.J. 1994. Sarıkum Dunes. Report for the protecton of northern dunes of Turkey App: 3, The Society for the Protection of Nature in Turkey (DHKD), Istanbul.

Can, Ö. and B. Taş 2012. Ecological and socio-economic importance of Cernek Lake and wetland in the Ramsar Area (Kızılırmak Delta, Samsun), (in Turkish). TUBAV Science Journal, 5(2): 1-11.

Demircan, S. 2003. Turkey, p. 155-164. In G. Marushevsky [ed.] Directory of Azov-Black Sea Coastal Wetlands. Wetlands International, Kyiv.

Demirkalp, Y., S.S. Çağlar, Y. Saygı, E. Gündüz, S. Kaynaş and S. Kılınç. 2004. Preliminary limnological assessment on the shallow lagoon Lake Çernek (Samsun, Turkey): plankton composition and in relation to physical and chemical variables. Fresenius Environ. Bull., 13: 508-518.

Demirkalp, F.Y. 2007. Some of the growth characteristics of carp (*Cyprinus carpio* L., 1758) in Çernek Lake (Samsun, Turkey). Hacettepe J. Biol. & Chem., 35(1): 57-65.

Demirtaş, M. and A. Altındağ. 2011. The seasonal infection distribution of *Ligula intestinalis* Plerocercoid L., 1758 on some fishes (Cyprinidae) living in Terkos Lake, (in Turkish). Van Vet. J., 22(3): 147-151.

Demirtaş, M. and Ü. Şenel. 2012. The seasonal infestation distribution of *Piscicola geometra* L., 1761 on some fishes (Cyprinidae) living in Terkos Lake, (in Turkish). KSU J. Nat. Sci., 15(1): 52-58.

Dijksen, L.J. and M. Kasparek. 1985. The birds of the Kızılırmak delta. Birds of Turkey. Heidelberg 4: 1-47.

Emir, N. 1990. The taxonomical investigation of Rotatoria fauna of Lake Bafra (Samsun), (in Turkish). Turk. J. Zool., 14: 89-106.

Erciyas, K., A. Gürsoy, C. Özsemir, and Y.S. Barış. 2010. Body mass and fat score changes in recaptured birds during the autumn migration in Cernek Ringing Station, Turkey. Ring, 32: 3-15.

Erciyas-Yavuz, K., P. Zduniak, and Y.S. Barış. 2015. Spring and autumn migration of the red-breasted flycatcher through the Kizilirmak delta, Turkey. Curr. Zool., 61(3): 412-420.

Ersanlı, E. and A. Gönülol. 2006. A study on the phytoplankton of lake Simenit, Turkey. Cryptogamie, Algol., 27(3): 289-305.

Ersanlı, E., A. Gönülol, H. Şehirli, and Ö. Baytut. 2006. The phytoplankton of Lake Akgöl, Turkey. J. Freshwater Ecol., 21(3): 523-526.

Ertan, A., A. Kılıç, and M. Kasperek. 1989. Important Bird Areas of Turkey, (in Turkish). pp. 160 + xvi. DHKD, Istanbul.

Gonulol, A., E. Ersanli, and O. Baytut. 2009. Taxonomical and numerical comparison of epipelic algae from Balik and Uzun Lagoon, Turkey. J. Environ. Biol., 30: 777-784.

Goradze, I. 2008. The Black Sea Coastal Wetlands Vision: Georgia. Black Sea Regional Initiative for the wise use of Coastal Wetlands. p. 1-32. PSOVI, Batumi, Georgia.

Gönençgil, B. 2008. An example of coastal zones under threat: Acarlar flooded forest area – Karasu, Sakarya, (in Turkish). TÜCAUM V. National Geogrpahy Symposium, 16-17 October, Ankara.

Güher, H. 2002. Cladocera and Copepoda (Crustacea) fauna of Lake Terkos (Durusu). Turk. J. Zool., 26: 283-288.

Güher, H., Kırgız, T., Çamur, B. and H. Güner 2004. A study on zooplankton organisms community of Lake Terkos (İstanbul-Turkey). Pak. J. Biol. Sci., 7(4): 566-570.

Gündüz, E. 1991a. A taxonomic study on the Cladoceran species of Bafra Balıkgölü (Balıkgölü-Uzungöl), (in Turkish). Turk. J. Zool., 15: 115-134.

Gündüz, E. 1991b. A taxonomic study on the Calanoida and Cyclopoida (Copepoda) species of Bafra Balıkgölü (Balıkgölü- Uzungöl), (in Turkish). Turk. J. Zool., 15: 296-305.

Gündüz, E., Saygı, Y., Demirkalp, F.Y., Çağlar, S.S., Atasağun, S. and S. Kılınç. 2013. Seasonal composition and population density of zooplankton in Lake Karaboğaz from the Kızılırmak Delta (Samsun, Turkey). Turk. J. Zool., 37: 544-553.

Güner, U. 2006. Some morphometric characteristics of crayfish (*Astacus leptodactylus* Eschscholtz, 1823) in Lake Terkos. EgeJFAS, 23 (1-2): 163-167.

IPCC, 2001. Climate Change 2001: Impacts, adaptation, and vulnerability, http://www.grida.no/climate/ipcc_tar/index.htm.

Kaya, M. 2015. Birds of Igneada Longoz Forests (Kırklareli) and its neighborhood. Trakya University Journal of Natural Sciences (TUJNS), 16(1): 31-43.

Korkmaz, H. and Ö. Sağlam 2010. An important natural heritage: Kızılırmak Delta-Plants (in Turkish). Erol Offset Printing Packaging Publishing Industry & Trade Limited Company, Society of Natural and Wildlife Conservation (SNWC) Published No: 1, Samsun, Turkey, 210 p (in Turkish).

Kosal Sahin, S. 2012. An investigation on the distribution of Mollusc fauna of Lake Terkos (Istanbul/Turkey) related with some environmental parameters. J. Anim. Vet. Adv., 11: 3045-3049.

Kuleli, T. 2010. Determination of shoreline changes in Kizilirmak and Yesilirmak Delta using Landsat TM and DSAS, (in Turkish). VIII. National Congress of Turkey's Coastal and Marine Areas, April 27 - May 1 2010, Trabzon, p. 1549-1556.

Kurt, S. 2015. The geographical analysis of the changes occurring in Terkos Lake (Istanbul) and its surroundings. JASSS, 34: 333-344.

Kurun, A., N. Balkıs, M. Erkan, H. Balkıs, A. Aksu, and M.S. Erşan. 2010. Total metal levels in crayfish *Astacus leptodactylus* (Eschscholtz, 1823), and surface sediments in Lake Terkos, Turkey. Environ. Monit. Assess., 169(1): 385-395.

Magnin, G. and M. Yarar. 1997. Important Bird Areas in Turkey, (in Turkish). 313 pp. The Society for the Protection of Nature in Turkey (DHKD), Istanbul.

Maktav, D., S.F. Erbek, and S. Kabdaşlı. 2002. Monitoring coastal erosion at the Black Sea coasts in Turkey using satellite data: A case study at the Lake Terkos, North-West Istanbul. Int. J. Remote Sens., 23(19): 4115-4124.

Marushevsky, G. 2003. Directory of Azov-Black Sea Coastal Wetlands. 235 pp. Wetland International, Kyiv.

Özhatay, N., A. Byfield, and S. Atay. 2003. Important Plant Areas of Turkey, (in Turkish). 88 pp. WWF-Turkey, MAS Press, Istanbul.

Öztürk, M. 1994. Macroscopic and microscopic algae of Sarıkum Lake (Sinop) which is a natural protection area, (in Turkish). XII. National Biology Congress, 6-8 July, Edirne, p. IV: 195-200.

Öztürk, S. 2015. Determining management strategies for the Sarıkum Nature Protection Area. Environ. Monit. and Assess., 187(3): 1-9.

Öztürk, T. 2013. Parasites of juvenile golden grey mullet *Liza aurata* Risso, 1810 in Sarıkum Lagoon Lake at Sinop, Turkey. Acta Parasitol., 58: 531-540.

Öztürk, T. and A. Özer 2007. Trichodinid fauna of the toothcarp Aphanius danfordii (Boulenger, 1890) (Osteichthyes: Cyprinodontidae), an endemic fish from Sarıkum Lagoon Lake in Sinop (Turkey). Acta Protozool., 46: 73-80.

Öztürk, T. and A. Özer 2008a. Parasitic fauna of the toothcarp *Aphanius danfordii* (Boulenger, 1890) (Osteichthyes: Cyprinodontidae), an endemic fish from Sarıkum Lagoon Lake in Sinop (Turkey), (in Turkish). J. Fishscicom, 2: 388-402.

Öztürk, T. and A. Özer 2008b. Parasitic fauna of the flounder, *Platichthyes flesus* L., 1758 caught in the Sarıkum Lagoon Lake in Sinop (Turkey) and the occurrence of parasites in relation to host factors, (in Turkish). J. Fishscicom, 2: 403-418.

Öztürk, T. and A. Özer 2010. The occurrence of epizoic ciliates (Protozoa: Ciliophora) of the juvenile flounder, *Platichthyes flesus* L., 1758, from Sarıkum Lagoon Lake (Sinop, Turkey). Turk. J. Zool., 34: 1-12.

Özyavuz, M. and M.E. Yazgan. 2010. Planning of Igneada Longos (Flooded) forests as a biosphere reserve. J. Coastal Res., 26(6): 1104-1111.

Özyavuz, M. 2011. Determination of temporal changes in lakes Mert and Erikli using remote sensing and geographic information systems. J. Coastal Res., 27(1): 174-181.

Regulation on the Protection of Wetlands, 2014. Official Gazette date: April 04, 2014, No: 28962, Ankara (in Turkish).

Saygı, Y., E. Gündüz, S.S. Çağlar, and F.Y. Demirkalp. 2011. Seasonal patterns of zooplankton community in the shallow, brackish Liman Lake in Kızılırmak Delta, Turkey. Turk. J. Zool., 35: 783-792.

Sıvacı, E., Ö. Yardım, A. Gönülol, L. Bat, and F. Gümüş. 2008. Benthic algae of Sarıkum (Sinop-Turkey) lagoon, (in Turkish). J. Fishscicom, 2(4): 592-600.

Soylu, E.N. and A. Gönülol 2006. Seasonal succession and diversity of phytoplankton in a eutrophic lagoon (Liman Lake). J. Environ. Biol., 31(5): 629-636.

Soylu, E.N. and A. Gönülol 2010. Functional classification and composition of phytoplankton in Liman Lake. Turk. J. Fish. Aquat. Sci., 10(1): 53-59.

Süzen M.L. and E. Özhan 2000. Monitoring of shoreline changes around Yesilirmak Delta by using remote sensing, MEDCOAST International Workshop on Applications of Remote Sensing to the Management of River Catchment Areas and their Coastal Margins in the Mediterranean and Black Sea, 10-12 April 2000, Joint Research Centre of the EC, Ispra (VA), Italy.

Taş, B., A. Gönülol, and E. Taş. 2002. A study on the seasonal variation of the phytoplankton of Lake Çernek (Samsun-Turkey). Turk. J. Fish. Aquat. Sci., 2: 121-128.

Taş, B. 2006. Wetlands, (in Turkish). Kuzey Noktası, 1(3): 46-49.

Taş, B. and A. Gönülol 2007a. Planktonic algae of Derbent Dam Lake (Samsun, Turkey), (in Turkish). J. Fishscicom, 1(3): 111-123.

Taş, B. and A. Gönülol 2007b. An ecologic and taxonomic study on phytoplankton of a shallow lake, Turkey. J. Environ. Biol., 28: 439-445.

Tunca, H., T. Ongun Sevindik, D.N. Bal, and S. Arabacı. 2014. Community structure of epiphytic algae on three different macrophytes at Acarlar floodplain forest (northern Turkey). Chin. J. Ocean. Limnol., 32(4): 845-857.

Uğurlu (Helli), S. and N. Polat. 2003. An investigation on fish fauna in Lake Simenit (Terme-Samsun), (in Turkish). FÜ Fen ve Mühendislik Bilimleri Dergisi, 15: 485-494.

Uğurlu, S., N. Polat, and Ş. Kandemir. 2008. Fish fauna of lagoons within the Kızılırmak and Yeşilırmak Deltas (Samsun-Turkey), (in Turkish).J. Fishscicom, 2(3): 475-483.

Uncu, L. 1995. Physical geography studies and natural environmental problems in Terme and Kocamandere Streams. MSc Thesis, Ankara Univ. Ankara (in Turkish).

URL1. http://www.turkiyesulakalanlari.com/

URL2. https//rsis.ramsar.org/ris/942

Ustaoğlu, M.R., D.Ö. Mis, and C. Aygen. 2012. Observations on zooplankton in some lagoons in Turkey. J. Black Sea/Mediterranean Environ., 18: 208-222.

Uzun, A. 2005. Anthropogenic changes in Samsun coast, (in Turkish). TURQUA-Fifth Quaternary symposium of Turkey, 02-03 June 2005, Istanbul, p. 183-190.

Uzun, A. 2006. Samsun plains and prospective changes, Samsun from the past to the future 1, (in Turkish). p. 541-548, Samsun Metropolitan Municipality, Samsun.

Uzun, A., M.A. Tabur, and Y. Ayvaz 2008. Birds of Lake Acarlar and environmental problems. Ekoloji 17(66): 1-14.

Yardım, Ö., E. Şendoğan, L. Bat, M. Sezgin, and M. Çulha 2008. Macrobenthic mollusca and crustacea fauna of Lake Sarıkum (Sinop), (in Turkish). EgeJFAS, 25(4): 301-309.

Yeniyurt, C., S. Çağırankaya, Y. Lise, and Y. Ceran. 2008. The Wetland Management Plan of Kızılırmak Delta (2008-2012), (in Turkish). Ministry of Environment and Forestry, General Directorate of Nature Protection and National Parks, Ankara.

Yılmaz, C. 2005. Ecocystem of Sarıkum Lake (Sinop), (in Turkish). TURQUA- Fifth Quaternary symposium of Turkey, 02–03 June 2005, Istanbul, p. 219-226.

Yılmaz, C., A. Uzun, and H.İ. Zeybek. 2013. The proposal of the management plan of Sarıkum Lake (Nature Preservation Area), (in Turkish). III. Congress of National Wetlands, 23-25 October, Samsun, p. 191-202.

Yılmaz, N. and Y. Güleçal. 2012. Phytoplankton community of Terkos Lake and its influent streams, Istanbul, Turkey. Pak. J. Bot., 44: 1135-1140.

Zeybek, H.İ., A. Uzun, C. Yılmaz, and S. Özdemir. 2012. Results of coastline changes in Kızılırmak Delta, (in Turkish). Samsun Symposium, 13-16.10.2011, Samsun, p. 2: 877-883.

GENETIC STUDIES IN THE BLACK SEA

Yılmaz ÇİFTCİ

Department of Fisheries Technology Engineering, Faculty of Marine Sciences, Ordu University, 52400 Fatsa, Ordu, Turkey
yciftci@odu.edu.tr

1. Introduction

The Black Sea is located between Eastern Europe and Asia and surrounded by Bulgaria, Georgia, Romania, Russia, Turkey and Ukraine. It is a semi-enclosed water body and connected to the Mediterranean Sea through the Sea of Marmara and Aegean Sea via Bosphorus and Dardanelles straits. On the other hand, it differs from the adjacent waters in terms of its biodiversity, oceanographical and ecological characteristics (Viaud-Martinez *et al.* 2008). Black Sea has anoxic deep waters due to low mixing rate of surface layer with the deeper waters and includes high level of hydrogen sulfide concentrations below 200m (Sorokin 1983). The high river discharge is an important feature for the Black Sea due to a very large drainage area which dilutes sea water and lowers the salinity to an average of 17-18.5 psu. Salinity of the surface water varies depending on the variability in river discharges between 12-19 psu, and sea water temperature also varies due to severity of winters from year to year between 7-27°C. On the contrary, pollutants carried by the major rivers from Central Europe and surrounding countries have seriously affected the north-eastern region of the Black Sea including Bulgarian and Romanian coasts. Changes in plankton community are represented as decreases in species and biomass in zooplankton and heavy abnormal algal blooms during the last decades coinciding seasonally with spawning season of the Black Sea fish species, which are assumed to be the main biotic factors negatively affecting fish larvae survival. A great number of environmental organizations and international protection agencies have signified their concern about decreasing fish stocks and extinctions of fish species because of the increasing pollution and over fishing in the Black Sea (Viaud-Martinez *et al.* 2008). Although some researchers noticed the increasing human impacts on these populations which can be biologically unique and isolation level are unknown, stocks of some economically important fish species like anchovy (*Eugraulis encrasiccolus*), horse mackerel (*Trachurus mediterraneus*), sprat (*Sprattus sprattus*) have been significantly reduced by overfishing and pollution (Kideys 1994, Tuncer *et al.* 1998). In additon, intensive human population around the drainage area effects aquatic biota through eutrophication, habitat destruction, and overfishing (Ducrotoy and Elliott 2008). So, eutrophication and over fishing have been co-acted to diminish fish stocks and eventually influence the marine diversity in that area. Whatever the reason is, the reduction in fish stocks which are important genetic resources in marine biota has been a significant fisheries management problem. Extinguishing of many thousands of populations and species and altering of the genetic diversity of many fish populations are caused by exploitation of natural stocks, habitat destruction, pollution, obstruction of the migration routes and other human-induced developments (Ferguson 1995). In all cases, fishery management is interested in the abundance of resources and size of fish suitable for harvesting (Ward and Grewe 1995). This point of view appears to be economically advantageous in a short time period, but may cause extinction of the stocks in a long time period. Declining of genetic resources in marine biota is a worrying situation for the genetic resources of the biosphere. Because of this reason, molecular genetic studies on fish stocks should be strongly supported, for the long-term management of fisheries resources (Park and Moran 1995).

2. Use of Genetic Markers in the Black Sea

Although there are a variety of characteristics and methods used to analyze the stock structure of the exploited fish species, the use of molecular genetic techniques in fisheries research has increased. Fisheries-related molecular genetic researchers make use of several marker systems to identify stock distinction of commercially important species. There are basically two types of molecular genetic markers, protein and DNA, each of which has advantages and disadvantages. While initial studies in the 1960's included proteins such as haemoglobin, transferrin and allozyme variation, which made it possible to survey mendelian variation in virtually any species, then attention quickly turned to many molecular methods which are available for studying fish populations and getting more popular in order to obtain information about allele frequencies, gene flow and other parameters that are very important in population biology (Neigel 1997). However, three methods have attracted much attention in particular; analysis of mitochondrial DNA (mtDNA) by sequencing or RFLP (Restriction FragmentLength Polymorphism) analysis, minisatellite and microsatellite loci.

In the past 20 years, mtDNA has attracted much attention in many species, especially for evolutionary studies and populations (Çiftci and Okumuş 2002). The reason for this obvious interest is that the mtDNA genome has several attractive features: it is haploid and almost maternally inherited. The short size of mtDNA (around 16.000bp) compared to the nuclear markers makes it more likely to provide a population-specific marker, resulting in generally greater genetic differentiation than nuclear markers (Ferguson *et al.* 1995). The geographic distributions of mitochondrial DNA lineages within species become a prime example for intraspecific phylogeography, which not only led to new insights in biogeography and population genetics but also prepared a generation of evolutionary biologists to work on both systematic and population genetic questions (Neigel 2009). Some markers have targeted the D-loop for population studies because it is highly variable in mammals but very little polymorphism for some fish species has been shown in that control region. Thus, the cytb and ND genes may be investigated more profitably (Carr and Marshall 1991).

One possible explanation for the failure of mtDNA analysis to provide enhanced resolution of subpopulation structure may be associated with the lack of recombination. This means that it behaves as a single locus. Many independent loci therefore can be examined using nuclear DNA analysis (Ward and Grewe 1995). Recently attention has turned to another type of variation, based on differences in the number of repeated copies of a particular DNA sequence. These sequences can be classified according to decreased size into satellites, minisatellites and microsatellites (Ferguson *et al.* 1995). The core sequence can vary from two bases to several kilobases. Loci with 10-60 base repeat units are generally termed "minisatellites", while the smaller ones are called "microsatellites" (Ashley and Dow 1994). Microsatellite loci are codominant markers (heterozygotes can bedistinguished from either homozygote) and provide complete genetic information at a single locus by using the combination of PCR amplification of each locus with primers homologous to short sequences of the flanking regions followed by electrophoresis to separate the alleles. Microsatellites are also becoming increasingly popular in population differentiation and estimation of population genetic parameters like effective population size and gene flow (Queller *et al.* 1993).

The selection of genetic markers for surveys of genetic variation in the Black Sea has paralleled the general trend in population genetic studies. All of these types of genetic markers continue to be used, and it has often been illuminating to compare results from different markers. There have been enough surveys of genetic variation in Black Sea species to suggest the possibility of a detailed comparative analysis. However, meaningful comparisons among genetic surveys are limited by differences in methodology, including differences in type of genetic marker, sampled localities, and methods of data analysis. Indeed, some fishery species (e.g., *Engraulis encrasiccolus* and sturgeon species) have been studied a lot for different genetic markers. Most of the studies were intended to detect regional patterns of differentiation corresponding to stocks that could be managed as units. In fishery management, a unit of stock is normally considered as a group of fish utilised in a specific area by using a specific method (Carvalho and Hauser 1995). A large proportion of the surveys included an explicit comparison between populations from the Black Sea and those from the Aegean and Mediterranean Seas.

3. **Genetic Studies on the Black Sea Marine Biota**

Despite the economic importance of fish species, little is known on their population structure along their natural range. Knowledge on stock structure will have significant implications for fishery management as well as aquaculture. Concerns about the vulnerability of the stock to over-fishing and variability in recruitment stimulated a number of studies on their biology, distribution of the eggs and larvae, possible migratory movements and population genetics. There are lots of genetic studies in the Black Sea which are involving with the living organisms of a region (Table 1). In this review, current studies have been described by genetic knowledge for the Black Sea species. Literature was reviewed by means of a total of 104 studies including around 40 different Black Sea macro-species. Most of the studies were interested in economically valuable fish species such as sturgeon, anchovy and horse mackerel with some publications reporting surveys of multiple species. Other studies were carried out on mammals, algae and microorganisms. A large number of genetic studies have shown a sharp rise after 2000. Most of these studies were conducted using mtDNA and nuclear DNA sequencing and microsatellite DNA markers and were on various species from different locations of the Black Sea marine biota. Genetic methods have greatly improved useful genetic information for the management of Black Sea species.

Table 1. Genetic studies in the Black Sea

Reference	**Species**	**Geographic area**	**Marker**	**Number of loci**
Zhukovskaya and Kodolova (1997)	*Mytilus galloprovincialis*	Black Sea coast	Allozyme analyses	2 enzyme loci
Dobrovolov and Ivanova (1999)	*Atherina boyeri* and *Atherina mochon pontica*	Bulgarian Black Sea Coast	Starch gel electrophoresis and isoelectric focusing	89 electrophoretic loci
Ladoukakis *et al.* (2002)	*Mytilus galloprovincialis*	Ukrainian Black Sea coast (Sevastopol)	mtDNA RFLP analysis (COI and 16S rRNA)	22 different composite mtDNA haplotypes
Launey *et al.* (2002)	*Ostrea edulis*	Ukrainian Black Sea coast (Sevastopol)	Microsatellite DNA analysis	5 microsatellite loci
Zhukovskaya and Kodolova (2003)	*Mytilus galloprovincialis*	Black Sea coast	Allozyme analyses	2 enzyme loci
Coyer *et al.* (2004)	*Zostera noltii*	Black Sea and Azov Sea	Microsatellite DNA analysis	9 microsatellite loci
Olsen *et al.* (2004)	*Zostera marina*	Black Sea and Azov Sea	Sequence analyses (nuclear rDNA–ITS and matK-intron), and Microsatellite DNA analysis	9 microsatellite loci

Peijnenburg *et al.* (2004)	*Sagitta setosa*	Northern Black Sea Coast	mtDNA Sequencing (cytochrome oxidase II)	88 sequenced individuals represented unique haplo-type
Śmietanka *et al.* (2004)	*Mytilus* species	Sea of Azov (Crime) and Black Sea (Ukraine) coast	The nuclear adhesive protein gene (Me15/16 fragments diagnostic) and RFLP analysis of The mtDNA ND2-COIII coding region	Three alleles and 69 composite mtDNA haplotypes of ND2-COIII
Astolfi *et al.* (2005)	*Atherina boyeri*	Danube Delta in the Romanian Black Sea coast	mtDNA Sequencing (Control region)	78 mtDNA haplotypes
Birstein *et al.* (2005)	*Acipenser gueldenstaedtii* (*A. persicus, A. naccarii and A.baerii*)	Black Sea	mtDNA Sequencing (cytochrome b gene and control region)	19 mtDNA haplotypes
Cristescu and Hebert (2005)	Crustacean species	The northwestern Black Sea coast	mtDNA (COI and 16S rRNA) and one nucleargene, (28S rRNA) Sequencing.	-
Doukakis *et al.* (2005)	*Acipenser gueldenstaedtii*, *A. stellatus*, and *Huso huso*	Sea of Azov and Black Sea coast	mtDNA Sequencing (control region, NADH5 and cytochrome b)	-
Ergüden and Turan (2005)	*Dicentrarchus labrax*	South-eastern Black Sea coast (Trabzon, Turkey)	Allozyme analyses	9 enzyme loci
Grant (2005)	*Engraulis encrasicolus*	Western Black Sea coast	Whole mtDNA RFLP	46 composite mtDNA haplotypes
Natoli *et al.* (2005)	*Tursiops truncatus*	Northern Black Sea off Crimea and Kerch Strait	mtDNA Sequencing (Control region) and Microsatellite DNA analysis	41 mtDNA haplotypes and 9 microsatellite loci
Papadopoulos *et al.* (2005)	*Calanus helgolandicus* and *C. euxinus*	Bulgarian Black Sea Coast	Sequencing of the mitochondrial genes (COI and partial Cytb)	24 mtDNA haplotypes in COI and 10 mtDNA haplotypes in Cytb sequences
Turan *et al.* (2005)	Mugilidae species	the Black Sea Turkish coast (Trabzon)	Allozyme analyses	11 enzyme loci
Chevolot *et al.* (2006)	*Raja clavata*	Bulgarian Black Sea Coast (Varna)	mtDNA Sequencing (Cyt-b) and Microsatellite DNA analysis	15 mtDNA haplotypes and 5 microsatellite loci

Ivanova and Dobrovolov (2006)	*Engraulis encrasicolus*	Sea of Azov and Black Sea (Bulgarian coast and near poti)	Starch gel electrophoresis and Isoelectric focusing (IEF)	6 enzyme loci
Magoulas *et al.* (2006)	*Engraulis encrasicolus*	Black Sea coast of Bulgaria, Ukraine and, Georgia	RFLP analysis of mtDNA following the DIG-non-radioactive method	88 composite mtDNA haplotypes
Peijnenburg *et al.* (2006)	*Sagitta setosa*	Northern Black Sea Coast	PCR- RFLP analysis of mitochondrial COII rDNA gene and Microsatellite DNA analysis	35 composite PCR–RFLP haplotypes and 4 microsatellite loci
Turan (2006)	Mullidae species	the Black Sea Turkish coast (Zonguldak)	Allozyme analyses	17 enzyme loci
Unal *et al.* (2006)	*C. helgolandicus, C. euxinus* and *P. elongatus*	Eight sampling locations in the Black Sea	mtDNA Sequencing (COI)	52 mtDNA haplotypes
Bektas and Belduz (2007)	*Merlangius merlangus euxinus*	Turkish Black Sea coast	The Randomly Amplified Polymorphic DNA (RAPD) technique	-
Viaud-Martinez *et al.* (2007)	*Phocoena phocoena*	Ukrainian, Georgian, Bulgarian and Turkish Black Sea coasts	mtDNA Sequencing (Control region)	22 mtDNA haplotypes
Audzijonyte *et al.* (2008)	*Paramysis* (Crustacea: Mysida)	Black Sea basin	Sequencing of two nuclear ribosomal RNA genes (18S, 28S); and mtDNA (COI) gene	-
Bektas and Belduz (2008)	*Trachurus trachurus, T. mediterraneus* and *T. picturatus*	Turkish Black Sea coast	mtDNA Sequencing (entire CR and the partial cyt b genes	28 Cyt b and 131 CR haplotypes
Bouchenak-Khelladi *et al.* (2008)	*Engraulis albidus* and *E.encrasicolus*	Black Sea coast of Bulgaria (Varna), and Georgia (Batumi)	Characterization of intron-length polymorphisms at creatine-kinase intron loci (CK6-1 and CK6-2)	6 loci
Chandler *et al.* (2008)	*Rapana venosa*	Black Sea coast of Turkey (Rize and Trabzon) and Russia (Tuapse)	mtDNA Sequencing (COI and ND2 gene regions)	110 mtDNA haplotypes (from the concatenated data set)
Debes *et al.* (2008)	*Sprattus sprattus*	Northern and the southern Black Sea	mtDNA Sequencing (5′-end of the control region)	128 mt DNA haplotypes
Dudu *et al.* (2008)	*Huso huso*	Romanian Black Sea Coasts	Microsatellite DNA analysis	7 microsatellite loci

Filipowicz *et al.* (2008)	*Mytilus* species	Sea of Azov and Black Sea (Odessa, Sevastopol and Feodosiia) coast	mtDNA Sequencing (Control region with parts of flanking genes; rnl, trnY, and cob)	3 mtDNA haplotypes
Ludwig (2008)	Acipenseriformes species	Russian and Romanian Black Sea coast	Various Mitochondrial DNA and Nuclear DNA techniques	-
Luttikhuizen *et al.* (2008)	*Crangon crangon*	Turkish Black Sea coast (Sinop)	mtDNA Sequencing (cytochrome-c-oxidase I)	79 mtDNA haplotypes
Natoli *et al.* (2008)	*Delphinus delphis*	Black seaSea	Mitochondrial (Control region) and nuclear microsatellite DNA analysis	45 mtDNA haplotypes and 9 microsatellite loci
Tsekov (2008)	Sturgeon Hybrids	Bulgarian Black Sea coast	Electrophoretical analyses using isoelectric focusing (IEF)	-
Turan (2008)	Rajiformes	Turkish Black Sea coast	mtDNA Sequencing (16S rDNA gene)	8 mtDNA haplotypes
Viaud-Martinez *et al.* (2008)	*Tursiops truncatus*	Black Sea coast	mtDNA Sequencing (Control region)	26 mtDNA haplotypes
Dudu *et al.* (2009)	*Huso huso*	Romanian Black Sea Coasts	mtDNA Sequencing (Cyt-b)	-
Erdoğan *et al.* (2009)	*Engraulis encrasicolus*	Turkish Black Sea coast (Trabzon, Sinop and Istanbul)	Allozyme analyses	2 enzyme loci
Keskin and Can (2009)	Mullidae species	Turkish Black Sea coast (Sinop, Samsun and Ordu)	mtDNA Sequencing (Cytb, COII and 12S rRNA	-
Mezhzherin *et al.* (2009)	*Alosa immaculata, A. caspia*, and *A. maeotica*	Sea of Azov–Black Sea basin	Allozyme analyses	19 enzyme loci
Shemesh *et al.* (2009)	*Chthamalus stellatus, C. montagui* and *Euraphia depressa*	Turkish (Kilyos) and Bulgarian (Sozopol) Black Sea coasts	Sequencing of the ITS, COI and EF-1α region	1-37 mtDNA haplotypes in three regions for three species
Stoica (2009)	Bacterioplankton; Archaea and Bacteria	Constanta Bay, Romanian coast of the Black Sea	Genetic fingerprinting method (T-RFLP analysis of amplified total community 16S rDNA)	74 different OTU

Timoshkina *et al.* (2009)	*Acipenser gueldenstaedtii*	Sea of Azov and Black Sea coast	Nuclear (RAPD and microsatellites) and mitochondrial (PCR identification of two mitotypes) markers	4 microsatellite loci
Turan *et al.* (2009a)	*Truchurus trachurus*	Turkish Black Sea coast (Sile and Samsun)	PCR- RFLP analysis of mitochondrial 16S rDNA gene	14 different composite haplotypes
Turan *et al.* (2009b)	*Trachurus mediterraneus*	Turkish Black Sea coast (Sile, Sinop and Trabzon)	PCR- RFLP analysis of mitochondrial 16S rDNA gene	10 composite mtDNA haplotypes
Virgilio *et al.* (2009)	*Hediste diversicolor* (Polychaeta: Nereididae)	Ukrainian Black Sea coast (Sevastopol)	mtDNA Sequencing (Cytb and COI)	74 mtDNA haplotypes (from the concatenated data set)
Erguden *et al.* (2010)	Mugilid Species	Turkish Black Sea coast near Trabzon	mtDNA Sequencing (16S rDNA)	7 mtDNA haplotypes
Kochzius *et al.* (2010)	Commercially important species such as anchovy, cod, flounder, hake, herring, plaice, sardine, and sole	Black Sea	mtDNA Sequencing (16S, Cyt b, and COI)	-
Reusch *et al.* (2010a)	*Mnemiopsis leidyi*	Turkish, Bulgarian and Ukrainian Black Sea coasts	Sequencing of the ITS region of rDNA and Microsatellite DNA analysis	2 microsatellite loci
Reuschel *et al.* (2010b)	*Palaemon elegans*	Bulgarian Black Sea coast (Sozopol)	mtDNA Sequencing (16S rRNA, and Cox1)	17 mtDNA haplotypes in 16s rRNA and 136 mtDNA haplotypes in Cox1
Turan *et al.* (2010)	*Alosa* Species	Black Sea Coast	Sequence analyses of mtDNA ND5/6 region	-
Atanassov *et al.* (2011)	*Psetta maxima*	Bulgarian and Romanian Black Sea Coasts	mtDNA Sequencing (Control region)	36 mtDNA haplotypes
Coolen (2011)	*Emiliania huxleyi*/ Viruses	Western Black Sea sediments	Genotypic of the viral major capsid protein (MCP) and phosphoglycerate mutase (PGM), by using and Denaturing gradient gel electrophoresis (DGGE)	33 unique genotypes

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Corinaldesi *et al.* (2011)	Prokaryotes and unicellular eukaryotes	the north-western sector of the Black Sea	Quantitative relevance and degradation rates of 16S rDNA and 18S rDNA sequences within the extracellular DNA pool	
Dudu *et al.* (2011)	*Huso huso*, *Acipenser stellatus*, *A. gueldenstaedtii* and *A.ruthenus*	Romanian Black Sea coastal waters or the Lower Danube River	Microsatellite DNA analysis	10 microsatellite loci
Gille *et al.* (2011)	*Alitta succinea* (Polychaeta: Nereididae)	Romanian coast of the Black Sea	PGM isozymes and RAPD markers analyses	-
Holostenco (2011)	*Acipenser stellatus*	Romanian coast of the Black Sea	mtDNA RFLP analysis (Cytb and D-loop) and Microsatellite DNA analysis	12 composite mtDNA haplotypes and 7 microsatellite loci
Kalkan *et al.* (2011)	*Mytilus galloprovincialis*	Turkish Black Sea coast (Kilyos and Riva)	mtDNA Sequencing (COIII) and Microsatellite DNA analysis	14 mtDNA haplotypes and 6 microsatellite loci
Kijewski *et al.* (2011)	*Mytilus* taxa	Sea of Azov and Black Sea (Odesa)	Allelic variation of nuclear (Me 15/16, EF-bis, ITS) markers and mtDNA RFLP analysis (ND2-COIII)	70 composite RFLP haplotypes
Sorokin *et al.* (2011)	*Proterorhinus* species	Sea of Azov and Black Sea (Sevastopol) coast	mtDNA Sequencing (Cytb)	8 mtDNA haplotypes
Wylezich and Jürgens (2011)	Protist species	Black Sea coast	Fingerprint analysis and 18S rRNA gene clone libraries	-
Yebra *et al.* (2011)	*Calanus helgolandicus* and *Calanus euxinus*	Bulgarian Black Sea coast	mtDNA Sequencing (16S rDNA)	48 mtDNA haplotypes
Dobrovolov *et al.* (2012)	*Alosa immaculata* and *Alosa caspia*	Bulgarian Black Sea Coast	Allozyme analyses	11 enzyme loci
Faria *et al.* (2012)	*Alosa alosa* and *Alosa fallax*	Turkish Black Sea coast near Rize	mtDNA Sequencing (Cyt-b and ND1)	65 mtDNA haplotypes
Keskin and Atar (2012)	*Engraulis encrasicolus*	Turkish Black Sea coast (Ünye, Bafra, Zonguldak and Karasu)	mtDNA Sequencing (COI)	10 mtDNA haplotypes
Nahavandi *et al.* (2012)	*Pontogammarus maeoticus*	Black Sea coast	Elongation Factor 1-Alpha	-

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Pujolar *et al.* (2012)	*Atherina* species	Black Sea	Sequencing of the mitochondrial genes (12S rRNA, 16S rRNA, control region) and one nuclear gene (rhodopsin)	
Tonay *et al.* (2012)	*Phocoena phocoena*	Turkish Western Black Sea	mtDNA Sequencing (D-Loop region)	3 mtDNA haplotypes
Çiftci *et al.* (2013a)	*A. stellatus, A. gueldenstaedtii* and *H. huso*	Turkish Black Sea coast	mtDNA Sequencing (Cyt-b)	19 mtDNA haplotypes
Çiftci *et al.* (2013b)	*A. stellatus, A. gueldenstaedtii* and *H. huso*	Turkish Black Sea coast	Heteroplasmy and length variation in the tRNApro-Dloop regions	2-6 copies of different mtDNA length variants
Çiftci *et al.* (2013c)	*A. stellatus, A. gueldenstaedtii* and *H. huso*	Turkish Black Sea coast	mtDNA PCR-RFLP analysis (Cytb gene) and Multiplex PCR analysis	-
Durand *et al.* (2013)	*Mugil cephalus*	Turkish and Ukrainian Black Sea coasts	mtDNA Sequencing (Cyt-b) and Microsatellite DNA analysis	24 mtDNA haplotypes and 6 microsatellite loci
Ghabooli *et al.* (2013)	*Mnemiopsis leidyi*	Eastern Black Sea (near Gelendzhik) and Sea of Azov (Yasenskaya Bay)	Sequencing of mtDNA (COI) and Nuclear marker (ITS) Analysis	17 mtDNA haplotypes and 18 different alleles for ITS
Gurlek *et al.* (2013)	*Trachurus trachurus, T. picturatus* and *T. mediterraneus*	Turkish Black Sea coast	RFLP analysis of the mtDNA 16 S, ND 3/4 and ND 5/6 genes	34 composite haplotypes
Ivanova *et al.* (2013)	Gobiid species	Bulgarian Black Sea Coast	Genetic-biochemical analysis (starch gel electrophoresis and isoelectric focusing)	6 enzyme loci
Keskin and Atar (2013a)	Commercially important fish species	Turkish Black Sea coast (Sinop, Samsun and Trabzon)	mtDNA Sequencing (COI)	267 unique haplotypes
Keskin and Atar (2013b)	*Aurelia aurita, Cancer pagurus* and *Rapana bezoar*	Turkish Black Sea coast (Sinop and Trabzon)	mtDNA Sequencing (COI)	One to five haplotypes were detected for each species
Nahavandi *et al.* (2013)	*Pontogammarus maeoticus*	Romanian Black Sea coast and Sea of Azov	mtDNA (COI & ND5 and COI only) and nDNA (EF1-a) Sequencing	51 haplotypes in COI & ND5; 53 haplotypes in COI and 27 haplotypes in EF1-a
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Pekmezci *et al.* (2013)	*Hysterothylacium aduncum*, *Merlangius merlangus euxinus* and *Trachurus trachurus*	Different sites of the Black Sea coast of Turkey	Sequencing of ITS rDNA gene	
Audzijonyte *et al.* (2014)	*Paramysis lacustris*	Black and Azov sea coasts, estuaries	Microsatellite DNA analysis	10 microsatellite loci
Dudu *et al.* (2014)	Sturgeon species	Romanian Black Sea Coasts	mtDNA Sequencing (entire control region and partial sequences of the flanking tRNA genes)	6 mtDNA haplotypes
Haley *et al.* (2014)	*Vibrio parahaemolyticus*	Georgian coast of the BlackSea	toxRS sequence of pandemic strains	-
Oueslati *et al.* (2014)	*Engraulis encrasicolus*	Bulgarian Black Sea Coast	Mitochondrial (Cyt-b) and nuclear microsatellite DNA analysis	6 Microsatellite loci
Pekmezci *et al.* (2014)	*Anisakid nematodes*	Turkish Black Sea coast (Sinop to Trabzon)	PCR-RFLP, ITS region, and the cox2 gene	-
Popa *et al.* (2014)	*Platynereis dumerilii* (Polychaeta, Nereididae)	Romanian Black Sea coast	Microsatellite DNA analysis	13 microsatellite loci
Slynko *et al.* (2014)	*Neogobius melanostomus*	The northwestern part of the Black Sea basin	mtDNA Sequencing (Cytb)	8 mtDNA haplotypes
Śmietanka *et al.* (2014)	*Mytilus* species	Sea of Azov (Crime) and Black Sea (Odessa) coast	mtDNA Sequencing (Control region: two variable domains and the conserved domain)	8-34 mtDNA haplotypes in all regions
Audzijonyte *et al.* (2015)	*Paramysis lacustris*	Black and Azov sea coasts, estuaries	mtDNA Sequencing (COI) and Microsatellite DNA analysis	5 microsatellite loci
Bayha *et al.* (2015)	*Mnemiopsis leidyi*	Southwestern Black Sea	mtDNA Sequencing (Cyt-b) and Microsatellite DNA analysis	74 mtDNA haplotypes and 6 microsatellite loci
Turan (2015)	*Sarda sarda*	Bulgarian (Varna) and Turkish (Igneada, Duzce, Samsun and Trabzon) Black Sea coasts	Microsatellite DNA analysis	5 microsatellite loci

Turan *et al.* (2015a)	*Sarda sarda*	the Black Sea Bulgarian Coast (Varna) and the Black Sea Turkish coast (Igneada, Duzce, Samsun, Trabzon)	mtDNA Sequencing (D-Loop region)	19 mtDNA haplotypes
Turan *et al.* (2015b)	*Alosa* species	Turkish Black Sea coast (Sile)	PCR- RFLP analysis of mitochondrial Cytb, COX, D-loop, ND 3-4, ND5-6, 16S rRNA genes	45 different combined haplotypes
Woodall *et al.* (2015)	*Hippocampus guttulatus*	Bulgarian (Varna) Black Sea coast	Mitochondrial (Control region and Cytb) and nuclear microsatellite DNA analysis	70 mtDNA haplotypes (from the concatenated data set) and 5 microsatellite loci
Boissin *et al.* (2016)	*Scorpaena porcus*	Whole Black Sea coast except Russia	mtDNA Sequencing (Cyt-b) and Microsatellite DNA analysis	64 mtDNA haplotypes and 11 microsatellite loci
Chassaing *et al.* (2016)	*Acipenser sturio*	Turkish and Bulgarian Black Sea Coasts	mtDNA CR sequencing	-
Firidin *et al.* (2016)	*Sciaena umbra* and *Umbrina cirrosa*	Turkish Black Sea coast	mtDNA Sequencing (Cytb and 16S rRNA)	4-25 mtDNA haplotypes in two gene regions for two species
Fratini *et al.* (2016)	*Pachygrapsus marmoratus*	Black Sea coast of Turkey (Sile, Sinop), Bulgaria, Georgia, Ukraine and Romania	mtDNA Sequencing (COI)	74 mtDNA haplotypes
Özer *et al.* (2016a)	*Henneguya sinova / Parablennius tentacularis*	Turkish Black Sea coast (Sinop)	Sequencing of nuclear SSU rDNA	-
Özer *et al.* (2016b)	*Myxobolus parvus* (Myxozoa)/*Liza saliens*	Turkish Black Sea coast (Sinop)	Sequencing of nuclear SSU rDNA	-
Terceti *et al.* (2016)	*Photobacterium damselae subsp. damselae / Dicentrarchus labrax*	Turkish Southeastern Black Sea coast	Sequencing of toxR gene	-
Terzi Gulel and Martinez-Urtaza (2016)	*Vibrio parahaemolyticus*	the Middle Black Sea coast of Turkey	Confirmation of Vibrio parahaemolyticus by conventional PCR and real-time PCR	-

4. Conclusion

Density and distribution of marine species in the Black Sea biota have declined substantially during the past several decades, leading to a critically endangered status of some species like sturgeons. The loss of biodiversity in the Black Sea is a serious concern for multiple reasons such as several types of human activities negatively influencing the status of the endangered species. In publications carried out, mainly four different genetic differentiations arise; first one is the fixed differences in allel frequencies between populations or differences in DNA sequences which are considered as an evidence of a complete barrier to ongoing gene flow for thousands of years. Second one is the moderate variation in the allel frequencies between populations. It is considered as an evidence of a partial barrier to gene flow. Third one is the slight but statistically significant differences in the allel frequencies which are the most difficult to be interpreted. In that point, genetic drift has been a subject of broad speculation for marine populations. It is assumed that genetic drift become weak in large populations. The last one is that complete absence of genetic differentiation implies extensive gene flow, or panmixia, among populations. When marine reserves are determined, genetic similarities among fish species are very important for management and conservation of species (Palumbi 2003). Alternatively, genetic variations among species suggesting life history differences are main components in formation of the genetic structure of a species in a spesific area (Kelly and Palumbi 2010). In such cases, the management of various groups separately, or species-specific management would be required. The Black Sea is a highly suitable aquatic system to evaluate the common genetic diversity and differentiation patterns in multiple species.

References

Ashley, M.V. and B.D. Dow. 1994. The use of microsatellite analysis in population biology: Background, methots and potential applications. Molecular Ecology and Evolution, 69: 185-201.

Astolfi, L., I. Dupanloup, R. Rossi, P.M. Bisol, E. Faure, and L. Congiu. 2005. Mitochondrial variability of sand smelt *Atherina boyeri* populations from north Mediterranean coastal lagoons. Marine Ecology Progress Series, 297: 233-243.

Atanassov, I., P. Ivanova, M. Panayotova, A. Tsekov, and K. Rusanov. 2011. Mitochondrial control region DNA variation in turbot populations from the Bulgarian and Romanian Black Sea coasts. Biotechnology & Biotechnological Equipment, 25(4): 2627-2633.

Audzijonyte, A., M.E. Daneliya, N. Mugue, and R. Väinölä. 2008. Phylogeny of Paramysis (Crustacea: Mysida) and the origin of Ponto-Caspian endemic diversity:

resolving power from nuclear protein-coding genes. Molecular Phylogenetics and Evolution, 46(2): 738-759.

Audzijonyte, A., J. Haugstetter, and K. Arbačiauskas. 2014. Characterization of ten polymorphic microsatellite markers in an invasive Ponto-Caspian mysid crustacean *Paramysis lacustris*. Conservation Genetics Resources, 6(2): 309-311.

Audzijonyte, A., L. Baltrūnaitė, R. Väinölä, and K. Arbačiauskas. 2015. Migration and isolation during the turbulent Ponto-Caspian Pleistocene create high diversity in the crustacean Paramysis lacustris. Molecular Ecology, 24(17): 4537-4555.

Bayha, K.M., M.H. Chang, C.L. Mariani, J.L. Richardson, D.L. Edwards, T.S. DeBoer, and G.R. Harbison. 2015. Worldwide phylogeography of the invasive ctenophore *Mnemiopsis leidyi* (Ctenophora) based on nuclear and mitochondrial DNA data. Biological Invasions, 17(3): 827-850.

Bektas, Y. and A.O. Belduz. 2007. Molecular characterization of the whiting (*Merlangius merlangus euxinus* Nordmann, 1840) in Turkish Black Sea coast by RAPD analysis. Journal of Animal and Veterinary Advances, 6(5): 739-744.

Bektas, Y. and A.O. Belduz. 2008. Molecular phylogeny of Turkish *Trachurus* species (Perciformes: Carangidae) inferred from mitochondrial DNA analyses. Journal of Fish Biology, 73(5): 1228-1248.

Birstein, V.J., G. Ruban, A. Ludwig, P. Doukakis, and R. DeSalle. 2005. The enigmatic Caspian Sea Russian sturgeon: how many cryptic forms does it contain?. Systematics and Biodiversity, 3(02): 203-218.

Boissin, E., D. Micu, J.L. Goff, V. Neglia, L. Bat, V. Todorova, and Ç. Keskin. 2016. Contemporary genetic structure and postglacial demographic history of the black scorpionfish, *Scorpaena porcus*, in the Mediterranean and the Black Seas. Molecular Ecology, 25(10): 2195-2209.

Bouchenak-Khelladi, Y., J.D. Durand, A. Magoulas, and P. Borsa. 2008. Geographic structure of European anchovy: a nuclear-DNA study. Journal of Sea Research, 59(4): 269-278.

Carr, S.M. and H.D. Marshall. 1991. Detection of intraspecific DNA sequence variation in the mitochondrial cytochrome *b* gene Atlantic cod (*Gadus morhua*) by the polymerase chain reaction. Canadian Journal of Fishies and Aquatic Science, 48: 48-52.

Carvalho, G.R. and L. Hauser. 1995. Molecular genetics and the stock concept in fisheries, p. 55-80. In G.R. Carvalho and T.J. Pitcher [eds.], Molecular Genetics in Fisheries. London: Chapman & Hall.

Chandler, E.A., J.R. McDowell, and J.E. Graves. 2008. Genetically monomorphic invasive populations of the Rapa whelk, *Rapana venosa*. Molecular Ecology, 17(18): 4079-4091.

Chassaing, O., N. Desse-Berset, C. Hänni, S. Hughes, and P. Berrebi. 2016. Phylogeography of the European sturgeon (*Acipenser sturio*): a critically endangered species. Molecular Phylogenetics and Evolution, 94: 346-357.

Chevolot, M., G. Hoarau, A.D. Rijnsdorp, W.T. Stam, and J.L. Olsen. 2006. Phylogeography and population structure of thornback rays (*Raja clavata* L., Rajidae). Molecular Ecology, 15(12): 3693-3705.

Coolen, M.J. 2011. 7000 years of *Emiliania huxleyi* viruses in the Black Sea. Science, 333(6041): 451-452.

Corinaldesi, C., M. Barucca, G.M. Luna, and A. Dell'Anno. 2011. Preservation, origin and genetic imprint of extracellular DNA in permanently anoxic deep-sea sediments. Molecular Ecology, 20(3): 642-654.

Coyer, J.A., O.E. Diekmann, E. Serrão, G. Procaccini, N. Milchakova, G.A. Pearson, and J.L. Olsen. 2004. Population genetics of dwarf eelgrass *Zostera noltii* throughout its biogeographic range. Marine Ecology Progress Series, 281: 51-62.

Cristescu, M.E. and P.D. Hebert. 2005. The" Crustacean Seas" an evolutionary perspective on the Ponto Caspian peracarids. Canadian Journal of Fisheries and Aquatic Sciences, 62(3): 505-517.

Çiftci, Y. and İ. Okumuş. 2002. Fish population genetics and applications of molecular markers to fisheries and aquaculture: I-basic principles of fish population genetics. Turkish Journal of Fisheries and Aquatic Sciences, 2: 145-155.

Çiftci, Y., O. Eroğlu, and Ş. Firidin. 2013a. Mitochondrial cytochrome b sequence variation in three sturgeon species (*A. stellatus* Pallas, 1771, *A. gueldenstaedtii* Brandt, 1833, *H. huso* Linnaeus, 1758) from the Black Sea Coasts of Turkey. Turkish Journal of Fisheries and Aquatic Sciences, 13(2): 291-303.

Çiftci, Y., O. Eroğlu, and Ş. Firidin. 2013b. Heteroplasmy and length variation in the tRNApro-Dloop regions of three sturgeon species (*A. stellatus, A. gueldenstaedtii* and *H. huso*) from the Turkish coast of the Black Sea. Turkish Journal of Biochemistry/Turk Biyokimya Dergisi, 38(3): 250-257.

Çiftci, Y., O. Eroglu, and S. Firidin. 2013c. Determination of sturgeon species living in the Black Sea Coasts of Turkey by Sequence, RFLP and multiplex PCR analysis methods. Journal of Animal and Veterinary Advances, 12(6): 676-682.

Debes, P.V., F.E. Zachos, and R. Hanel. 2008. Mitochondrial phylogeography of the European sprat (*Sprattus sprattus* L., Clupeidae) reveals isolated climatically vulnerable populations in the Mediterranean Sea and range expansion in the northeast Atlantic. Molecular Ecology, 17(17): 3873-3888.

Dobrovolov, I.S. and P.P. Ivanova. 1999. Biochemical genetic comparison of the *Atherina boyeri* and *Atherina mochon pontica* (Pisces, Atherinidae). Folia Zoologica (Czech Republic), 48(1): 55-60.

Dobrovolov, I., P. Ivanova, Z. Georgiev, M. Panayotova, V. Raykov, and V. Nikolov. 2012. Allozyme variation and genetic identification of shad species (Pisces: Clupeidae, Genus Alosa) along Bulgarian Black Sea coast. Acta zool. Bulg., 64(2): 175-183.

Doukakis, P., V.J. Birstein, and R. Salle. 2005. Intraspecific structure within three caviar-producing sturgeons (*Acipenser gueldenstaedtii*, *A. stellatus*, and *Huso huso*) based on mitochondrial DNA analysis. Journal of Applied Ichthyology, 21(6): 457-460.

Ducrotoy, J.P. and M. Elliott. 2008. The science and management of the North Sea and the Baltic Sea: natural history, present threats and future challenges. Mar Pollut Bull., 57: 8-21.

Dudu, A., S.E. Georgescu, R. Suciu, A.N.C.A. Dinischiotu, and M. Costache. 2008. Microsatelitte DNA variation in the black sea beluga sturgeon (*Huso huso*). Romanian Biotechnological Letters, 13(3): 3779-3783

Dudu, A., S.E. Georgescu, A.N.C.A. Dinischiotu, and M. Costache. 2009. Four new polymorphisms of the mitochondrial gene cytochrome b in the beluga sturgeon (*Huso huso*) from the Black Sea. Roumanian Biotechnol Letters, 14(3): 4420-4424.

Dudu, A., R. Suciu, M. Paraschiv, S.E. Georgescu, M. Costache, and P. Berrebi. 2011. Nuclear markers of Danube sturgeons' hybridization. International Journal of Molecular Sciences, 12(10): 6796-6809.

Dudu, A., S.E. Georgescu, and M. Costache. 2014. Molecular analysis of phylogeographic subspecies in three Ponto-Caspian sturgeon species. Genetics and Molecular Biology, 37(3): 587-597.

Durand, J.D., H. Blel, K.N. Shen, E.T. Koutrakis, and B. Guinand. 2013. Population genetic structure of *Mugil cephalus* in the Mediterranean and Black Seas: a single mitochondrial clade and many nuclear barriers. Marine Ecology Progress Series, 474: 243-261.

Erdoğan, Z., C. Turan, and H.T. Koç. 2009. Morphologic and allozyme analyses of European anchovy (*Engraulis encrasicolus* (L. 1758)) in the Black, Marmara and Aegean Seas. Acta Adriat, 50(1): 77-90.

Ergüden, D. and C. Turan. 2005. Examination of genetic and morphologic structure of sea-bass (*Dicentrarchus labrax* L., 1758) populations in Turkish coastal waters. Turkish Journal of Veterinary and Animal Sciences, 29(3): 727-733.

Erguden, D., M. Gurlek, D. Yaglioglu, and C. Turan. 2010. Genetic identification and taxonomic relationship of Mediterranean Mugilid species based on mitochondrial 168 rDNA sequence data. Journal of Animal and Veterinary Advances, 9(2): 336-341.

Faria, R., S. Weiss, and P. Alexandrino. 2012. Comparative phylogeography and demographic history of European shads (*Alosa alosa* and *A. fallax*) inferred from mitochondrial DNA. BMC Evolutionary Biology, 12(1):1.

Ferguson, M. 1995. The role of molecular genetic markers in the management of cultured fish, p. 81-104. In G.R. Carvalho and T.J. Pitcher [eds.], Molecular Genetics in Fisheries, London: Chapman & Hall.

Ferguson, A., J.B. Taggart, P.A. Prodohl, O. McMeel, C. Thompson, C. Stone, P. McGinnity, and R.A. Hynes. 1995. The application of molecular markers to the study and conservation of fish populations, with special reference to *Salmo*. Journal of Fish Biology, 47: 103-126.

Filipowicz, M., A. Burzyński, B. Śmietanka, and R. Wenne. 2008. Recombination in mitochondrial DNA of European mussels Mytilus. Journal of Molecular Evolution, 67(4): 377-388.

Firidin, S., O. Eroglu, and I. Altinok. 2016. Genetic characterization of brown meagre (*Sciaena umbra*) and Shi drum (*Umbrina cirrosa*) populations. Biochemical Systematics and Ecology, 68: 200-209.

Fratini, S., L. Ragionieri, T. Deli, A. Harrer, I.A.M. Marino, S. Cannicci, L. Zane and C.D. Schubart. 2016. Unravelling population genetic structure with mitochondrial DNA in a notional panmictic coastal crab species: sample size makes the difference. BMC Evolutionary Biology, 16(1): 1-15.

Ghabooli, S., T.A. Shiganova, E. Briski, S. Piraino, V. Fuentes, D. Thibault-Botha, D.L. Angel, M.E. Cristescu and H.J. MacIsaac. 2013. Invasion pathway of the ctenophore *Mnemiopsis leidyi* in the Mediterranean Sea. Plos One, 8(11): e81067.

Gillet, P., V. Surugiu, R. Vasile, I. Metais, M. Mouloud, and P. Simo. 2011. Preliminary data on population dynamics and genetics of *Alitta succinea* (Polychaeta: Nereididae) from the Romanian coast of the Black Sea. Italian Journal of Zoology, 78(1): 229-241.

Grant, W.S. 2005. A second look at mitochondrial DNA variability in European anchovy (*Engraulis encrasicolus*): assessing models of population structure and the Black Sea isolation hypothesis. Genetica, 125(2-3): 293-309.

Gurlek, M., D. Erguden, D. Yaglioglu, F. Turan, C. Turan, and I. Kemal. 2013. Molecular systematics of genus *Trachurus* in Turkish marine waters. Rapp. Comm. int. Mer Médit., 40: 705.

Haley, B.J., T. Kokashvili, A. Tskshvediani, N. Janelidze, N. Mitaishvili, C.J. Grim, G. Constantin de Magny, A.J. Chen, E. Taviani, T. Eliashvili, M. Tediashvili, C.A. Whitehouse, R.R. Colwell and A. Hug. 2014. Molecular diversity and predictability of *Vibrio parahaemolyticus* along the Georgian coastal zone of the Black Sea. Frontiers in Microbiology, 5: 45-66.

Holostenco, D.N. 2011. Conservation of genetic diversity in populations of stellate sturgeon (*Acipenser stellatus*) of the NW Black Sea and Lower Danube River, 58 p. Norwegian University of Science and Technology Department of Biology.

Ivanova, P.P. and I.S. Dobrovolov. 2006. Population–genetic structure on European anchovy (*Engraulis encrasicolus*, Linnaeus, 1758) (Osteichthyes: Engraulide) from Mediterranean Basin and Atlantic Ocean. Acta Adriat., 47(1): 13-22.

Ivanova, P., I. Dobrovolovr, A. Apostolou, M. Vasilev, and B. Velkov. 2013. Protein biomarkers for identification of some Gobiid species (Actinopterygii: Gobiidae) along the Bulgarian Black Sea Coast. Acta Zoologica Bulgarica, 65(4): 429-438.

Kalkan, E., A. Kurtuluş, Ö. Maraci, and R. Bilgin. 2011. Is the Bosphorus Strait a barrier to gene flow for the Mediterranean mussel, *Mytilus galloprovincialis* (Lamarck, 1819)?. Marine Biology Research, 7(7): 690-700.

Kelly, R.P. and S.R. Palumbi. 2010. Genetic structure among 50 species of the northeastern pacific rocky intertidal community. PLoS ONE, 5(1): e8594.

Keskin, E. and A. Can. 2009. Phylogenetic relationships among four species and a sub-species of Mullidae (Actinopterygii; Perciformes) based on mitochondrial cytochrome B, 12S rRNA and cytochrome oxidase II genes. Biochemical Systematics and Ecology, 37(5): 653-661.

Keskin, E. and H.H. Atar. 2012. Genetic structuring of European anchovy (*Engraulis encrasicolus*) populations through mitochondrial DNA sequences. Mitochondrial DNA, 23(2): 62-69.

Keskin, E. and H.H. Atar. 2013a. DNA barcoding commercially important fish species of Turkey. Molecular Ecology Resources, 13(5): 788-797.

Keskin, E. and Atar, H.H. 2013b. DNA barcoding commercially important aquatic invertebrates of Turkey. Mitochondrial DNA, 24(4): 440-450.

Kideys, A.E. 1994. Recent dramatic changes in the Black Sea ecosystem: the reason for the sharp decline in the Turkish anchovy fisheries. Journal of Marine Systems, 5: 171-181.

Kijewski, T., B. Śmietanka, M. Zbawicka, E. Gosling, H. Hummel, and R. Wenne. 2011. Distribution of Mytilus taxa in European coastal areas as inferred from molecular markers. Journal of Sea Research, 65(2): 224-234.

Kochzius, M., C. Seidel, A. Antoniou, S.K. Botla, D. Campo, A. Cariani *et al.*, 2010. Identifying fishes through DNA barcodes and microarrays. PLoS One, 5(9): e12620.

Ladoukakis, E.D., C. Saavedra, A. Magoulas, and E. Zouros. 2002. Mitochondrial DNA variation in a species with two mitochondrial genomes: the case of *Mytilus galloprovincialis* from the Atlantic, the Mediterranean and the Black Sea. Molecular Ecology, 11(4): 755-769.

Launey, S., C. Ledu, P. Boudry, F. Bonhomme, and Y. Naciri-Graven. 2002. Geographic structure in the European flat oyster (*Ostrea edulis* L.) as revealed by microsatellite polymorphism. Journal of Heredity, 93(5): 331-351.

Ludwig, A. 2008. Identification of Acipenseriformes species in trade. Journal of Applied Ichthyology, 24(1): 2-19.

Luttikhuizen, P.C., J. Campos, J. van Bleijswijk, K.T. Peijnenburg, and H.W. van der Veer. 2008. Phylogeography of the common shrimp, *Crangon crangon* (L.) across its distribution range. Molecular Phylogenetics and Evolution, 46(3): 1015-1030.

Magoulas, A., R. Castilho, S. Caetano, S. Marcato, and T. Patarnello. 2006. Mitochondrial DNA reveals a mosaic pattern of phylogeographical structure in Atlantic and Mediterranean populations of anchovy (*Engraulis encrasicolus*). Molecular Phylogenetics and Evolution, 39: 734-746.

Mezhzherin, S.V., L.V. Fedorenko, and D.B. Verlatyi. 2009. Differentiation and allozyme variability of shads' genus *Alosa* (Clupeiformes, Alosiinae) from Azov-Black Sea basin. Cytology and Genetics, 43(2): 118-122.

Nahavandi, N., V. Ketmaier, and R. Tiedemann. 2012. Intron structure of the elongation factor 1-Alpha gene in the Ponto-Caspian amphipod *Pontogammarus maeoticus* (Sowinsky, 1894) and its phylogeographic utility. Journal of Crustacean Biology, 32(3): 425-433.

Nahavandi, N., V. Ketmaier, M. Plath, and R. Tiedemann. 2013. Diversification of Ponto-Caspian aquatic fauna: Morphology and molecules retrieve congruent evolutionary relationships in *Pontogammarus maeoticus* (Amphipoda: Pontogammaridae). Molecular Phylogenetics and Evolution, 69(3): 1063-1076.

Natoli, A., A. Birkun, A. Aguilar, A. Lopez, and A.R. Hoelzel. 2005. Habitat structure and the dispersal of male and female bottlenose dolphins (*Tursiops truncatus*). Proceedings of the Royal Society of London B: Biological Sciences, 272(1569): 1217-1226.

Natoli, A., A. Canadas, C. Vaquero, E. Politi, P. Fernandez-Navarro, and A.R. Hoelzel. 2008. Conservation genetics of the short-beaked common dolphin (*Delphinus delphis*) in the Mediterranean Sea and in the eastern North Atlantic Ocean. Conservation Genetics, 9(6): 1479-1487.

Neigel, J.E. 1997. A comparison of alternative strategies for estimating gene flow from genetic markers. Annual Review of Ecology and Systematics, 28: 105-128.

Neigel, J.E. 2009. Population Genetics and Biogeography of the Gulf of Mexico, pp. 1353-1369. In D.L. Felder, and D.K. Camp [eds.], Gulf of Mexico–Origins, Waters, and Biota. Biodiversity. Texas A&M University Press, College Station, Texas.

Olsen, J.L., W.T. Stam, J.A. Coyer, T.B. Reusch, M. Billingham, C. Boström, *et al.* 2004. North Atlantic phylogeography and large-scale population differentiation of the seagrass *Zostera marina* L. Molecular Ecology, 13(7): 1923-1941.

Oueslati, S., K. Fadhlaoui-Zid, O. Kada, M.T. Augé, J.P. Quignard, and F. Bonhomme. 2014. Existence of two widespread semi-isolated genetic entities within Mediterranean anchovies. Marine Biology, 161(5): 1063-1071.

Özer, A., C.T. Gürkanlı, H. Özkan, G. Acar, Y. Çiftçi, and V. Yurakhno. 2016. Molecular characterization and morphological aspects of *Myxobolus parvus* (Myxozoa) from *Liza saliens* (Mugilidae) off the Turkish Black Sea coasts. Parasitology Research, 115: 3513-3518.

Özer, A., H. Özkan, C.T. Gürkanlı, V. Yurakhno, and Y. Çiftçi. 2016. Morphology, histology and phylogeny of *Henneguya sinova* sp. nov. (Myxobolidae: Myxozoa) infecting gills of *Parablennius tentacularis* in the Black Sea, Turkey. Diseases of Aquatic Organisms, 118(3): 207-215.

Palumbi, S.R. 2003. Population genetics, demographic connectivity, and the design of marine reserves. Ecol Appl., 13:146-158.

Papadopoulos, L.N., K.T.C.A. Peijnenburg, and P.C. Luttikhuizen. 2005. Phylogeography of the calanoid copepods *Calanus helgolandicus* and *C. euxinus* suggests Pleistocene divergences between Atlantic, Mediterranean, and Black Sea populations. Marine Biology, 147(6): 1353-1365.

Park, L.K. and P. Moran. 1995. Developments in molecular genetic techniques in fisheries. In G.R. Carvalho, and T.J. Pitcher [eds.], Molecular Genetics in Fisheries. London: Chapman & Hall.

Peijnenburg, K.T., J.A. Breeuwer, A.C. Pierrot-Bults, and S.B. Menken. 2004. Phylogeography of the planktonic chaetognath *Sagitta setosa* reveals isolation in European seas. Evolution, 58(7): 1472-1487.

Peijnenburg, K.T.C.A., C. Fauvelot, J.A.J. Breeuwer, and S.B.J. Menken. 2006. Spatial and temporal genetic structure of the planktonic *Sagitta setosa* (Chaetognatha) in European seas as revealed by mitochondrial and nuclear DNA markers. Molecular Ecology, 15(11): 3319-3338.

Pekmezci, G.Z., C.S. Bolukbas, A.T. Gurler, and E.E. Onuk. 2013. Occurrence and molecular characterization of *Hysterothylacium aduncum* (Nematoda: Anisakidae) from *Merlangius merlangus euxinus* and *Trachurus trachurus* off the Turkish coast of Black Sea. Parasitology Research, 112(3): 1031-1037.

Pekmezci, G.Z., E.E. Onuk, C.S. Bolukbas, B. Yardimci, A.T. Gurler, M. Acici and S. Umur. 2014. Molecular identification of Anisakis species (Nematoda: Anisakidae) from marine fishes collected in Turkish waters. Veterinary Parasitology, 201(1): 82-94.

Popa, L.O., O.P. Popa, A.M. Krapal, E.I. Iorgu, and V. Surugiu. 2014. Fine-scale population genetics analysis of *Platynereis dumerilii* (Polychaeta, nereididae) in the Black Sea: How do local marine currents drive geographical differentiation? Journal of Experimental Zoology Part A: Ecological Genetics and Physiology, 321(1): 41-47.

Pujolar, J.M., L. Zane, and L. Congiu. 2012. Phylogenetic relationships and demographic histories of the Atherinidae in the Eastern Atlantic and Mediterranean Sea re-examined by Bayesian inference. Molecular Phylogenetics and Evolution, 63(3): 857-865.

Queller, D.C., J.E. Strassmann, and C.R. Hughes. 1993. Microsatellites and kinship. Trends in Ecology & Evolution, 8(8): 285-288.

Reusch, T.B., S. Bolte, M. Sparwel, A.G. Moss, and J. Javidpour. 2010a. Microsatellites reveal origin and genetic diversity of Eurasian invasions by one of the world's most notorious marine invader, *Mnemiopsis leidyi* (Ctenophora). Molecular Ecology, 19(13): 2690-2699.

Reuschel, S., J.A. Cuesta, and C.D. Schubart. 2010b. Marine biogeographic boundaries and human introduction along the European coast revealed by phylogeography of the prawn *Palaemon elegans*. Molecular Phylogenetics and Evolution, 55(3): 765-775.

Shemesh, E., D. Huchon, N. Simon-Blecher, and Y. Achituv. 2009. The distribution and molecular diversity of the Eastern Atlantic and Mediterranean chthamalids (Crustacea, Cirripedia). Zoologica Scripta, 38(4): 365-378.

Slynko, Y.V., V.V. Stolbunova, S.V. Chebotar, V.V. Zamorov and A.N. Gurovskiy. 2014. Haplotype diversity in the mtDNA cyt b gene in round goby (*Neogobius melanostomus* (Pallas)) from the northwestern part of the Black Sea basin. Russian Journal of Genetics, 50(3): 274-279.

Śmietanka, B., M. Zbawicka, M. Wołowicz, and R. Wenne. 2004. Mitochondrial DNA lineages in the European populations of mussels (*Mytilus* spp.). Marine Biology, 146(1): 79-92.

Śmietanka, B., A. Burzyński, H. Hummel, and R. Wenne. 2014. Glacial history of the European marine mussels *Mytilus*, inferred from distribution of mitochondrial DNA lineages. Heredity, 113(3): 250-258.

Sorokin, P. A., D.A. Medvedev, V. Vasil'ev, E.D. Vasil'eva. 2011. Further studies of mitochondrial genome variability in Ponto-Caspian Proterorhinus species (Actinopterygii: Perciformes: Gobiidae) and their taxonomic implications. Acta Ichthyol. Piscat. 41(2): 95-104.

Sorokin, Y.U.I. 1983. The Black Sea, p. 253-292. In B.H. Ketchum [ed.], Ecosystems of the World, Estuaries and Enclosed Seas. Elsevier, New York, USA.

Stoica, E. 2009. Application of T-RFLP analysis to the study of the coastal Black Sea bacterioplankton. Romanian Biotechnological Letters, 14(5): 4710-4719.

Terceti, M.S., H. Ogut, and C.R. Osorio. 2016. *Photobacterium damselae* subsp. damselae, an emerging fish pathogen in the Black Sea: evidences of a multiclonal origin. Applied and Environmental Microbiology, 82(13): 3736-3745.

Terzi Gulel, G. and J. Martinez-Urtaza. 2016. Molecular characterizations of Vibrio parahaemolyticus in seafood from the Black Sea, Turkey. Letters in Applied Microbiology, 62(6): 494-500.

Timoshkina, N.N., A.E. Barmintseva, A.V. Usatov, and N.S. Mugue. 2009. Intraspecific genetic polymorphism of Russian sturgeon *Acipenser gueldenstaedtii*. Russian Journal of Genetics, 45(9): 1098-1106.

Tonay, A.M., A. Dede, Ö. Maracı, and R. Bilgin. 2012. A preliminary genetic study on the harbour porpoise (*Phocoena phocoena*) in the Turkish Seas. Journal of Black Sea/Mediterranean Environment, 18(1): 83-89.

Tsekov, A. 2008. Natural sturgeon hybrids along Bulgarian Black Sea coast and in Danube River. Acta Zoologica Bulgarica, 60(3): 311-316.

Tuncer, G., T. Karakas, T.I. Balkas, C.F. Gökçay, S. Aygun, C. Yurteri, G. Tuncel, 1998. Land-based sources of pollution along the Black Sea coast of Turkey: concentrations and annual loads of the Black Sea. Marine Pollution Bulletin, 36: 409-423.

Turan, C., M. Caliskan, and H. Kucuktas. 2005. Phylogenetic relationships of nine mullet species (Mugilidae) in the Mediterranean Sea. Hydrobiologia, 532(1-3): 45-51.

Turan, C. 2006. Phylogenetic relationships of Mediterranean Mullidae species (Perciformes) inferred from genetic and morphologic data. Scientia Marina, 70(2): 311-318.

Turan, C. 2008. Molecular systematic analyses of Mediterranean skates (Rajiformes). Turkish Journal of Zoology, 32(4): 437-442.

Turan, C., M. Gurlek, D. Yaglioglu, and B. Ozturk. 2009a. Genetic differentiation of Mediterranean horse mackerel (*Trachurus mediterraneus*) populations as revealed by mtDNA PCR-RFLP analysis. Journal of Applied Ichthyology, 25(2): 142-147.

Turan, C., B. Ozturk, M. Caliskan, E. Duzgunes, M. Gurlek, D. Yaglioglu, *et al.* 2009b. Genetic variation of Atlantic horse mackerel (*Trachurus trachurus*) in the Turkish waters. Cah. Biol. Mar., 50(3): 207-213.

Turan, C., D. Erguden, and F. Turan. 2010. Phylogenetic relationship among the Black Sea *Alosa* species from Mtdna Nd5/6 Sequences. Rapp. Comm. int. Mer Médit., 39: 687.

Turan, C. 2015. Microsatellite DNA reveals genetically different populations of Atlantic bonito *Sarda sarda* in the Mediterranean Basin. Biochemical Systematics and Ecology, 63: 174-182.

Turan, C., M. Gurlek, D. Erguden, D. Yaglioglu, A. Uyan, A.N. Reyhaniye, *et al.* 2015a. Population genetic analysis of Atlantic bonito *Sarda sarda* (Bloch, 1793) using sequence analysis of mtDNA D-loop region. Fresenius Environ. Bull., 24 (10): 3148-3154.

Turan, C., D. Ergüden, M. Gürlek, C. Çevik, and F. Turan. 2015b. Molecular systematic analysis of *Shad* species (*Alosa* spp.) from Turkish marine waters using mtDNA Genes. Turkish Journal of Fisheries and Aquatic Sciences, 15: 149-155.

Unal, E., B.W. Frost, V. Armbrust, and A.E. Kideys. 2006. Phylogeography of *Calanus helgolandicus* and the Black Sea copepod *Calanus euxinus*, with notes on *Pseudocalanus elongatus* (Copepoda, Calanoida). Deep Sea Research Part II: Topical Studies in Oceanography, 53(17): 1961-1975.

Viaud-Martínez, K.A., M.M. Vergara, P.E. Gol'din, V. Ridoux, A.A. Öztürk, B. Öztürk, *et al.* 2007. Morphological and genetic differentiation of the Black Sea harbour porpoise *Phocoena phocoena*. Marine Ecology Progress Series, 338: 281-294.

Viaud-Martinez, K.A., R.L. Brownell, A. Komnenou, and A.J. Bohonak. 2008. Genetic isolation and morphological divergence of Black Sea bottlenose dolphins. Biological Conservation, 141(6): 1600-1611.

Virgilio, M., C. Fauvelot, F. Costantini, M. Abbiati, and T. Backeljau. 2009. Phylogeography of the common ragworm *Hediste diversicolor* (Polychaeta: Nereididae) reveals cryptic diversity and multiple colonization events across its distribution. Molecular Ecology, 18(9): 1980-1994.

Ward, R.D. and M. Grewe. 1995. Appraisal of molecular genetic techniques in fisheries, p. 29-54. In G.R. Carvalho, and T.J. Pitcher [eds.], Molecular Genetics in Fisheries, London: Chapman & Hall.

Woodall, L.C., H.J. Koldewey, J.T. Boehm, and P.W. Shaw. 2015. Past and present drivers of population structure in a small coastal fish, the European long snouted seahorse *Hippocampus guttulatus*. Conservation Genetics, 16(5): 1139-1153.

Wylezich, C. and K. Jürgens. 2011. Protist diversity in suboxic and sulfidic waters of the Black Sea. Environmental Microbiology, 13(11): 2939-2956.

Yebra, L., D. Bonnet, R.P. Harris, P.K. Lindeque, and K.T. Peijnenburg. 2011. Barriers in the pelagic: population structuring of *Calanus helgolandicus* and *C. euxinus* in European waters. Marine Ecology Progress Series, 428: 135-149.

Zhukovskaya, E.A. and O.P. Kodolova. 2003. Effects of genotypes at the unspecific Esterase (Est) and Leucine Aminopeptidase (Lap) Loci on the temporal dynamics of morphological variation in the Black Sea mussel *Mytilus galloprovincialis* Lam. Biology Bulletin of the Russian Academy of Sciences, 30(3): 262-270.

Zhukovskaya, E.A. and O.P. Kodolova. 1997. Time-related genetic variability in the Black Sea mussel *Mytilus galloprovincialis* Lam. Izv. Ross. Akad. Nauk, Ser. Biol. 3: 297-305.

PHYTOPLANKTON PIGMENTS AND USING A MONITORING TOOL FOR THE PHYTOPLANKTON SIZE CLASSES (PSC) IN THE BLACK SEA

Ertuğrul AĞIRBAŞ

Recep Tayyip Erdogan University, Faculty of Fisheries, Rize, Turkey
ertugrul.agirbas@erdogan.edu.tr

1. Introduction

Phytoplankton account for nearly half of the total primary production on Earth and constitute the base of the marine food web (Jeffrey and Vesk 1997, Falkowski *et al.* 2004). They have important role in modulating the total CO_2 concentration, pH of the ocean and global carbon cycle (Takahashi *et al.* 2002, Brewin *et al.* 2010). Changes in phytoplankton populations also impact the pelagic ecosystem throughout changing trophic transfer, food web and nutrient dynamics (Nagata *et al.* 1996, Pedersen *et al.* 1999). Identifying changes in phytoplankton community composition and diversity is essential to improve our understanding of the responses to climate forcing (Rykaczewski and Dunne 2011). Moreover, phytoplankton quickly response to environmental disturbance, and can be used as indicator for trophic levels, eutrophication and different environmental circumstances (Margalef 1978, Brettum and Andersen 2005).

Studies on phytoplankton are generally conducted by using microscopy (Booth 1993, Eker-Develi *et al.* 2008), which needs taxonomic expertise, time for sample preparation and counting samples. In addition, it is not possible to identify smaller groups (*e.g.* picoplankton) with microscopy due to lack of taxonomically useful external morphological features (Jeffrey *et al.* 1997). However, some photosynthetic pigments (*e.g.* fucoxanthin, peridinin, 19-hexanoyoxifucoxanthin, Chl-*b,* and zeaxanthin etc.) for specific phytoplankton groups derived from high-performance liquid chromatography (HPLC) provide information about the composition of the phytoplankton community (Mantoura and Llewellyn 1983, Wright and Jeffrey 2006). The introduction of HPLC pigment analysis facilitated easy and fast separation, identification and quantification of phytoplankton pigments (Mantoura and Llewellyn 1983). A large number of samples can be processed by HPLC allowing a more thorough examination of the structure and dynamics of phytoplankton populations compared to microscopy (Schlüter *et al.* 2000).

Chlorophyll *a* (Chl-*a*) is accepted as a unique molecular marker of phytoplankton biomass and used as a convenient proxy for phytoplankton biomass (Gibb *et al.* 2000). The major role of Chl-*a* is to absorb light for photosynthesis, however, there are additional accessory pigments such as the chlorophylls *b* (Chl-*b*) and *c* (Chl-*c*) and various carotenoids, which have a significant role in extending the light-harvesting spectrum in different phytoplankton groups (Barlow *et al.* 2004). While Chl-*a* is used as a convenient proxy of phytoplankton biomass, many other phytoplankton pigments (*e.g.*

fucoxanthin, 19-hexanoyloxyfucoxanthin, and 19-butanoyloxyfucoxanthin is accepted as biomarkers for diatoms, prymnesiophytes and chyrsophytes, respectively) exhibit chemotaxonomic associations which may be exploited to map the oceanographic distribution and composition of phytoplankton assemblages (Barlow *et al.* 1993, Gibb *et al.* 2000). Traditionally, spectrophotometry and fluorometry have been used to determine Chl-*a* (*e.g.* Holm-Hansen *et al.* 1965, Lorenzen 1967). However, these methods suffer from inaccuracies associated with spectral interferences from Chl-*b*, carotenoids and from Chl-*a* degradation products (*e.g.* chlorophyllides, phaeophytins and phaeophorbides). Alternatively, using of high performance liquid chromatography (HPLC) facilitated the separation and quantification of other pigments in marine phytoplankton. The exploitation of pigment data generated from HPLC analysis of phytoplankton extracts has greatly advanced our understanding of the distribution, composition and functionality of phytoplankton in the global ocean (Wright *et al.* 1991, Jeffrey, 1997).

A summary of the taxonomic distribution of chlorophyll and carotenoid pigments is presented in Table 1. Photosynthetic pigments also provide the physiological condition of the phytoplankton community, which indicates environmental condition and trophic status for a given area (Roy *et al.* 2006). The majority of phytoplankton carotenoids are photosynthetic. While photosynthetic carotenoids (PSC) absorb light energy and transfer it to chlorophyll, photoprotecting carotenoids (PPC) protect the organism against stressful high light conditions. PPC are capable of quenching excited radicals, and converting their excess energy to heat and dissipating it harmlessly. Moreover, the ratio of PSC to PPC may be used to provide some additional characterisation of transitions in phytoplankton community composition across biogeochemical province boundaries and hence the identification of these boundaries (Gibb *et al.* 2000). Furthermore, PPC and PSC absorb light in different remote sensing spectral bands (*e.g.* SeaWiFS). Thus, variability in their relative abundances has the potential to affect the performance of algorithms used to retrieve Chl *a* values from remotely sensed ocean colour data (Gibb *et al.* 2000).

Table 1. Chemotaxonomic relationships between phytoplankton groups and pigments (Bolds indicate major taxonomic pigments for algal classes. Modified from Aiken *et al.* 2009 and Gibb *et al.* 2001)

Pigments	Occurrence
Chlorophyll a	**Photosynthetic pigment, Total algal biomass**
Divinyl chlorophyll a	**Prochlorophytes**
Chlorophyll b	**Chlorophytes, Prasinophytes,** Prochlorophytes (as DV Chl-*b*)
Chlorophyll c1 c2	**Diatoms,** Prymnesiophytes, Chrysophytes, Dinoflagellates
Chlorophyll c3	Prymnesiophytes, Chrysophytes,
Peridinin	**Dinoflagellates**
19-Butanoyloxyfucoxanthin	**Chrysophytes,** Prymnesiophytes
Fucoxanthin	**Diatoms,** Prymnesiophytes, Chrysophytes,
19-Hexanoyloxyfucoxanthin	**Prymnesiophytes,** Dinoflagellates
Diadinoxanthin	Diatoms, Dinoflagellates, Prymnesiophytes, Chrysophytes,
Alloxanthin	**Cryptophytes**
Lutein	Green algae (Chlorophytes, Prasinophytes)
Diatoxanthin	Diatoms, Dinoflagellates, Prymnesiophytes, Chrysophytes,
Violaxanthin	**Chlorophytes, Prasinophytes**
Zeaxanthin	**Cyanobacteria, Prochlorophytes**
Prasinoxanthin	**Prasinophytes**
β-Carotene	Photoprotective carotenoids

2. Deriving Phytoplankton Size Classes (PSC) from Diagnostic Pigments

Phytoplankton Size Classes (PSC) approach comprises splitting the autotrophic pool into picoplankton (0.2-2 μm), nanoplankton (2–20 μm) and microplankton (>20 μm). These approaches provide relative proportions of classes within the phytoplankton assemblages (Uitz *et al.* 2006). A strong link has been established between PSC and environmental factors (*e.g.* nutrients and light *etc*.) which regulate photosynthesis, phytoplankton dominancy and succession (Chisholm 1992, Bouman *et al.* 2005, Platt *et al.* 2005, Aiken *et al.* 2008). There is also an established connection between the size and the physiology of phytoplankton (Platt and Denman 1976, Chisholm 1992, Raven 1998), the marine food web (Parsons and Lalli 2002), areas of high fish production (Caddy *et al.* 1995) and various metabolic rates (Platt and Denman 1977, 1978).

The pigment index was introduced as an index of trophic status, based on seven diagnostic pigments (DP): Fucoxanthin (Fuco), peridinin (Perid), 19-Hexanoyloxyfucoxanthin (Hex-fuco), 19-Butanoyloxyfucoxanthin (But-fuco), zeaxanthin (Zea), total chlorophyll-b (TChlb =Chl *b* + DVChl *b*), and alloxanthin (Allo).

The relative biomass proportions of phytoplankton size classes [picoplankton (< 2 μm); nanoplankton (2-20 μm) and microplankton (20-200 μm)] are determined depending on the approaches of Uitz *et al.* (2006), Vidussi *et al.* (2001) and Claustre (1994).

$$\Sigma DPw = 1.41[Fuco] + 1.41[Perid] + 1.27[Hex - fuco] + 0.35[But - fuco] + 0.60[Allo] + 1.01[TChlb] + 0.86[Zea]$$

where DP_W represents the chlorophyll a concentration, which can be reconstructed from the knowledge of the concentration of the seven diagnostic pigments. The fractions of the three pigment-based phytoplankton size classes are computed following equations:

$$fmicro = (1.41[Fuco] + 1.41[Perid])/\Sigma DPw$$

$$fnano = (1.27[Hex - fuco] + 0.35[But - fuco] + 0.60[Allo])/\Sigma DPw$$

$$fpico = (1.01[TChlb] + 0.86[Zea])/\Sigma DPw$$

The actual chlorophyll a concentration associated with each class is derived from following equations:

$$Micro - [Chla] = fmicro \times [Chla]$$

$$Nano - [Chla] = fnano \times [Chla]$$

$$Pico - [Chla] = fpico \times [Chla]$$

It should be noted that the pigment grouping here proposed does not strictly reflect the true size of phytoplankton communities (Vidussi *et al.* 2001). Indeed, some taxonomic pigments might be shared by various phytoplankton groups (*e.g.* small amounts of fucoxanthin, the main carotenoid for diatoms, may also be found in some prymnesiophytes and pelagophytes), and also some phytoplankton groups may encompass a wide size range (*e.g.* diatoms are sometimes observed in the nano-size range, even if generally they belong to microplankton; Vidussi *et al.* 2001, Uitz *et al.* 2006).

3. Studies on PSC in the Black Sea

The Black Sea is a unique marine environment which has suffered from severe ecological deteriorations over the last three decades (Oguz 2005). It is a semi-enclosed and largest anoxic marine ecosystem in the world ocean (Tolmazin 1985). Phytoplankton community composition and group ratios have drastically changed due to intense eutrophication occurred in the Black Sea. During that time, phytoplankton responded to qualitative and quantitative changes in community composition, for example, intense blooms and changes in phytoplankton class structure and bloom timing with a pronounced dominance of dinoflagellates compared to diatoms (Kideys 1994). In more recent years, there have been some signs of recovery with a reduction in nutrient loading (McQuatters-

Gollop *et al.* 2008). Phytoplankton in terms of abundance, biomass and species composition, have been measured in the Black Sea over many decades (Eker *et al.* 1999, Agirbas *et al.* 2015). Traditionally, phytoplankton studies in the Black Sea are conducted by microscopic examination (*e.g.* Bologa 1986, Cociasu *et al.* 1997, Moncheva and Krastev 1997 *etc*.). Despite significant roles of phytoplankton communities, information about phytoplankton size classes (PSC) derived from pigment profiles by using HPLC are limited in the Black Sea (Ediger *et al.* 2006, Eker-Develi *et al.* 2012, Agirbas *et al.* 2015).

Pigment data revealed that phytoplankton community in the south-western Black Sea was dominated by dinoflagellates, diatoms and coccolithophores (Ediger *et al.* 2006). Strong correlations (r^2 = 0.56–0.67) between marker pigment concentrations and abundance or biomass in the south-western Black Sea indicated that HPLC pigment analysis can be used to quantify phytoplankton assemblages in the Black Sea (Figure 1).

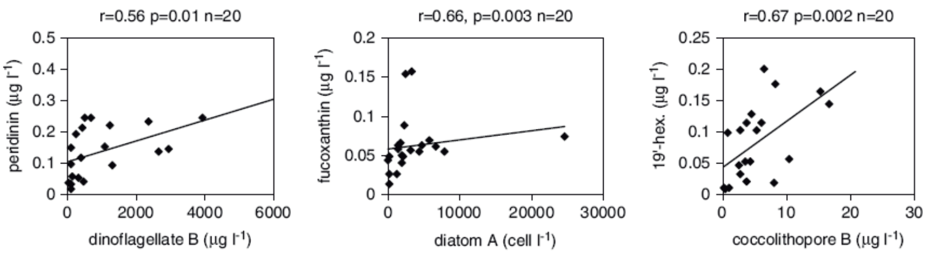

Figure 1. Relationship between phytoplankton abundance (A) or biomass (B) and marker pigments in the south-western Black Sea (Ediger *et al.* 2006)

A strong chemotaxonomic relationship between phytoplankton groups and pigments (*e.g.* between dinoflagellate-C and peridinin; between dinoflagellate-C and diadinoxanthin; between dinoflagellate-C and 19-Hex and between coccolithophore-C and 19'-Hex) was also reported from the south-eastern Black Sea (Figure 2; Agirbas *et al.* 2015). Similarly, high 19-Hex concentrations corresponding to high dinoflagellate-C from the north-western Black Sea was reported (Eker-Develi *et al.* 2012). Besides, fucoxanthin and 19-Hex containing dinoflagellates were reported in the English Channel, previously (Irigoien *et al.* 2004).

There is still certain controversy in interpretation by using diagnostic pigments to infer phytoplankton size classes, and some diagnostic pigments such as fucoxanthin (main indicator of diatoms) may also be found in some flagellates (Vidussi *et al.* 2001). Therefore, the pigment grouping does not strictly reflect true size of phytoplankton communities, and PSC derived from HPLC pigments are indicative but not definitive (Brewin *et al.* 2010).

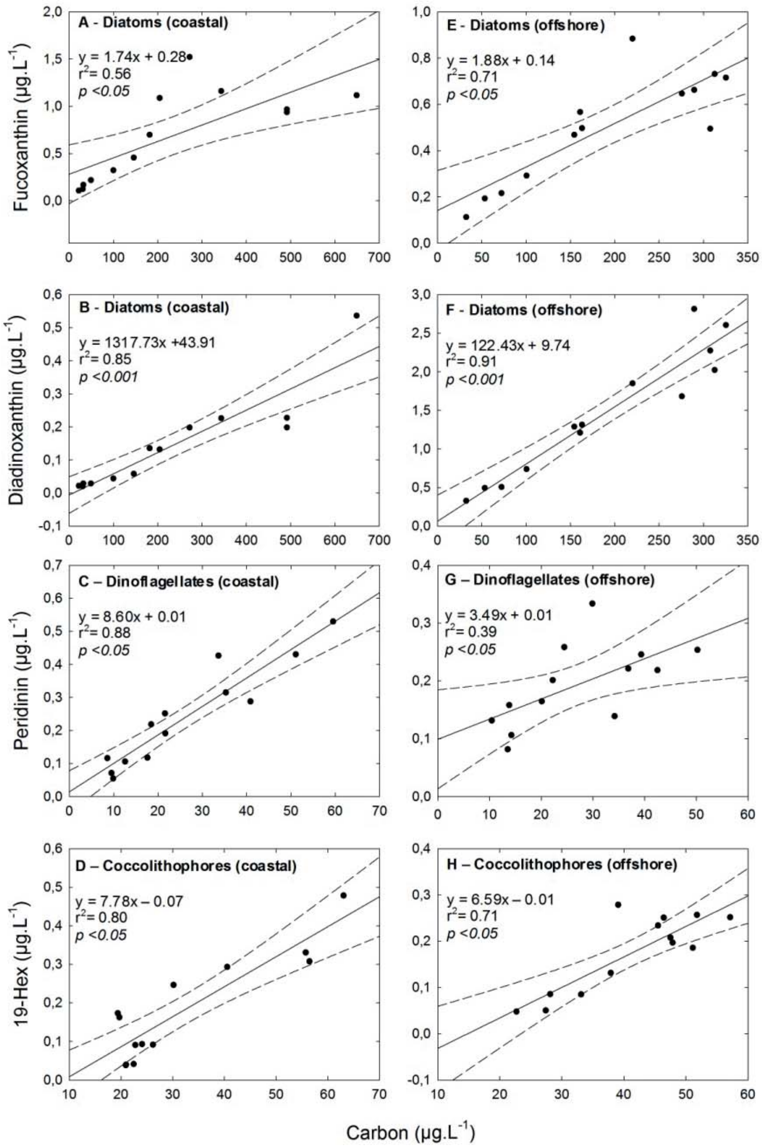

Figure 2. Relationship between phytoplankton groups and marker pigments with 95% confidence intervals (A, C and E indicate coastal station, and B, D and F indicate offshore station in the south-eastern Black Sea, Agirbas *et al.* 2015).

Recently, in another research which was conducted seasonally within the scope of TUBITAK project (113Y189) along the south-eastern coast of the Black Sea (Figure

3), PSC derived from HPLC pigment data revealed a high degree of spatio-temporal variability between November 2014 and August 2015 (Figure 4-6).

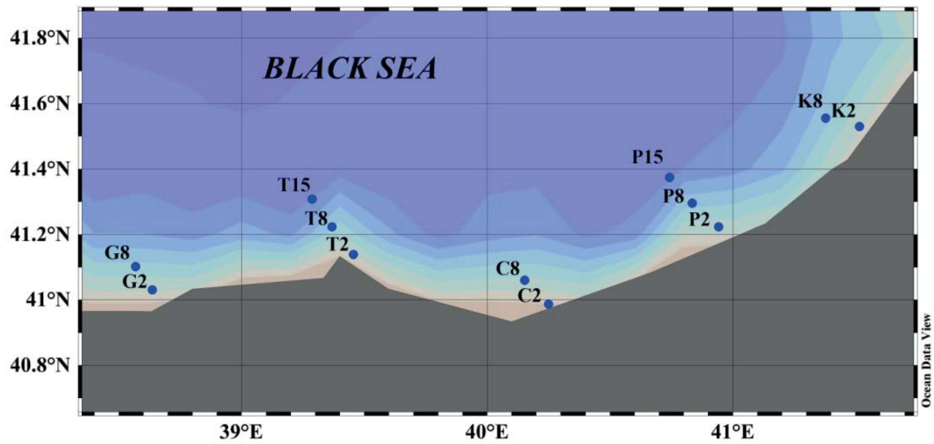

Figure 3. Location map for the project of TUBITAK 113Y189 showing the sampling points in the South-Eastern Black Sea (G2: Giresun 2 nm, G8: Giresun 8 nm, T2: Trabzon 2 nm, T8: Trabzon 8 nm, T15: Trabzon 15 nm, C2: Camburnu 2 nm, C8: Camburnu 8 nm, P2: Pazar 2 nm, P8: Pazar 8 nm, P15: Pazar 15 nm, K2: Kemalpasa 2 nm, K8: Kemalpasa 8 nm)

During this project, the contribution of microplankton ratio (8-93%) was substantial in autumn and spring. On the other hand, the contribution was low in summer (Figure 4). Nanoplankton contribution (1-70%) was generally high in winter and moderately in spring (Figure 5). On the other hand, picoplankton (1- 80%) relatively contributed to PSC in summer at surface waters (Figure 6). Overall, contribution of microplankton to PSC was higher than pico- and nanoplankton contribution along the south-eastern Black Sea. These observations coincide with previous studies reported from the Black Sea (*e.g.* Agirbas *et al.* 2015, Mikaelyan *et al.* 2013). Due to eutrophication, phytoplankton community composition, abundance, biomass, and bloom patterns of phytoplankton changed in the Black Sea. During that period, the biomass of dinoflagellates increased notably in the water column (Mikaelyan *et al.* 2013). However, Black Sea has shown some signs of recovery (*e.g.* increases in diatoms abundance, decrease in the number of monospecific algal blooms etc.) in recent years (McQuatters-Gollop *et al.* 2008). In the present observation, high dominancy of microplankton indicates the recovery reported from pervious observations in the Black Sea.

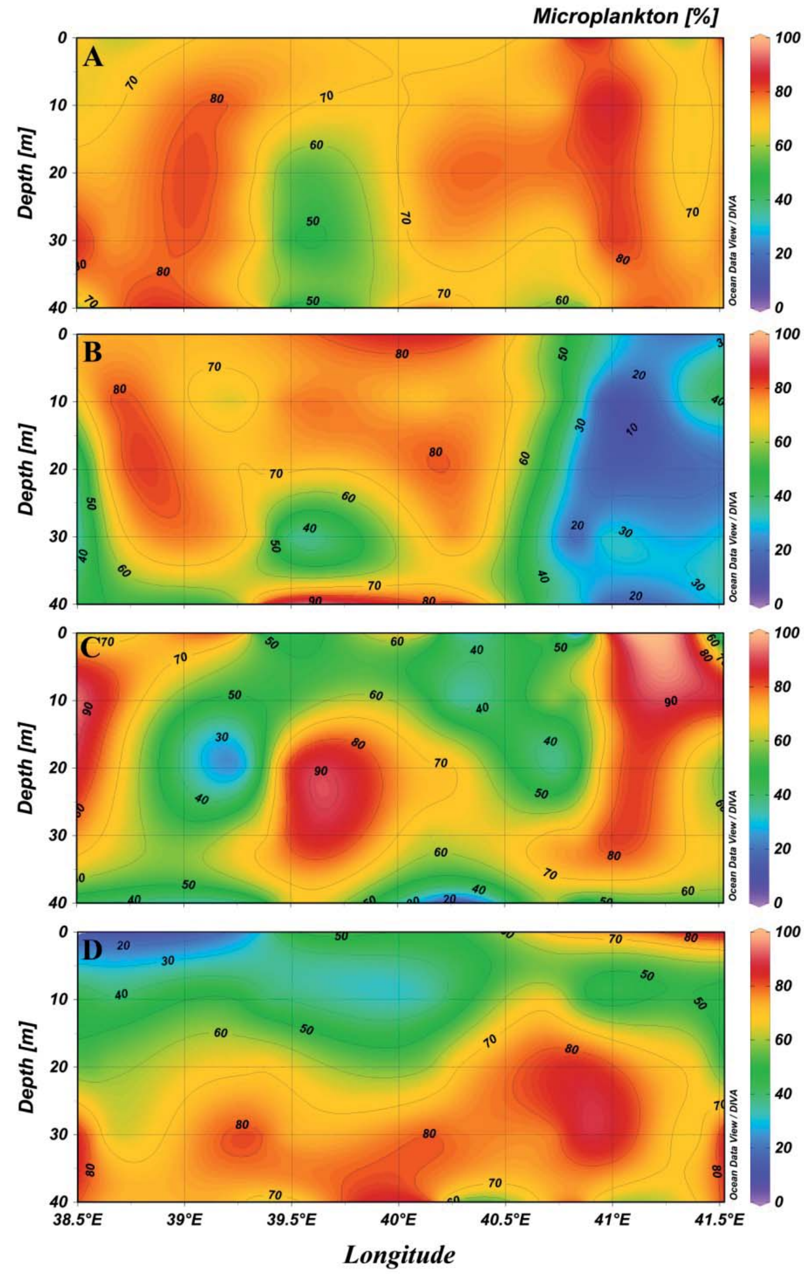

Figure 4. Spatio-temporal variation of microplankton contribution (%) along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

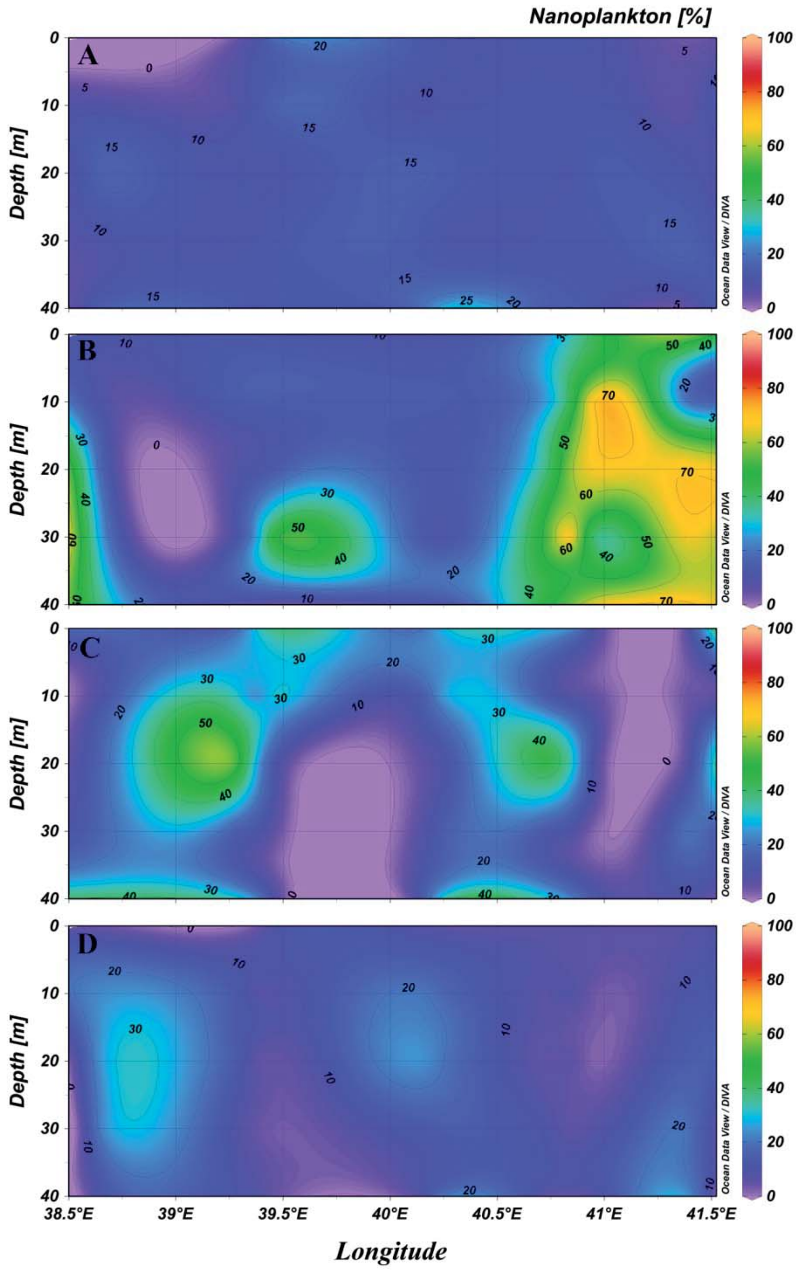

Figure 5. Spatio-temporal variation of nanoplankton contribution (%) along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

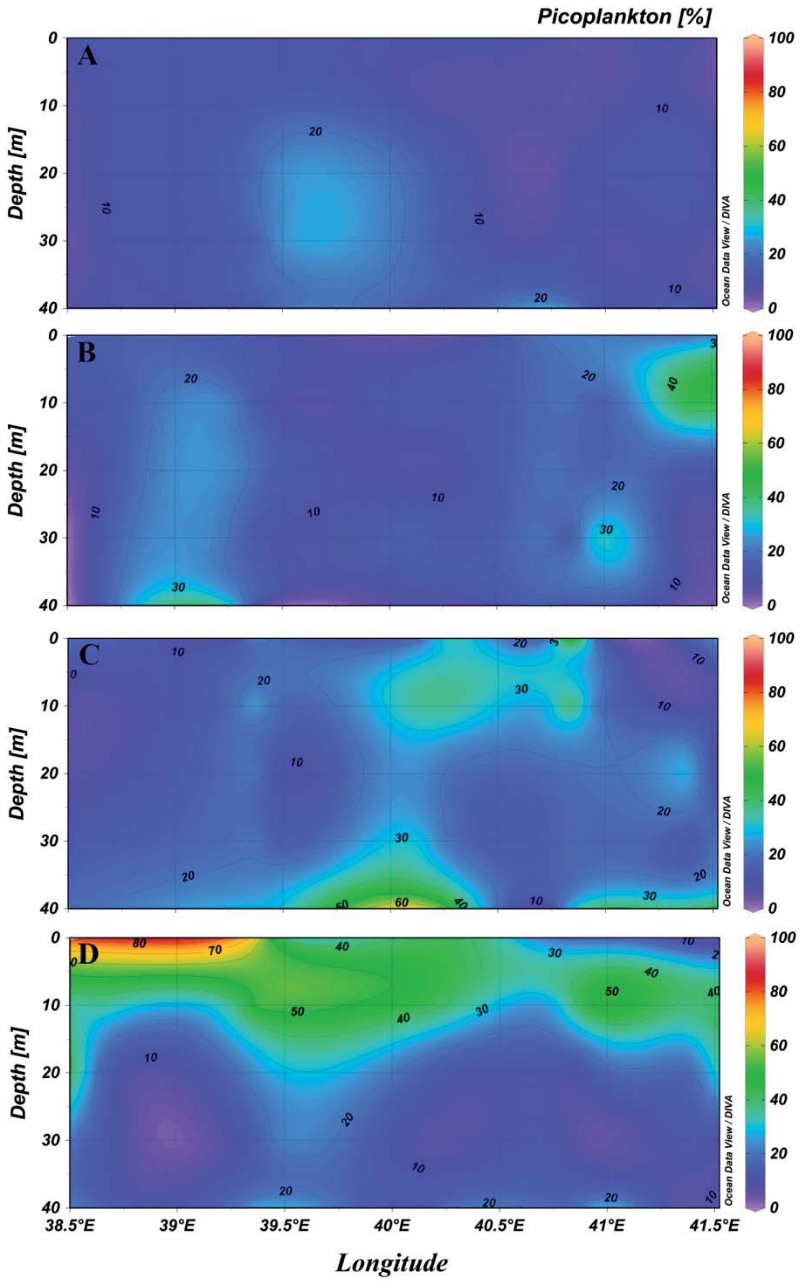

Figure 6. Spatio-temporal variation of picoplankton contribution (%) along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

Phytoplankton community composition, and hence pigment concentration are affected by changing environmental factors (Trees *et al.* 2000). Moreover, PSC are closely associated with the trophic status of the environments. Picoplankton generally dominate the surface layers of warm, oligotrophic, low N waters; nanoplankton are more abundant in cooler, mesotrophic, moderate N waters; microplankton are dominant in eutrophic, high N waters (Aiken *et al.* 2009). In this project, the majority of microplankton was observed in autumn and spring, when new nutrient input occurred by vertical mixing and river runoff. Similarly, high picoplankton contribution to total PSC was detected in summer period at the surface waters, where the nutrients were depleted in the water column. On the other hand, nanoplankton contribution was generally substantial in winter and spring below the Chl-*a* maximum, when the extensive vertical mixing occurred throughout the water column. The presence of microplankton in up-welled waters in the Arabian Sea and the dominance of the picoplankton in oligotrophic, low chlorophyll waters along the equator were also reported (Latasa and Bidigare, 1998; Barlow *et al.* 2004). Similarly, high diatom dominancy in nitrate-rich coastal waters and dominancy of picoplankton (*e.g.* Cyanophyta) in nitrate-poor mid-ocean regions from across the north Pacific were also reported (Ondrusek *et al.* 1991). Moreover, surface pigment adaptations are likely to be related to or controlled by the nutrient dynamics (Barlow *et al.* 2004). Diatoms are opportunistic organisms that are able to respond quickly to nitrate enrichment (Fogg, 1991), and Chl-*a* molecules contain nitrogen atoms, while carotenoids do not (Porra *et al.* 1997). Hence, the nitrogen characteristic of diatoms and chlorophylls probably explain high contribution of microplankton in nutrient rich waters during autumn and winter along the study area.

There was great variability in vertical profile of PSC along the south-eastern Black Sea (see also Figures 4-6). Microplankton ratios were high in the whole water column in autumn and spring, relatively in winter. On the other hand, their contribution was low in summer (especially at surface waters), and in winter below the Chl-*a* maximum. Nanoplankton proportions were generally greatest in winter and spring at Chl-*a* maximum or below. In contrast, picoplankton had great proportions at surface waters in summer or at the base of euphotic zone.

Several mechanisms were suggested about vertical structure of phytoplankton size classes (Perez *et al.* 2006). Claustre and Marty (1995) proposed that nanoplankton can develop close to the nutricline and their presence at very low light levels may be governed by nitrate availability as opposed to photoadaptation. They also suggested that reason for nanoplankton below the Chl-*a* maximum may include a decoupling between nitrate assimilation and CO_2 fixation, vertical migration and heterotrophic growth. Similar pattern was also reported from oligotrophic gyres of south pacific with high contribution of nanoplankton below the Chl-*a* maximum (Ras *et al.* 2008). On the other hand, decreasing pattern in picoplankton with depth down to Chl-*a* maximum, and an increasing pattern of nanoplankton contribution below the Chl-*a* maximum were reported (Brewin 2010).

Chl-*a* is typically used as phytoplankton biomass. It can be routinely estimated *in-situ* (*e.g.* spectrophotometrically, fluorometrically, HPLC) or by using satellite remote-sensing of ocean colour (O'Reilly *et al.* 1998). On the other hand, size-fractionated chlorophyll is used as a metric for phytoplankton size classes and can be estimated through either HPLC diagnostic pigment analysis (*e.g.* Brewin *et al.* 2010, Hirata *et al.* 2011, Uitz *et al.* 2006, Vidussi *et al.* 2001), or through size-fractionated filtration of Chl-*a* (*e.g.* Brewin *et al.* 2014).

Studies revealed a good correlation between Chl-*a*, PSC and physical environment (Behrenfeld *et al.* 2006, Martinez *et al.* 2009, Kostadinov *et al.* 2010, Brewin *et al.* 2012). However, studies on size fractioned Chl-*a* and PSC has remained poorly characterized. Recently, spatio-temporal distribution of *in-situ* Chl-*a*, size fractioned Chl-*a* and their correlation were well established in the south-eastern coast of the Black Sea (Figures 7-11). The data presented here clearly explain general pattern of *in-situ* Chl-*a* and phytoplankton size-classes in relation to seasons and stations. *In-situ* Chl-*a* was ranged from 0.16 µg/L (August 2015) to 4.96 µg/L (February 2015) along the stations, and revealed sub-surface maxima (Figure 7). Sub-surface Chl-*a* maxima was detected between 10 and 20 m depth, except for winter. Seasonally, autumn and winter periods was characterised high Chl-*a* concentrations along the stations.

Size-fractioned Chl-*a* along the station showed high degree of spatio-temporal fluctuation (Figures 8-10). Majority of size-fractioned Chl-*a* was consisted of microplankton, ranged from 0.04-4.79 µg/L (Figure 8). The second group along the stations was nanoplankton and their size-fractioned Chl-*a* concentrations varied between 0.01 and 3.78 µg/L (Figure 9). Picoplankton fractioned Chl-*a* was relatively low along the stations and its concentration ranged from 0.01 to 2.24 µg/L at the base of photic depth (Figure 10). In general stations were dominated by microplankton, however, the contribution of size-fractioned Chl-*a* varied vertically and seasonally. Especially in autumn and occasionally in winter, the water column was dominated by microplankton. However, the majority of microplankton formed at the base of photic depth in spring and summer (see Figure 8). Nanoplankton and picoplankton fractioned Chl-*a* was generally low along the stations except from some periods (*e.g.* winter for nanoplankton and summer for picoplankton).

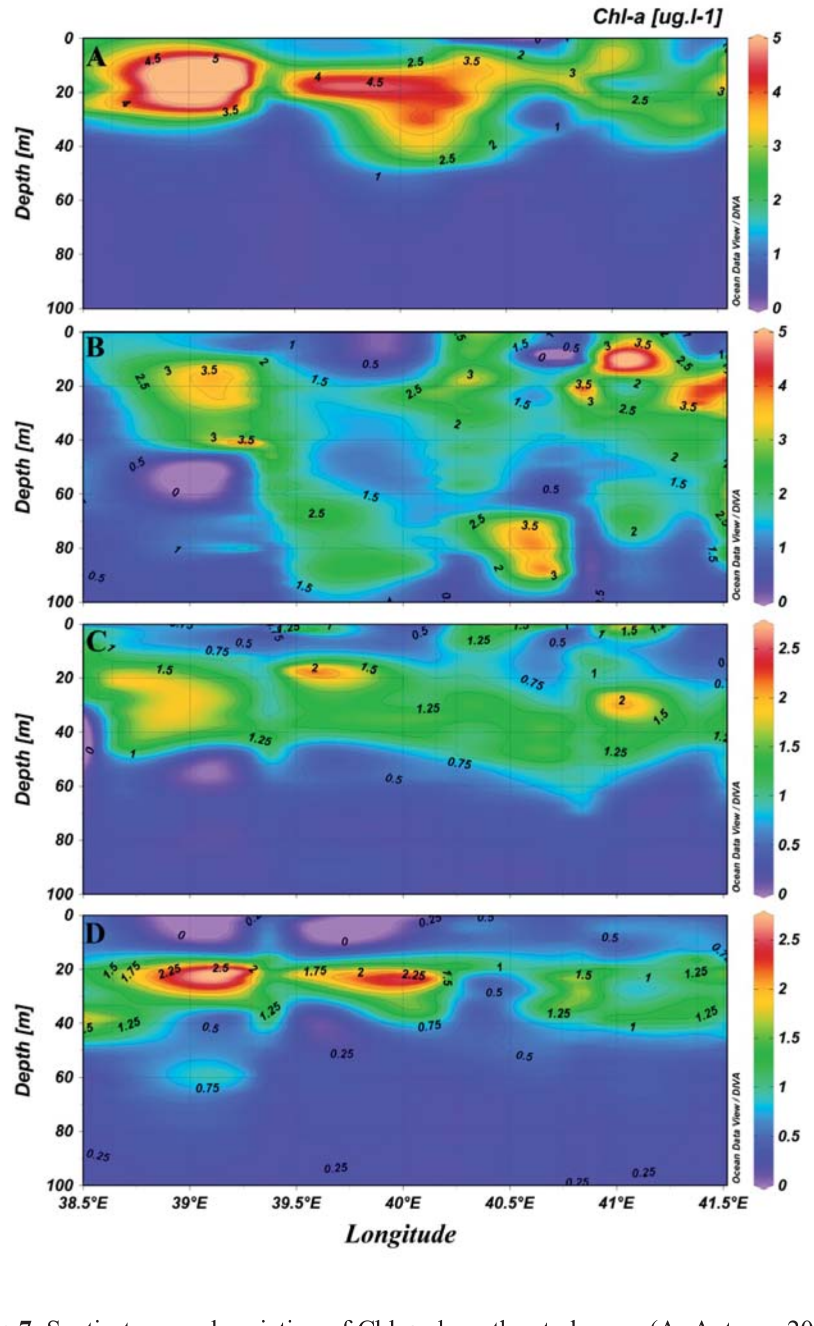

Figure 7. Spatio-temporal variation of Chl-*a* along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

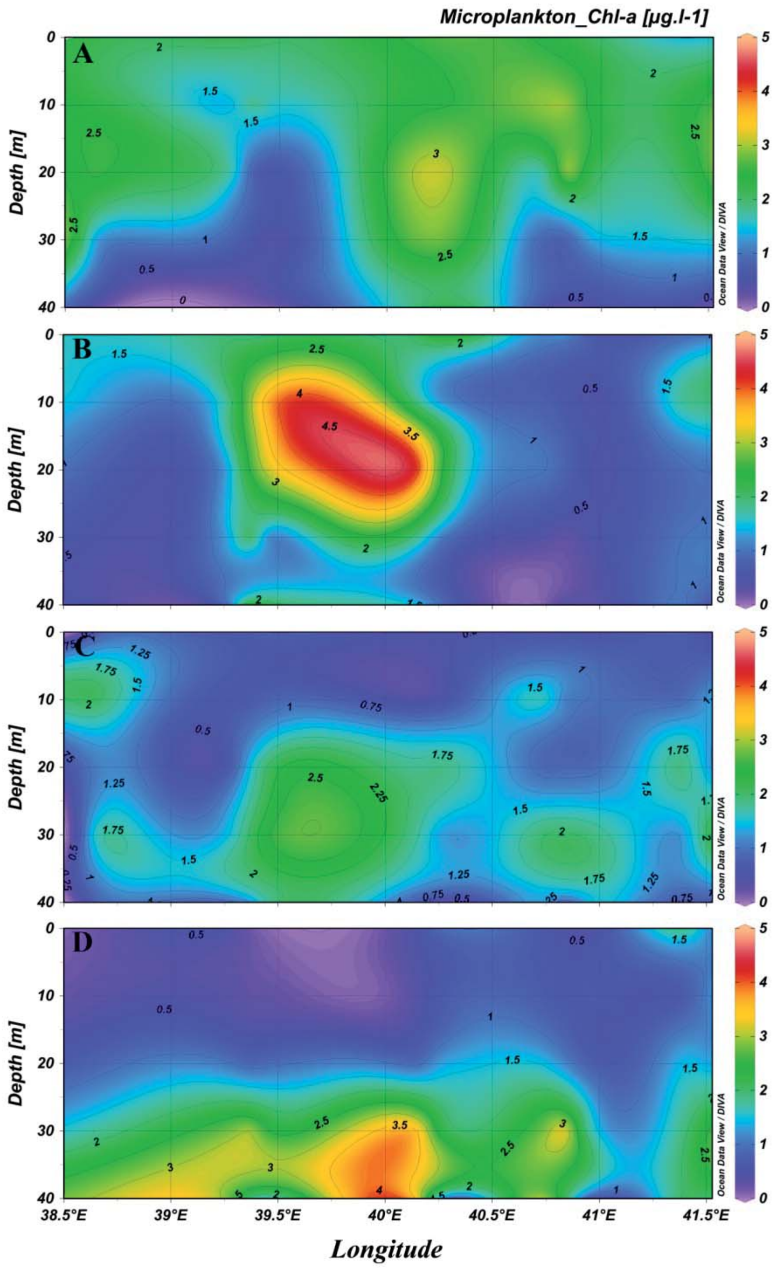

Figure 8. Spatio-temporal variation of microplankton fractioned Chl-*a* along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

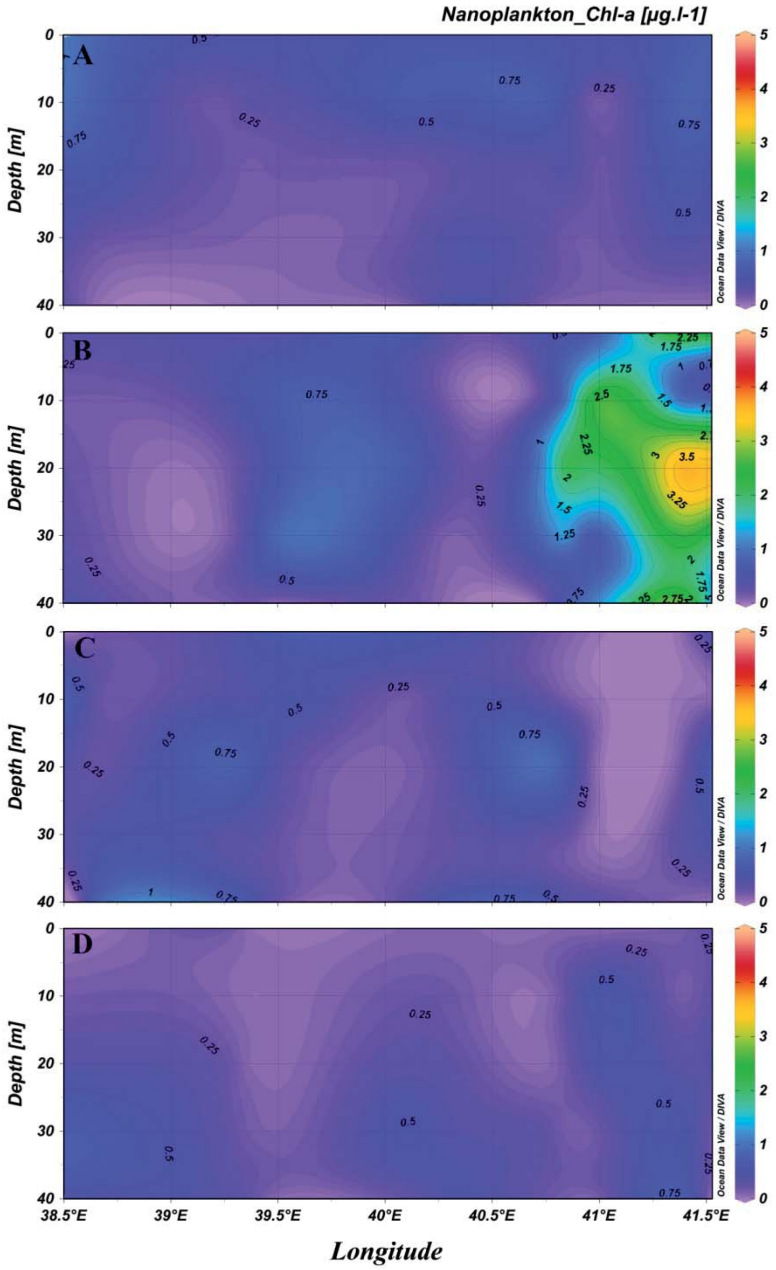

Figure 9. Spatio-temporal variation of nanoplankton fractioned Chl-*a* along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

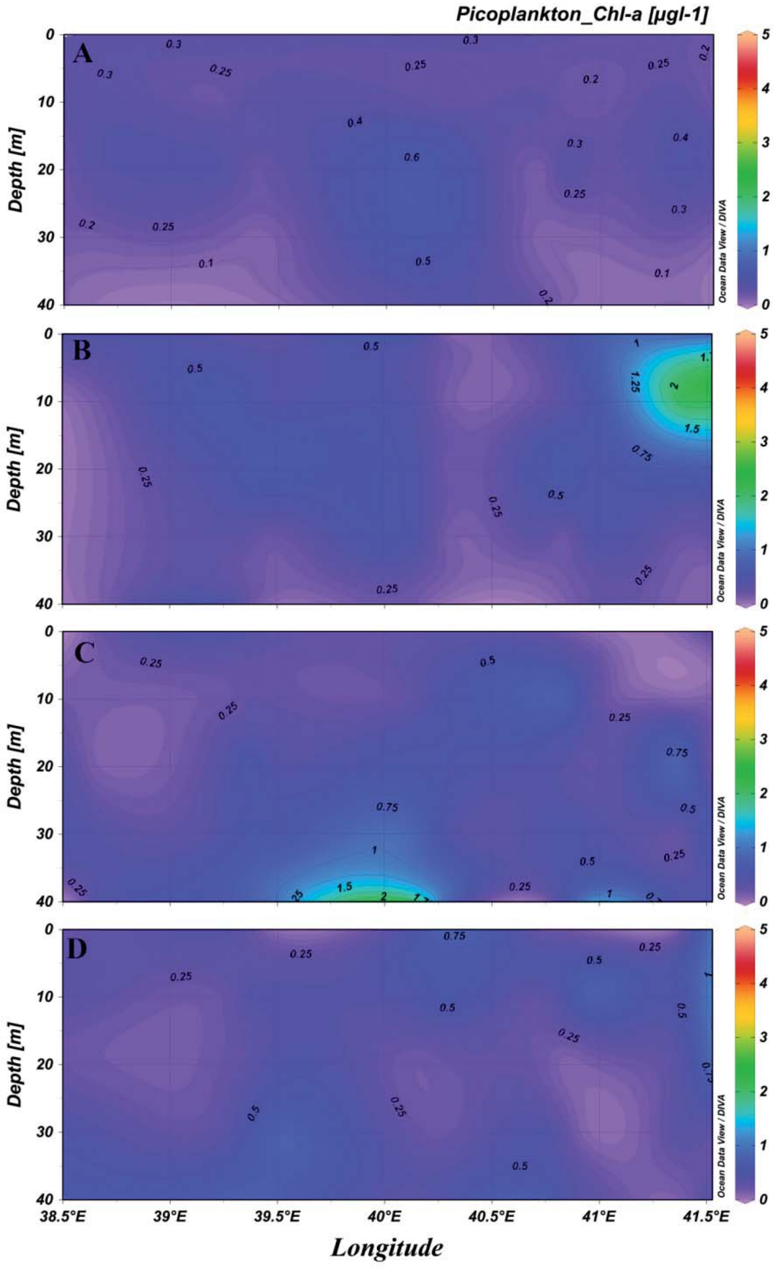

Figure 10. Spatio-temporal variation of picoplankton fractioned Chl-*a* along the study area (A: Autumn 2014, B: Winter 2015, C: Spring 2015 and D: Summer 2015)

The correlation between PSC and size fractioned Chl-*a* was also important along south-eastern Black Sea (Figure 11). However, correlation between nanoplankton fraction and nanoplankton fractioned Chl-*a* was much greater than micro- and picoplankton correlations ($p<0.001$). Overall, statistically significant correlations suggest that pigment derived size fraction give an information about phytoplankton assemblages in the south-eastern Black Sea.

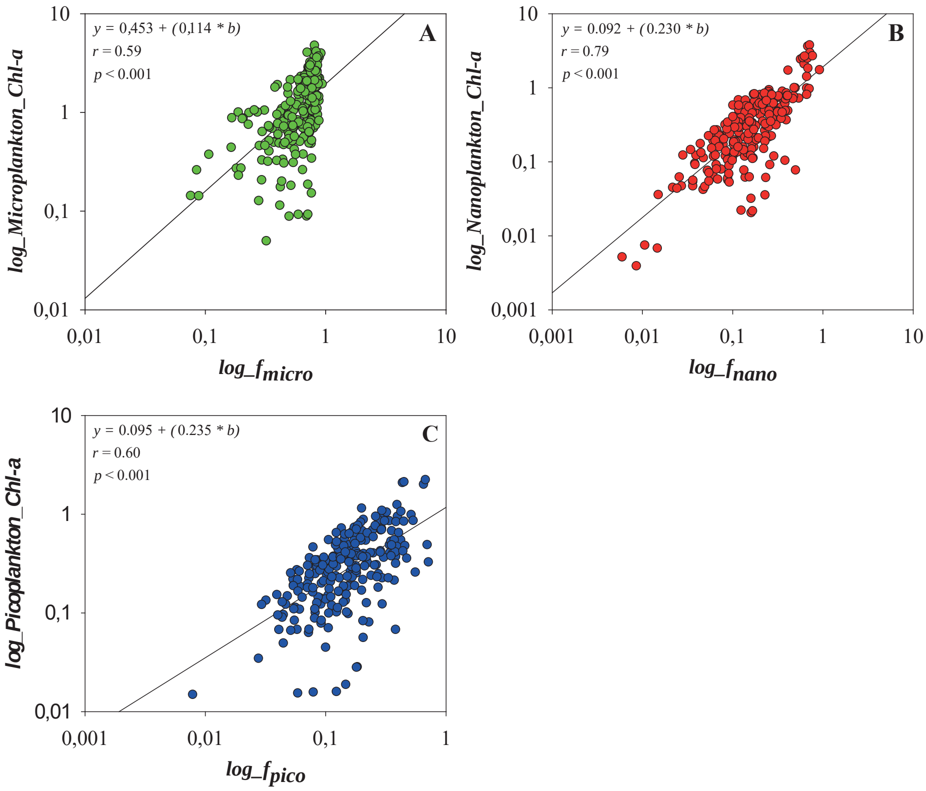

Figure 11. Linear regression between phytoplankton size classes (PSC) and size fractioned Chl-a (A: microplankton, B: nanoplankton, C: picoplankton)

4. Conclusions

In this chapter, phytoplankton pigments and using them as monitoring tool for phytoplankton size classes (PSC) in the Black Sea have been considered and reviewed. Phytoplankton community composition and size structure are admitted as key ecological indicators in the marine environment (Platt and Sathyendranath 2008). Hence, determination of changes in these indicators and monitoring them may help to detect how the marine ecosystem may respond to natural variability (*e.g.* climate changes) and human induced change (*e.g.* anthropogenic changes).

The data presented here illustrate current state of PSC and mainly dominated by microplankton. In addition, obtained good correlation between PSC and size fractioned Chl-*a* was clearly indicate that pigment derived phytoplankton size classes can be used as a monitoring tool along the south-eastern Black Sea. However, limited researches on PSC deriving from diagnostic pigments have not allowed for comparison present results for the south-eastern Black Sea. Improving the long-term understanding of changes in pelagic ecosystem is only possible by continuous monitoring programmes. Besides, monitoring of such indicators provides comprehensive ecosystem management.

The enclosed seas (*e.g.* Black Sea, Baltic Sea etc) have noticeably undergone far more dramatic changes than the more open seas during the past decades. Even, small changes in the frequency of inflow (as in the Baltic Sea) or in temperature (as in the Eastern Mediterranean and Black Sea) had a strong effect on large parts of the ecosystem, indicating the high sensitivity of these enclosed systems to climate change (Anadon *et al.* 2005). Hence, it is important to determine how the Black Sea ecosystem will respond to changing climate and changes. Finally, the results obtained in the present study provide more comprehensive picture of the phytoplankton size classes for the region, however, it should be validated with other techniques.

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References

Agirbas, E., A.M. Feyzioglu, U. Kopuz, and C.A. Llewellyn. 2015. Phytoplankton community composition in the south-eastern Black Sea determined with pigments measured by HPLC-CHEMTAX analyses and microscopy cell counts. J. Mar. Biol. Assoc. U.K., 95 (1): 35-52.

Aiken, J., N.J. Hardman-Mountford, R. Barlow, J.R. Fishwick, T. Hirata, and T.J. Smyth. 2008. Functional links between bioenergetics and bio-optical traits of phytoplankton taxonomic groups: An overarching hypothesis with applications for ocean colour remote sensing. J. Plankton Res., 30(2): 165-181.

Aiken, J., Y. Pradhan, R. Barlow, S. Lavender, A. Poulton, P. Holligan, and N. Hardman-Mountford. 2009. Phytoplankton pigments and functional types in the Atlantic Ocean: A decadal assessment, 1995-2005. Deep-Sea Res. Pt. II, 56 (15): 899-917.

Anadon, R., R. Danovaro, J.W. Dippner, K.F. Drinkwater, S.J. Hawkins, G. O'Sullivan, and T. Oguz. 2005. Impacts of climate change on the European marine and coastal environment. Marine Board Position, Paper 9.

Barlow, R.G., R.F.C. Mantoura, M.A. Gough, and T.W. Fileman. 1993. Pigment signatures of the phytoplankton composition in the north-eastern Atlantic during the 1990 spring bloom. Deep-Sea Res. Pt. II, 40: 459-477.

Barlow, R.G., J. Aiken, G.F. Moore, P.M. Holligan, and S. Lavender. 2004. Pigment adaptations in surface phytoplankton along the eastern boundary of the Atlantic Ocean. Mar. Ecol. Prog. Ser., 281: 13-26.

Behrenfeld, M.J., R.T. O'Malley, D.A. Siegel, C.R. McClain, J.L. Sarmiento, G.C. Feldman, A.J. Milligan, P.G. Falkowski, R.M. Letelier, and E.S. Boss. 2006. Climate-driven trends in contemporary ocean productivity. Nature, 444.

Bologa, A.S. 1986. Planktonic primary productivity of the Black Sea: A Review. Thalassia Jugoslavica, 21-22: 1-22.

Booth, B.C. 1993. Estimating cell concentration and biomass of autotrophic plankton using microscopy, p. 199-205. In P.F. Kemp, B.F. Sherr, J.J. Cole [eds.], Handbook of Methods in Aquatic Microbial Ecology. Lewis Publishers, Boca Raton, FL.

Bouman, H., T. Platt, S. Sathyendranath, and V. Stuart. 2005. Dependence of light saturated photosynthesis on temperature and community structure. Deep-Sea Res Pt I, 52: 1284-1299.

Brettum, P. and T. Andersen. 2005. The Use of Phytoplankton as Indicators of Water Quality. NIVA Rep. SNO, 4818-2004, 33 pp.

Brewin, R.J.W., S. Sathyendranath, T. Hirata, S.J. Lavender, R.M. Barciela, and N.J. Hardman-Mountford. 2010. A three-component model of phytoplankton size class for the Atlantic Ocean. Ecol. Model., 221(11): 1472-1483.

Brewin, R.J.W., S. Sathyendranath, P.K. Lange, and G. Tilstone. 2014. Comparison of two methods to derive the size-structure of natural populations of phytoplankton, Deep-Sea Res. Pt. I, 85: 72-79.

Caddy, J.F., R. Fefk, and T. Do-Chi. 1995. Productivity estimates for the Mediterranean: evidence of accelerating ecological change. Effects of riverine inputs on coastal ecosystems and fisheries resources. FAO Tech. Rep 249: 1-17. FAO, Rome.

Chisholm, S.W. 1992. Phytoplankton size, p. 213-237. In P.G. Falkowski, A.D. Woodhead [eds.], Primary Productivity and Biogeochemical Cycles in the Sea. Springer, New York.

Claustre, H. 1994. The trophic status of various oceanic provinces as revealed by phytoplankton pigment signatures, Limnol. Oceanogr., 39(5): 1206–1210.

Claustre, H. and J.C. Marthy. 1995. Specific phytoplankton biomasses and their relation to primary production in the tropical North Atlantic. Deep-Sea Res Pt I, 42(8): 1475-1493.

Cociasu, A., V. Diaconu, L. Popa, L. Buga, I. Nae, L. Dorogan, and V. Malciu. 1997. The nutrient stock of the Romanian shelf of the Black Sea during the last three decades, p. 49-63. In E. Ozsoy and A. Mikaelyan A. [eds.], Sensitivity to change: Black Sea, Baltic Sea and North Sea. Dordrecht: Kluwer Academic Publishing.

Ediger, D., N. Soydemir, and A.E. Kideys. 2006. Estimation of phytoplankton biomass using HPLC pigment analysis in the South western Black Sea. Deep-Sea Res. Pt. II, 53: 1911-1922.

Eker E., L. Georgieva, L. Senichkina, and A.E. Kideys. 1999. Phytoplankton distribution in the western and eastern Black Sea in spring and autumn 1995. ICES J. Mar. Sci., 56: 15-22.

Eker-Develi, E., J.F. Berthon, and D. Linde. 2008. Phytoplankton class determination by microscopic and HPLC-CHEMTAX analyses in the southern Baltic Sea. Mar. Ecol. Prog., Ser. 359: 69-87.

Eker-Develi, E., J.F. Berthon, E. Canuti, N. Slabakova, S. Moncheva, G. Shtereva, and B. Dzhurova. 2012. Phytoplankton taxonomy based on CHEMTAX and microscopy in the Northwestern Black Sea. J. Mar. Systems, 94: 18-32.

Falkowski, P.G., M.E. Katz, A.H. Knoll, A. Quigg, J.A. Raven, O. Schofield, and F.J.R. Taylor. 2004. The evolution of modern eukaryotic phytoplankton. Science, 305: 354-360.

Falkowski P.G. and J.A. Raven. 2007. Aquatic Photosynthesis, 2nd edition. Princeton University Press.

Fogg, G.E. 1991. The phytoplanktonic ways of life. New Phytol. 118: 191-232.

Gibb, S.W., R.G. Barlow, D.G. Cummings, N.W. Rees, C.C. Trees, P. Holligan, and D. Suggett. 2000. Surface phytoplankton pigment distributions in the Atlantic Ocean: an assessment of basin scale variability between 50°N and 50°S. Prog Oceanogr. 45: 339-368.

Gibb, S.W., D.G. Cummings, X. Irigoien, R.G. Barlow, R. Fauzi, and C. Mantoura. 2001. Phytoplankton pigment chemotaxonomy of northeastern Atlantic. Deep-Sea Res Pt II, 48 (4-5): 795-823.

Hirata, T., N.J. Hardman-Mountford, R.J.W. Brewin, J. Aiken, R. Barlow, K. Suzuki, T. Isada, E. Howell, T. Hashioka, M. Noguchi-Aita, and Y. Yamanaka. 2011. Synoptic relationships between surface chlorophyll-a and diagnostic pigments specific to phytoplankton functional types. Biogeosciences, 8: 311-327.

Holm-Hansen, O., C.J. Lorenzen, R.W. Holmes, and J.D.H. Strickland. 1965. Fluorometric determination of chlorophyll. Journal du Conseil Permanent International pour l'Exploration de la Mer., 301: 15.

Irigoien, X., B. Meyer, R. Harris, and D. Harbour. 2004. Using HPLC pigment analysis to investigate phytoplankton taxonomy: the importance of knowing your species. Helgoland Mar. Res., 58: 77-82.

Jeffrey, S.W. 1997. Application of pigment methods to oceanography, p. 127-166. In S.W. Jeffrey, R.F.C. Mantoura and S.W. Wright [eds.], Phytoplankton Pigments in Oceanography. Vol. 10, UNESCO, Paris.

Jeffrey S.W. and M. Vesk. 1997. Introduction to marine phytoplankton and their pigment signatures, p. 19-36. In S.W. Jeffrey, R.F.C. Mantoura, and S.W. Wright [eds.], Phytoplankton Pigments in Oceanography: Guidelines to Modern Methods. UNESCO, Paris.

Jeffrey, S.W., R.F.C. Mantoura, and S.W. Wright. 1997. Phytoplankton Pigments in Oceanography: Guidelines to Modern Methods. Unesco Monograph in Oceanographic Methods. Report for SCOR WH 78, SCOR-UNESCO Monographs on Oceanographic Methodology, Paris.

Kideys, A.E. 1994. Recent dramatic changes in the Black Sea Ecosystem: the reason for the sharp decline in Turkish Anchovy Fisheries. J. Mar. Systems, 5: 171-181.

Kostadinov, T.S., D.A. Siegel, and S. Maritorena. 2010. Global variability of phytoplankton functional types from space: assessment via the particle size distribution. Biogeosciences, 7: 3239-3257.

Latasa, M. and R.R. Bidigare. 1998. A comparison of phytoplankton populations of the Arabian Sea during the Spring Inter monsoon and Southwest Monsoon of 1995 as described by HPLC-analyzed pigments. Deep-Sea Res Pt I, 45: 2133-2170.

Lorenzen, C. 1967. Determination of chlorophyll and pheopigments: spectrophotometric equations. Limnol. Oceanogr. 12: 343.

Mantoura, R.F.C. and C.A. Llewellyn. 1983. The rapid determination of algal Chlorophyll-a and carotenoid pigments and their breakdown products in natural waters by reverse-phase high performance liquid chromatography. Anal. Chim. Acta, 151: 297-314.

Marañón, E. 2009. Phytoplankton size structure. In J.H. Steele, K. Turekian, S.A. Thorpe [eds.], Encyclopaedia of Ocean Sciences. Academic Press, Oxford.

Margalef, R. 1978. Life forms of phytoplankton as survival alternatives in an unstable environment. Oceanol. Acta, 1: 493-509.

Martinez, E., D. Antoine, F. D'Ortenzio, and B. Gentili. 2009. Climate-driven basin scale decadal oscillations of oceanic phytoplankton. Science, 326: 1253-1256.

McQuatters-Gollop, A., L.D. Mee, D.E. Raitsos, and G.I. Shapiro. 2008. Non-linearities, regime shifts and recovery: the recent influence of climate on Black Sea chlorophyll. J. Mar. Systems, 74: 649-658.

Mikaelyan, A.S., A.G. Zatsepin, and V.K. Chasovnikov. 2013. Long-term changes in nutrient supply of phytoplankton growth in the Black Sea, J. Mar. Systems, 117-118: 53-64.

Moncheva, S. and A. Krastev. 1997. Some aspects of phytoplankton long-term alterations off Bulgarian Black Sea shelf, p. 79-94. In E. Ozsoy and A. Mikhaelian [eds.], Sensitivity to Change: Black Sea, Baltic Sea and North Sea. NATO ASI Series, 2. Environment-vol.27. Kluwer Academic Publishers.

Nagata, T., K. Takai, K.I. Kawabata, M. Nakanishi, and J. Urabe. 1996. The trophic transfer via a picoplankton-flagellate-copepod food chain during a picocyanobacterial bloom in Lake Biwa. Arch. Hydrobiol., 137: 145-160.

O'Reilly, J.E., S. Maritorena, B.G. Mitchell, D.A. Siegel, K.L. Carder, S.A. Garver, M. Kahru, and C. McClain, 1998. Ocean chlorophyll algorithms for SeaWiFS. J. Geophys. Res., 103 (C11): 24937-24953.

Oguz, T. 2005. Black Ecosystem Response to Climatic Teleconnections. Oceanography, 18: 122-133.

Ondrusek, M., R. Bidigare, S. Sweet, D. Defreitas, and J. Brooks. 1991. Distribution of phytoplankton pigments in the North Pacific Ocean in relation to physical and optical variability. Deep-Sea Res Pt I: 243-266.

Parsons, T.R. and C.M. Lalli. 2002. Jellyfish populations explosions: revisiting a hypothesis of possible causes. La Mer. 40: 111-121.

Pedersen, L., H.M. Jensen, A. Burmeister, and B.W. Hansen. 1999. The significance of food web structure for the condition and tracer lipid content of juvenile snail fish (Pisces: *Liparis* spp.) along 65-72° N off West Greenland. J. Plankton Res., 21: 1593-1611.

Perez, V., E. Fernandez, E. Maranon, P. Serret, R. Varela, A. Bode, M. Varela, M.M. Varela, X. Moran, E.M.S. Woodward, V. Kitidis, and C. Garcia-Soto. 2005. Latitudinal distribution of microbial plankton abundance, production, and respiration in the Equatorial Atlantic in Autumn 2000. Deep-Sea Res Pt I, 52: 861-880.

Platt, T. and K.L. Denman, 1976. The relationship between photosynthesis and light for natural assemblages of coastal marine phytoplankton. J. Phycol., 12(4): 421-430.

Platt, T. and K.L. Denman, 1977. Organisation in the pelagic ecosystem. Helgoa Ender Wissenschaftliche Meeresuntersuchungen, 30: 575-581.

Platt, T. and K.L. Denman, 1978. The structure of pelagic marine ecosystems. Rapp. P.-v. Réun. Cons. perm. int. Explor. Mer., 60-65.

Platt, T., H. Bouman, E. Devred, C. Fuentes-Yaco, and S. Sathyendranath. 2005. Physical forcing and phytoplankton distributions. Sci. Mar., 69(1): 55-73.

Platt, T. and S. Sathyendranath. 2008. Ecological indicators for the pelagic zone of the ocean from remote sensing. Remote Sens. Environ., 112: 3426-3436.

Porra, R.J., E.E. Pfundel, and N. Engel. 1997. Metabolism and function of photosynthetic pigments. In S.W. Jeffrey, R.F.C. Mantoura, S.W. Wright [eds.], Phytoplankton Pigments in Oceanography: Guidelines to Modern Methods. UNESCO Monograph in Oceanographic Methods, Report for SCOR WH 78, SCOR-UNESCO Monographs on Oceanographic Methodology, Paris.

Ras, J., H. Claustre, and J. Uitz. 2008. Spatial variability of phytoplankton pigment distributions in the Subtropical South Pacific Ocean: a comparison between in situ and predicted data. Biogeosciences, 5: 353-369.

Raven, J.A. 1998. Small is beautiful: the picophytoplankton. Functional Ecology, 12, 503-513.

Roy, R., A. Pratihary, G. Mangesh, and S.W.A. Naqvi. 2006. Spatial variation of phytoplankton pigments along the southwest coast of India. Estuar. Coast. Shelf Sci., 69(1-2): 189-195.

Rykaczewski, R.R. and J.P. Dunne. 2011. A measured look at ocean chlorophyll trends. Nature, 472 (7342): E5-E6.

Schlüter, L., F. Mohlenberg, H. Havskum, and S. Larsen. 2000. The use of phytoplankton pigments for identifying and quantifying phytoplankton groups in coastal areas: testing the influence of light and nutrients on pigment/chlorophyll a ratios. Mar. Ecol. Prog. Ser., 192: 49-63.

Takahashi, T., S.C. Sutherland, C. Sweeney, A. Poisson, N. Metzl, B. Tilbrook, N. Bates, R. Wanninkhof, R.A. Feely, C. Sabine, J. Olafsson, and Y. Nojiri. 2002. Global sea-air CO_2 flux based on climatological surface ocean pCO_2 and seasonal biological and temperature effects. Deep-Sea Res Pt II, 49: 1601-1622.

Tolmazin, D. 1985. Changing coastal oceanography of the Black Sea, I: Northwestern shelf. Prog Oceanogr., 15: 217-276.

Trees, C.C., D.K. Clark, R.R. Bidigare, M.E. Ondrusek, and J.L. Mueller. 2000. Accessory pigments versus chlorophyll a concentrations within the euphotic zone: aubiquitous relationship. Limnol. Oceanography, 45: 1130-1143.

Uitz, J., H. Claustre, A. Morel, and S.B. Hooker. 2006. Vertical distribution of phytoplankton communities in open ocean: An assessment based on surface chlorophyll. J. Geophys. Res-Oceans., 111 (C8).

Vidussi, F., H. Claustre, B.B. Manca, A. Luchetta, and J.C. Marty. 2001. Phytoplankton pigment distribution in relation to upper thermocline circulation in the eastern Mediterranean Sea during winter. J. Geophys. Res-Oceans., 106 (C9): 19939-19956.

Wright, S.W., S.W. Jeffrey, R.F.C. Mantoura, C.A. Llewellyn, T. Bjornland, D. Repeta, and N. Welschmeyer. 1991. Improved HPLC method for the analysis of chorophylls and carotenoids from marine phytoplankton. Mar. Ecol. Prog. Ser., 77: 183-196.

Wright, S.W. and W. Jeffrey. 2006. Pigment markers for phytoplankton production. In J.K. Volkman [ed.], Marine Organic Matter: Biomarkers, Isotopes and DNA, Spriner-Verlag, Berlin.

A SYNTHESIS OF ICHTHYOPLANKTON STUDIES IN TURKISH PART OF THE BLACK SEA

Sinan MAVRUK [1] and Yeşim AK ÖREK [2]

[1]Fisheries Faculty, Department of Marine Biology, Cukurova University, Adana, Turkey
[2]Institute of Marine Sciences, Middle East Technical University, Erdemli, Turkey
smavruk@cu.edu.tr

1. Introduction

The Black Sea is one of the largest semi-enclosed and anoxic marine areas throughout the world. The average salinity is usually 16-18 ppt at the surface water. Due to the strong density stratification, different water column characteristics are observed. The anoxic layer occupies the most of its volume from the boundary of sulfidic to the bottom and restricts the inhabitable area for fishes. These unique characters make the knowledge on ichthyoplankton assemblages of the Black Sea particularly important.

Studies concerning the early life stages of fishes can provide significant knowledge on the biology and ecology of fishes. The composition, abundance, distribution and temporal variability of ichthyoplankton play important roles for understanding the recruitment mechanisms of fish species in marine ecosystem. Besides, important amount of information for management policies such as spawning times and areas, species interactions and the effects of environmental conditions in early life stages can also be achieved with these surveys. Therefore, a considerable amount of literature has been published on ichthyoplankton of the southern Black Sea which is among the most important fishery grounds for not only Turkish seas but also for the whole Mediterranean Sea.

The studies on ichthyoplankton of the southern Black Sea were started in the late fifties (Arim 1957, Altan 1957, 1958). During that period, efforts were mostly focused on the taxonomical characteristics of pelagic fish eggs and larvae. There were several investigations also on the spawning times and areas of the major commercial fish stocks such as anchovy, Mediterranean horse mackerel and jack mackerel (Demir and Arim 1957, Einarsson and Gürtürk 1960). Among those of the commercial fishes, early life stages of anchovy get particular attention in the following years (Niermann *et al.* 1994, Kideys *et al.* 1999, Fach 2014, Gucu *et al.* 2016). For the past three decades, there has been an increasing interest on biodiversity patterns of ichthyoplankton assemblages along the southern coasts of the Black Sea (Mater and Cihangir 1990, Ince 2013, Satilmis *et al.* 2014).

In this chapter, we have presented a synthesis of the scientific literature based on ichthyoplankton researches conducted in Turkish part of the Black Sea. In addition to this, we investigated the samples collected with an opportunistic sampling strategy at 20 stations in offshore waters of the southern Black Sea in April and October 2008 (Figure 1).

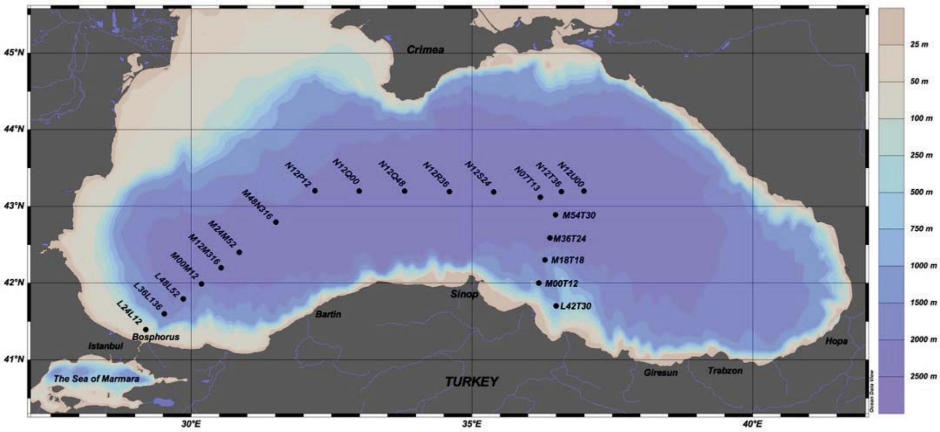

Figure 1. Bathymetry map of the Black Sea and the sampling stations in this study

2. History of Ichthyoplankton Studies in Turkish Part of the Black Sea

2.1. Taxonomy and Biodiversity of Ichthyoplankton

In Turkish marine research history, the first reported effort on ichthyoplankton was written out about the identification characteristics of seven Black Sea and the Sea of Marmara fishes by Arim (1957). Altan (1957, 1958) investigated the taxonomic characteristics of *Thunnus thynnus* and *Mullus barbatus* distributed in the Black Sea. Demir (1958a) overviewed embryonic and larval morphology of *Trachurus mediterraneaus*. After a long while, Yüksek and Gücü (1994) developed a software to identify pelagic fish eggs distributed in the Black Sea. In addition to these studies, morphological details of identified ichthyoplankton samples were traditionally given in the dissertations which were discussed below with their ecological outcomes (Basar 1996, Ak 2009, Sahin 2011, Ince 2013, Uygun 2015).

The studies conducted towards the biodiversity of ichthyoplankton assemblages were relatively new. Mater and Cihangir (1990) performed a cross-sectional survey in the western Black Sea in August and encountered early life stages of 10 genera. Anchovy constituted the most dominant group amongst all the eggs and larvae. Ozcan (2005) collected ichthyoplankton samples in spring 2003 with an opportunistic sampling strategy and identified larvae and juveniles of three species. Postlarvae of *Sprattus sprattus* were the most dominant constituting 99% of all individuals. In another cross-sectional survey conducted in the southwestern Black Sea, Ince (2013) sampled 35 stations in late summer, August. The author identified early life stages of 35 species belonging to 19 families in which anchovy was the dominant fish. Ince (2013) detected that the number of ichthyoplanktonic species increased towards the coasts.

Gordina *et al.* (2005) investigated ichthyoplankton dynamics in the northern (Sevastopol, Crimea) and the southern coasts of the Black Sea in summer months. They emphasized that food supply was an important constraint on larval fish survival and the nutritional quality of the Black Sea ecosystem revealed recovery after the decrement of *Mnemiopsis leidyi* biomass.

There are significant efforts towards ichthyoplankton assemblages of the south central Black Sea, especially off Sinop. Satilmis *et al.* (2003) investigated the seasonal distribution of fish eggs and larvae at two stations off Sinop, the south central Black Sea. They reported eggs and larvae of 23 species. Anchovy was dominant among eggs, whereas Gobiids were the most abundant group among larval stages. The ichthyoplankton abundance increased in summer months in parallel with the sea water temperature. In a full annual cycle, Satilmis *et al.* (2006) identified planktonic stages of eight species belonging to eight family off Sinop. In this study, sprat and anchovy were the dominant components of ichthyoplankton. There was a remarkable match between the increment periods of *M. leidyi* and ichthyoplankton. Both groups increased towards summer months. In another effort on the ichthyoplankton dynamics off Sinop, Gürcan (2012) identified eggs and larvae of 28 species belonging to 21 families. Anchovy dominated ichthyoplankton assemblages in all groups. The maximum ichthyoplankton diversity was observed in summer. Seasonal variations in species composition significantly correlated with the temperature, oxygen and wind speed. The results of Satilmis *et al*. (2014) also confirmed the previous efforts in the same area. Authors identified early life stages of 27 Teleost fish species and stated that the expected species richness was 34 for ichthyoplankton off Sinop. Ichthyoplankton richness increased towards summer in parallel with the temperature. Uygun (2015) identified larval stages of 27 Teleost fish species belonging to 14 families.

In the southeastern Black Sea, Surmene Bay-Trabzon, Basar (1996) and Basar and Okumus (1997) performed a one-year study towards the biodiversity of ichthyoplankton. They encountered eggs and larvae of 18 Teleost fish species. The richness and abundance of ichthyoplankton were reported to increase during spring and summer seasons when early life stages of anchovy were dominant. In winter, sprat (*S. sprattus*) and rockling (*Gaidropsaurus mediterraneus*) eggs and larvae dominated the ichthyoplankton assemblages in this area. Thereafter, Ak (2009) sampled early life stages of 18 species belonging to 17 family off Trabzon, southeastern Black Sea.

Anchovy was the dominant species among egg and larval stages. Sahin (2011) identified eggs and larvae of 45 species in adjacent areas, Giresun, Surmene and Hopa. The diversity was higher in summer months and significantly correlated with the temperature. In accordance with Ak (2009), anchovy was the most abundant species among all the early life stages.

In the context of this study, we also investigated the samples collected with an opportunistic sampling strategy at a total of 20 stations (13 in spring and 14 in autumn) in the southern Black Sea in April 2008 and October 2008 (Figure 1). Other sampling details are present in Table 1. During the sampling periods, ichthyoplankton were found to be generally in low density, even completely absent in some stations since the stations were in open waters. In the April survey, we encountered larvae of *S. sprattus*, *Engraulis encrasicolus*, *Aphia minuta* and *G. mediterraneus*. Fish eggs were found to be absent in all stations. In accordance with the previous studies, sprat was the dominant component of ichthyoplankton. Additionally, planktonic stages of *A. minuta* (4.70 mm) were firstly recognized in the southern Black Sea with this study. Along with the individuals identified at species level, we also detected unidentified larval stages of the families Clupeidae and Gobiidae in April. In October 2008, we detected eggs of *S. sprattus* and larvae of *E. encrasicolus*, *G. mediterraneus* and an unidentified Gobiid larvae in the study area. In average, a significant amount of sprat eggs was dead. The abundance and the rate of abnormal eggs were presented in Figure 2. Ozcan and Cihangir (2005) reported that *S. sprattus* larvae and juveniles were found as the most abundant species in the coastal and off shore regions of the Black Sea. In addition to this, authors specified that density of sprat individuals in the stations around western gyre were found to be higher than the eastern gyre during April-May period. Similar results had been observed at the same period in our study. In the western part of the Black Sea, the larvae of sprat were observed intensely during the spring period, while sprat eggs were found to be more abundant in the autumn period in this study.

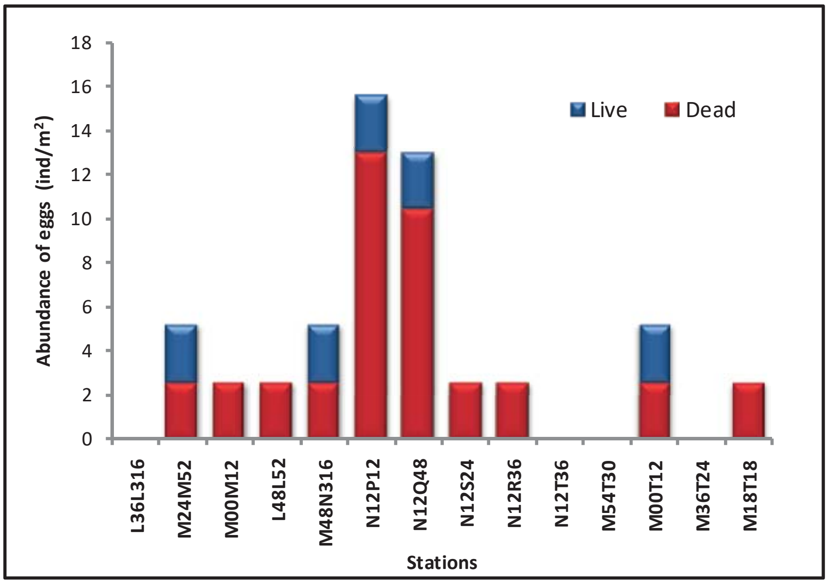

Figure 2. Distribution of dead and alive sprat eggs in October 2008

2.2. Spawning Strategies of Fishes

Over the past sixty years, there has been a considerable attention on ichthyoplankton studies in the Black Sea towards understanding the spawning strategies of commercial fish species. Demir and Arim (1957) investigated the planktonic stages of *Scomber scombrus* in the samples of ichthyoplankton surveys conducted in the northeastern Aegean Sea, the Sea of Marmara and the Black Sea. Early stages of *S. scombrus* were encountered only in the Sea of Marmara during the spring months. The absence of eggs or larvae in the Black Sea was explained by the low saline conditions. Even though spawning may occur in the Black Sea, the eggs sink to the bottom and die (Demir and Arim 1957). Thereafter, Mater and Cihangir (1990) observed several *S. scombrus* eggs around the entrance of Bosphorus. These samples were probably vagrants drifted via the current of Bosphorus Strait.

Further studies on the spawning strategies of the Black Sea fishes mostly focused on three major commercial species such as *E. encrasicolus* (anchovy), *S. sprattus* (sprat) and *Trachurus mediterraneus* (Mediterranean horse mackerel). Demir (1958b) investigated the distribution of *T. mediterraneus* and reported that this species could spawn during warm months throughout the coastal zone in the Black Sea. Satilmis (2005) investigated the egg production, spawning periods as well as the vertical distribution of early life stages of these three commercial small pelagic fish off south-central Black Sea, Sinop in 2003. The authors have confirmed that anchovy (Satilmis *et* *al.* 2007) and Mediterranean horse mackerel spawn in warm months while sprat is a winter spawner. The same results were also obtained in further, eastern part, off Trabzon and Rize (Hacimurtazaoglu 2007, Sahin and Hacimurtazaoglu 2013).

2.3. Special Considerations on the Spawning of Anchovy

Since the anchovy (*E. encrasicolus*) is the most important fish species in Black Sea fishery (Anonymous 2017), its spawning patterns have attracted significant attention during the last seventy years. In the first comprehensive survey effort covering also Turkish coasts, Einarsson and Gürtürk (1960) detected the important spawning areas of anchovy in the Black Sea. They reported that Romanian coasts were the primary spawning area in the western Black Sea. In the southwestern part, the entrance of Bosphorus also constituted another important area. In the eastern part, there were important areas around Georgian coasts and southeastern coasts of Crimean Peninsula. Eggs were also abundant around the Central coasts of Anatolia, Samsun, however; the intensity of spawning was much higher in the northern part. Ivanov and Beverton (1985) also reported that the main spawning area of anchovy was the northern coasts. In June 1991 and July 1992, Niermann *et al.* (1994) performed another comprehensive survey covering the whole Black Sea. They found out a remarkable shift in the main spawning areas of anchovy. Accordingly, the egg abundance in offshore waters and the southern coasts was detected significantly higher than those of three decades before.

Mater and Cihangir (1997) investigated the distribution of anchovy and horse mackerel (*T. mediterraneus*) eggs in southwestern Black Sea in July. In accordance with the observations of Einarsson and Gürtürk (1960), eggs of the both species concentrated towards Bosphorus. On the other hand, egg abundance reported also by Mater and Cihangir (1997) were much higher than that of reported by Einarsson and Gürtürk (1960) in the southwestern Black Sea. Thereafter, the abundance of anchovy eggs was reported even to be higher in July 2013 than in 1990s in this area (Gucu *et al.* 2016).

Niermann *et al.* (1994) explained this shift with the following potential causes; (1) the northern spawning habitats deteriorated due to the pollution and distrophication, (2) the food conditions improved in offshore waters and in the southern coasts due to the eutrophication. Kideys *et al.* (2000) stated that the long-term shifts in the composition of zooplankton community might have also effected the patterns in ichthyoplankton in the Black Sea.

Gucu *et al.* (2016) explained the mechanism of this shift with the entrainment hypothesis of Petitgas *et al.* (2006). According to their hypothesis, the knowledge of the northern spawning grounds, shown by Einarsson and Gürtürk (1960), was being transferred by the way of social learning from elders. In addition to overfishing and predation by *M. leidyi*, deteriorations mentioned above caused a significant decline in the Black Sea anchovy stock. In the absence of repeat spawners, vagrants might have adopted to their new spawning grounds in the southern Black Sea (Gucu *et al.* 2016). In addition, they specified that the hydrographical properties of the Black Sea might have played a key role in the development of this new spawning area (Gucu *et al.* 2016).

Kideys *et al.* (1999) investigated the spatial distribution of anchovy eggs and larvae throughout the southern Black Sea and found significant correlations between the distribution of ichthyoplanktonic stages and environmental conditions such as temperature, salinity, food abundance and jelly fish. Additionally, although Gucu *et al.* (2016) did not detect a significant correlation, they observed that the abundance of anchovy was more variable in the areas where jellyfish abundance was high and underlined that this might have been a result of predation pressure.

Fach (2014) evaluated the distribution of planktonic stages of anchovy in the Black Sea via particle tracking simulations. The author observed that the larval dispersal was forming under the influence of rim current as well as basin-wide gyres and mesoscale eddies. According to the results of simulations, southwestern part of the Black Sea was well connected with northwestern part, whereas south central Black Sea connected with the Azov Sea. The connectivity among the other areas was weaker due to the circulation characteristics. Fach (2014) additionally stated that there were significant inter-annual variations in current patterns and consequently in larval dispersal of anchovy.

In addition to the studies concerning to the abundance of ichthyoplanktonic stages of anchovy, the shape differences of anchovy eggs also attracted significant attention. In 1959, Demir recognized significant differences among the morphometry of *E. encrasicolus* eggs from the Black Sea, Sea of Marmara, the Aegean Sea and Mediterranean Sea. The short axis was decreasing and the eggs were getting more elongate towards the southern seas. Gordina *et al.* (1997) sampled Marmara type eggs in the southern Black Sea. These elongate eggs were not observed in Surmene Bay, southwestern Black Sea in which all the samples had Black Sea forms (Basar *et al.* 2000). This might be a result of eastward advection of anchovy eggs spawned in the Marmara and drifted to the Black Sea via Bosphorus (Gucu *et al.* 2016) or a spawning migration from the Sea of Marmara to the Black Sea (Gordina *et al.* 1997).

2.4. Sampling Methods in Ichthyoplankton Surveys

In the early period of ichthyoplankton studies in the southern Black Sea, samplings were generally performed by using standard plankton nets which were mounted on meshes made of various materials such as silk or stramin. Closing nets were also used in this term. The frame size of these nets differed from 50 cm to 200 cm. Demir and Arim (1957) gave the details of designs of these sampling tools. Recently, standard plankton nets are still in use in addition to the more specific ichthyoplankton samplers such as Hensen and Bongo nets. The study area and sampling details of major studies are present in Table 1.

2.5. Biodiversity of Ichthyoplankton in Turkish Part of the Black Sea

In the course of 28 studies conducted throughout the southern Black Sea, a total of 73 species belonging to 33 families and 11 orders was reported. The jackknife estimate of maximum species richness was calculated as 103±16 (95% CI; Appendix 1). As for the number of species recorded in the southern Black Sea, Blennidae was the richest family with 8 species (11 %), followed by Labridae and Sparidae with 6 species (8%) (Figure 3).

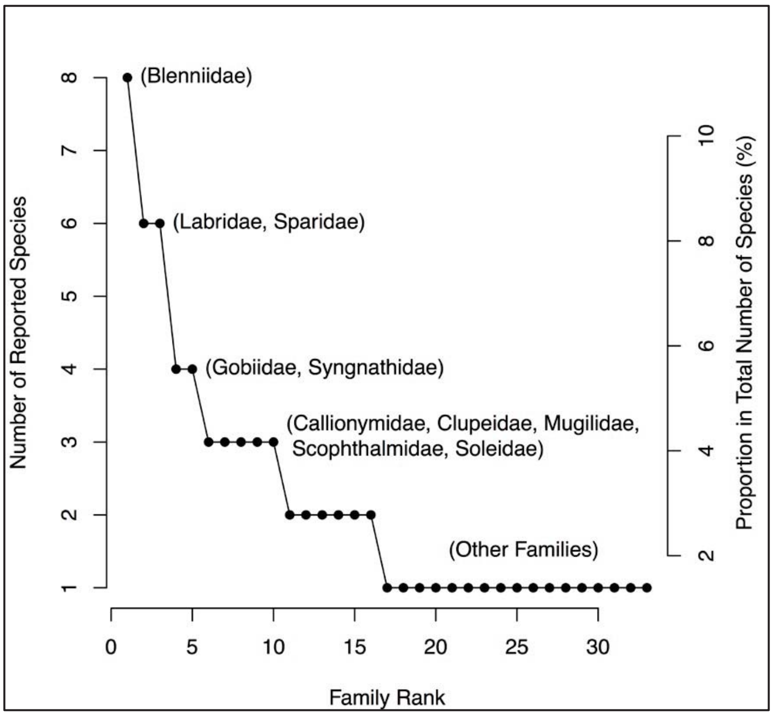

Figure 3. The distribution of reported species to the families

Table 1. Study area and sampling methods of major studies in Turkish part of the Black Sea

Reference	Net Type	Mesh Size(µm)	Type of Haul	Study Area
1. Arim (1957)	Standard Plankton Net Closing Net	~239µ[2,4]	Horizontal, Oblique and Vertical	Istanbul and Trabzon[1]
2. Demir and Arim (1957)	Standard Plankton Net Closing Net	~239µ[2,4]	Horizontal, Oblique and Vertical	Istanbul and Trabzon[1]
3. Demir (1958)	-	-	-	Trabzon
4. Demir (1958)	-	-	-	Trabzon
5. Demir (1959)	Standard Plankton Net	-	Oblique and Horizontal	Istanbul
6. Einarsson and Gürtürk (1960)	a) Egg Net (West) b) Hensen Net (East)	a) ~200µ[2] b) ~239µ[2]	a) Horizontal[3] b)Vertical	All over Black Sea
7. Mater and Cihangir (1990)	Standard Plankton Net	380µ	Vertical	South western Black Sea
8. Nierman *et al.* (1994)	a) Hensen Net b) BogorovRass Net c) Djedi Net	a) 300µ b) 500µ c)150µ	a) Vertical b) Vertical and Horizontal c)Vertical	All over Black Sea
9. Basar (1996)	Hensen Net	300µ	Horizontal	Trabzon
10. Gordina *et al.* (1997)	a) Hensen Net b) Bogorov-Rass Net	a) 300µ b) 500µ	Vertical	All over Black Sea
11. Mater and Cihangir (1997)	Bongo Net	200µ	Vertical	South western Black Sea
12. Kideys *et al.* (1999)	Hensen Net	300µ	Vertical	Southern Black Sea
13. Basar *et al.* (2000)	Hensen Net	300µ	Vertical	Trabzon

Table 1. Continue

14. Satilmis *et al.* (2003)	Standard Plankton Net	112µ	Horizontal and Vertical	Sinop
15. Gordina *et al.* (2005)	a) Hensen Net b) Bogorov-Rass Net	a) 300 µ b) 500 µ	Horizontal and Vertical	South west and South central Black Sea[1]
16. Ozcan (2005)	Hamburg Plankton Net	500µ	Horizontal	Southern Black Sea
17. Satilmis (2005)	a) Standard plankton net b) Closing net	a) 500µ b) 210µ	Horizontal and Vertical	Sinop
18. Satilmis *et al.* (2006)	Standart Plankton Net	a) 500µ b) 210µ	Horizontal and Vertical	Sinop
19. Hacimurtazaoglu (2007)	Standard Plankton Net	a) 500µ b) 100µ	Horizontal and Vertical	Trabzon and Rize
20. Ak (2009)	Standard Plankton Net	a) 500µ b) 200µ	Horizontal and Vertical	Trabzon
21. Sahin (2011)	a) Standard plankton net b) WP-2	a) 500µ b) 330µ	Horizontal and Vertical	South eastern Black Sea
22. Gürcan (2012)	Standard Plankton Net	a) 500µ b) 100µ	Horizontal	Sinop
23. Ince (2013)	Nansen Closing Net	a) 500µ b) 200µ	Horizontal and Vertical	South western Black Sea
24. Satilmis *et al.* (2014)	Standard Plankton Net	a) 500µ b) 210µ	Horizontal and Vertical	Sinop
25. Kaya (2015)	Standard Plankton Net	500µ	Horizontal	Sinop
26. Uygun (2015)	Standard Plankton Net	500µ	Horizontal	Sinop

27. Gucu *et al.* (2016)	Hensen Net	500µ	Vertical	Southern Black Sea
28. This Study	Hensen Net	300 µ	Vertical	Southern Black Sea

[1]: The stations in the southern Black Sea were taken into consideration. [2]: Approximate values show the mesh size of dry silk plankton net, there may be a shrinkage up to 20% during operation (Currie and Foxton, 1957). [3]: Horizontal tows were performed near surface. [4]: Only used in quantitative samplings. References were given in chronological order.

3. Conclusions

Yankova *et al.* (2014) reported that a total of 189 fish species is inhabiting throughout the Black Sea. Bilecenoglu *et al.* (2014) listed 140 Teleost fish species from the southern coasts. Among them 130 species produce planktonic eggs and/or larvae (Froese and Pauly 2017), which are potentially in the extent of ichthyoplankton studies. For the last seven decades, a significant effort has been directed to clarifying the biodiversity of ichthyoplankton assemblages in this area. In these studies, total 73species were recorded. Based on this value, the expectation of maximum richness was calculated as 103±16 (95% CI) species. The upper limit of this expectation is quite close to the total number of species inhabiting in the Black Sea. The unrecognized part is generally arises from the lack of taxonomic details. Therefore, further investigations, especially molecular approaches, are required for understanding the early life stages of these unrecognized part.

Among the species recorded in ichthyoplanktonic stages there were instances which were previously unknown in adult stages such as *Echiichthys vipera* and *Pagrus pagrus* (Ince 2013, Bilecenoglu *et al.* 2014). These were mostly sampled around the entrance of Bosphorus. In the same area, Mater and Cihangir (1990) encountered early life stages of *S. scombrus* which was a well-known species spawning in the Marmara. Therefore, the ichthyoplankton assemblages in southwestern part of the Black Sea seems to be connected with the Sea of Marmara via Bosphorus current. Although, comprehensive surveys covering the whole Black Sea are present, most of them were performed around south central and southeastern parts. Therefore, the biodiversity of ichthyoplankton assemblages remain as an open question in southwestern coasts.

In accordance with the studies conducted in other regions in the middle latitudes (Sabatés *et al.* 2007), the diversity and abundance of ichthyoplankton assemblages increased in summer period in the Black Sea. Anchovy was the dominant species in summer, whereas winter assemblages dominated by especially *S. sprattus*. *G. mediterraneus* and *Merlangius merlangius* was also abundant in winter.

Abundance and distribution of ichthyoplankton are strongly influenced by the biological, physical and/or chemical properties at seasonal and spatial scales (Sabatés *et al.* 2007, Muelbert *et al.* 2008). This generalization also appears to be valid for ichthyoplankton of the Black Sea. The egg and larval dispersal was controlled by the coastal current (Rim Current) and two sub-basin scale cyclonic eddies (Fach 2014, Gucu *et al.* 2016).

Anchovy was the most dominant species also in the pooled data. Due to its economic importance, a significant effort was focused on detecting its spawning strategies and population ecology in early life stages. Significant changes were found in the spawning patterns of this species in time. The previous main spawning area which was in the northern coasts of the Black Sea shifted to the Anatolian coasts due to the deteriorating conditions in the northern part.

Acknowledgement

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Appendix 1. List of identified Teleost eggs and larvae in Turkish part of the Black Sea

Species	Reference Code*
ANGUILLIFORMES	
Congridae	
Conger conger (Linnaeus, 1758)	24
CLUPEIFORMES	
Clupeidae	
Sardina pilchardus (Walbaum, 1792)	1
Sardinella aurita Valenciennes, 1847	23
Sprattus sprattus (Linnaeus, 1758)	7,9,14,16,17,18,20,21,22,24,25,26,28
Engraulidae	
Engraulis encrasicolus (Linnaeus, 1758)	1,5,6,7,8,9,10,11,12,13,14,15,17,18,19,20,21,22,23,24,25,26,27,28
GADIFORMES	
Gadidae	
Merlangius merlangus (Linnaeus, 1758)	9,14,15,16,18,20,21,23,24,25,26
Lotidae	
Gaidropsarus mediterraneus (Linnaeus, 1758)	9,20,21,22,24,25,28
OPHIDIIFORMES	
Ophidiidae	
Ophidion rochei Müller, 1845	14,21,22,24,25
GOBIESOCIFORMES	
Gobiesocidae	
Diplecogaster bimaculata (Bonnaterre, 1788)	14,26

Species	Reference Code*
Lepadogaster lepadogaster (Bonnaterre,1788)	26
ATHERINIFORMES	
Atherinidae	
Atherina boyeri Risso, 1810	9,21,22,23,24,26
BELONIFORMES	
Belonidae	
Belone belone (Linnaeus, 1761)	21,22,26
SYNGNATHIFORMES	
Syngnathidae	
Hippocampus hippocampus (Linnaeus, 1758)	20,26
Syngnathus abaster Risso, 1827	21
Syngnathus acus Linnaeus, 1758	20,21,22,24,25,26
Syngnathus typhle Linnaeus, 1758	26
SCORPAENIFORMES	
Scorpaenidae	
Scorpaena porcus Linnaeus, 1758	7,14,15,20,21,22,23,24
Triglidae	
Chelidonichthys lucerna (Linnaeus, 1758)	21,24
PERCIFORMES	
Moronidae	
Dicentrarchus labrax (Linnaeus, 1758)	21
Serranidae	
Serranus hepatus (Linnaeus, 1758)	23
Serranus scriba (Linnaeus, 1758)	14,15,21,24
Pomatomidae	
Pomatomus saltatrix (Linnaeus, 1766)	14,23,24
Carangidae	
Trachurus mediterraneus (Steindachner,1868)	1,3,4,7,11,14,15,17,18,19,20,22, 23,24,25,26
Trachurus trachurus (Linnaeus, 1758)	1,21
Sparidae	

Species	Reference Code*
Boops boops (Linnaeus, 1758)	23
Dentex dentex (Linnaeus, 1758)	23
Diplodus annularis (Linnaeus, 1758)	9,14,21,22,23,24,25
Diplodus puntazzo (Walbaum, 1792)	21
Pagrus pagrus (Linnaeus, 1758)	23
Spicara smaris (Linnaeus, 1758)	21
Sciaenidae	
Sciaena umbra Linnaeus, 1758	21,24
Mullidae	
Mullus barbatus barbatus Linnaeus, 1758	1,9,14,15,18,20,21,22,23,24,25,26
Mullus surmuletus Linnaeus, 1758	1
Pomacentridae	
Chromis chromis (Linnaeus, 1758)	21
Mugilidae	
Liza aurata (Risso, 1810)	21,22
Liza saliens (Risso, 1810)	24
Mugil cephalus Linnaeus, 1758	9,15,20,21,22,23,24,25
Labridae	
Coris julis (Linnaeus, 1758)	9,21
Ctenolabrus rupestris (Linnaeus, 1758)	9,14,20,21,23
Symphodus cinereus (Bonnaterre, 1788)	21
Symphodus ocellatus (Linnaeus, 1758)	14,21,24,26
Symphodus roissali (Risso, 1810)	26
Symphodus tinca (Linnaeus, 1758)	21
Ammodytidae	
Gymnammodytes cicerelus (Rafinesque, 1810)	21
Trachinidae	
Echiichthys vipera (Cuvier, 1829)	23
Trachinus draco Linnaeus, 1758	7,14,20,21,22,23,24
Uranoscopidae	
Uranoscopus scaber Linnaeus, 1758	9,20,21,22,24,25

Species	Reference Code*
Blenniidae	
Aidablennius sphynx (Valenciennes, 1836)	14,22
Blennius ocellaris Linnaeus, 1758	9,21,22,23,24,26
Coryphoblennius galerita (Linnaeus, 1758)	26
Parablennius gattorugine (Linnaeus, 1758)	21,26
Parablennius sanguinolentus (Pallas, 1814)	9,14,21,22,26
Parablennius tentacularis (Brünnich, 1768)	14,21,22,23,24,26
Parablennius zvonimiri (Kolombatovic, 1892)	14,18,22,24,26
Salaria pavo (Risso, 1810)	14,22,26
Callionymidae	
Callionymus lyra Linnaeus, 1758	20,21,22,26
Callionymus maculatus Rafinesque, 1810	23
Callionymus pusillus Delaroche, 1809	21
Gobiidae	
Aphia minuta (Risso, 1810)	28
Gobius niger Linnaeus, 1758	20,23,26
Gobius paganellus Linnaeus, 1758	26
Pomatoschistus microps (Krøyer, 1839)	26
Pomatoschistus minutus (Pallas, 1770)	26
Scombridae	
Sarda sarda (Bloch, 1793)	21
Scomber scombrus Linnaeus, 1758	7
PLEURONECTIFORMES	
Scophthalmidae	
Scophthalmus maeoticus (Pallas, 1814)	9
Scophthalmus maximus (Linnaeus, 1758)	20,21,24,25
Scophthalmus rhombus (Linnaeus, 1758)	25
Bothidae	
Arnoglossus kessleri Schmidt, 1915	21,22,24,25
Pleuronectidae	
Platichthys flesus (Linnaeus, 1758)	20,22,25
Soleidae	

Species	Reference Code*
Buglossidium luteum (Risso, 1810)	9,21,22,25
Pegusa lascaris (Risso, 1810)	9,14,15,18,21,22,24,25,26
Solea solea (Linnaeus, 1758)	23

*: The reference codes are explained in Table 1.

References

Ak, O. 2009. Fish egg and larvae distribution with egg production and distribution of economic demersal fishes whiting (*Merlangius merlangus euxinus* Nordmann, 1840) and red mullet (*Mullus barbatus ponticus*, Ess. 1927) in Trabzon coast (in Turkish). Ph.D. Thesis. Ataturk University, Department of Aquaculture, Erzurum, 151 pp.

Altan, H. 1957. A Key to pelagic eggs and larvae of the Black Sea fishes 4- Blue fin tuna, *Thunnus thynnus* (LINN), (in Turkish). Fish and Fishery, The Meat and Fish Office, 5(7): 16-17.

Altan, H. 1958. A key to pelagic eggs and larvae of the Black Sea fishes, VIIA- The red mullet of the Black Sea, *Mullus barbatus ponticus*, (in Turkish). Fish and Fishery, The Meat and Fish Office, 6(10): 21-23.

Anonymous, 2017. FAO Fish Stat Dataset. URL http://www.fao.org/?shery/statistics/global-capture-production [accessed 1 January 2017].

Arim, N. 1957. The morphology and ecology of eggs and larvae of some bony fishes Teleost in Sea of Marmara and The Black Sea. Izmir Bay, (in Turkish). Journal of Hydrobiology, İ.Ü.F.F. Hidrobiology Research Institute Publications, Series A, 5(1-2): 7-56.

Basar, E. 1996. Seasonal distribution of pelagic eggs and larvae of some marine Teleost fishes in Bay of Sürmene, (in Turkish). Karadeniz Technical University, Institute of Natural and Applied Sciences, MSc Thesis. 79 p.

Basar, E. and I. Okumus. 1997. Seasonal distribution of pelagic eggs and larvae of some Teleost fishes in Bay of Sürmene (The Eastern Black Sea), (in Turkish). Mediterranean Fisheries Congress, 9-11 April 1997, Izmir, 579-584.

Basar, E., A.M. Feyzioglu, and C. Erüz. 2000. Determination of distribution and diameter ratio of Anchovy eggs in Camburnu between 1999-2000, (in Turkish). 1. National Conference of Marine Sciences. 30 May-2 June 2000. Ankara. 261-262.

Bilecenoglu, M., M. Kaya, B. Cihangir, and E. Cicek. 2014. An updated checklist of the marine fishes of Turkey. Turkish Journal of Zoology, 38: 901-929.

Currie, R.I. and P. Foxton 1957. A new quantitative plankton net. Journal of the Marine Biological Association of the United Kingdom, 36 (1): 17-32.

Demir M. and N. Arim 1957. Researches on the reproduction on the mackerel of the Black and Marmara Seas, (in Turkish). Journal of Hydrobiology, İ.Ü.F.F. Hidrobiology Research Institute Publications, 4 (I-2).

Demir, N. 1958a. On morphological characteristics of eggs and larvae of *Trachurus mediterraneus* Lutken (Mediterranean horse mackerel) in the Black Sea population. Journal of Hydrobiology, İ.Ü.F.F. Hidrobiology Research Institute Publications, 4(3-4): 85-92.

Demir, M. 1958b. On reproduction of the Mediterranean horse mackerel (*Trachurus mediterraneus* Lutken, 1880). I- Black Sea, (in Turkish). Journal of Hydrobiology, İ.Ü.F.F. Hidrobiology Research Institute Publications, Series A. 4(3-4): 93-102.

Demir, N. 1959. Notes on the variations of the eggs of anchovy (*Engraulis encrasicholus* CUV.) from Black, Marmara, Aegean and Mediterranean Seas. Journal of Hydrobiology, İ.Ü.F.F. Hidrobiology Research Institute Publications. Series B. 4(4): 180-187.

Einarsson, H. and N. Gürtürk 1960. Abundance and distribution of eggs and larvae of the anchovy (*Engraulis encrasicholus ponticus*) in the Black Sea. Journal of Hydrobiology, İ.Ü.F.F. Hidrobiology Research Institute Publications. Series B, 5(1-2): 72-94.

Fach, B.A. 2014. Modeling the influence of hydrodynamic processes on anchovy distribution and connectivity in the Black Sea. Turkish Journal of Fisheries and Aquatic Sciences, 14: 353-365.

Froese, R. and D. Pauly. 2017. Fishbase. Retrieved from www.fishbase.org, version (02/2017).

Gordina, A.D., V.N. Nikolskiy, U. Niermann, F. Bingel, and A.A. Subbotin 1997. New data on the morphological differences on anchovy eggs (*Engraulis encrasicholus* L.) in the Black Sea. Fisheries Research, 31: 139-145.

Gordina, A.D., J.A. Zagorodnyaya, A.E. Kideys, L. Bat, and H.H. Satilmis. 2005. Summer ichthyoplankton, food supply of fish larvae and impact of invasive ctenophores on the nutrition of fish larvae in the Black Sea during 2000 and 2001. Journal of the Marine Biological Association of the United Kingdom, 85: 537-548.

Gucu, A.C., Ö.E. Inanmaz, M. Ok, and S. Sakinan. 2016. Recent changes in the spawning grounds of Black Sea anchovy, *Engraulis encrasicolus.* Fisheries Oceanography, 25(1): 67-84.

Gürcan, E.S. 2012. The Ichthyoplankton dynamics of the Sinop Coasts, (in Turkish). Sinop University. Institute of Natural and Applied Sciences, Department of Hydrobiology, MSc Thesis, 79p.

Hacimurtazaoglu, N. 2007. The abundance of the eggs and larvae of European anchovy (*Engraulis encrasicolus*, Linnaeus, 1758) and horse mackerel (*Trachurus mediterraneus*, Steindachner, 1868) coast of Trabzon and Rize. MSc Thesis, Karadeniz Technical University, Institute of Natural and Applied Sciences, 63p.

Ince, S. 2013. Preliminary research on the Western Black Sea summer ichthyoplankton (İğneada-Istanbul Strait), Istanbul University, Institute of Marine Sciences and Management, MSc thesis, 146 p.

Ivanov, L. and R.J.H. Beverton 1985. The fisheries resources of the Mediterranean. Part two: The Black Sea. Studies and Reviews, GFCM, FAO No.60, 135.

Kaya, M. 2015. Composition of fish eggs in Sinop-Akliman coast, Master of Science Thesis, (in Turkish). 63p

Kideys, A.E., A.D. Gordina, F. Bingel, and U. Niermann. 1999. The effect of environmental conditions on the distribution of eggs and larvae of anchovy (*Engraulis encrasicolus* L.) in the Black Sea. ICES Journal of Marine Science, 56: 58-64.

Kideys, A. E., A.V. Kovalev, G. Shulman, A. Gordina, and F. Bingel. 2000. A review of zooplankton investigations of the Black Sea over the last decade. Journal of Marine Systems, 24: 355-371.

Mater, S. and B. Cihangir. 1990. An investigation on the fish-larva distribution in the Black Sea entrance of the Bosphorus, (in Turkish). In X. National Congress of Biology Proceedings Book, Atatürk University, Erzurum, 209-216 p.

Mater, S. and B. Cihangir 1997. Distribution and abundance of the European anchovy (*Engraulis encrasicolus* (L. 1758)) and Mediterranean Horse mackarel (*Trachurus mediterraneus* (Steindachner, 1868)) eggs from the South-west Black Sea. Turkish Journal of Zoology, 21: 417- 420.

Muelbert, J.H., M. Acha, H. Mianzan, R. Guerrero, R. Reta, E.S. Braga, V.M.T. Garcia, A. Berasategui, M. Gomez-Eracheand, and F. Ramírez 2008. Biological, physical and chemical properties at the Subtropical Shelf Front Zone in the SW Atlantic Continental Shelf. Continental Shelf Research, 28: 1662-1673.

Niermann, U., F. Bingel, A. Gorban, A.D. Gordina, A.C. Gucu, A.E. Kideys, A. Konsulov, G. Radu, A.A. Subbotin, and V.E. Zaika. 1994. Distribution of anchovy eggs and larvae (*Engraulis encrasicolus* Cuv.) in the Black Sea in 1991-1992. ICES Journal of Marine Science, 51: 395-406.

Ozcan, I. 2005. Distribution of juvenile fish and larvae in Black Sea in spring period of 2003. Dokuz Eylul University, Institute of Natural and Applied Sciences, MSc Thesis, 62p.

Ozcan, I. and B. Cihangir. 2005. Juvenile fish and larvae distribution in spring period 2003 in the Black Sea. Turkish Journal of Aquatic Life, 3(4): 1-8.

Petitgas, P., D. Reid, B. Planque, E. Nogueira, B. O'Hea, and U. Cotano. 2006. The entrainment hypothesis: an explanation for the persistence and innovation in spawning migrations and life cycle spatial patterns. ICES Document, CM 2006/B:07.

Sabatés A, M.P. Olivar, J. Salat, I. Palomera, and F. Alemany 2007. Physical and biological processes controlling the distribution of fish larvae in the NW Mediterranean. Prog Oceanogr, 74: 355-376.

Sahin, A. 2011. Distribution and seasonal changes of ichthyoplankton in southeastern Black Sea, (in Turkish). Karadeniz Technical University, Institute of Natural and Applied Sciences, Department of Fisheries Technology Engineering, Ph.D. Thesis, 100 p.

Sahin, C. and N. Hacimurtazaoglu. 2013. Abundance and distribution of eggs and larvae of anchovy (*Engraulis encrasicolus*, Linnaeus, 1758) and horse mackerel (*Trachurus mediterraneus*, Steindachner, 1868) on the coasts of the eastern Black Sea. Turkish Journal of Zoology, 37: 773-781.

Satilmis, H.H., A.D. Gordina, L. Bat, R. Bircan, M. Culha, M. Akbulut, and A.E. Kideys. 2003. Seasonal distribution of fish eggs and larvae off Sinop (the Southern Black Sea) in 1999-2000. Acta Oecologica, 24: 275-280.

Satilmis, H.H. 2005. Egg production and distribution of egg and larvae of small pelagic fish in Sinop coast, (in Turkish). Ph.D. Thesis, Ondokuz Mayıs University, Graduate School of Sciences, 174 p.

Satilmiş, H.H., L. Bat, Z. Birinci Ozdemir, F. Ustun, F. Sahin, A.E. Kideys, and Y. Erdem. 2006. Composition of eggs and larvae of fish and macrogelatinious zooplankton in Sinop Region (The Central Black Sea) during 2002. E.U. Journal of Fisheries and Aquatic Sciences, 23(1/1): 135-140.

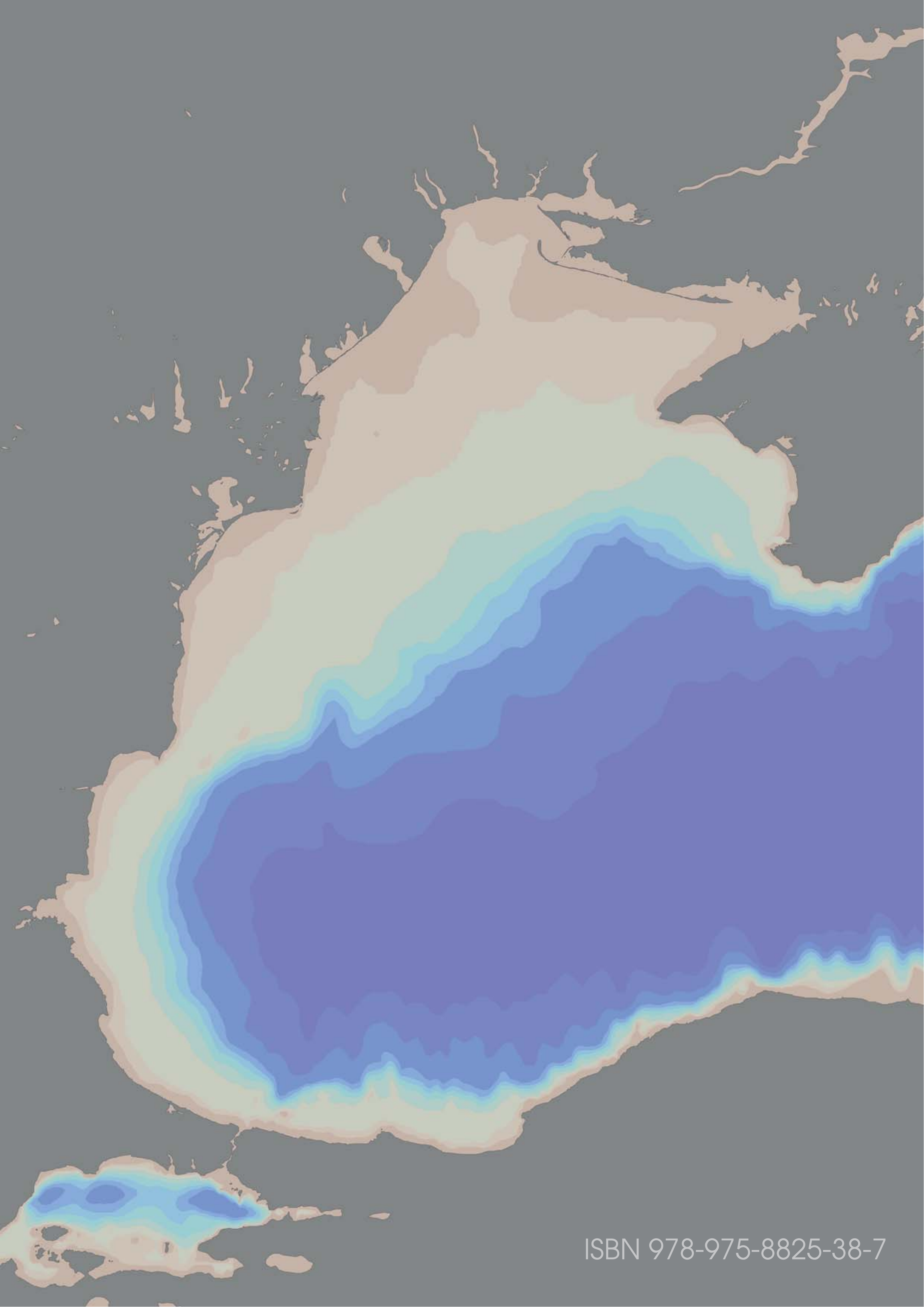
Satilmis, H.H., L. Bat, F. Sahin, F. Ustun, Z.B. Ozdemir, and A.E. Kideys. 2007. Distribution of anchovy (*Engraulis encrasicolus ponticus*) eggs and larvae off Sinop in 2003 (southern Black Sea). Rapp. Comm. Int. Mer Médit, 38: 589.

Satilmis, H.H., S. Mavruk, L. Bat, and D. Avsar. 2014. Seasonal changes of ichthyoplankton assemblages of Sinop coasts in southern of the Black Sea, Turkey. Turkish Journal of Fisheries and Aquatic Sciences, 14: 403-411.

Uygun, O. 2015. Composition of fish larvae in Sinop-Akliman coast of the Black Sea, (in Turkish). Sinop University, Institute of Natural and Applied Sciences, MSc Thesis. 164 p.

Yankova, M., D. Pavlov, P. Ivanova, E. Karpova, A. Boltachev, B. Oztürk, L. Bat, M. Oral, and M. Mgeladze. 2014. Marine fishes in the Black Sea: Recent conservation status. Mediterranean Marine Science,15: 366-379.

Yüksek, A. and A.C. Gücü. 1994. Computerized identification of the Black Sea pelagic fish eggs-version 1.2 (in Turkish). Black Sea Education, Culture and Environment Foundation, Istanbul, 65 p.



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