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EUROPE, THE AMERICAS AND WEST AFRICA

World Seas: An Environmental Evaluation

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Chapter 8

Black Sea

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8.1 GEOGRAPHY, TOPOGRAPHY, AND GEOLOGICAL DESCRIPTION

The Black Sea, is situated in south-eastern Europe, partly bordering Asia. Its south coast is the Pontic Mountains with the Caucasus Mountains to the northeast, while the topography of the north-western (NW) coast (except for Crimea) is relatively low and flat. Its coastline is about 4400 km long. The Black Sea is classified geomorphologically into a shelf, the continental slope and a deep-sea depression (Fig. 8.1). The shelf edge slope is steep and the shelf is basically narrow except for the NW.

Its connection to the World Ocean is through the Aegean and Mediterranean Sea, where 300 km^3 $year^{-1}$ of mesohaline water passes out through the Bosphorus Strait (Ludwig, Dumont, Meybeck, & Heussner, 2009). As part of a two-way hydrological exchange, the Black Sea's cooler and less saline outflow floats over the warm, more saline Mediterranean inflow. Part of this passage include the Sea of Azov and the Strait of Kerch.

Although total basin precipitation is less than evaporation (Jaoshvili, 2002), the water supply from several big rivers, such as Danube, Dnieper, Rioni, etc. with a total river catchment area of about 2.4×10^6 km^2, give a positive freshwater balance, resulting in a low salinity in the upper layer of between 18 psu in the open sea to 16 psu close to the shore. The river input in the NW causes a drop of salinity of up to 5 psu close to river mouth regions. The amount of freshwater and nutrient input into the southern parts of the Black Sea is relatively small.

Beach sediment texture is variable, and coarse and medium sediments form about 35% of the beaches (Fig. 8.2) (Allenbach et al., 2015), providing sedimentation rates in the NW part of 2.3 mm $year^{-1}$ (Gulin, Aarkrog, Polikarpov, Nielsen, & Egorov, 1997).

Terrigenous fine sand supplied by the big rivers forms the main new accumulations of sediments, actively transported by wave-induced longshore currents. Deep sediment depositions contain three layers, with the uppermost containing organic carbonates and pyrite, followed by one of low-carbonate high organic content and a bottom layer with very low organic content (Yucel, Moore, Butler, Boyce, & Luther III, 2012).

The Black Sea margin is well studied, but as it is sediment-starved, its subsidence record is difficult to reconstruct (Shillington et al., 2008). The region has experienced several episodes of extension and shortening since the Permian (Robertson et al., 2014) and can be subdivided into eastern and western basins according to its basement structures. For extended periods during the Quaternary, it formed a lacustrine environment. The Holocene flooding over the shallow sill of the Bosphorus Strait (Esin, Yanko-Hombach, & Kukleva, 2010), was followed by a more gradual marine transgression. The modern sedimentary environments of the basin comprise continental shelves, canyon-scarred continental slopes and deep-sea fans (Allenbach et al., 2015).

1. Except the corresponding author (NT), all other co-authors are listed alphabetically and have equivalent contributions.

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FIG. 8.1 The Black Sea.

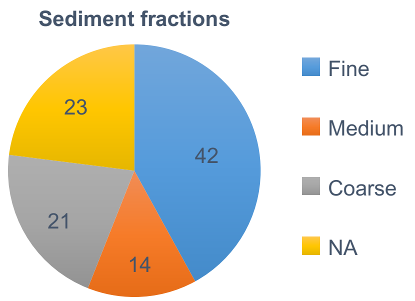

FIG. 8.2 Characteristics of the Black Sea beach sediment texture (according to Allenbach et al., 2015).

8.2 PHYSICAL OCEANOGRAPHY AND CLIMATE

8.2.1 Circulation Characteristics

The horizontal flow is strongly influenced by the cyclonic Rim Current, a permanent feature of the upper layer circulation (Kubryakov & Stanichny, 2015). This current is meandering and encircles the entire basin, forming a large cyclonic gyre and two cyclonic cells in the central basin (see Fig. 8.1). The general circulation is driven by buoyancy difference caused by the large freshwater input on the NW shelf, and by water from the Bosphorus Strait (Ivanov & Belokopytov, 2013), in addition to the wind stress curl, and it follows the steep continental slope. Current speed varies with the amount of discharge from rivers and variations in the wind. Current speeds of 50–150 cm s^{-1} have been measured in the upper layer of the Rim Current (Oguz & Besiktepe, 1999) and its meanders typically have a timescale of 50–150 days (Korotaev, Oguz, Nikiforov, & Koblinsky, 2003).

The Rim Current is most intense in winter–spring. Strong mesoscale variability is observed causing the formation of a number of quasi-permanent anticyclonic eddies on the coastal side of this current. The dynamic events of meandering, eddy formation, and detachment take place on weekly timescales and may lead to considerable exchange between coastal regions and offshore areas (Oguz, Deshpande, & Malanotte-Rizzoli, 2002).

Intermediate and deep layers have strong currents and a well-organized flow structure (Korotaev, Oguz, & Riser, 2006). A well-defined cyclonic circulation extends from the surface to the bottom, without reversal in its direction. Deep currents are steered by the steep topographic slope, and are well correlated with surface currents.

8.2.2 Main Physical Features and Freshwater Discharges

The Black Sea exhibits strong and permanent vertical stratification, with well-mixed low-salinity surface waters of river origin and precipitation, overlying high-salinity deep waters of Mediterranean origin (Ozsoy & Unluata, 1997). An important thermal feature is the cold intermediate layer (CIL), a structure conventionally identified by temperatures <8°C and a vertical extent that is limited to the upper 100 m layer, corresponding typically to ~15.4 kg m^{-3} isopycnal. The CIL forms as a result of intense cooling of surface waters during winter and it prevails in the form of a distinct subsurface water mass during the rest of the year when the surface-mixed layer is stratified by warming, and/or increased river runoff (Akpinar, Fach, & Oguz, 2017). Decoupling of vertical mixing leads to a deep-water salinity increase to 22.3 psu and temperatures rise to around 8.9°C (Fig. 8.3) (Ostrovskii & Zatsepin, 2016). The main source of oxygen for deeper waters is the permanent CIL at depths of 50–130 m.

The hydrochemical environment also shifts from oxygenated to anoxic, as bacterial decomposition of sunken biomass utilizes all of the free oxygen. Weak geothermal heating and a long residence time create a very thick convective bottom layer (Korotaev et al., 2003).

The biologically productive, oxic layer extends to nearly 50 m, after which there is undetectable dissolved oxygen (<5 mmol O_2/m^3) (Gregg & Yakushev, 2005). This deoxygenation process is different to that in the deep sea and is induced by intrinsic hydrodynamic reasons, and on human-induced NW shelf hypoxic events. Model-based simulations and observations show distinct evidence of both phenomena (Vandenbulcke, Capet, & Grégoire, 2017). Seasonal hypoxic events occur annually in the northern part of the shelf, and the oxygen-rich top layer of the Black Sea shallowed from 140 to 90 m deep between 1955 and 2015 (Capet, Stanev, Beckers, Murray, & Grégoire, 2016).

The buoyancy flux affects Black Sea circulation dynamics (Korotaev et al., 2006). Net buoyancy flux, that is, buoyancy due to net heat flux and freshwater flux at the sea surface (thermal/haline buoyancy flux), shows a gain (i.e., the upper ocean stabilizes from March through September, and shows a loss (i.e., destabilizes) in other months. River runoff, in particular the Danube, has a large influence on the dynamics of the continental shelf by changing the heat and freshwater

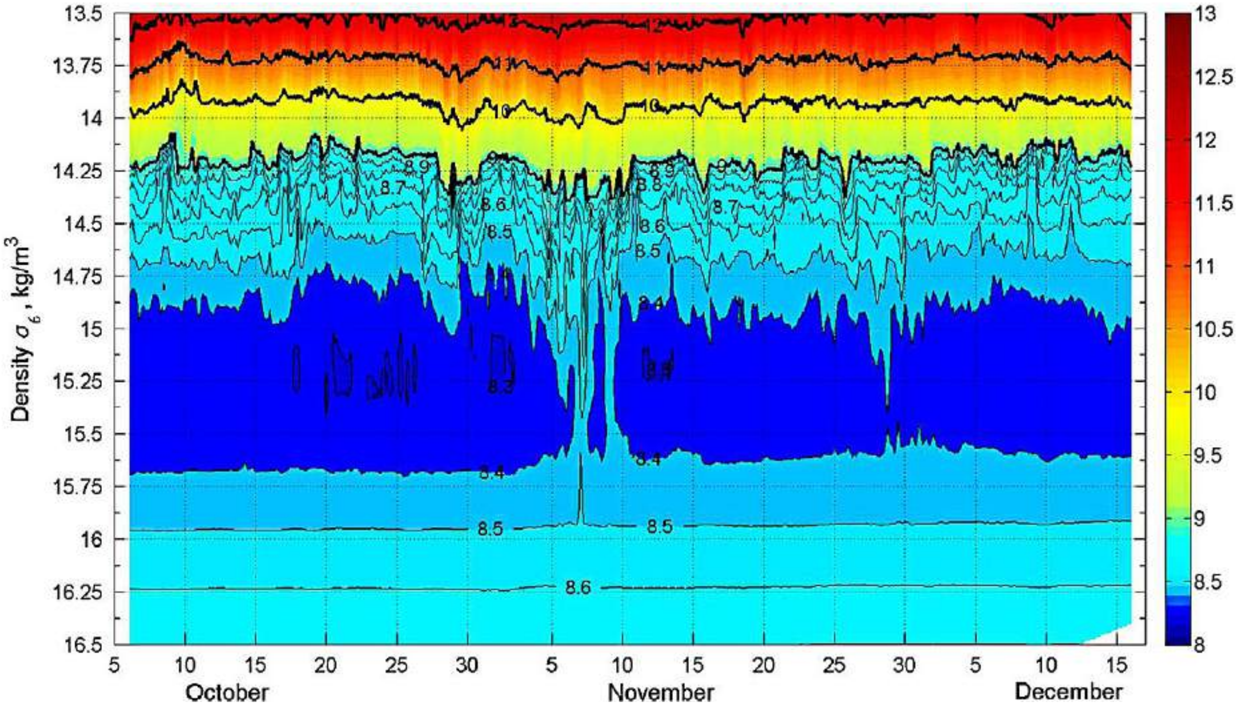

FIG. 8.3 Time-potential density diagram of sea temperatures in Gelendzhik Bay, Rim Current area, derived in December 2014 (according to Ostrovskii & Zatsepin, 2016).

fluxes, especially in the NW shelf. The Danube monthly mean discharge ranges from 4000 to 9000 $m^3 s^{-1}$ on climatological timescales (Vorosmarty et al., 1997), which contributes to the dilution of surface waters (Stanev, Bowman, Peneva, & Staneva, 2003).

Interruptions in the permanent pycnocline current velocity and related increases of vertical turbulent mixing may occur sporadically throughout the entire year in the core area of the Rim Current, being more frequent in the autumn or winter. The deep ventilation mechanism in the aerobic zone may be important for maintaining the thickness of the aerobic layer and for keeping the upper boundary of the H_2S zone within the permanent pycnocline area (Ostrovskii & Zatsepin, 2016). In the Black Sea, the most important phenomena sustaining the ecosystem is the retention of the H_2S boundary in the permanent pycnocline layer.

8.2.3 Atmospheric Circulation

The Black Sea is influenced by North Atlantic climate through cross-Europe atmospheric connections. High- and low-pressure centers over the Caspian and North Seas, alongside the North Atlantic Oscillation, provide coherent synchronous fluctuations with Black Sea hydrometeorological properties (Oguz, Dippner, & Kaymaz, 2006).

In summer, clear and dry weather is mainly due to the extension of the Azores anticyclone ridge across Europe and Mediterranean to the Black Sea. In winter, a vast anticyclone over Siberia has a ridge extending to NW coasts of the Black Sea, where pressure is generally lower. If a separate high-pressure center develops over the Baltic and Scandinavia, very cold Arctic air is brought to the Black Sea. It was found, however, that extreme daily minimum temperatures have increased in south-east Romania during recent decades (Croitoru & Piticar, 2013). Snow storms and regional strong winds in the NW Black Sea are due to the coupling between this cold advection and the warmer air brought by mobile depressions coming mostly from the Mediterranean Sea (Georgescu, Tascu, Caian, & Banciu, 2009).

8.3 MAJOR COASTAL AND SHALLOW HABITATS

The Black Sea is a basic European watershed, with higher productivity than the neighboring Mediterranean (Oral, 2013), with dynamic wetland ecosystems in coastal areas and in the mouths of rivers. According to the Habitat Directive (92/43/EEC) and the Interpretation Manual of European Union Habitats—EUR28, 2013 (Milchakova, Aleksandrov, Bondareva,

FIG. 8.4 *Left*: Coast near *Zostera* sp. field after a storm, photo by Miroslav Rangelov IOCCP-BAS. *Right*: *Zostera*_fields, photo by Sonya Tsoneva & Valeri Georgiev IBER-BAS, Roman Tashev INB-BAS.

Pankeeva, & Chernysheva, 2015; Zaharia, Micu, Todorva, Maximov, & Nita, 2008), coastal and halophytic habitat classes of prior importance are as follows:

1110–1 *Zostera* meadows on clear or slightly muddy fine sands, with very high conservation value. These are highly productive zones and provide a number of ecosystem services, such as provision of habitat and enhanced biodiversity. As an important bioindicator of system health, they stabilize sediments and are natural hotspots for carbon sequestration. The seagrass beds are being reduced as a result of human activities such as turbidity increase, eutrophication, dredging and fishing, direct clearance due to coastal or harbor constructions, and negative effects of climate change (Duarte, 2002) (Fig. 8.4).

1110–4 Well-sorted sands. These are inhabited by indicator species as *Tellina tenuis*, *Diogenes pugilator*, *Donax trunculus*, *Chamelea gallina*, etc., with very high conservation value.

1130 Estuaries. The Danube's mouths, with its former estuary filled with sediments, form a Delta, that, with the Black Sea water, form a characteristic mixing zone shaping specific biocenoses, down to 20 m depth.

1140–3 Midlittoral sands. These are of particular importance as feeding grounds of water birds, and contain diverse invertebrate and algal communities.

1150 Coastal lagoons. These support both marine and brackish species, with characteristic fish species and rich and diverse vegetation.

1170–4 Boulders and blocks. Occurring in the midlittoral and infralittoral of rocky shores, this habitat has high structural complexity, forming mosaics of microhabitats, allowing species of deeper areas to inhabit nearshore zones.

1170–8 Infralittoral rock with *Cystoseira* sp., *Phylliphora* sp., etc. This habitat is the richest in species and has highest diversity in the Black Sea. Its dynamics are influenced by their seasonally diverse vegetation. *Phyllophora* fields are nursery areas for many species of aquatic organisms.

1170–9 Infralittoral rock with *Mytilus galloprovincialis.* Overlapping with 1170–8, but continuing to deeper waters, this habitat contains highly diverse fauna of endangered invertebrates and fishes, and has a crucial ecological role in benthic-pelagic coupling.

The countries of the Black Sea have attempted to synchronize their legislation (Milchakova & Phillips, 2003) of Protected Areas based on the EU NATURA 2000 list, the European Red List of Habitats (http://ec.europa.eu/environment/nature/knowledge/redlist_en.htm), EUNIS (http://eunis.eea.europa.eu/) classification, and other interacting directives. These instruments review the current status of all natural and seminatural marine habitats, highlight the pressures they face, and provide guidelines for environmental protection and restoration within the EU2020 Biodiversity Strategy.

8.4 OFFSHORE SYSTEMS

Coastal biogeochemical processes are connected dynamically to the deep sea (Zatsepin et al., 2003). Productivity of the shelf system appears to be primarily phosphorus-limited, whereas the open sea system would appear to be nitrogen-limited and much more dependent on mixing processes for nutrient supply (Garnier et al., 2002).

The physiochemical conditions dictate seasonal dynamics that support food webs that are well adapted to the brackish, nutrient-rich conditions (Oguz et al., 2002). Predation at upper- and mid-trophic levels drives system-wide trophic cascades (Daskalov, 2002). The annual cycle of phytoplankton in the Black Sea has been well studied, but only limited studies have focused on deep waters. The main groups of phytoplankton are dinoflagellates, diatoms, coccolithophores, and cyanobacteria near river estuaries (Agirbas, Koca, & Aytan, 2017). Generally, there is a usually high phytoplankton biomass in winter, represented mainly by diatom and dinoflagellate-dominated species, with maxima in open waters in January to March (Berseneva, Churilova, & Georgieva, 2004), often containing the same species as during the spring and this is recognized as the winter–spring bloom (Mikaelyan, Chasovnikov, Kubryakov, & Stanichny, 2017). This is often followed by a weaker mixed assemblage below the seasonal thermocline during summer months, forming marked vertical stratification and a warm, shallow mixed layer (Oguz & Merico, 2006), and a surface-intensified autumn production. The benthic zone also plays an important role in Black Sea nutrient cycling, as chemosynthetic organisms and anoxic geochemical pathways recycle nutrients that can be upwelled to the photic zone, enhancing productivity (Friedrich et al., 2002).

In recent decades, the spring bloom has become smaller than the autumn proliferation of algae and often is not observed at all. This is atypical for temperate seas, where the prominent spring phytoplankton increases occur. A new Pulsing-Bloom hypothesis was proposed by Mikaelyan et al. (2017), for the highly stratified waters of the Black Sea. It relates the biological response to physical forcing and chemical fluxes and predicts the pulsing episodes of phytoplankton in the upper layer in winter–spring during cold and regular years. This is supported by chlorophyll dynamics, and the pattern of depleted inorganic nitrogen during the winter–spring period, when the phosphate concentration remains relatively high.

The Pulsing-Bloom hypothesis predicts that in the absence of cold winters, spring blooms will disappear, with unpredictable consequences for higher trophic levels. Decoupling the periods of food abundance and reproduction of zooplankton and pelagic fish can lead to decreases in their populations (Arashkevich et al., 2014). These changes induced by climate shifts should receive more attention (Mikaelyan et al., 2017).

The Black Sea's pelagic ecosystem has experienced substantial changes since the 1960s. Nutrient enrichment was followed by food web changes, such as additional phytoplankton summer blooms (Dorofeyev et al., 2012) and large increases of gelatinous and opportunistic species. This lasted till the early 1990s, and resulted in regime shifts in zoo- and phytoplankton populations (Daskalov, Grishin, Rodionov, & Mihneva, 2007).

Since then, less eutrophication and a decline of the invasive ctenophore *Mnemiopsis leidyi* (Shiganova, 1998) has occurred. This has been followed by oscillations of blooms of the comb jelly and the collapse and recovery of the anchovy fishery (Miladinova, Stips, Garcia-Gorriz, & Macias Moy, 2016). Changes in the planktonic food web are also reported for ciliate protists, which are especially sensitive to the changes in the Black Sea food chain (Gavrilova & Dolan, 2007).

Although some potential for partial recovery have been observed in the Black Sea, whether the Black Sea will continue its current way to recovery or will return to its highly eutrophic state will depend, to a large degree, on socioeconomic choices (Langmead et al., 2009). Even in the most optimistic scenario, the Black Sea will never revert to the pre-1960s state after the introduction of *Mnemiopsis* (Llope et al., 2010).

8.5 CLIMATE CHANGE IMPACTS

8.5.1 Shrinking of the Habitable Area

Capet et al. (2016) discovered that the oxygen-rich top layer of the Black Sea decreased in its vertical extent from 140 to 90 m deep, which amounts to a >40% decrease in habitable waters.

The report stated two causes: an abundance of nutrients leading to algal blooms and increased oxygen consumption, and global warming. Warmer winters lower the volume of dense water, and this lowers the oxygen content as well. Further atmospheric warming will directly affect the vertical stability of the Black Sea oxygenated layer, thus causing ecological and economic damage in the region.

8.5.2 Air Temperature Rise and Precipitations

The Black Sea experiences alternating warm and cold regional climatic periods with a mean duration of about 10–12 years (Oguz et al., 2006). The last cold period was replaced by a warm period in the mid-1990s, but the expected return to a cold period in the 2000s did not occur (Agirbas, Feyzioglu, Aytan, Valente, & Yildiz, 2015), with winters of 2014 and 2015 being two of the warmest in last 30 years.

Future projections for air temperatures and precipitation (IPCC AR4, 2007) show that the most significant projected changes by 2080 relate to the increase in air temperature (warmer summers, more frequent/intense heat-wave periods) and to a reduction in precipitation for the Black Sea region, with more intense rainstorms, drought, and heat-waves.

8.5.3 Sea Surface Temperatures

Seasonal sea surface temperatures (SST) characteristics, based on AVHRR data from 1982 to 2012, show average summer temperatures of 23.24°C for the Black Sea, with winter temperatures being 7.49°C (Shaltout & Omstedt, 2014). Sea ice is more frequent in the NW but it can form along the west coast during the coldest winters. Ice disappears completely by the end of March.

As with air temperature, long-term anomaly data since 1885 shows a linear warming trend with an overall temperature rise of 0.9°C (Oguz & Merico, 2006).

During recent decades, the upper water column layer has shown distinct physical changes. There is a clear warming trend (von Schuckmann et al., 2017), as high as 0.08°C $year^{-1}$ between 1982 and 2012 and 1993–2015, and an average increase of 1.9°C over the 23-year period. This increase was low between 1982 and 1994, and was followed by a pronounced warming phase during 1993–2014. Similar variations were observed in the summer–autumn (May–November) mean subsurface CIL temperature fields. This indicates climatic changes within the upper 100 m water column above the permanent pycnocline. Oguz et al. (2006) found that strengthening of the NAO coincided with the general warming trend and its positive phase resulted in colder, drier winters in the Black Sea. Decadal scale temperature changes in the Black Sea are much more pronounced with respect to the global warming signal (oceanic average increase since the 1980s is 0.5°C in the upper 100 m). This has likely impacted the flow, stratification, and mixing characteristics of the Black Sea as well as its ecosystem (Shaltout & Omstedt, 2014).

8.5.4 Sea Level Rise (SLR) and Erosion

Sea level change along the Black Sea coast is monitored from long-term station information and new applicable satellite data (Avsar, Jin, Kutoglu, & Gurbuz, 2016). Tsimplis, Josey, Rixen, and Stanev (2004) observed a trend of 2.2 mm $year^{-1}$ sea level change rate over the period 1960–2000, attributed largely to the surface fresh water flux. The reported tide gauge data collected from 1930 to 2000 for cities around the Black Sea are as follows: 3.7 mm $year^{-1}$ for Pito (Georgia), 6.8 mm $year^{-1}$ for Batumi (Georgia), and 1 to 2 mm $year^{-1}$ for the other cities (Varna in Bulgaria, Constantza in Romania, Sevastopol in Ukraine, Tuapse in Russia), which is consistent with global trends (Karaca & Nicholls, 2008). The Copernicus Marine Environment Monitoring Service (CMEMS) Black Sea Monitoring and Forecasting Center (BS-MFC) operates daily analysis and forecasts for the Black Sea, covering the period 2005–2015. Argo floats have been the main observing network for measuring sub-surface temperature and salinity in the Black Sea over the last decade (Balan et al., 2017).

Significant sea level (SLR) rise could cause flooding over large areas in the Danube Delta and NW part of the Black Sea coast. This risk is limited as SLR is expected to be modest, tides are nonexistent and currents very weak along the Black Sea shoreline. However, most of the coastline is potentially vulnerable to erosion processes. Since sea level will continue to rise, changes in water level and increased storminess could lead to beach erosion, cliff retreat, and to the degradation of protective structures such as breakwaters.

The Black Sea catchment is facing important climatic and land use changes that may increase pollution, vulnerability of water resources, and beach erosion through SLR, while appropriate decision-making is hindered by the lack of reliable environmental monitoring data (Lehmann et al., 2017).

8.5.5 pH Change

The surface layer shows a pH change as a result of increased uptake of carbon dioxide in the troposphere. This phenomenon is potentially dangerous for marine biota (Polonsky, 2012), but acidification can also be a result of seawater pollution.

Significant century-scale acidification of the upper Black Sea layer cannot be determined from available data for the last century because of its incompleteness, high level of noise, and strong interannual to decadal variability. Decadal-scale acidification for the periods 1960, 1980, and 2000, was 0.4 pH units $decade^{-1}$ at the surface, and 0.2 pH units $decade^{-1}$ at 10 m. This high rate of upper layer acidification is mostly due not to the concentration of CO_2 in the atmosphere, but to intensification of the upward motion in the subsurface layer transporting low-pH water to the surface (Polonsky, 2012).

8.5.6 Storms

The western and north-eastern parts of the Black Sea have the most intense storms, with waves estimated as 7.8 m in height and period of 11.0 s with a return period of 100 years, maximal possible height being >14 m (Gippius, Arkhipkin, & Surkova, 2012).

>50% of storm events identified for 32 years are the consequence of “coupling” of a continental anticyclone with a Mediterranean cyclone arriving over the Black Sea (Chiotoroiu & Ciuchea, 2009).

Storm distribution along the Romanian and Bulgarian coast shows a contrast between a very active interval (1961 until the 1980s), which caused high-intensity coastal erosional and accretion processes with high sediment transport rates, and a relatively quiet period with low variability (1979–2000) (Valchev, Trifonova, & Andreeva, 2012; Vespremeanu-Stroe & Tatui, 2005). The same study, based on a 63-year period (1948–2010), found a shortening of storm duration due to a shift to the north of the prevailing direction of storm forcing winds.

Extreme storms in the NW region have a mean recurrence rate of 7 years and are considered to be responsible for the sediment transport south from the Danube delta coast (Zainescu, Tatui, Valchev, & Vespremeanu-Stroe, 2017). Critical thresholds for storm impacts on Bulgarian coastal morphology (Trifonova, Valchev, Andreeva, & Eftimova, 2012) showed that storms with integral wave energy varying within threshold values $0.4\text{–}0.7 \times 10^6\,\mathrm{J\,m^{-2}}$ are regarded as capable of causing significant morphological changes.

Estimations of wave height with return periods between 1 and 100 years, based on SWAN models showed that waves of >8 m height are common during autumn storms, occurring about once in 10–20 years (Lopatoukhin, Boukhanovsky, & Chernysheva, 2009).

8.6 HUMAN POPULATIONS AFFECTING THE AREA

8.6.1 Cities and People

About 140 million people live along the Black Sea coast (Allenbach et al., 2015), the highest population densities being in big port cities (see Fig. 8.1).

The Black Sea region and its surrounding territories have served as a crossroad between Europe, Asia, and Africa. The ports around it owed their prosperity to commercial connections, as they developed secure trade routes to a network of overseas locations (Lyratzopouoou & Zarotiadis, 2014). One major change to the region is the Danube–Black Sea Canal, completed in 1984, which made a link to the North Sea (through the Rhine–Main–Danube Canal) and the traffic through the river and the industry along it has increased substantially since then. Aquaculture, fishing, and agriculture alongside transport, accommodation, and food services are some of the basic elements of the economy in the coastal area (EUNETMAR, 2014, Black Sea).

In many coastal areas, high population density is seasonal due to the large number of tourist resorts that increase populations 10-fold, causing serious anthropogenic pressure. This, based on intense urbanization of some valuable land and protected areas including dunes and sea beaches, has damaged many of the natural areas along the Black Sea coast.

From the beginning of the 21st century to the 2008 world economic crises, the region had sustained growth, with high levels of trade and investment, but following the collapse of financial markets the growth of the Black Sea region was interrupted sharply (Gavras, 2010).

All of the port cities are situated in naturally protected bays and their favorable geographic position gives the cities significant dynamics. Some ports like Burgas, Mangalia, Sochi, and Sevastopol are attractive resorts with transport and commercial importance, while others like Constanta, Odessa, Novorossiysk, Samsun, Varna are trade ports with facilities for crude oil refining, gas stocking capacity (Zygiaris, 2012), and are hubs for container traffic for cereals and grains (Martin, 2002). The port of Constanta enjoy a special position on several Pan-European Corridors and its water depth of up to 19 m can accommodate tankers with capacity of 165,000 dwt (deadweight) and bulkcarriers of 220,000 dwt (www.portofconstantza.com).

Measures such as activities to facilitate trade, elimination of dual taxation, and agreements for investments could work to benefit mutually the different countries, some of them being EU members, while others share historical connections.

8.6.2 Marine-Based Pollution; Pollutants and Pollution Hotspots

Land-based sources account for >70% of pollution entering the sea through rivers, one of the most important groups being nutrients. They have, however, showed a decline since the 1990s, although nutrients coming from the Danube River in recent years (mainly nitrates) remain significant but stable (ICPDR, 2010, Water Quality in the Danube river basin).

Pesticide concentrations in water have seldom been measured. In the frame of the international monitoring program 2004–2005 on the Black Sea (BSIMAP) very low-level pesticide pollution (DDT and lindane) was observed in coastal waters in general, with some occasional patches with very high pesticide concentrations related to large freshwater discharge into the sea after floods. Unexpectedly, the entire coastline contained a very high level of DDTs in bottom sediments without any clear indication of reduction, while other pesticides were close to their detection limits for all costal zones (Koroshenko, n.d., SER 2001–2006/7).

FIG. 8.5 Tourism increases. Sozopol Marina, photo by Miroslav Rangelov IOCCP-BAS.

Decreasing eutrophication measured as N and P discharges continue, but their 2000–2005 average values are still 1.5 times higher than their levels in 1955–1965, with P-PO4 flux supplied by the Danube maintaining a steady level between 10 and 20 kt year^{-1} at the Sulina discharge point to the sea. Hypoxia has decreased in Romanian coastal waters compared to the previous decade, and no hypoxia cases were observed in Bulgarian waters in 2001–2005. Relatively low oxygen concentrations tend to occur more predominantly in the northern sector upstream of the Danube delta region (Oguz, 2007).

The coastal regions face increasing development pressures due to high urbanization, population increase, and tourism, as climatic conditions are favorable in the whole Black Sea coastal belt (Guclu, 2011). Although tourism is considered a generally environment-friendly sector (Fig. 8.5), its uncontrolled development and excessive use of natural resources could become a crucial factor in environmental degradation (Dimadama & Chantzi, 2014), with tourism investment in almost all countries expected to rise by 2022 (Kereselidze, 2013).

The Black Sea has been subject also to (as of May 2010) >234 recorded exotic species (Daskalov, 2002; Zaitsev & Mamaev, 1997).

8.6.3 Coastal Hydrocarbons

Petroleum pollution is a major problem for the whole sea, with levels that usually exceed standard Maximum Allowed Concentration (0.05 mg L^{-1}), almost everywhere in the open sea. Very high spatial heterogeneity of total petroleum hydrocarbons (TPH) distribution is observed, such that about half of samples can be considered pollution-free. During a survey in the period 2005–2007, TPH content in bottom sediments were taken and analyzed, with the average concentration of TPH being about 0.05 mg g^{-1} at most sites. However, some samples from extremely polluted sites near large ports, oil refineries, or oil terminals in Romania, Turkish, and Russian waters exceeded the threshold 13–16 times. Higher concentrations were also detected in bottom sediments close to big cities, where municipal and manufacturing waste and the discharges from rivers play a substantial role (Koroshenko, n.d., SER 2001–2006/7). Heavy fractions of TPH, polycyclic aromatic hydrocarbons (PAH), some of them being carcinogens and threats to human health, tend to persist in bottom sediments close to their source point, with no clear legislation relating to their monitoring, and their elimination is exclusively performed by prokaryotic communities (Todorova, Mironova, & Karamfilov, 2014). Based on 16 priority PAH, bottom sediments near big cities and ports, such as Odessa, Sochi, Istanbul, Danube delta, the Bosphorus strait and some places on the Romanian and Bulgarian coast, tend to be classified as being highly polluted (Tiganus, Coatu, Lazar, Oros, & Spinu, 2013) (see Box 8.1).

BOX 8.1 Case Study/Sevastopol Bay: Long-Term Anthropogenic Impact

Being a regional center, the city of Sevastopol (southern-western part of the Crimean Peninsula) is one of the most urbanized areas of the Crimea because of its big commercial and industrial port. Its coastal area is a series of enclosed bays among which Sevastopol Bay is one of the largest in the Black Sea and, as a consequence, is most heavily subjected to human impact. Long-term anthropogenic loads have already caused adverse changes in the environment, affected marine organisms at every taxonomic level and, beginning at the end of the 1980s, Sevastopol Bay has been classified as an impacted zone with a wide spectra of contaminating substances among which oil hydrocarbons dominate (Mironov, Kirjukhina, & Alymov, 2003; Osadchaya, Alyomov, & Shadrina, 2004).

Persistent sources of the pollution (Fig. B.8.1) shape its zones and inhabiting biota. Long-lasting pollution determines the different status of all benthic habitats along established gradients of oil pollution. The recorded spread of pollution to the areas previously considered as environmentally being in good condition is accompanied by deterioration of biological (macrobenthic) quality (Fig. B.8.2).

Evaluation the bottom macrofauna quality using the index M-AMBI (Borja, Josefson, Miles, et al., 2007) has shown a detectable deterioration of overall environmental status in Sevastopol Bay: by 2009, number the sites with “good ecological status” decreased up to 7% compared with 26% in 2000, and the area with “poor” environmental conditions has expanded up to 33% from 20%.

The natural remediation period by the benthic organisms in these polluted marine ecosystems is estimated to be 10–20 years.

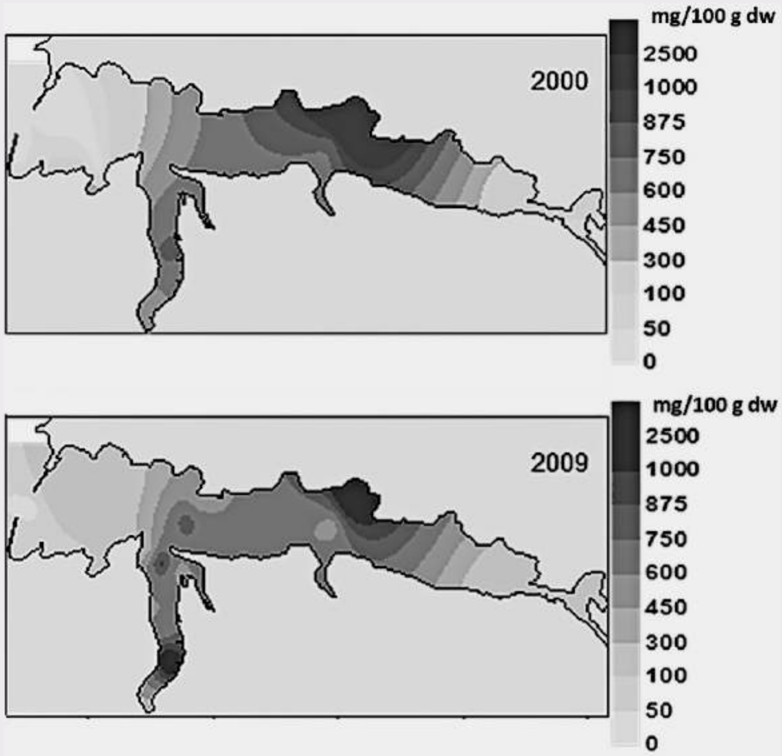

FIG. B.8.1 Patterns of oil hydrocarbon distribution in Sevastopol Bay, mg per 100 g of sediment dry weight (Osadchaya, 2017, current article).

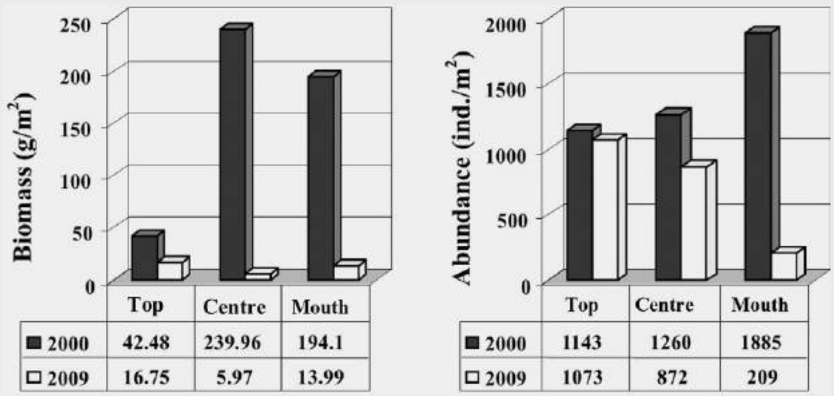

FIG. B.8.2 Long-term changes of the biomass and abundance of macrozoobenthos in different regions of the Sevastopol Bay (Osadchaya, 2017, current article).

8.6.4 Oil Pollution in Open Waters, Pollution From Ships

Marine oil spills, from illegal bilge water discharges or from accidents, pose serious risks of ecological damage and socio-economic losses (ClearSeaNet).

The Black Sea is vulnerable due to intense transportation of oil products and its semi-enclosed nature. Pipelines and tankers for oil and gas from the Caspian basin and Russia to the West cross the region (Lyratzopouoou & Zarotiadis, 2014). CleanSeaNet, a satellite-based pan-European oil spill and vessel monitoring service has been available since 2007 from the European Maritime Safety Agency. This service aims to provide information about oil spills and pollution alerts (and related data) to national authorities in 27 coastal states in near real-time (Fig. 8.6).

Maritime accidents caused by severe weather phenomena.

Storms in the Black Sea are frequent from November to March, being stronger in the NW. Along the Romanian coast they have been defined using two parameters: wind speed $>12\,\mathrm{m\,s^{-1}}$ for at least 12 consecutive hours and sea state 4 near the coast (wave height between 1.25 and 2.50 m). The highest number of accidents at sea caused by severe weather phenomena for a 26-year period occurred in Romanian waters in winter, between October and March, with a maximum in January and December (Chiotoroiu & Ciuchea, 2009).

8.6.5 Invasive Species

Exotic species brought by ships through exchange of ballast waters or other wastewaters affect the Black Sea ecosystem, since they tend to proliferate due to lack of natural predators, and among them new invasive species are regularly discovered.

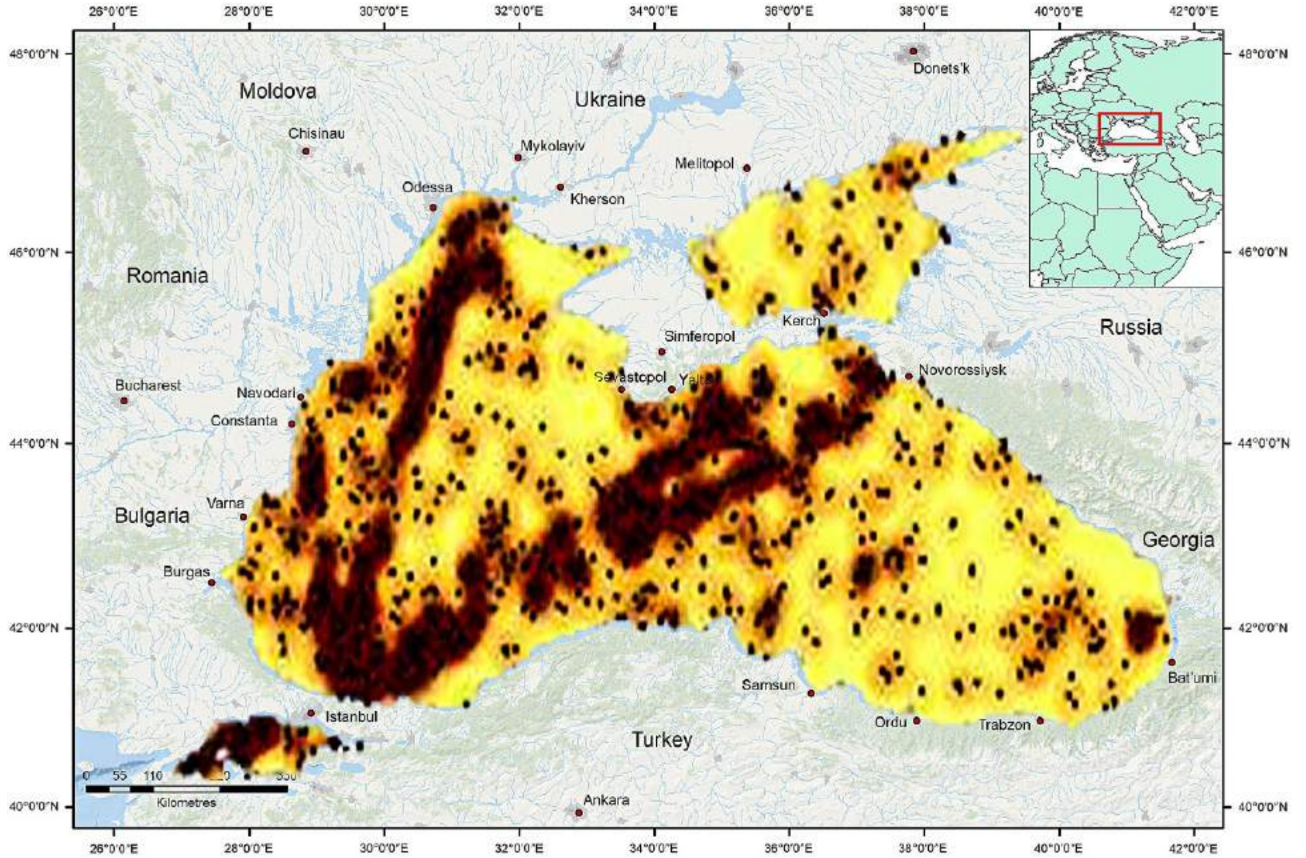

FIG. 8.6 The oil spills in the Black Sea for period 2000–2004. Map of oil spills based on images taken by synthetic aperture radars (SARs) of European satellites ERS-2 and Envisat (State of Environment Report 2001–2006/7).

8.7 RESOURCES

8.7.1 Oil and Gas

There are considerable stocks of hydrogen sulfide, gas, and oil available in the Black Sea and the full-scale extraction of some of these resources will require the development of new and complex technologies (www.eea.europa.eu). Most exploitation occurs in the shallow NW shelf, with Ukraine and Romania being traditional oil and gas producers and exporters (Popovici, 2009). The first deep-water well drilled in 2012 in the Black Sea has a potential gas production of approximately $17.8 \times 10^6\,m^3\,day^{-1}$ (ROPEPCA, 2016).

There is a need for renovating gas distribution systems and operational environmental protection, as the long-term impacts of such large-scale activities will have to be carefully assessed given the potential consequences on the marine ecosystem.

8.7.2 Fisheries

The Black Sea does not have an ecosystem-wide management authority, and the exploitation of resources is largely regulated by national commitment. There are attempts at bilateral mechanisms for regional fishery cooperation as a semienclosed sea that is party to UNCLOS (IP/B/PECH/IC/2012–069). All Black Sea countries exhibit similar trends in their industrial fish catch as most of the assessed stocks are overfished. In the late 1960s and early 1970s, Atlantic mackerel (*Scomber scombrus*), bonito (*Sarda sarda*), and bluefish (*Pomatomus saltatrix*) catches dramatically decreased, followed by turbot (*Scophthalmus maximus*), one of the most important commercial species, whose catch also had declined by the 1980s (Zaitsev & Mamaev, 1997). In the 1970s, overexploitation of larger pelagic predators, combined with increased eutrophication in the NW led to a dramatic increase in the catches of small pelagics such as sprat (*Sprattus sprattus*), anchovy (*Engraulis encrasicolus*), and Mediterranean horse mackerel (*Trachurus mediterraneus*), which was thought to be sustained by the extensive eutrophication that caused the ecosystem to be overproductive (STECF, 2015).

In the late 1980s, an alien invasive species, the ctenophore *Mnemiopsis leidyi* reached its maximum abundance in the Black Sea, and became a powerful food competitor of adult planktivorous fish (the anchovy fishery in the entire Black Sea collapsed in 1989/90), and a significant predator of their eggs and larvae (Keskin et al., 2015). After the collapse, the eastern region became the only region sustaining a relatively high anchovy catch (400,000 t), whereas the total catch within the rest of the sea was reduced to nearly one-third (Oguz, 2017). Today the most abundant and commercially important target species are anchovy and sprat (*Sprat sprattus*) (STECF, 2015). The most commonly caught species in the western Black Sea are European sprat (56%) targeted mainly by large-scale pelagic trawls from February to November. Anchovy in the Black Sea exhibits migration behavior mainly driven by the ambient temperature (Shulman et al., 2008). When cold temperatures approach in fall, anchovy adults and juveniles aggregate to form dense schools and start their wintering migration toward warmer waters in the southern Black Sea. A return migration commences in spring when water temperatures rise again (Fig. 8.7).

The coastal fishery has traditionally been carried out by small vessels (<12 m), which use mainly passive types of fishing gear, such as trap nets (uncovered pound nets), and beach seines in the inshore area, while target species vary according to season. In Bulgaria and Romania the bottom trawl fishery was banned, due to protection of vulnerable benthic biotic communities (Keskin et al., 2015). The Turkish fishery uses purse seiners to fish schools of overwintering anchovy along the southeastern Turkish coast during winter time (September to mid-April) after which industrial fishing is banned for 4.5 months. To control harvest, fishing is restricted to night time only, however there is no total allowable catch (TAC) in place. In an effort to reduce fishing pressure, the licensing of new fishing boats has been halted since 2015 and a periodic, voluntary fishing vessel decommissioning program has been applied since 2012 (Gucu et al., 2017).

Sustainable fishing in the Black Sea is under serious threat by illegal, unreported, and unregulated (IUU) fishing, which includes ghost fishing, and by destruction of the benthic ecosystem. A total of 65 illegal fishing cases have been reported in various exclusive economic zones (EEZs) in the Black Sea from 1992 to 2012 (Ozturk, 2013).

The Black Sea is still in an unstable condition, with a serious overfishing/recovery problem. Unfortunately, the quotas are enforced under political and social pressures to support short-term fishing prospects instead of the long-term sustainability. A variety of fisheries management actions such as quotas, effort reduction, area, and season closure of fisheries, can be applied by the authorities to improve the situation. Therefore, more straightforward management actions against overcapacity and overexploitation of fish stocks are urgently needed (Oguz, 2017).

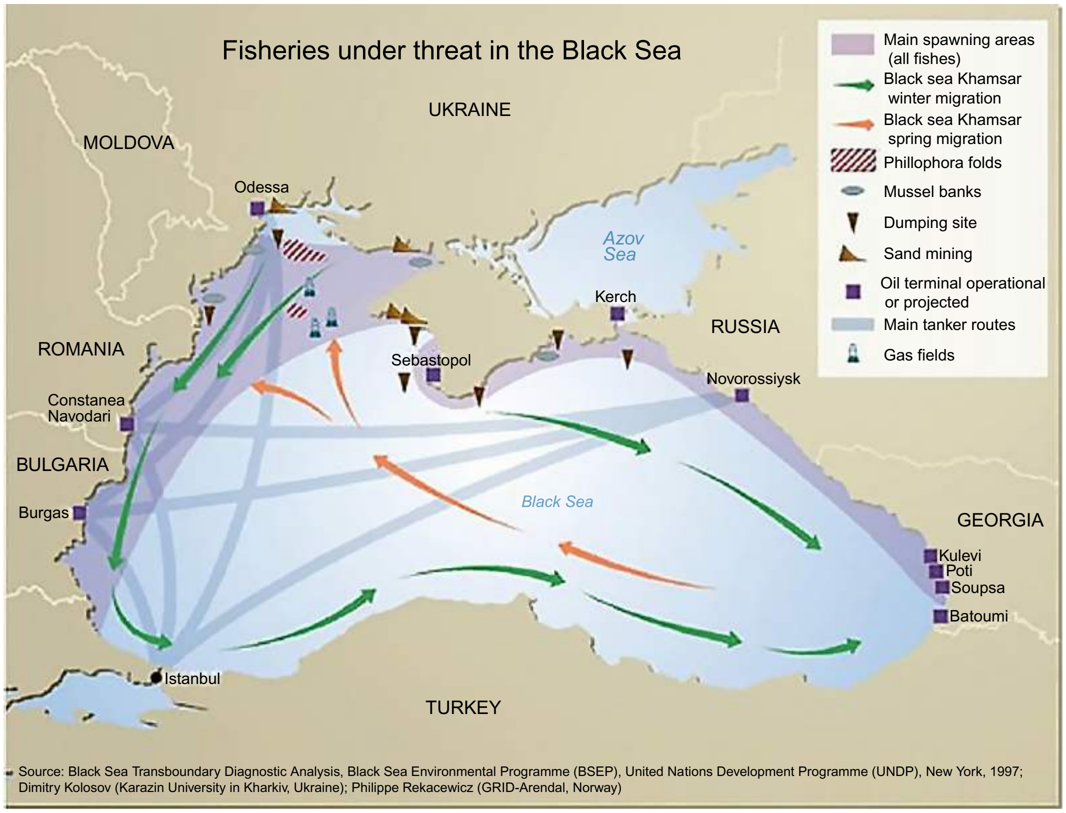

FIG. 8.7 Main routes of anchovy migration (according to Rekacewicz, 2006, http://www.grida.no/resources/6522).

8.8 THREATS AND MANAGEMENT

The main threats for the Black Sea ecosystem are water pollution, notably nutrients from land-based sources and by inputs of other harmful substances, including oil from vessels or land-based sources; invasive species from deballasting of vessels; overfishing and IUU fishing; erosion driven by sea level rise, extreme storm events, diminishing sediment supply from the heavily managed rivers; coastal development and poorly designed coastal protection schemes; river, coastal, and near-shore sediment mining; uncontrolled urban, tourist, and industrial development; and discharge of wastes straight into the waterways without treatment.

Thus, the Black Sea is a subject to multiple stressors, whose cumulative effects are neither well understood nor are they easy to be modeled for future prognosis. No sign of appreciable ecosystem rehabilitation is obvious (Oguz, 2017) and there is scientific uncertainty as to whether a more desirable equilibrium state is even possible, or when it might be reached. Real assessment of the current state, needed for management development, is hindered by the lack of systematic time series.

8.8.1 Protection and Conservation Measures, Deficiencies

The marine strategy framework directive (MSFD), is a long-awaited EU instrument central to the Integrated Maritime Policy, despite the lack of an EU Black Sea strategy. It requires EU Member States to reach or maintain good environmental status (GES) in the marine environment by 2020 (Lyons, Thain, Hylland, Davies, & Vethaak, 2010). Marine protected areas (MPAs) have been identified as crucial components of the program of measures to achieve GES.

Mapped classifications of biodiversity patterns are an important tool in conservation planning. Marine Ecoregions as defined by Spalding et al. (2007) are the smallest unit of their classification system. They are areas of relatively homogeneous species composition that are clearly distinct and are strongly cohesive units, sufficiently large to encompass ecological or life history processes for most sedentary species. The Black Sea has been defined as one ecoregion in that classification. Ozturk et al. (2017), however, suggest that there are four subregions based on biodiversity characteristics, which are the Pre-Bosphoric Region reaching from the Romanian border to Sile, the NW Shelf, Kerch Strait, and the Southern Black Sea.

To enable the MPA network to fulfill its critical role in the delivery of GES, both national progress and transboundary agreements toward designation of adequate MPAs will be required, as well as coordination at a regional scale and cooperation between Member State governments.

8.8.2 Marine Protected Areas

Oguz (2017) described the Black Sea as one of the most polluted and mismanaged semienclosed seas in the world. The adoption of appropriate management strategies requires an understanding of the potential response of the system to individual drivers of change.

Establishing MPAs is a key element toward the ecosystem-based approach of marine management in order to maintain ecological integrity and a sustainability (Fig. 8.8).

Bulgaria, Romania, and Turkey have established MPAs with similar categories of protection. Natura 2000 in Bulgaria and Romania and the Emerald Network and RAMSAR Convention in Turkey have been the basis of their MPAs. Bulgaria has 15 MPAs both marine and terrestrial, Romania has two with the largest being the marine part of the Danube Delta Biosphere (Begun et al., 2012). Ozturk et al. (2013) proposed five ecologically important regions along the Turkish Black Sea coast, containing the internationally important wetland of Kizilirmak Delta, a Ramsar Site since 1998, and Yesilirmak Delta in the Samsun region. These sites were proposed taking into account the criteria of the Convention on Biological Diversity and modeling studies of larval dispersal within the Black Sea (Fach, Arkin, & Salihoglu, 2016), confirming connectivity between each of the regions to form a network of protected areas. Other counties in the region, Georgia, Russia, Ukraine, although also not EU members, try to harmonize their protected zones with the European Directives (Milchakova et al., 2015).

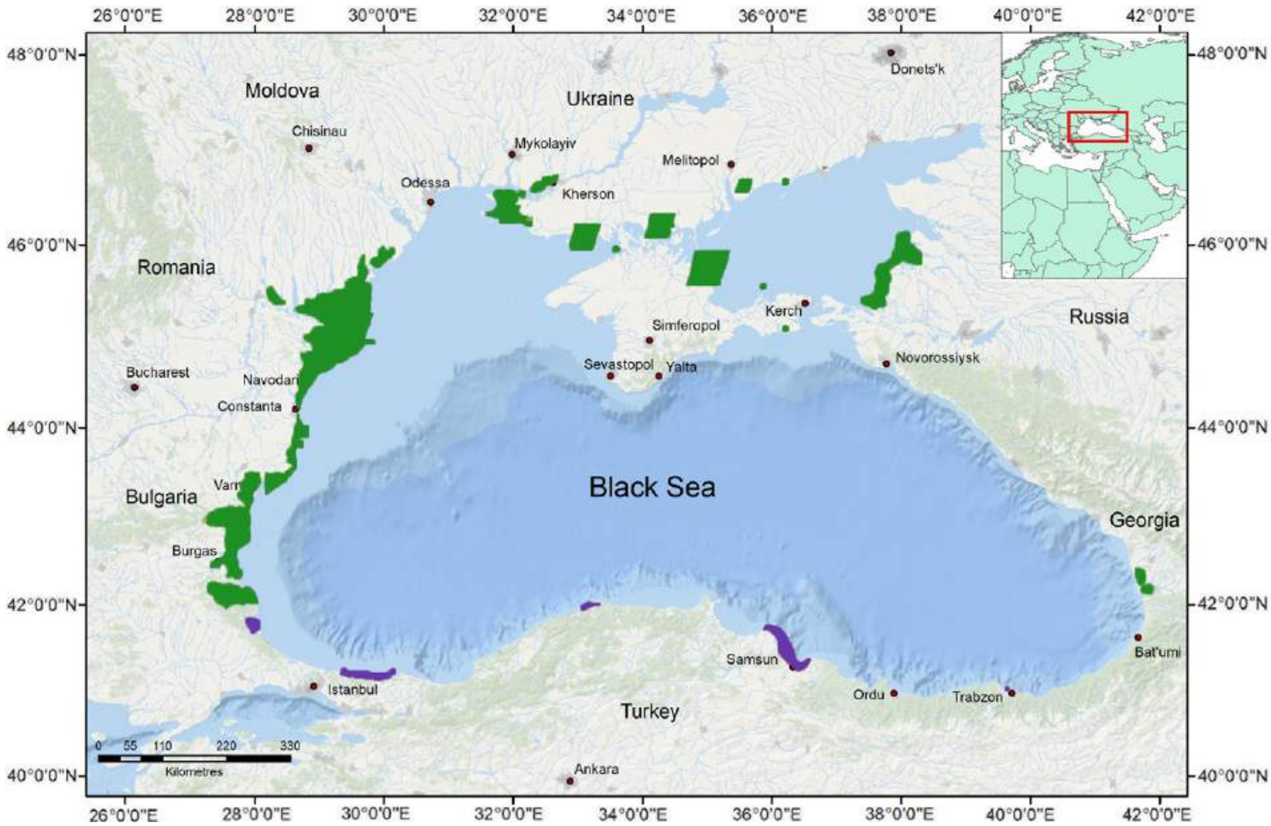

FIG. 8.8 MPA in Black Sea region (in blue proposed MPA) (according to CoCoNet and Ozturk et al., 2013).

8.9 SUMMARY, PROGNOSES, OR NEEDS

The present Black Sea ecosystem is undergoing a slow recovery from its degraded state of the 1970s. The low rate of recovery may be related to inappropriate management as well as to continuing impacts. Additional ecosystem-level planning and integrated assessments are urgently needed, including reducing eutrophication, reducing fleet capacity, and banning fisheries for particular stocks or regions.

Due to decades of unsustainable fishing efforts, with the exception of the southeastern part, the Black Sea does not support much fish. This is a unique case among the large marine ecosystems in the world and represents an almost collapsed ecosystem whose size is ~400,000 km^2 (Oguz, 2017). The implementation of ecosystem-based management strategies requires tools that are being developed collaboratively and which will lead to a more stable and sustainable Black Sea functional ecosystem.

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Index

Note: Page numbers followed by *f* indicate figures, *t* indicate tables and *b* indicate boxes.

B

C

D

E

F

J

K

L

M

N

O

P

T

U

V

W

X

Y

Z

WORLD SEAS

AN ENVIRONMENTAL EVALUATION

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Charles Sheppard is Emeritus Professor in the School of Life Sciences at the University of Warwick, UK. He has also worked for a range of United Nations, governmental, and aid agencies in tropical marine and coastal development issues. He has advised several governments on marine and coastal management and science, including the UK Government on its tropical overseas territories. He organized and led the scientific input to the 2010 creation of the world's largest fully protected marine area in the Chagos Archipelago, Indian Ocean. He has received several awards for his scientific contributions to marine conservation and has been editor of leading marine science journals for over 25 years.

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