V BLACK SEA

V-8 Black Sea LME

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The Black Sea LME is almost cut off from the rest of the world's oceans, connected only through the Istanbul Strait, a 35 km natural channel, as little as 40 m deep in places. The Black Sea is linked to the Mediterranean Sea by the narrow Bosphorus and Dardanelles Straits, and to the shallow Sea of Azov by the Kerch Strait in the north. The LME covers a surface area of about 460,150 km^2,including the Sea of Azov. of which 2.21% is protected (Sea Around Us 2007). The northwestern part of the Black Sea is shallow but in other places its waters reach a depth of more than 2,200 m. The Black Sea catchment area entirely or partly extends over 18 countries: Austria, Belarus, Bosnia and Herzegovina, Bulgaria, Croatia, Czech Republic, Georgia, Germany, Hungary, Moldova, Slovakia, Slovenia, Romania, Russia, Turkey, Ukraine, Yugoslavia-- about one third of the area of continental Europe and containing in excess of 160 million people. Every year, Europe's second, third and fourth largest rivers, (the Danube, Dnieper and Don, carry about 350 km^3 of river water into the Black Sea. As a consequence of its almost landlocked nature and lack of circulation in its deep waters, the LME is particularly vulnerable to environmental stresses originating from human activities in the catchment area, especially the Danube, Dnieper and Don River basins. Book chapters and articles pertaining to this LME include Mee (1992), Caddy (1993), Zaitsev & Mamaev (1997), Black Sea Commission (2002), UNEP (2002), Daskalov (2003), Borysova *et al.* (2005) and Paleari *et al.* (2005).

I. Productivity

The LME is considered a Class I, highly productive ecosystem (>300 $gCm^{-2}year^{-1}$). High primary production is associated with fluvial discharge (Balkas *et al*. 1990) as well as natural winter production (Sur *et al*. 1994, Nezlin *et al*. 1999). In addition, data from the CZCS and the Advanced Very High Resolution Radiometer indicated the presence of patches of upwelling in summer in some areas of the Black Sea (Sur *et al*. 1994, Shalovenkov 2000). Historically important seagrass as well as macroalgal communities, for example the red alga *Phyllophora* sp. and the brown alga *Cystoseira barbata*, contribute to benthic primary production in shallow areas.

A strong density stratification, which effectively inhibits vertical mixing, results in permanent anoxia within almost 90% of the Black Sea's volume (below 200 m), making this LME the largest anoxic basin of the global ocean. The deep anoxic layer with its high hydrogen sulfide content is a 'dead' zone. Marine life is confined to the upper layer, while the bottom is void of invertebrates and fish in most parts of the Black Sea.

Chemical profiles in the deep basin demonstrate that the whole water column of the Black Sea can be divided into 4 sub-layers, based on its oxygen content; namely:

- The oxygenated upper layer, which is relatively thick (80-90m) in the coastal margins, becoming much thinner (40m) in deeper waters.
- The oxycline, in which oxygen concentrations decrease steeply This extends down to only 60-70m in the cyclonic gyre but may reach as much as 150m depth in the coastal margins. Since the oxycline is thicker in the coastal margin, the oxygen gradient is lower in the coastal zone than in the open sea.

- The suboxic zone, in which oxygen levels decline slowly to where sulphide-bearing water begins.
- The anoxic (sulphide-bearing) layer, extending down to the sea bed.

The nutrient content of seawater is also related to oxygen status. Surface nutrient concentrations were usually low, since they are sequestered by phytoplankton, seaweed and higher plant growth, where sufficient light is available. Surface nutrient concentrations exhibit pronounced seasonality, with maximum concentrations occurring in late winter/early spring.

Below the mixed surface water layer, lies a nutrient-rich cold intermediate layer, separated from the surface layer by a rapid change in temperature (the thermocline) or salinity (halocline). This lies within the suboxic zone. The depths of the oxygen saturated and suboxic zones varies from coastal waters to the interior basin, depending on the thickness of the brackish upper layer and ventilation rate of the halocline waters. The nitrate and phosphate profiles indicate nutrient deficiency in the near surface waters and then display maxima within the halocline. Phosphate profiles also exhibit a second maximum at the anoxic boundary of the deep basin. These features appear at different depths with region, being consistently shallower in the cyclonic gyres where the permanent halocline displays a ‘dome’ shape.

Large changes in livestock numbers have occurred in Black Sea coastal countries since 1960. For example, livestock numbers reached a clear maximum in 1988, just prior to the economic collapse, fell sharply to 1997, and the numbers of cattle, pigs, sheep and goats continued to fall until 2003 (by 33, 26 and 31%, respectively), while poultry increased (by 23%)in the same time period). During the period 1988-2003, numbers of cattle fell by 64%, pigs by 62%, sheep and goats by 67% and poultry by 21%. By 2003, there was a major decrease in mammalian livestock numbers (44-67%) compared with the 1960 values.

The increasing costs of sheep production in particular have resulted in lower consumer demand for lamb products. The number of poultry has increased dramatically since 1960 due to the adoption of more intensive and cheaper production practices, bringing with them increasing demand.

During the late 1960s, there was a major change in agricultural production in the region (‘the Green Revolution’), which involved the use of large amounts of fertilisers as well as the establishment of extensive animal farms (Mee & Topping 1999). The subsequent increased riverine nutrient input, particularly from the Danube River, resulted in severe eutrophication and greatly enhanced primary production, including frequent abnormal phytoplankton blooms in the Black Sea LME (Balkas *et al*. 1990, Sur *et al*. 1994, Mee & Topping 1999). This and other factors promoted dramatic changes in the ecosystem in recent decades (Black Sea Transboundary diagnostic Analysis 2007).

When compared to livestock figures, similarly dramatic changes have happened with regard to the use of inorganic fertilisers in arable farming. This is shown dramatically by Romanian data (Black Sea TDA 2007) indicating that in 1960 only very low levels of inorganic fertilisers were applied, but by 1988 the amount of inorganic nitrogen fertiliser had increased 27-fold and inorganic phosphorus fertiliser 7-fold. Following the economic collapse and independence of Romania, fertiliser application rates fell to below the levels applied in 1970, with a continuing decrease still evident in 2003. Levels applied in 2003 were about one third of those applied in 1988 (Black Sea Transboundary Diagnostic Analysis 2007).

The structure of the Black Sea ecosystems differs from that of the neighbouring Mediterranean Sea in that species variety is lower and the dominant groups are different. However, the abundance, total biomass and productivity of the Black Sea are much higher than in the Mediterranean Sea. Plankton community composition and biomass suggest that improvements are taking place, albeit that a reduction in organic enrichment is key to this recovery.

Formerly “dead” areas of the NW Shelf sediment are once again colonised by biota, with evidence of biodiversity continuing to increase. However, the once massive area dominated by Zernov’s *Phyllophora* (a red seaweed) field has decreased hugely in area, having been replaced by other, opportunistic macroalgae. Similarly, during the last two decades, the area covered by eelgrass (*Zostera*) has decreased tenfold in shallow waters. The *Phyllophora* field once provided a habitat for 118 species of invertebrates and 47 species of fish. The Black Sea macrozoobenthos is represented by approximately 800 species, and the fish fauna by 171 species. There are 320 bird species in the Danube Delta and 4 species of Mammals are found in the Sea.

Higher species richness in shallower waters is associated with good dissolved oxygen conditions whilst in deeper areas there is lower diversity due to natural oxygen depletion with increasing depth in the Black Sea. Consequently, the number of macrobenthic species decreases rapidly with increasing depth - only the polychaete worm *Notomastus profundus* is found below a depth of about 120 m. Species diversity is high in the Black Sea LME, with a total of 3,800 species having been identified (Zaitsev & Mamaev 1997). Four species of mammals inhabit the LME: the monk seal (*Monachus monachus*), the bottlenose dolphin (*Tursiops truncatus ponticus*), the common dolphin (*Delphinus delphis ponticus*) and the harbour porpoise (*Phocaena phocaena relicta*).

The invasion of *Mnemiopsis leidyi* (a comb jelly) contributed to a catastrophic decline in fish productivity in the 1980s. The subsequent invasion of another comb jelly (*Beroe ovata*), which feeds on the original invader, means that opinions are now split as to whether *Mnemiopsis* is still has a major impact on fish communities and catches.

The number of registered alien species at the regional level amounts to 217 (parasites and mycelium excluded). Nearly half of them (102) are permanently established, and a quarter - highly or moderately invasive (20 and 35 species respectively). This high ratio of invasive aliens suggests a serious impact on the Black Sea native biological diversity, with negative consequences for human activities and economic interests.

Between 1996 and 2005 a total of 48 new alien species were recorded, which represents over 22 % of all registered aliens. The majority belong to phytoplankton (16) and zoobenthos (15), followed by zooplankton (8), fish (5), macroalgae (3) and mammals (1).

Habitat status is a critical component of maintaining high levels of biodiversity within the Black Sea. The status of marine habitats is therefore assessed. All 5 habitats within the coastal margin ecotones category are considered to be in a critical status in at least one country; both types of benthic pelagic habitat (neritic and open sea) are considered critical in at least one country; and 13 of the 37 types of benthic habitat are considered to be critical in at least one country. No data were available on Russian Black Sea habitats. The ecosystem(s) of the Black Sea are, therefore, seriously damaged and in need of legal protection. Those habitats most at risk include the neritic water column, coastal lagoons, estuaries/deltas and wetlands/saltmarshes.

Oceanic fronts** (*after Belkin et al. 2008)**: A major front has been recently described from satellite data (Figure V-8.1). It extends along the 50-m isobath from Cape Tarhankut (Crimean Peninsula) southwestward toward the Bulgarian coast, with the cross-frontal surface temperature step of up to 4°C and salinity step of up to 1 ppt (Belkin *et al*. 2008). This front develops in winter and peaks in February-March. Another large-scale front is associated with the Rim Current that flows around the Black Sea. Even though this front largely follows the shelf edge, it is less robust because the Rim Current meanders and spawns eddies and rings. Estuarine fronts off the Dnijeper and Dnijester River mouths and off the Danube River delta are expected, as well as a front off Kerch Strait that connects the Azov Sea and Black Sea; these fronts have not been studied in detail.

Figure V-8.1. Fronts of the Black Sea LME. NEF, Northeast Front; NWF, Northwest Front; WSSF, West Shelf-Slope Front (after Belkin 2008).

Black Sea SST (after Belkin 2008):
Linear SST trend since 1957: -0.08°C.
Linear SST trend since 1982: 0.96°C.

The thermal history of the Black Sea since 1957 was non-uniform. The all-time maximum of 16.1°C achieved in 1966 has not been exceeded since then. Long-term cooling from 1966 through 1987 switched to long-term warming from 1988 through 2001. The all-time minimum of 13.8°C in 1987was followed by a switch to the long-term warming through 2001. Even though the 50-year trend of SST from 1957-2006 was slightly negative, -0.08°C, the 25-year trend of SST from 1982-2006 was strongly positive, 0.96°C.

Given the strong year-to-year variability of the Black Sea SST, any trend analysis would strongly depend on the choice of end points. For example, Ginzburg et al. (2004) processed nighttime satellite SST during the period from November 1981 to December 2000 to find a positive trend of the Black Sea mean SST of approximately 0.09°C per year, which is more than twice the warming rate found in this study. Note that the year of 2000 was one of the warmest years since 1967, which explains the very rapid warming rate obtained by Ginzburg et al. (2004) from the 1981-2000 data. From our data, the most rapid warming was observed from 1987 through 2001 when the mean SST rose from 13.8 to 15.8°C, a 2.0°C increase in 14 years, at an average warming rate of 0.14°C/year. Since the Black Sea is land-locked, having a very limited water exchange with the Mediterranean Sea through Turkish straits, the observed recent warming of the Black Sea could only have been caused by large-scale atmospheric forcing. The debate is on whether the North Atlantic Oscillation (NAO) has played a key role in the Black Sea long-term variability and whether the Black Sea went through regime shifts following the NAO switch from one wind regime to another (Kazmin and Zatsepin, 2007).

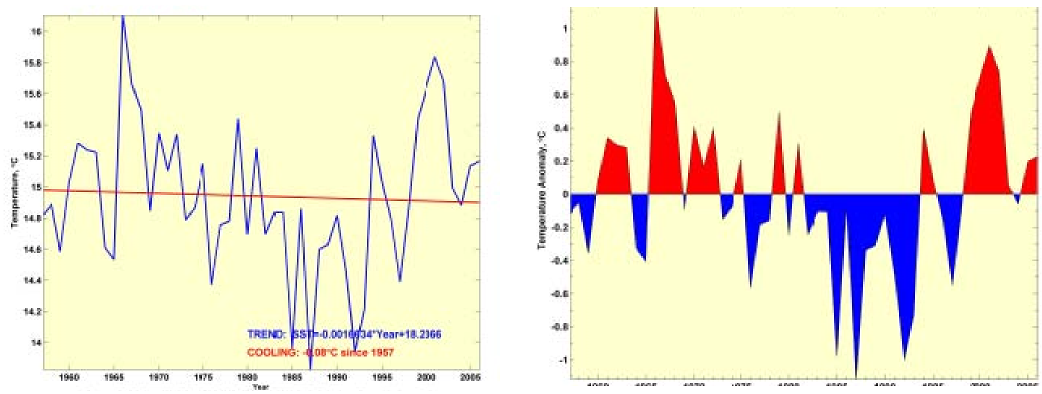

Figure V-8.2 Annual mean Black Sea LME SST, 1957-2006 and SST anomalies in the Black Sea, 1957-2006, based on Hadley climatology, (after Belkin, 2008).

Black Sea LME Trends in Chlorophyll and Primary Productivity: The LME is considered a Class I, highly productive ecosystem (>300 $gCm^{-2}year^{-1}$).

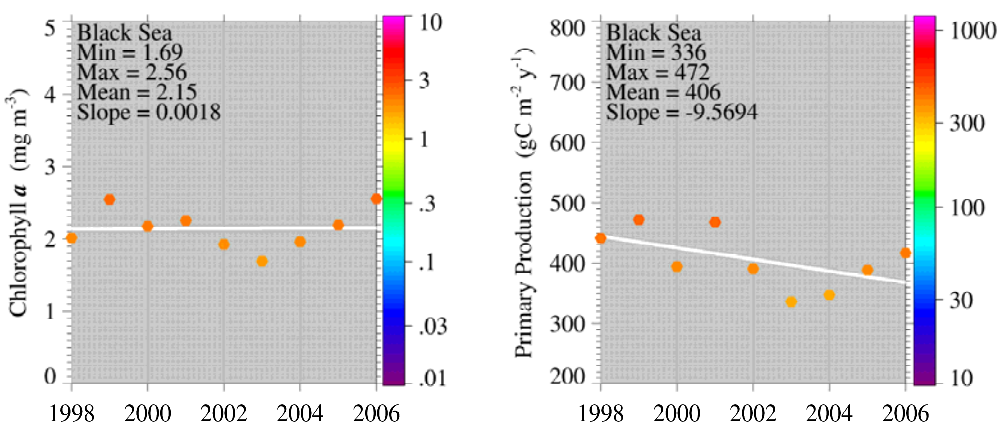

Figure V-8.3 Black Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Marine fisheries are an important economic sector in the countries bordering the Black Sea LME, and virtually all its commercial fish stocks are shared among the bordering countries. In addition to capture fisheries, there is a long history of sturgeon aquaculture in the Azov Sea and more recently, the cultivation of mussels, oysters, shrimp and some finfish (FAO 2005). Prior to the 1970s, there were abundant stocks of several valuable species in the LME, such as tuna (*Auxis rochei rochei* and *Thunnus thynnus*), swordfish (*Xiphias gladius*), mackerel (*Scomber japonicus*, *S. scombrus*, *Trachurus mediterraneus and T. trachurus*), turbot (*Psetta maxima*) and sturgeon (*Acipenser* sp.). In the early

1970s, the stocks of small planktivorous species such as anchovy (*Engraulis* sp.) increased considerably, which might have been a result of the transition of the LME from an oligotrophic to eutrophic state caused by nutrient enrichment (Caddy 1993). These species, which were then fished on an industrial scale, constituted about 65% of the catch in the mid-1980s, while sprat and the smaller variety of horse mackerel made up about 20% (Prodanov *et al*. 1997).

Total reported landings in this LME showed several peaks and troughs, driven primarily by the fluctuation in the landings of European anchovy, with a peak landing of 790,000 tonnes recorded in 1984 (Figure V-8.4). The landings have increased following a precipitous decline from 1989 to 1991, however, have not returned to the level achieved in the mid 1980s. The value of the reported landings reflected the trend in the landings, peaking in 1985 at about 1.3 billion US$ (in 2000 real US$; Figure V-8.5).

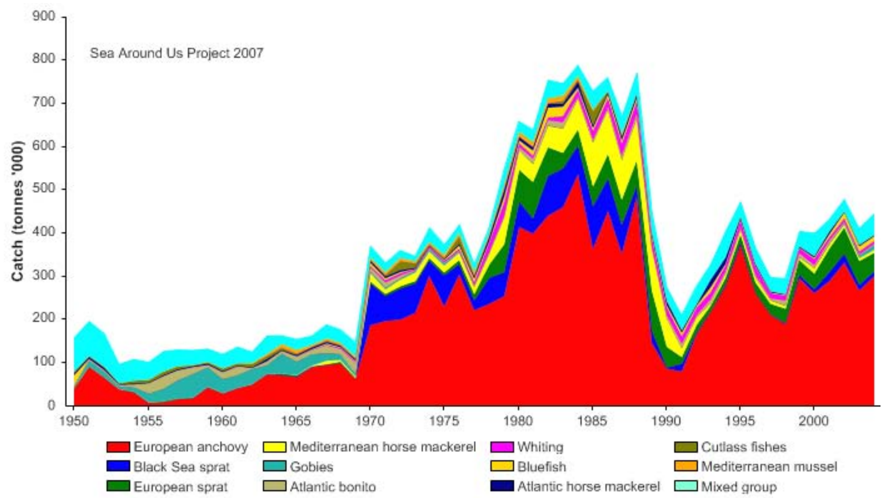

Figure V-8.4. Total reported landings in the Black Sea LME by species (Sea Around Us 2007).

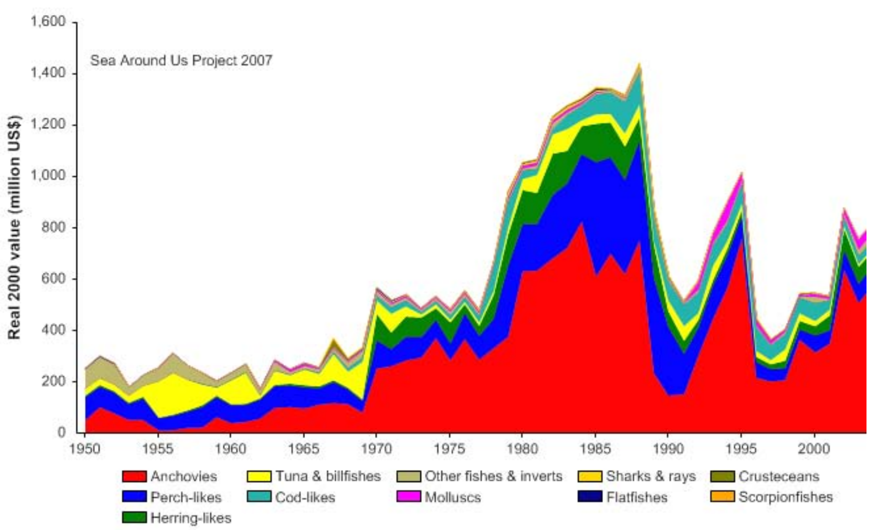

Figure V-8.5. Value of reported landings in the Black Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 18% of the observed primary production in the 1983, but has declined in recent years to 8% (Figure V-8.6). Turkey has by far the largest ecological footprint in the LME.

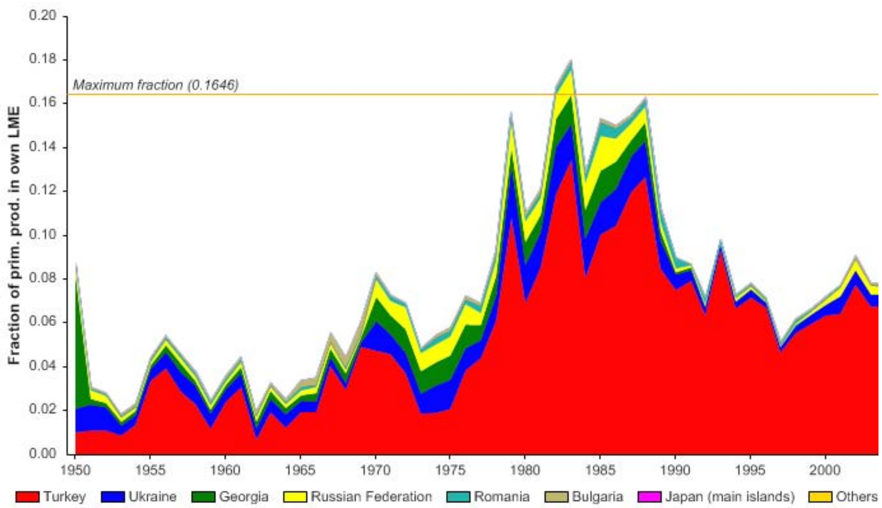

Figure V-8.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Black Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) has been on a decline since the 1950s, with very low values being observed in the 1990s (Figure V-8.7 top). The increase in the FiB index from the 1970s to the mid 1980s is driven by the increased reported landings during this period (mainly of European anchovy). In contrast, the decrease in the MTI values since 1990 is not countered by an increase in landings, thus the FiB index has also declined in the early 1990s (Figure V-8.7 bottom). Together, these recent trends indicate a 'fishing down' of the food web in the LME (Pauly *et al*. 1998).

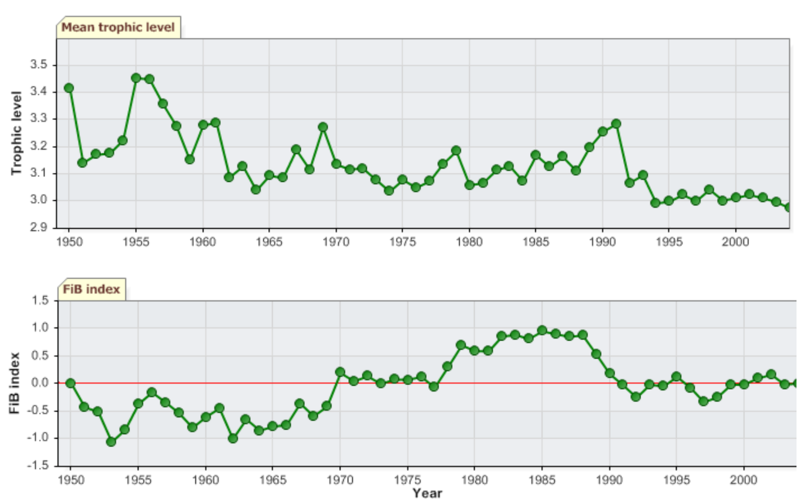

Figure V-8.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Black Sea LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate a high level of collapsed stocks (Figure V-8.8, top) with close to 90% of the reported landings coming from overexploited stocks (Figure V-8.8, bottom).

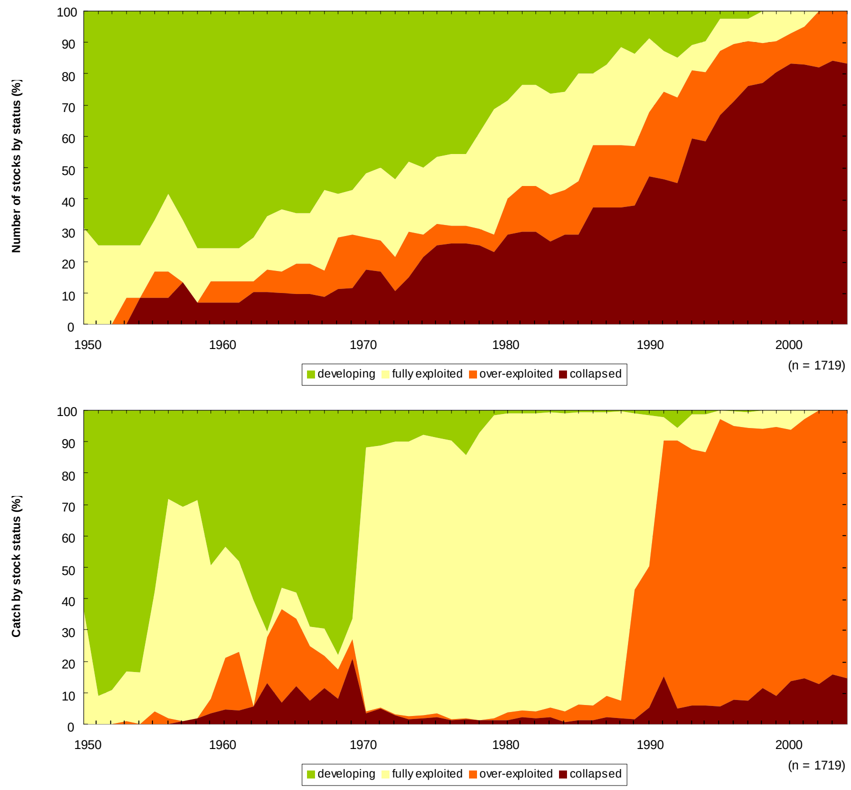

Figure V-8.8. Stock-Catch Status Plots for the Black Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', i.e., individual landings time series, only include taxonomic entities at species, genus or family level, i.e., higher and pooled groups have been excluded (see Pauly *et al.*, this vol. for definitions).

Intense and unregulated fishing pressure (including illegal fishing) in the 1960s-1970s led to severe overexploitation of most of the LME's major fish stocks (Caddy 1993, Black Sea Commission 2002, UNEP 2002). Only five of the 26 commercial stocks fished in the 1960s-1970s were viable by the 1980s (Black Sea Commission 2002). Large pelagics, especially tuna and swordfish, were heavily exploited with the introduction of purse seining in the 1960s and 1970s and through large-scale surface longline and gill net fisheries in the 1980s (Caddy 1993). Landings of turbot, migratory pelagics and anadromous species, especially sturgeon, have declined to low levels in recent decades (Caddy 1993). Some valuable species such as mackerel, bonito (*Sarda sarda*), horse mackerel (Trachurus *mediterraneus*), pike (*Esox* sp.), perch (*Sander* sp.), roach (*Rutilus* sp.) and bream (e.g., *Abramis* sp.) have practically disappeared. By the early 1970s, most of the demersal resources were also being intensively exploited (Caddy 1993). This has been exacerbated by destructive fishing practices such as catching of under-sized fish (UNEP 2002). The dramatic fall in the Black Sea LME's fish catch was most pronounced for small pelagic species, especially anchovies, with a four-fold reduction in the catches between 1988 and 1991 (FAO 2005), although the landings of these species have partially recovered over the past decade (Figure V-8.4).

In addition to overfishing, increasing eutrophication is thought to have contributed to the decline in the Black Sea fisheries (Gucu 2002, Daskalov 2003) (see Pollution and Ecosystem Health). An alien ctenophore, *Mnemiopsis leidyi*, which invaded the Black Sea in the 1980s (Vinogradov *et al*. 1989), is also thought to have played an important role in this decline, as this active mesozooplankton and ichthyoplankton feeder out-competed anchovy for edible zooplankton and consumed their eggs and larvae (Kideys 1994). However, Gucu (2002) argues that *M. leidyi* may play a minimal role in the decline of the Black Sea's fish stocks, particularly as anchovy stocks have started to recover despite the continued presence of *M. leidyi* in the LME.

The decline in the commercial fish stocks in the Black Sea LME has been identified as a major transboundary problem by the Black Sea TDA (UNEP/GEF 1997). However, some stocks, such as anchovy, horse mackerel and shad (*Alosa* sp.), have begun to show signs of recovery, while others are still depleted (Black Sea Commission 2002, FAO 2005).

III. Pollution and Ecosystem Health

Pollution: In recent decades, the Black Sea LME has suffered significant ecological perturbation as a result of pollution, principally from land-based sources (Mee 1992). Intense land-based industrial and agricultural activities, uncontrolled urban development in the river basins and coastal areas as well as sea-based activities have led to an overall moderate level of pollution in this LME (UNEP 2002). Pollution is severe in coastal hotspots, 49 of which have been identified and include the industrial centres on the coast and along the rivers (UNEP/GEF 1997). Non-compliance with national water quality standards for wastewater discharges has been reported for most of the Black Sea coastal states (Black Sea Commission 2002). Most pollutants enter the LME through the international rivers, mainly the Danube but also the Dnijeper, Dnijester and Don (Balkas *et al*. 1990). Nevertheless, a large body of evidence suggests that nutrient loads to the Black Sea from the Danube River have fallen substantially over the last 10-15 years (Lipan 2006).

The most significant process degrading the LME has been the massive nutrient enrichment of the sea by nitrogen and phosphorus, largely as a result of agricultural, domestic as well as industrial sources (Mee & Topping 1999). A study by the Black Sea Environmental Programme suggests that, in 1992, 70% of the nutrient inputs were coming from the six Black Sea countries while the remaining 30% came from the non-coastal countries, mostly of the upper Danube (Mee & Topping 1999). Atmospheric deposition of nitrogen was considerable (Black Sea Commission 2002) but the data for pollutants remain incomplete (Black Sea TDA, 2007). In 1999, the average yearly input of nutrients from agriculture and other human activities amounts to 647,000 tonnes of nitrogen and 50,000 tonnes of phosphorus (Mee & Topping 1999). As previously mentioned, eutrophication has caused dramatic changes in the structure of the Black Sea ecosystem (see also Habitat and Community Modification). Reductions in both N and P concentrations have been observed in upper/idle reaches of the Danube during the 2000s, but not in the lower reaches, suggesting that excess nutrients stored in the catchment are finally being flushed from soils, sediments and groundwaters as a result of previously improved nutrient regulation.

Another problem of major general concern is the discharge of raw or insufficiently treated sewage directly into the sea or into rivers (Mee & Topping 1999). Analyses of faecal steroids in coastal sediments taken from throughout the LME indicate chronic sewage contamination in some locations (Readman *et al*. 2005), although microbiological pollution is mostly a localised problem.

Contamination by toxic chemicals such as pesticides and heavy metals does not appear to be a basin wide problem. Elevated concentrations of heavy metals in bottom sediments and biota near river mouths as well as ports and priority point pollution sources are now decreasing (Black Sea Commission 2002). Pesticides are mostly introduced through rivers and streams discharging from agricultural areas. However, as a result of economic change, the use of these substances has decreased considerably and no longer presents a major hazard, except where their use was very intensive in the past. Elevated concentrations of lindane as well as other isomers of hexachlorocyclohexane (HCH) along the coastal areas influenced by the Danube River indicate the application of this pesticide in the Danube River Basin (Black Sea Commission 2002). In fact, concentrations of HCHs at sites influenced by the Danube Delta were found to be among the highest recorded globally (Fillmann *et al*. 2002). While the concentrations of DDTs and PCBs were not especially high in relation to levels worldwide, low DDE/DDT ratios indicated fresh inputs and hence current usage of DDT within the region (Fillmann *et al*. 2002), or inappropriate storage of expired pesticides (Black Sea Commission 2002; Black Sea TDA 2007).

Although current levels of oil pollution are not high in the open Black Sea, oil continues to threaten coastal habitats as a result of accidental and operational discharges from vessels as well as from land-based sources. The highest concentrations of total hydrocarbons in sediments are associated with discharges from Odessa, Sochi and the Danube River, of which the latter also is the major contributor of fresh oil to the Black Sea (Readman *et al*. 2005). Offshore exploration of oil and gas constitutes an additional source of oil pollution (Black Sea Commission 2002; Black Sea TDA 2007). The threat of a major oil spill is increasing as a result of increased tanker traffic and the construction of new oil terminals in the region. Another threat is the continual release of contaminated ballast water by large ships.

Erosion, dumping and coastal construction have contributed to high levels of suspended solids in some coastal areas (UNEP 2002). As an enclosed sea, the LME is particularly vulnerable to pollution by solid waste dumped from ships and coastal towns. Any floating or half-submerged waste inevitably finds its way to the shore, contributing to the high accumulation of garbage on the beaches (Mee & Topping 1999).

Habitat and community modification: The coastal habitats of the Black Sea LME have been severely impacted as a result of anthropogenic factors including pollution, coastal development, alteration of freshwater inflow, introduction of alien species and overfishing (UNEP 2002). The Black Sea TDA identified eutrophication as one of the major threats to the Black Sea environment, which still remains a priority problem (Lipan 2006). Severe eutrophication of the LME in the past three decades has significantly modified the structure and functioning of the ecosystem as a whole (Zaitsev 1993, Bologa *et al*. 1995, Zaitsev & Mamaev 1997, Mee & Topping 1999). The trophic cascade mechanism driven by uncontrolled fishing and eutrophication was invoked by Daskalov (2003) to explain the alterations in the structure and dynamics of the Black Sea LME. These changes first became evident in the 1980s, with abnormal phytoplankton and harmful algal blooms (Caddy & Griffiths 1990, Zaitsev 1993, Zaitsev & Mamaev 1997). Changes also occurred in the structure of the zooplankton community, with several fodder zooplankton species having either disappeared or substantially decreased in number in some areas (Kideys *et al*. 2000). Meanwhile, some zooplankton species adapted to thrive in eutrophic conditions either appeared or increased in quantity (e.g., the dinoflagellate *Noctiluca*). However, these are often regarded as 'dead end' species as they do not serve as prey for zooplankton or the rest of the food chain (Mee & Topping 1999).

Another change that occurred in the Black Sea ecosystem was the considerable increase in the biomass of jellyfish. A dramatic increase in the abundance of the large scyphozoan (*Rhizostoma pulmo*) occurred in the early 1970s (Zaitev & Mamaev 1997) while in the early 1980s, another species (*Aurelia aurita*) became dominant (Shushkina & Musaeva 1983). By the late 1980s however, this species was replaced by the invading *M*. *leidyi* (Vinogradov *et al*. 1989). This ctenophore contributed to the dramatic changes in the structure of the ecosystem and is also thought to have contributed to the collapse of the Black Sea fisheries (Mee & Topping 1999). The levels of *M*. *leidyi* were subsequently reduced, however, by the introduction of one of its predators, another ctenophore, *Beroe ovata* (Black Sea Commission 2002; Black Sea TDA 2007).

The development of hypoxic conditions in the shallow, otherwise oxic habitats of the northwestern Black Sea LME as well as the reduction in light penetration in shallow areas impacted by eutrophication led to massive loss of bottom living flora and fauna. Among the most notable cases was the sudden and catastrophic collapse of the northwest shelf system, as demonstrated by the sharp reduction of the Zernov's *Phyllophora* field (a submerged meadow of red algae). This undersea meadow shrank from 10,000 km^2 to 500 km^2 in the 1990s while its biomass decreased from 10 million to 500,000 tonnes (Black Sea Commission 2002). The loss in the *Phyllophora* field was disastrous because of its valuable resources and, more importantly, because of its unique biocenoesis with its specific fauna as well as its habitat value for a large number of juvenile and bottom dwelling fish. The Black Sea brown alga, *Cystoseira barbata,* began disappearing from the coastal waters of Ukraine and Romania in the 1980s. This large perennial alga, unable to survive in the eutrophic coastal waters, was replaced by filamentous green and red algae.

Hypoxic conditions were also accompanied by fish and zoobenthos mass mortality each year. Vast amounts of dead plants and animals covered the beaches of Romania as well as western Ukraine between 1973 and 1990. The biological losses over this 18-year period were estimated as 60 million tonnes of bottom animals including 5 million tonnes of fish (Black Sea Commission 2002). The benthos community structure of the shelf and nearshore areas was significantly modified. For instance, some areas showed a predominance of polychaete and oligochaete worms and species such as *Mya arenaria*, which are better adapted to low-oxygen conditions (Caddy 1993).

There are some signs of benthic community recovery, but this recovery is far from being total. From the dark days of its decline into the severely degraded ecosystem that it once was (in 1990, 80% of the NW Shelf was considered to be a 'dead zone'), the Black Sea represents a pattern of adaptation rather than one of true recovery. Invasive species, not (or rarely) present in the 1960s now occupy (and dominate) critical ecological niches. To a large extent mussels, which once acted as a huge filter for the overlying water, have now been replaced by tunicates (sea squirts), which fulfil a similar role; and the once huge *Phyllophora* (a red seaweed) field has overwhelmingly been replaced by fine filamentous algae. Between the Danube and Dniester river inputs, very rapidly growing green algae (*Enteromorpha* and *Cladophora)* have largely been replaced by more robust *Polysiphonia elongata*. However, *Cystosiera*, which dominated before the 1960s, is not yet re-established in this area.

Human activities have affected other communities of the LME. For example, until 1966, dolphins were hunted but their numbers declined from over 1 million to under 300,000 and this practice was banned (Mee & Topping 1999). The deterioration in the state of the ecosystem must also have impacted their numbers (Mee & Topping 1999). The accidental capture of marine mammals by fishing gear is a particularly serious problem for the harbour porpoise. Other marine mammals are critically endangered and the monk seal is virtually extinct in this LME (Black Sea Commission 2002; Black Sea TDA 2007).

Degradation of rivers and estuaries in the Black Sea region has also affected the population of migratory species of fish. For instance, the construction of dams and hydraulic structures kept anadromous species like sturgeons from their natural spawning grounds in the estuaries of Danube and Dnijeper Rivers. These anadromous species currently depend on artificial breeding (Black Sea Commission 2002). Increased salinity in the Sea of Azov, due to the reduction of freshwater inflow related to irrigation schemes, has modified the migratory pattern of many fish species and has also changed the species composition of the ichthyofauna (Caddy 1993). The health of the Black Sea ecosystem has started to show some improvement in recent years, as a result of several measures and initiatives at national as well as international levels (See Governance) (Black Sea Commission 2002).

IV. Socioeconomic Conditions

Since ancient times, people have depended on the Black Sea LME for various economic activities (Ascherson 1995). The coastal zone, defined as one 'administrative unit' (oblast, Municipal area, etc.) inland from the coast, is densely populated with approximately 20 or 30 million inhabitants depending on whether the Istanbul administrative unit is included in the total. This unit has a short Black Sea coastline. More than 4 million tourists visiting the coast in summer (Black Sea Commission 2002). The Sea has six coastal countries: Bulgaria, Georgia, Romania, the Russian Federation, Turkey and Ukraine. The 17 countries in the Black Sea drainage basin have diverging socio-economic as well as political structures. Bulgaria and Romania became EU members in 2007. Turkey is a candidate for European Union membership. In the immediate area of the Black Sea LME and in its river basins, there is virtually every type of heavy industry, including oil refining, metallurgy, chemicals, coal, pulp and paper production as well as energy production (hydraulic, thermal, nuclear). Agriculture is another important activity in the Black Sea Basin. In the coastal and marine areas, shipping, fisheries and tourism are important revenue-earners.

Fisheries overexploitation and environmental degradation of the Black Sea LME have had serious economic and social consequences for the bordering countries. For example, the value of the annual reported landings declined from about 2 billion US$ in the 1980s to about 500 million US$ in the late 1990s (Sea Around Us 2007). The worst affected country has been Turkey, which in the 1970s and 1980s relied on the Black Sea for 80% of its supply of fish. Despite the recent upward trend in the Black Sea fisheries, economic returns have not recovered, due to the dominance of the catch by the low-value anchovy stock, while higher valued species have remained depressed or continued to decline (FAO 2005). The fisheries collapse has also created a crisis in employment in the fisheries sector. The total job losses resulting from the collapse of Black Sea fisheries has been estimated at some 150,000 (UNEP 2002).

Pollution of the Black Sea LME by sewage as well as harmful chemicals poses a threat to human health, both from the consumption of contaminated seafood and direct contact with polluted waters. The degradation of the Black Sea LME environment has also had a major impact on recreational activities, with regular beach closures due to sewage discharges affecting the region's tourist industry. The loss of income from tourism could be at least 400 million US$, assuming a modest loss in revenue of 10 US$ per visitor (UNEP 2002).

V. Governance

The Black Sea LME countries have embarked on several initiatives at national and regional levels to address the environmental problems in this LME. If Bulgaria, Romania and Turkey were to accede to the European Union, the strict European legislation would benefit the Black Sea environment (Black Sea Commission 2002). A fisheries convention is being negotiated by the six Black Sea States to adopt an ecosystem approach for the management of the region's fisheries. Reforms in policy, laws, institutions and investments are now being supported by GEF in each country for nitrogen abatement from the agricultural, municipal as well as industrial sectors.

MARPOL, which was ratified by all Black Sea countries, declared the Black Sea as a 'Special Area' for protection where countries agreed to apply more rigorous environmental standards. These provisions have, however, never been applied, partly because of a lack of port facilities for receiving and treating oily wastes and garbage from visiting ships. Major regional frameworks include the Black Sea Regional Seas Programme and the Bucharest Convention on the Protection of the Black Sea against Pollution and its four Protocols. The convention is implemented by the Commission on the Protection of the Black Sea against Pollution (Black Sea Commission - www.blacksea-commission.org). The Odessa Ministerial Declaration on the Protection of the Black Sea Environment was signed by the countries of the Black Sea Region in 1993 in order to set goals, priorities and timetable for remedial actions.

GEF is supporting 12 projects for environmental improvements in this LME and its drainage basin. The UNDP-GEF Black Sea Ecosystem Recovery Project is addressing basin wide eutrophication issues through reform of agricultural policies, improved municipal and industrial wastewater treatment, rehabilitation of key basin ecosystems and strengthening the legislative framework (www.blacksea-environment.org). The Black Sea Environmental Programme (BSEP) was launched in 1993. Among the most important achievements of BSEP were the TDA and SAP. The SAP focuses on three major issues: controlling pollution, conserving and restoring marine and coastal ecosystems, as well as promoting sustainable use of the coastal areas. The GEF-supported project 'Developing the Implementation of the Black Sea Strategic Action Plan' has been completed. This project facilitated the development of the National Black Sea Strategic Action Plans and supported institution-building at the national and regional level for the development as well as implementation of such plans. The Black Sea Commission implements the provisions of the Bucharest Convention and the SAP. Other GEF-supported projects include the Strategic Partnership for Nutrient Reduction in the Danube River and Black Sea and Control of Eutrophication, Hazardous Substances and Related Measures for Rehabilitating the Black Sea Ecosystem.

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