MARINE BOARD

CLAMER
CLIMATE CHANGE & EUROPEAN MARINE ECOSYSTEM RESEARCH

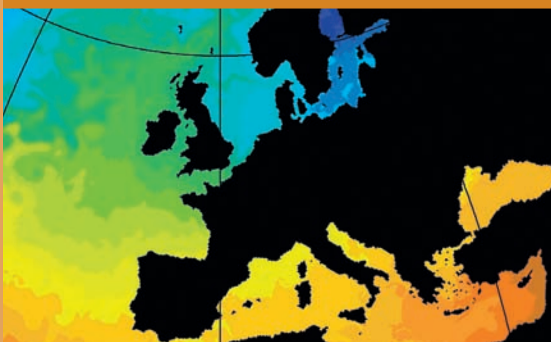
SEVENTH FRAMEWORK PROGRAMME

Marine Board Special Report

Climate Change and Marine Ecosystem Research

Synthesis of European Research on the Effects of Climate Change on Marine Environments

September 2011



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Climate Change and Marine Ecosystem Research

Synthesis of European Research on the Effects of Climate Change on Marine Environments

Marine Board Special Report

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3.6.1 Introduction

The Black Sea is a well-known example of the highly stressed and degraded marine ecosystems. In the 1970s and 1980s, it has been impacted synergistically by the effects of over-exploitation of fish resources, intense eutrophication, invasions by opportunistic species (BSC-SoE, 2008). These anthropogenic pressures have introduced major transformations on the structure and functioning of the ecosystem (Daskalov, 2003; Bilio and Niermann, 2004; Daskalov *et al.,* 2007; Oguz & Gilbert, 2007; Oguz *et al*., 2008; Oguz and Velikova, 2010). They have also been accompanied with major changes in the hydrometeorological properties in relation to changes in large-scale atmospheric systems over the Eurasia (Oguz *et al*., 2006). The climate change and variability have therefore played a major role on the Black Sea ecological changes in spite of difficulty of substantiating their relative contributions with respect to the other drivers. It is also not clear how much of the changes in the ecosystem properties are introduced by the natural mode of climate variability and by the antropogenic climate changes due to fossil-fuel combustion, land-use including agriculture and deforestation. The present section provides an overview of the changes in the physical (i.e. abiotic) and biogeochemical (i.e. biotic) properties of the Black Sea, and their possible link to the large scale atmospheric systems of the Northern Hemisphere. It further describes likely future climate change projections, socio-economic consequences of climate change, and research gaps and uncertainties, and relevance to EU funding. The data presented below are taken from BSC-SoE (2008).

3.6.2 Abiotic Changes

3.6.2.1 Temperature

The Black Sea winter-mean sea surface temperature anomaly (blue curve in Figure 78) indicate (i) a cooling phase from 1880 to 1910 of about 0.7°C; (ii) an approximately 1.0°C warming trend during 1910-1970 modulated by sub-decadal scale fluctuations; (iii) roughly 1.5°C cooling during the next 20 years (up to 1993); and (iv) an equally strong warming afterwards during 1994-2002. The latter warming trend brought the temperature back to its level at the beginning of 1970s, indicating that the Black Sea did not build up a net warming after the 1970s contrary to the North-eastern Atlantic and the North Sea. The winter-mean SST correlates well with the annual-mean SST (red curve in Figure 78) and the May-November mean temperature of the Cold Intermediate Layer below the seasonal thermocline (green curve Figure 78) that therefore suggests persistence of the winter cooling-warming signatures within the entire upper layer above the permanent pycnocline (i.e. within ~100 m depth) and during the entire year. The Black Sea SST is therefore characterized by a multi-decadal strong cooling-warming cycle with almost 2.0°C temperature changes after 1970 with respect to a weak but continuous global warming trend with ~0.4°C temperature rise (black curve in Figure 78). The warming trend observed in the winter SST during 1910-1970 is, however, consistent with the global one except its more pronounced fluctuations.

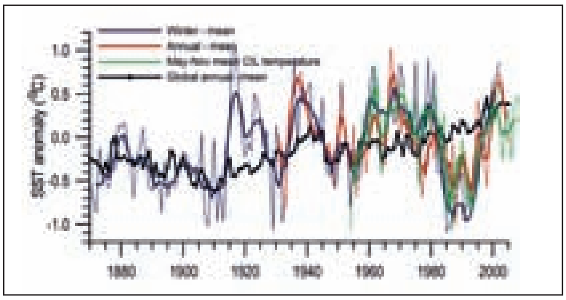

Figure 78. Time series of the basin-averaged winter and annual mean sea surface temperature anomalies, the May-November mean temperature anomaly of the Cold Intermediate Layer (CIL) located below the seasonal thermocline for the Black Sea, and the annual mean global sea surface temperature anomaly. The thin lines show the original data and the thick lines are the smoothed curves by means of five point moving averaging. The CIL is customarily defined as a layer with temperatures less than 8°C below the mixed layer and typically covers the lower part of euphotic zone. Note that the axis for the NAO index on the right is inverted.

In addition to strong interannual changes, considerable regional variability is evident by about 3°C differences between winter temperatures of the colder interior basin and the relatively warm peripheral zone and/or between the northwest and southeast sectors (Figure 79). In general, regional meteorological conditions in the eastern part favour milder winters and warmer winter temperatures in the surface mixed layer. The western coastal waters that receive the freshwater discharge from Danube, Dniepr and Dniestr rivers and are subject to more frequent and stronger cold arctic air outbreaks, correspond to the coldest part of the Black Sea (Figure 79). Thus, the southeastern part might often be roughly twice as warm than the northwestern part for both cold winter (plot in Figure 79 above) and warm winter (plot in Figure 79 below) climatological years.

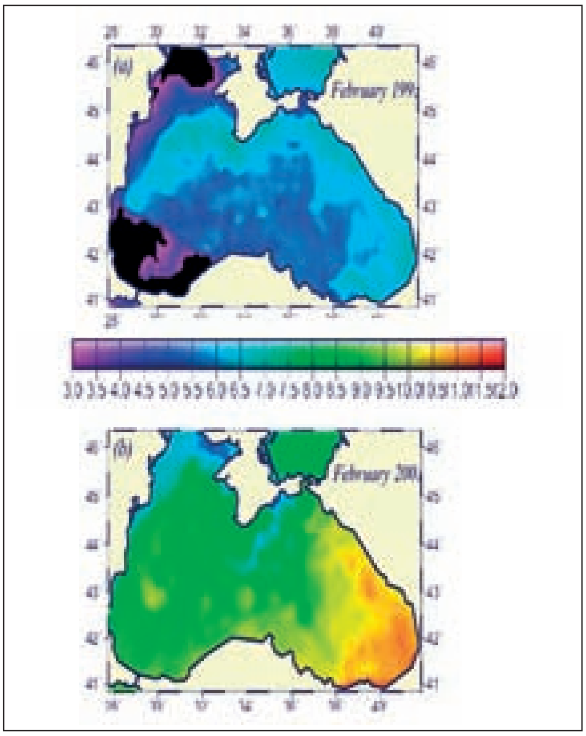

Figure 79. The mean SST distribution in February for 1993 and 2001 corresponding to one of the coldest and warmest cases in the Black Sea, respectively, during the 20th century. The SST data are obtained from 9 km monthly-mean, gridded NOASS/NASA AVHRR Oceans Pathfinder data set (From Oguz *et al.*, 2003).

Figure 80 compares the annual mean Black Sea SST with those of the Eastern and Western Mediterranean Seas. The SST in all areas undergoes to a rapid cooling from the mid-1960s to the beginning of the 1980s, after which the Western Mediterranean SST switches to a warming mode whereas the Black Sea continues to cool until 1993 and then switches to the warming mode. The Eastern Mediterranean SST represents a weak warming in the 1980s followed by stronger warming in the 1990s. A common characteristic of all the three time series is the reduction of temperature during 1992-1993 that is also observed in the global SST time series (Figure 80). This reduction is evidently related to the global cooling induced by the eruption of Mount Pinatubo in the Philippines during June 1991 (Soden *et al.* 2002). As documented by satellite measurements, peak global cooling of ~0.5°C in the lower troposphere was attained nearly 18 months after the eruption that then gradually approached to pre-Pinatubo levels at 1995.

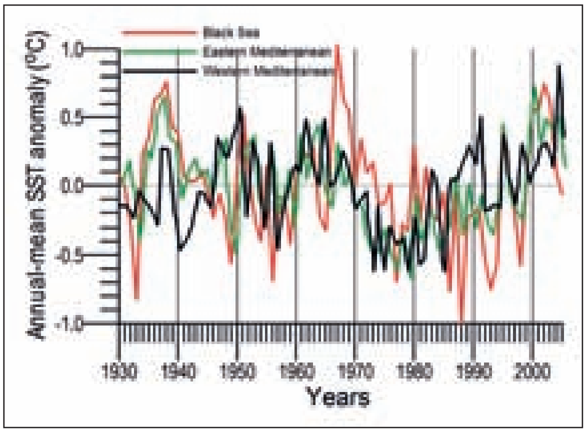

Figure 80. Time series of the annual mean sea surface temperature anomaly for the Eastern and Western Mediterranean and Black Seas

3.6.2.2 Sea-level

Based on examination of 12 long-term (1923–1999) tide gauge records around the Black Sea, the sea-level rise occurs in 2.0 - 4.0 mm yr^{-1} range over the last 60 years (Mikhailov and Mikhailova, 2008). The satellite altimeter data, on the other hand, reveal a higher rate of rise of about 7.5 mm yr^{-1} during 1993-2007. The mean rise for Tuapse (northeast coast) of 2.5 mm yr^{-1}, being comparable with the basin average conditions, is shown in Figure 81. This is slightly higher than the global average of 1.8 mm yr^{-1} from 1961 to 2003 (IPCC, 2007), 1.7 mm yr^{-1} of the Atlantic Ocean and 1.1-1.3 mm yr^{-1} of the Mediterranean. We also note a relatively minor contribution of the thermosteric effect (< 5 cm) to the overall sea-level rise (Figure 81). In fact, the sea-level due to the thermosteric effect decreased during 1970-1993 in response to excessive cooling of the sea, whereas actual sea-level has been rising. On the other hand, the thermosteric effect explains much of the observed global sea-level rise in the second half of the 20^{th} century (Antonov *et al.* 2002).

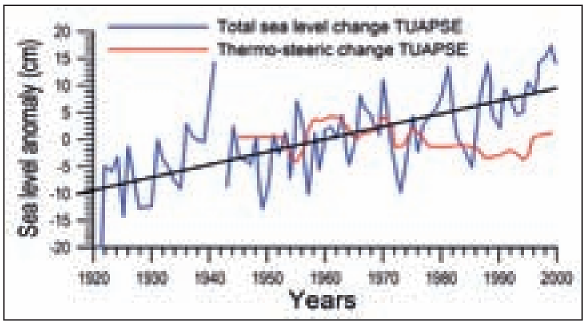

Figure 81. Sea-level anomaly changes around the mean (blue curve) and the thermosteric contribution (red curve) at Tuapse located along the northeastern coast of the Black Sea

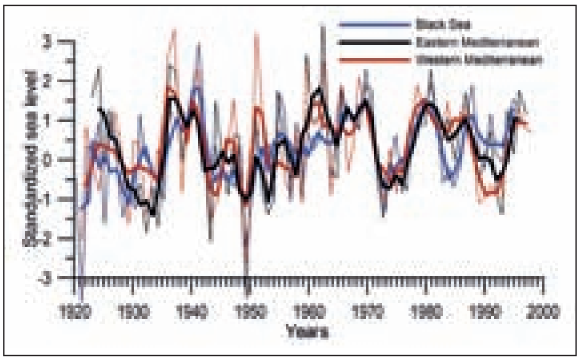

Figure 82. Detrended and standardized annual-mean sea-level time series for the Black Sea, Eastern and Western Mediterranean Seas. (Data are from Tsimplis & Josey, 2001)

Furthermore, subdecadal-to-decadal fluctuations of the detrended and standardized annual-mean sea-level time series for the Black Sea agree fairly well with those of the Eastern and Western Mediterranean Seas although the Black Sea and the Mediterranean Sea have an opposite hydrological balance (Figure 83).

3.6.2.3 Net Fresh Water Input

Temporal changes of the net fresh water input into the Black Sea (river inflow plus precipitation minus evaporation) indicate a net long-term positive trend consistent with the sea-level changes (Figure 83). The positive trend is contributed by increasing river discharge and precipitation and decreasing evaporation (Ilyin, 2010). Subdecadal-to-decadal changes in the net fresh water input also agree well with the mean detrended sea-level anomaly (Figure 83). Periods with low fresh water input generally correspond to those of relatively low sea-level that also coincides with relatively low sea surface temperature (Figure 78).

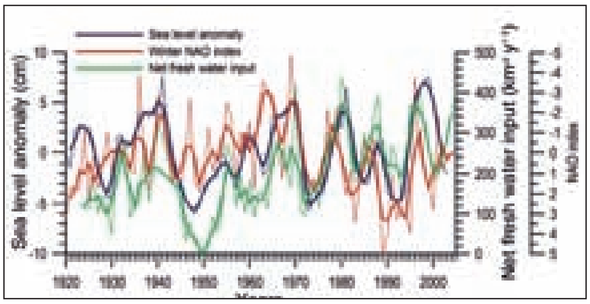

Figure 83. Time series of the detrended annual mean sea-level anomaly (blue), net fresh water input into the Black Sea defined as a the sum of river inflow and precipitation minus evaporation (green), and the winter mean North Atlantic Oscillation index (red). The thin lines show the original data and the thick lines are the smoothed curves using 3 point moving averaging. Note the inverted scale of NAO index.

3.6.3 Biogeochemical Impacts and Effects on Biodiversity

Figure 84 displays variations of long-term annual-mean oxygen concentration for the layer between σ_t ~14.45 and 14.6 kg m^{-3} density surfaces, corresponding roughly to the base of the euphotic zone, in the northeastern basin. Oxygen concentrations increase from 170 µM in the early 1980s to ~300 µM in the early 1990s, then decrease to 240 µM for another 10 years up to 2002, and slight increase again afterwards. These changes are inversely related with the subsurface summer-autumn CIL temperature changes. Relatively high subsurface oxygen concentrations observed during cold years should be associated with higher rates of ventilation of the euphotic zone and thus accumulation of more oxygen in the upper layer water column.

Cold years also characterize relatively higher phytoplankton biomass (Figure 84). Normally, years with high phytoplankton production are expected to have low oxygen concentrations due to more intense oxygen consumption associated with more intense remineralisation process. This is however not the case in Figure 84 and the positive correlation between oxygen concentration and phytoplankton biomass may suggest that the rate of oxygen production during cold years is apparently a more dominant process than its consumption due to more enhanced plankton production.

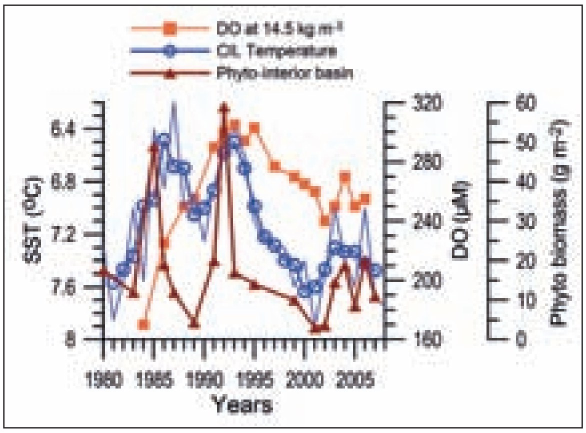

Figure 84. Changes in the average dissolved oxygen concentration within the density layer of σt ~14.45 and 14.6 kg m^{-3} density surfaces (roughly corresponding to the base of euphotic zone) in the region off the eastern coast (Yakushev *et al.*, 2005), and the summer- autumn mean CIL temperature (Belikopitov, 2005) and phytoplankton biomass (g m^{-2}) (Mikaelyan, 2005) within the euphotic zone of the interior basin.

Bacillariophyceae abundance (i.e. mostly diatoms) in western coastal waters also closely follows temperature variations. It persists with much higher abundance in relatively cold years, as clearly displayed by a linear rising trend from 1970 to 1993 in Figure 85. On the other hand, the abundance tends to decrease during the intense warming period after 1993. A similar decrease is also noted during the warming phase before 1970.

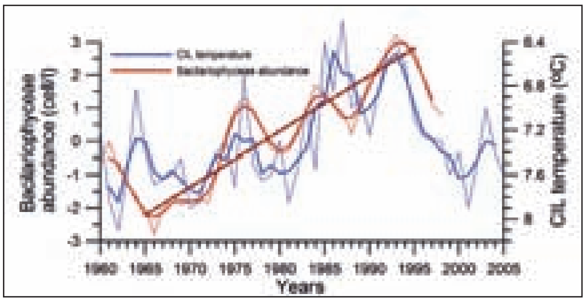

Figure 85. Time series of standardized bacilariophyceae abundance along the Bulgarian coastal waters (after Moncheva, 2005) and CIL temperature. The dash line shows the linear trend of bacilariophyceae abundance during 1965-1995 period.

Mesozooplankton biomass fluctuations of the central-eastern Black Sea are also in phase with those of temperature (Figure 86). The biomass tends to increase (decrease) in warm (cold) years.

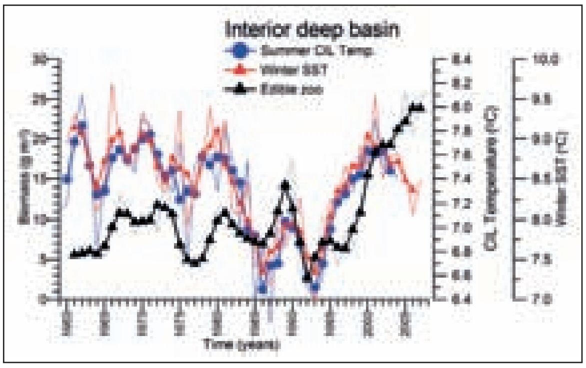

Figure 86. Time series of the annual-mean edible zooplankton biomass in the northeastern basin (g m^{-2}), and the mean CIL temperature (°C) (blue dots; after Belikopitov, 2005) averaged over all stations within interior basin and mean winter (December-March) sea surface temperature (SST) as an average of Hadley2, NCEP-Reynolds and Pathfinder5 data sets.

According to measurements along the Bulgarian coast, a boreal cold-water organism *Noctiluca scintillans* maintained a more favourable reproduction capability during cooler late-spring (May–June) temperatures following more severe winters (Figure 87). *Noctiluca* biomass therefore increased an order of magnitude during the 1970s cooling period and then declined gradually during the subsequent warming phase of the 1990s. But factors like species food competition and prey-predator interactions should also control the biomass changes in the 1980s and 1990s.

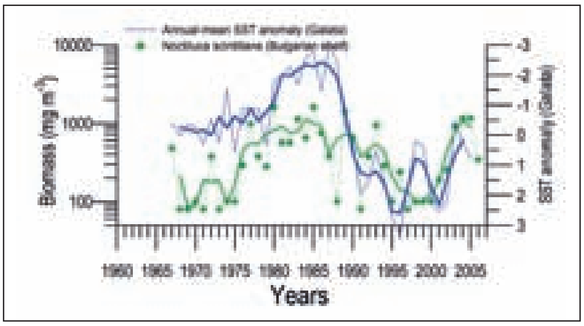

Figure 87. Time series of Noctiluca scintillans biomass in Bulgarian shelf and the annual-mean SST variations at the coastal station Galata.

A similar link exits between summer (August) surface temperature and *Mnemiopsis* abundance in the eastern Black Sea during August in the 1989-2003 period (Figure 88). A positive correlation between warm temperatures (26-27°C) and high abundances (> 2,000 ind/m²) is clearly indicated during 1989-1991 and 2000-2001. Similarly, the cold periods (~24°C) of 1992-1993 and 2003-2004 are characterized by an order of magnitude lower abundances (~200 ind/m²).

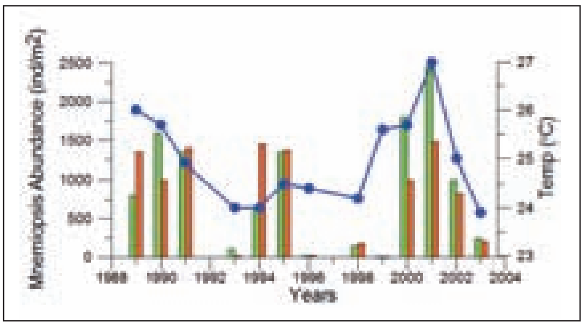

Figure 88. Time series of Mnemiopsis abundance in the eastern Black Sea offshore waters (green bars) and inshore waters (red bars) during August of 1989-2003 period, and August surface water temperature (blue dots) (from Shiganova *et al.*, 2004).

Planktivore fish stocks (mostly anchovy and sprat) have been subject to dramatic changes during the second half of the last century (Oguz, 2007). They were at relatively low levels during the 1960s prior to the depletion of pelagic piscivore stocks and dolphins. During the 1970's the stocks increased due to weakening of predator control as well as increasing level of eutrophication and thus more active biological production (Daskalov *et al*., 2007). At the end of the 1980's planktivorous fishes collapsed due to the combined effect of overfishing and the outburst of the ctenophore *Mnemiopsis leidyi* (Oguz *et al*., 2008). Even though anchovy and sprat stocks are exposed to such complex environmental controls, they nevertheless appear to be regulated by climatic changes. Figure 89 shows a clear correlation between the sum of anchovy and sprat catch increase and the climatic cooling during the 1970s and 1980s and vice versa for the 1990s. Erdogan *et al*. (2010) provided a similar correlation between anchovy catch size and monthly temperature changes during November-February and thus the number of fishing days with an optimum temperature range of 9.4-14.5°C.

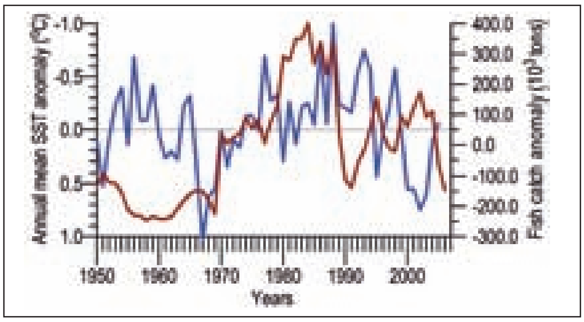

Figure 89. Time series of annual-mean basin-averaged temperature and the sum of sprat and anchovy catch anomalies. Note the inverted temperature axis on the left.

Long term data from the interior basin suggest that the share of coccolithophores within the total May-June phytoplankton biomass was about 19 % prior to 1985, and 16 % during 1985-1994, but decreased to 2.5 % after 1994 when the Black Sea shifted to the warming phase. The reduced cocolithophore populations in the Black Sea is consistent with the reduced calcification rates under global warming and ocean acidification but it may be related to, at least partly, to the decadal warming-cooling cycles associated with NAO changes.

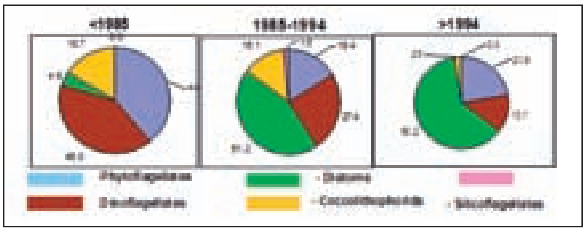

Figure 90. % share of different taxonomic groups in the total phytoplankton biomass during May-June within deep interior basin of the Black Sea for different phases of the ecosystem.

3.6.4 Link between Observed Changes and Climate

A high and significant correlation between the basin-averaged winter-mean SST and the winter-mean air temperature anomaly and the NAO index (Figure 90) provides compelling evidence for regulation of the regional hydro-meteorological conditions by large scale climatic teleconnection patterns. We refer to Figure 90 to show how the long-term (1910-1970) warming trend coincides with declining NAO index values toward more negative values whereas the subsequent cooling up to the mid-1990s is related to strengthening of the NAO toward its more positive phase. Therefore, more positive NAO values imply colder, drier and more severe winters in the Black Sea (Oguz *et al*., 2006) which is opposite to the conditions of wetter and milder winters in the northwestern European seas (Osborn *et al*., 1999).

The changes in long-term detrended average sea-level reveal a negative correlation with the winter-mean NAO index (Figure 82). In general, positive NAO index values are associated with relatively low sea-level. The correlation is highest for the western Mediterranean ($r = -0.48$) and decreases to $r = -0.37$ for the Eastern Mediterranean Sea and $r = -0.40$ for the Black Sea. A high degree of agreement between temporal variations of biogeochemical variables and temperature also indirectly indicates a link between Black Sea ecosystem changes and large scale climate systems. Reconstructing annual temperature variations for the Mediterranean Sea and Middle East (between 30-40°N latitude and 20-50°E longitude) since 1750 also points to the role of the NAO in the region (Mann, 2002). In addition, the North Sea - Caspian pattern (NCP) is shown to explain some of the variability on the Mediterranean, Black and Caspian Seas hydro-meteorological properties (Gunduz & Ozsoy, 2005). This index is constructed based on mid-tropospheric (500 hPa) geopotential height difference between the North Sea and the Caspian Sea regions. A similar index, but based on the surface pressure differences of these two regions, is referred to as the East Atlantic – West Russia (EAWR) index. These two indices characterize motions of jet streams over Europe, and therefore represent eastward zonal extension of the NAO pattern originating in the Atlantic sector.

As pointed by Oguz *et al.* (2006), their combination explains better the Black Sea climatic variability, although the NAO constitutes the primary atmospheric system. In addition, cold air outbreaks developing in the Gulf of Genoa of the Mediterranean Sea affect the Black Sea climate in both winter and summer months once they move to the northeast over the Aegean Sea and then the Black Sea. In contrast, while the El Nino/Southern Oscillation (ENSO) phenomenon constitutes a major source of interannual climate variability over much of the globe, it has only a weak influence on the climate of the Eastern Mediterranean-Black Sea region (Price *et al*., 1998).

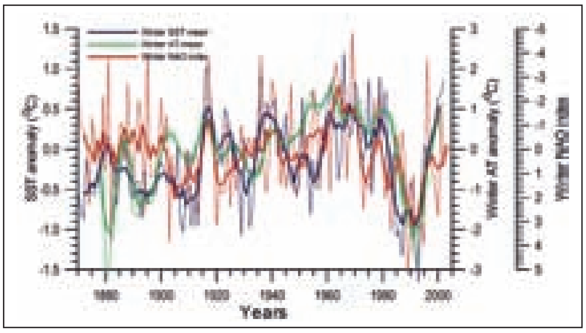

Figure 91. Time series of the basin-averaged winter mean sea surface and air temperatures, and the winter mean North Atlantic Oscillation index. The thin lines show the original data and the thick lines are the smoothed curves by 5 point moving averaging. Note that the axis for the NAO index on the right is inverted.

3.6.5 Future Climate Change Projections

No specific future climate change scenarios have been accomplished for the Black Sea yet, but the studies conducted for Europe in general and the Mediterranean and Middle East in particular by Giorgi and Lionello (2008), Evans (2009) may be used to infer the fate of the Black Sea climate towards the end of the present century. The model predictions use different projections of the Intergovernmental Panel on Climate Change (IPCC) greenhouse gas emissions. They show consistently a northward shift of the Atlantic storm tracks to higher latitudes. As a result, the Mediterranean region will exhibit a general reduction in precipitation, while northern Europe will be subject to an increase (10 - 50 %). The Black Sea lies in the transitional zone between these two regimes and thus it is hard to identify its definitive future climate state. In the case of precipitation increase, a simultaneous increase in air temperature (and thus sea temperature) is projected over the Black Sea. Otherwise, colder and drier climatic conditions will prevail in agreement with projections due to likely changes in the NAO pattern in response to the global warming described in the previous section.

3.6.6 Socio-Economic Consequences of Climate Change in the Black Sea

Marine ecosystems, particularly coastal seas, are generally regulated by multiple environmental pressures and therefore it is often difficult to separate the effects of climate change from those of eutrophication, overfishing and other site specific environmental factors. The most important socio-economic impact of climate change in the Black Sea was felt in the fisheries sector. Temperature appears to be a key environmental factor for conditioning migration and schooling behaviour of anchovy. Increasing winter temperatures adversely affected anchovy migration patterns by shortening the main fishing season from the late February to the early January (Erdogan *et al.* 2010). Disruption of the existing patterns due to climatic warming affected nearly 20,000 fishermen employed in the Turkish Black Sea fishing sector because 80 % of the Black Sea fish catch was attributed to Turkey (Shivarov, 2010).

Figure 92. Increasing winter temperatures adversely affect anchovy migration patterns by shortening the main fishing season from the late February to the early January with important effects on the employment of fishermen in Turkey (Erdogan *et al.* 2010). (©Leen Vandepitte)

These socio-economical impacts on the fishery sector followed even a more dramatic one that took place earlier at the beginning of the 1990s when the total fish catch declined from 900,000 tons in the mid 1980s to 100,000 tons. As documented by Knowler (2008), it roughly amounted to an economical loss of about USD 240 million, based on a unit catch value of USD 300/ton. Moreover, processing plant losses were roughly estimated at about USD 10 million for 50 plants in the

Black Sea region, on the basis of the costs of switching over to an alternative production line. Using the more extreme replacement cost approach, the estimate for Turkish processing plants alone suggests losses of USD 20 to 30 million. Up to 150,000 people were estimated to depend directly on the Black Sea fisheries, but income losses have been more difficult to estimate. Wages lost in processing plants alone totalled approximately USD 10 million annually (Knowler, 2008).

The Turkish coastal waters, particularly on the eastern side, include an important aquaculture industry based mainly on rainbow trout. Raising temperatures during the last decade have however increased the frequency of disease outbursts, decreased breeding efficiency and shortened their growing season. These events led to a shift to farming of new species, such as European seabass, more suitably adapted to new conditions. While this could be a solution to the local economy, it raises new environmental problems (Erdogan *et al.,* 2010).

3.6.7 Research Gaps, Uncertainties and Relevance to EU Funding

There are many knowledge gaps regarding likely impacts of climate change on the Black Sea ecosystem. The present assessment studies are limited in scope due to dispersed and often unreliable data sets. A better understanding of the interplay between the environment and well-beings of the people living in the region demands more comprehensive research in the fields of environmental and natural resources. The lack of systematic observations by the riparian countries hinders better understanding of the natural and anthropogenic climate changes and their impacts on the coastal and interior basin ecosystems. Unless critical information gaps can be closed by improved monitoring of social and natural system indicators, it will not be possible to develop reliable scenario models that will serve as a basis for decision making towards sustainable use of ecosystem goods and services.

EU funding for conducting scientific research in the Black Sea ecosystem studies in general and climate change impacts in particular have been very limited so far as compared to those provided for other European Seas. The EU FP6 SESAME project was the first and the only EU-funded project that included a climate change research component so far.

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