2 Current Understanding of Environmental and Water Resource Impacts in the Eastern Mediterranean
(A subdomain of the greater Euro-Mediterranean Middle-Eastern Seas region)

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2.1 Preamble

While this presentation in its title aims to review the environmental and water resource impacts in the eastern Mediterranean, in the subtitle emphasis is given to the fact that regional issues are inseparably linked with the environment/climate of a greater area.

The mid-latitude water bodies extending from Gibraltar eastwards to the Aral Sea can be identified as a true "medi-terra"nean complex of seas locked between continents increasingly isolated from the world ocean, which together form an interconnected climatic unit. The climates of the "downstream" water bodies, i.e., the Eastern Mediterranean, and Black and Caspian seas, are linked with the climates of the adjoining continents of Europe, Africa and Asia, which in turn are affected by the climates of the adjoining Atlantic and Indian oceans. Ocean-atmosphere-land interactions and consequent feedbacks between regional and global climate systems could be disproportionately large in this region of contrasts between marine and continental climates, and complex land/sea bottom topography (Özsoy 1999). High gradients in physical characteristics, as well as in so-

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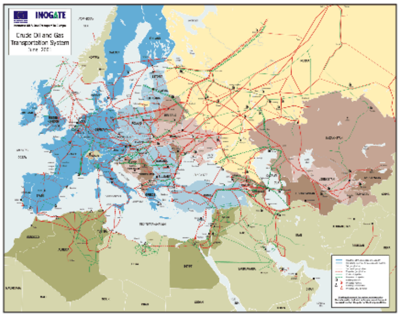
cioeconomics, make the region prone to impacts of climate change, implying possible changes in hydrology and ecosystems.

On the basis of our present understanding, it is not clear how the global climate system is projected onto the region, or how the region contributes to the global system. Unexpectedly large impacts could occur, as they have done in the past, in such a complex system, in response to global change. On the other hand the typically delayed human response to environmental emergencies can result in irreparable damage.

2.2 Climatic and Anthropogenic Impacts in Interconnected Seas

Although the region where we live turns out to be interconnected and dependent on neighboring areas of the globe, we often focus our attention on local problems of direct consequence. While nature as a function of the sun's inclination and geography seems to favour some of us more than others on Earth, through the ages differences in our common inheritance have been tolerated by human settlement and adaptation. In the age of global change, inequalities in the distribution of resources, energy and people are extremely demanding for human adaptation, let alone their sharing. The situation implies a serious geo-potential for conflicts that in turn could result in further environmental damage.

The well-being of the region's inhabitants is affected by the particular patterns of climate, transport of atmospheric or marine pollutants or by the distribution of resources. While some of the effects such as the North Atlantic Oscillation (NAO) or the long-range transport of atmospheric pollutants from industrial Europe may originate west of the region, others, such as the Indian Monsoon, can have their origin in the east, being in reality a



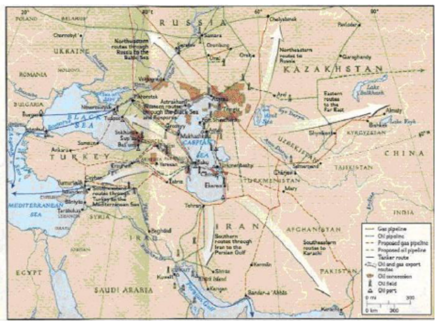


Fig. 1a. Oil and gas pipelines in the Euro-Asian-African junction
Fig. 1b. Transport effects of the Caspian Sea oil and gas

Figs. 2a, b. Shipping accidents in the Bosphorus — the Nassia accident spilled more than 1000 tons of oil in the Turkish Straits in 1994

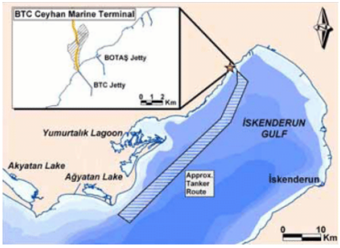


Fig. 2c. Baku-Tblisi-Ceyhan pipeline terminal in the Gulf of İskenderun

part of the global pattern. Similarly, the distribution of water, food or energy, and their exploitation have regional impacts.

While oil and gas pipeline transport networks (Figure 1) and shipping redistribute the hydrocarbon resources, they can give rise to environmental threats in regions remote from the source, for example in the Turkish Straits System, and the Gulf of İskenderun in the eastern Mediterranean, as shown in Figure 2.

The Turkish Straits System connects the Eurasian hinterland to the Mediterranean through the Black and Caspian seas. Among the 264 straits used by shipping worldwide, the narrow Bosphorus with rapid currents (a 30km long winding channel with a minimum width of 700m and a navigable section of 200m, current speeds of up to 4 m/s, and ship lengths occasionally greater than 200m) is currently four times busier than the Panama Canal, already congested by local traffic serving İstanbul, a world heritage city of 10 million people. The ship traffic has increased by about 20 times by weight in the last 70 years, carrying more than half the Russian oil exports, and the load is further expected to triple by export of hydrocarbons from Caspian/Eurasian fields in the next decades. The saturation of its traffic-carrying capacity makes the Turkish Straits extremely predisposed to accidents involving collision, grounding, fires and explosions. The second sensitive area with potential to be affected by the same traffic, but different route, is the Gulf of İskenderun, where the recently finished Baku-Tblisi-Ceyhan pipeline terminates (Figure 2).

An important natural resource of regional significance is water. Again, the distribution is determined by geometry, but also by socioeconomics. In some cases there are fewer people where the water resources are poor (or vice versa). In general there is a north-south gradient of water availability, though the population increase is faster in the south where there is a shortage of water (Figure 3). In some other countries that appear to be rich in water, the population increase is so fast that the per capita share is comparable to water-poor countries (Figure 4).

It should also be noted that the general rule of inequality also applies in the way water is consumed. Globally the production of meat in the second half of the last century increased by more than fourfold, and preferentially in the developed world. The production of meat requires 7 times more land and 10–20 times more energy and water compared to the production of grain. The side effects are disturbed marine and land ecosystems due to over-grazing, over-fishing, and the use of fertilizers and pesticides, etc.

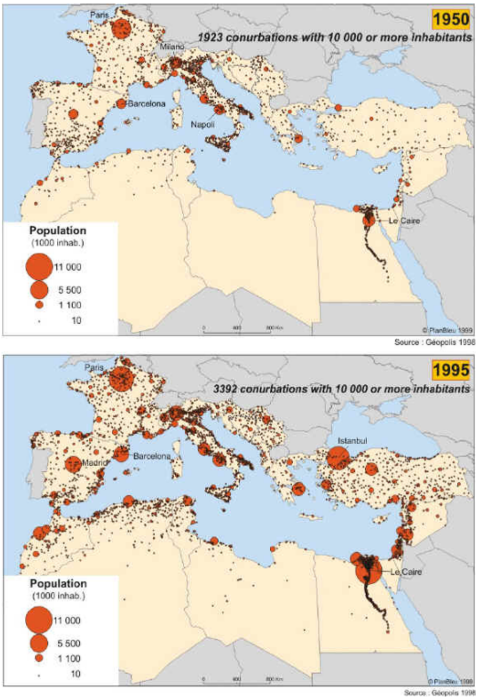


Fig. 3a. Comparison of urban populations in the Mediterranean during the second half of the last century (The Blue Plan http://www.planbleu.org)

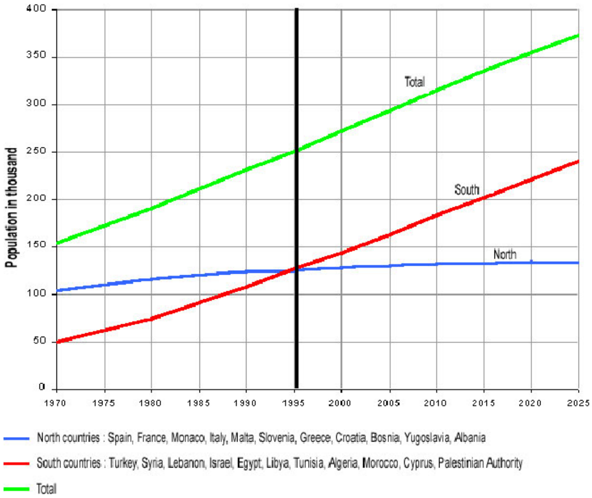


Fig. 3b. The change in population in the Mediterranean's northern and southern coasts (The Blue Plan http://www.planbleu.org)

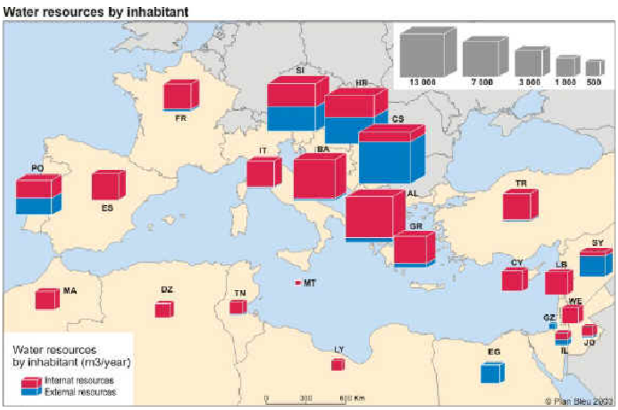


Fig. 4. Per capita internal and external water resources in the Mediterranean countries (The Blue Plan http://www.planbleu.org)

There have been important changes in the use of water for irrigation. The surface area of irrigated land has doubled or tripled in most Mediterranean countries in the last 50 years. A large number of dams for irrigation and energy production have changed runoff patterns and have had significant effects on land and marine ecosystems. For example, the 90 percent decrease in water as well as nutrients carried by the Nile River in the eastern Mediterranean after the construction of the Aswan high dam in the 1960s (Figure 5a) reduced the primary and fish productivity near the Egyptian and eastern Levantine coast up to the 1980s, after which waste dis-

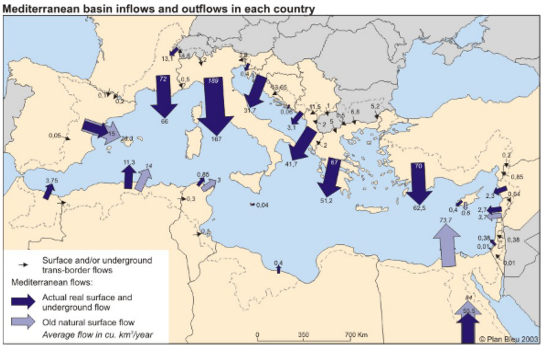


Fig. 5a. Surface and ground water inputs into the Mediterranean (The Blue Plan http://www.planbleu.org) showing old and new transports from catchments in each country, and cross-border transports of water

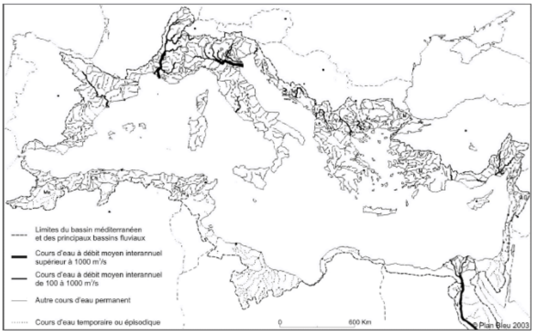


Fig. 5b. The watersheds of the rivers discharging into the Mediterranean

charges from major population centers and drainage seems to have more than made up for the losses, and once again have increased eutrophication in the 1990s (Nixon 2003).

With the recent decline of the Nile discharge, the Turkish rivers in the north (Figure 5a) presently constitute the only available runoff water into the entire oligotrophic eastern Mediterranean, concentrated in the relatively small area of the Cilician Basin (between Cyprus and Turkey). Because of the significant inputs of these rivers the region has all the characteristics of the ROFI (regions of freshwater influence) but in an oligotrophic deep water environment.

The Cilician Basin coastal system including the wide continental shelf of the bays of Mersin and İskenderun occupies the northeastern part of the eastern Mediterranean Levantine Basin between Cyprus and Turkey. Perennial rivers such as Göksu, Lamas, Tarsus, Seyhan, Ceyhan and Asi, and smaller rivers account for a significant total freshwater flux of 27km^3/yr,

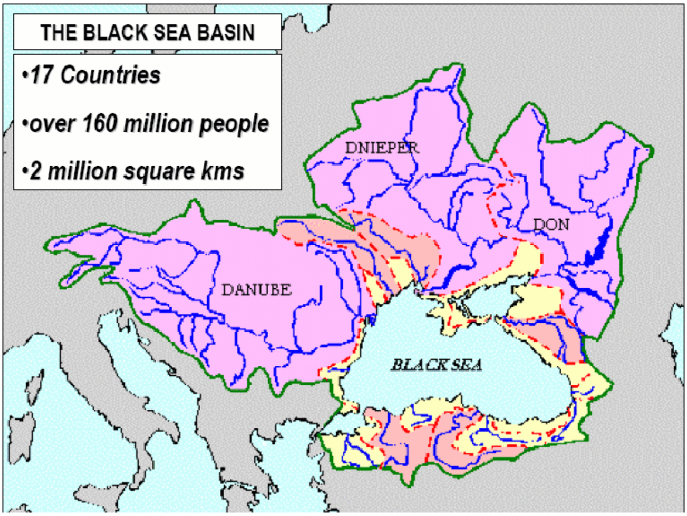


Fig. 5c. The watersheds of the rivers discharging into the Black Sea

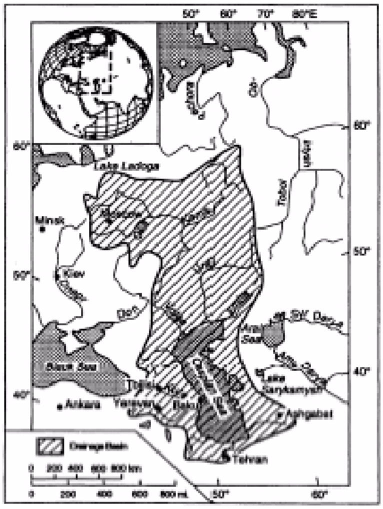


Fig. 5d. The watersheds of the rivers discharging into the Caspian Sea (after Rodionov, 1994)

or about half of all rivers along the Turkish Mediterranean and Aegean coasts, which is still greater than the present discharge of the Nile in the eastern Mediterranean. The Cilician Basin coastal system embodies important natural resources of strategic importance, presently experiencing rapid growth in population, industry, agriculture and tourism, resulting in significant environmental stresses.

The watershed areas of rivers discharging into the Mediterranean and, Black and Caspian seas (Figures 5b, c, d) make up different ratios when compared to the target sea areas. For the Mediterranean, the rivers are spread over watersheds limited to coastal margins and plains (except for the Nile which is now dammed), while the catchments of the major rivers of the Black and Caspian seas cover much larger areas of continent compared to the destination sea. The balance between evaporation, runoff and precipitation, combined with the geometrical constraints determine the vertical structure of these seas, with the Mediterranean being a better ventilated concentration basin, and the Black Sea being a poorly ventilated and therefore an anoxic dilution basin. Interestingly, the Caspian Sea, with evaporation almost balancing the river runoff has been observed in the past apparently to switch between poorly ventilated and ventilated states depending on the relatively much larger sea-level changes on the order of several meters in the last decades, and tens of meters in the ancient past.

Physical characteristics determine the state of the ecosystem in each individual basin and its various eco-zones (Figure 6). Riverine and atmospheric supply of nutrients into the sea provide the fuel with which the ecosystems run. The Caspian and Black seas and especially their shelf areas influenced by large rivers are therefore extremely productive, while the eastern Mediterranean appears as a “blue desert”, apart from limited coastal stretches near river mouths.

The establishment of the fluxes of water, nutrients and other materials into each of the basins and that are transported between them is essential to

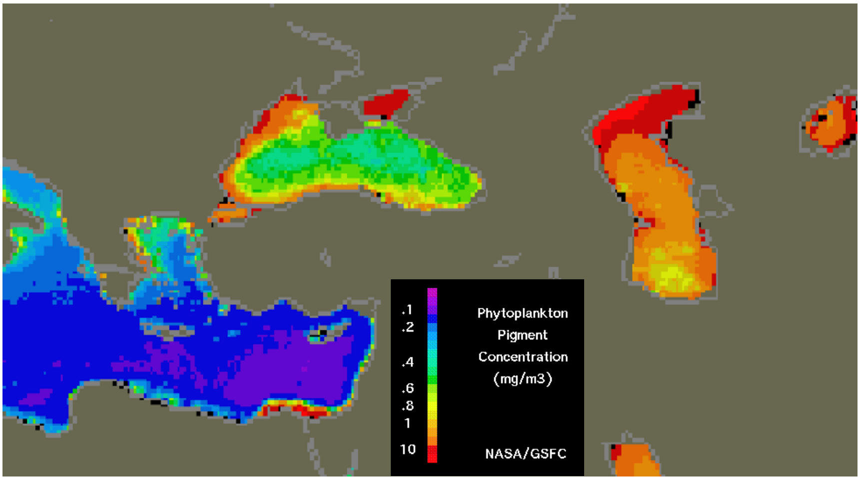


Fig. 6. Satellite derived mean CZCS chlorophyll pigments (mg/m3) based on NASA/GSFC data

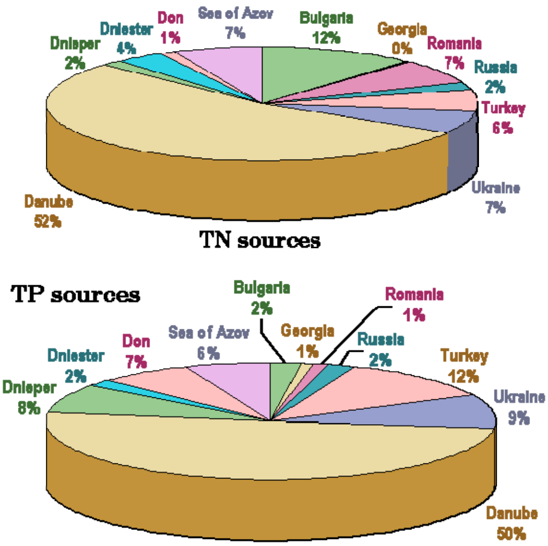


Fig. 7. Results from the Black Sea Transboundary Diagnostic Analysis showing source contributions to total nitrogen (TN) and total phosphorus (TP) (http://www.grid.unep.ch/bsein/tda/main.htm)

evaluate the present state of the ecosystems of individual seas. Transboundary Diagnostic Analyses have been performed for the Black Sea (Figure 7) and the Caspian Sea, but the gathering of such information appears largely incomplete for the Mediterranean Sea basins. It should also be remarked that the mean fluxes obtained by such analyses is a starting point, but largely insufficient, because of the need to better assess the seasonal, interannual and long-term changes in the sources, as a result of agricultural/industrial activity. In the case of the Black Sea, the nutrient inputs carried from continental Europe by large rivers such as the Danube multiplied by several factors, before the changes in economics of Eastern Europe in the mid-1990s put a halt to the trend, and had a positive impact.

An understanding of the sinister threat of eutrophication in semi-enclosed basins and the coastal ocean is not sufficiently developed, although scientific awareness has improved over the years. In the Mediterranean, eutrophication in coastal seas advances against an oligotrophic deep sea background. In comparison, the Black Sea and Caspian Sea are mesotrophic seas which are under greater risk of eutrophication. The environmental crisis in the Black Sea has resulted in major loss of fisheries and habitats, increased occurrence of harmful algal blooms (red tides) and altered food web and community structure. It appears that climatic oscillations, fishing pressure and eutrophication processes all had their fair shares in the resulting crisis (Oğuz 2003), which appears to go through a partial recovery until the present.

One of the culprits in the Black Sea ecosystem collapse was the introduction of the foreign species *Mnemiopsis Leidyi* brought by ships from the Atlantic. The opportunistic organism occupied a new link in the food web, competing with anchovy larvae for food, and therefore had a drastic effect. Similar changes are now being observed in the Caspian Sea, as a result of the introduction of the same organism through the Volga-Don canal connecting the two seas.

2.3 Internal Variability of Euro-Mediterranean Middle-Eastern Seas

The sensitivity (i.e., response to an incremental change in forcing) of an ocean basin is a function of its system characteristics and internal processes. The inability to separate natural variability of the system from man-induced changes, confounded by incomplete observations makes it difficult to understand extreme conditions that often arise unexpectedly in a system.

With today's global warming expectations it is somewhat unclear if we have already started to see measurable effects in our environment. Yet, in the last few decades we have become increasingly aware of previously unobserved extreme conditions. One example of such events is the "Eastern Mediterranean Transient", which has led to massive replacement of the eastern Mediterranean by a rapid series of events in the early 1990s (Roether et al. 1996). Another case is the anomalous warm summer season of 2003 which primarily affected the western Mediterranean (Beniston 2004), heating up the surface waters (Figures 8a, b, c) to rare levels in the available record. It is expected that such warm events would take place with increasing frequency and variability, as a result of global warming.

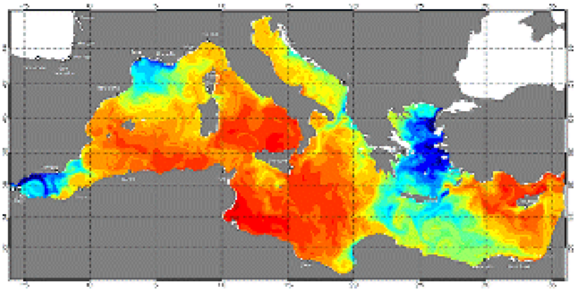


Fig. 8a. Winter sea surface temperature average for individual basins

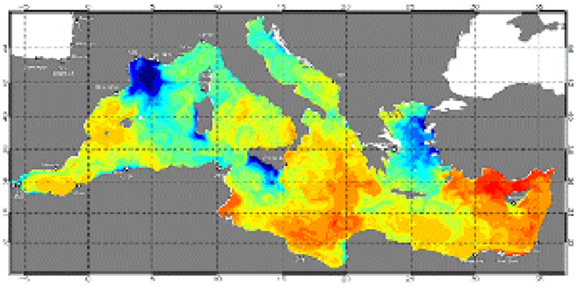


Fig. 8b. Surface temperature of the sea on 28 July 2002

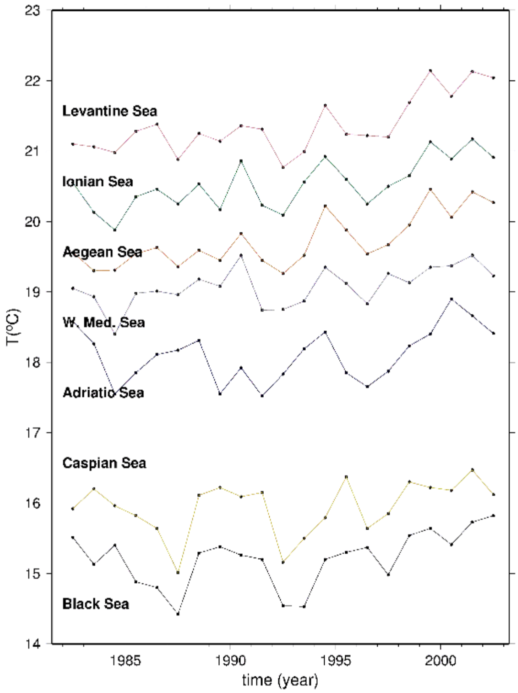
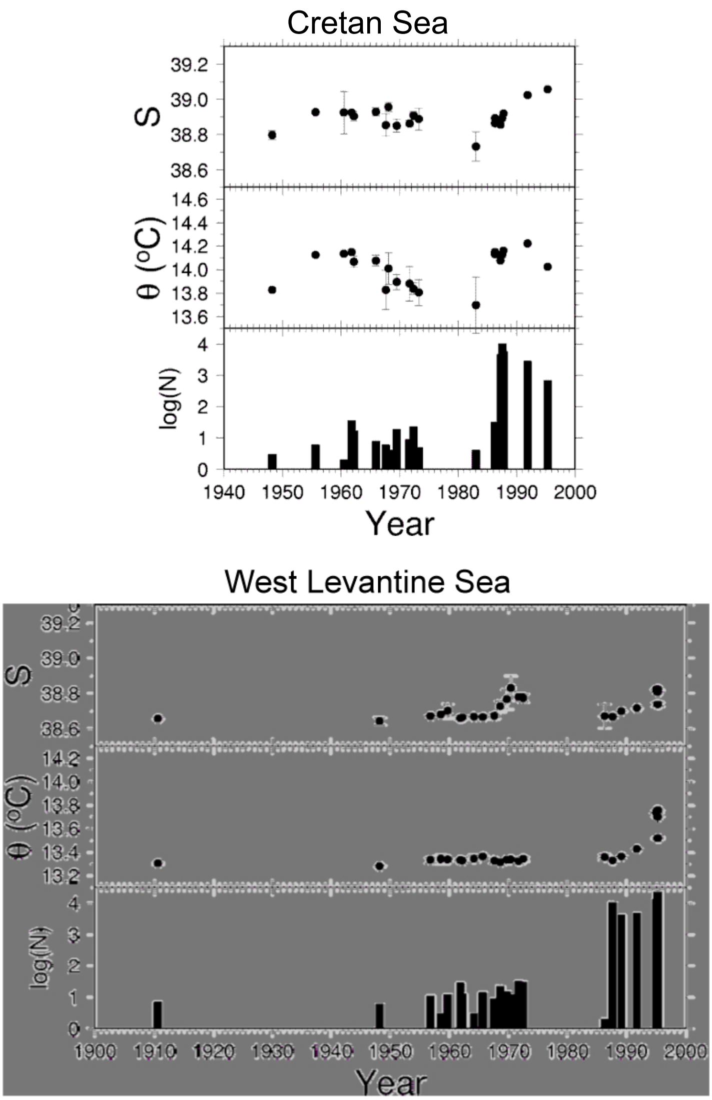


Fig. 8c. Surface temperature of the sea on 28 July 2003 (http://www.mercator-ocean.fr/html/produits/buoc/buoc_n04/buoc_n04_en.html)

Despite their isolated appearance, the internal machinery of each individual marine basin is both a significant driver and participant of regional climate. The mean residence time varies considerably from 7 years for the Marmara, to 25 years for the Caspian, 100 years for the Mediterranean, and up to about 2000 years for the deeper part of Black Sea, resulting in widely differing characteristics of these basins.



Figs. 9a, b. Average salinity, potential temperature and log number of observations in the depth interval of 1000–2000m in the Cretan Sea and of 2000–4000m in the western Levantine Sea areas. The error bars denote standard deviation. The averages are obtained from individual data sets contained within the combined MODB/POEM data and grouped into 1 year intervals falling within the specified depth range (Özsoy and Latif, 1996).

The Mediterranean thermo-haline circulation (i.e., western and eastern basin cells, with a "conveyor belt" partly connected to the North Atlantic) has undergone recent abrupt changes (Figure 9), with previously unforeseen deep water renewal of the entire eastern basin from the Aegean Sea in the 1990s (Roether et al. 1996), and recurrent deep water formation at the Rhodes Gyre core observed in 1987 and 1992 (Sur et al. 1992). Shelf processes and episodic events of deep water renewal are also evidently important in the north Aegean Sea (Zervakis et al. 2000). Abrupt changes in the surface circulation and water masses have been repeatedly recognized on decadal time scales in the eastern Mediterranean (e.g., Malanotte-Rizzoli et al. 1999).

In the relatively stable Holocene period there have been significant changes in climate with repeated periods of enhanced productivity associated with surface water budgets (especially in relation to dramatic changes in the Nile outflow) reflected in the hydrographic structure of the eastern Mediterranean (Schilman 2001).

In comparison, the Black Sea is considerably less mixed. Wind and boundary mixing processes control the permanent pycnocline in the Black Sea (Özsoy and Ünlüata 1997). Below the pycnocline, both the temperature and the salinity increase towards the bottom, their competing effects on static stability leading to double diffusive convection driven by lateral sources of Mediterranean water entering from the Bosphorus and modified along the continental shelf. The present day penetration of anomalous waters is limited to the upper 500m and does not reach the bottom of the Black Sea. Saline water intrusion from the Aegean Sea fills and ventilates the three interconnected deep basins of the Marmara Sea, which could otherwise become anoxic as there is little exchange across the sharp interface separating the main water body from the surface layer (Beşiktepe et al. 1993, 1994). The surface water injected into the northern Aegean from the Dardanelles Strait is thought to have a similar function in controlling wind-induced mixing there.

The Black Sea is the largest anoxic basin of the world, with a Holocene history of transformation from a freshwater lake to a sea with low salinity. Recurrent plankton productivity events have occurred at intervals of a few hundred years within the last millennium (Figure 10), recorded in bottom sediments when the basin has evolved to sufficiently saline conditions allowing *Emiliana Huxleyi* blooms (Hay and Honjo 1989). A series of recent ecosystem changes has occurred as a result of the freshwater and increased nutrient supplies and poor ventilation (Özsoy and Ünlüata 1997).

The sea level, besides being a good indicator of climatic fluctuations, is a sensitive measure of climate in enclosed and semi-enclosed seas driven by large rivers. In the Black Sea, sea level is controlled by atmospheric pressure and the total water budget, which are both highly variable themselves (Özsoy and Ünlüata 1997; Özsoy et al. 1998). Basin hydrometeorology driving sea level appears linked to ENSO and Monsoon regimes in the Caspian Sea (Bengtsson 1998; Arpe and Roeckner 1999) and to NAO in the Black Sea (Stanev and Peneva 2002). The recent sea-level change in the neighboring Caspian Sea is demonstrative of the magnitude of problems that could occur. The abrupt sea level drop in the 1930s and rise in the 1980s, by more than 2m each time, flooding the surrounding flat lands, is perhaps an isolated decadal event within the observed past (Radionov 1994) and forecasted future changes (Arpe and Roeckner 1999) of even greater magnitude. Sea-level fluctuations have been linked with subsequent changes in ventilation and biochemical cycles alternatively leading either to anoxia or well-mixed conditions (Kosarev and Yablonskaya 1994; Dumont 1998; Kosarev and Toujilkine 2002). It is not known whether the Holocene periods of increased productivity in Figure 2 were a consequence of sea level variations, but much greater impacts on both the Aegean and the Black seas are known to have occurred in the Quaternary (Ryan et al. 1997; Aksu et al. 1999).

Exchange through straits and transports between basins play significant roles in short-and long-term modulation of climate in each basin and the coupling between them. It is implied that the hydrological and biogeo–chemical cycles also depend critically on sub-basin-scale, meso-scale and

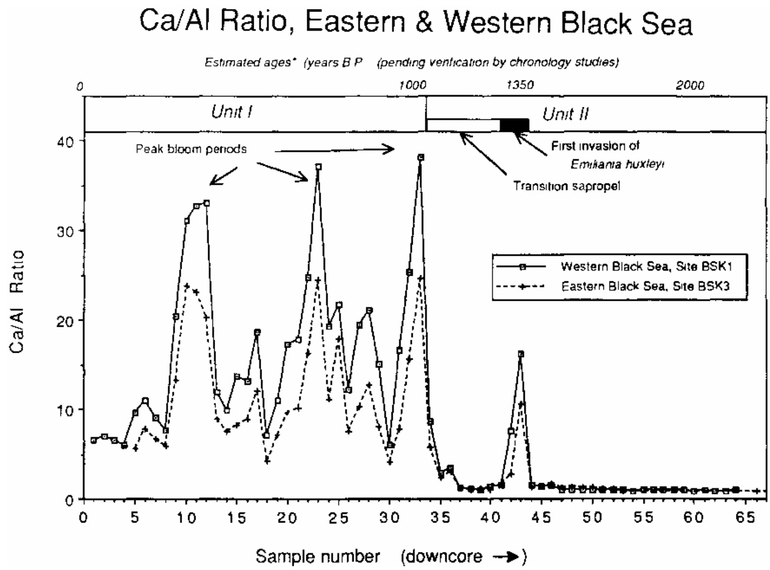


Fig. 10. Ca/Al ratio of core samples from the eastern and western Black Sea, representing the ratio between biologically produced/terrigenous deposition of particles, as a function of core depth and time in years (top scale) (after Hay and Honjo, 1989)

inter-basin exchanges and land-ocean-atmosphere interactions including the effects of coastal processes.

The Turkish Straits System (the Straits of Dardanelles, Bosphorus and the Sea of Marmara) is a highly stratified (fjord-like) two-layer system, acting as a buffer for waters flowing in both directions between the Black and Aegean seas. Mixing and turbulent entrainment processes in the two straits and at their junctions dominate the evolution of the salinity of waters transported away from their original reservoirs (Beşiktepe et al. 1993, 1994; Gregg and Özsoy 1999; Gregg et al. 1999; Özsoy et al. 2001). Straits conveying waters of foreign origin, as well as freshwater from large rivers act as buoyancy sources for the adjacent basins of the Aegean, Marmara and Black seas. The complex topography of the straits, continental shelf, slope and abyssal regions play important roles in channeling and the subsequent transformation of waters of different origin.

The complexity of the marine and atmospheric climate processes, and the scarcity of some resources in the region, calls for integrated scientific investigations. Networks of observing systems, shared databases and models integrated through supporting institutions are essential for answering key questions with respect to the impact of climate change in the region, and to enable environmental prediction and management from the perspective of global change.

References

Aksu AE, Hiscott RN, Yaşar D (1999) Oscillating Quaternary water levels of the Marmara Sea and vigorous outflow into the Aegean Sea from the Marmara Sea-Black Sea drainage corridor. Marine Geology 153: 275–302

Arpe K, Roeckner E (1999) Simulation of the hydrological cycle over Europe: Model validation and impacts of increasing greenhouse gases. Advances in Water Resources 23: 105–119

Bengtsson L (1998) Climate modeling and prediction: Achievements and challenges. WMO/IOC/ICSU Conference on the WCRP Climate Variability and Predictability Study (CLIVAR), UNESCO, Paris, 2–4 December 1998

Beniston M (2004) The 2003 heat wave in Europe: A shape of things to come? Geophys Res Lett 31: L02022

Beşiktepe Ş, Özsoy E, Ünlüata Ü (1993) Filling of the Sea of Marmara by the Dardanelles Lower Layer Inflow. Deep-Sea Res 40: 1815–1838

Beşiktepe Ş, Sur Hİ, Özsoy E, Latif MA, Oğuz T, Ünlüata Ü (1994) The Circulation and Hydrography of the Marmara Sea. Prog Oceanogr 34: 285–334

Gregg MC, Özsoy E, Latif MA (1999) Quasi-Steady Exchange Flow in the Bosphorus. Geophysical Research Letters 26: 83–86

Gregg MC, Özsoy E (1999) Mixing on the Black Sea Shelf North of the Bosphorus. Geophysical Research Letters 26: 1869–1872

Gregg MC, Özsoy E (2002) Flow, Water Mass Changes and Hydraulics in the Bosphorus. J Geophys Res 107(C3): 10.1029/2000JC000485

Hay, BJ, Honjo S (1989) Particle Deposition in the Present and Holocene Black Sea. Oceanography 2(1): 26–31

Kosarev AN, Tuzhilkin VS (1995) Climatological thermohaline fields of the Caspian Sea. Moscow University Press and State Oceanographic Institute, Moscow (in Russian)

Kosarev AN, Yablonskaya EA (1994) The Caspian Sea. Backhuys Publishers, Haague, 259 pp

Malanotte-Rizzoli P, Manca B, d'Alcala MR, Theocharis A, Brenner S, Budillon G, Özsoy E (1999) The Eastern Mediterranean in the 80s and in the 90s: The Big Transition in the Intermediate and Deep Circulations. Dyn Atm Oceans 29: 365–395

Nixon SW (2003) Replacing the Nile: Are anthropogenic nutrients providing the fertility once brought to the Mediterranean by a great river? Ambio 32(1): 30–39

Oğuz T (2003) Climatic Warming Impacting Pelagic Fish Stocks in the Black Sea Due to an Ecological Regime Shift During Mid-1990s. Globec International Newsletter 9(2): 3–5

Özsoy E, Beşiktepe S (1995) Sources of Double Diffusive Convection and Impacts on Mixing in the Black Sea, pages 261–274. In: Brandt A, Fernando HJS (editors), Double-Diffusive Convection, Geophysical Monograph 94, American Geophysical Union, 334 pp

Özsoy E, Latif MA (1996) Climate Variability in the Eastern Mediterranean and the Great Aegean Outflow Anomaly. International POEM-BC/MTP Symposium, Molitg les Bains, France, 1–2 July 1996, pp 69–86

Özsoy E, Ünlüata Ü (1997) Oceanography of the Black Sea: A Review of Some Recent Results. Earth Sci Rev 42(4): 231–272

Özsoy E, Latif MA, Beşiktepe S, Çetin N, Gregg N, Belokopytov V, Goryachkin Y, Diaconu V (1998) The Bosphorus Strait: Exchange Fluxes, Currents and Sea-Level Changes. In: Ivanov L, Oğuz T (editors), Ecosystem Modeling as a Management Tool for the Black Sea. NATO Science Series 2: Environmental Security 47, Kluwer Academic Publishers, Dordrecht, vol 1, 367 pp + vol 2, 385 pp

Özsoy E (1999) Sensitivity to Global Change in Temperate Euro-Asian Seas (the Mediterranean, Black Sea and Caspian Sea): A Review. In: Malanotte-Rizzoli P, Eremeev VNT (editors), The Eastern Mediterranean as a Laboratory Basin for the Assessment of Contrasting Ecosystems. NATO Science Series 2, Environmental Security 51, Kluwer Academic Publishers, Dordrecht, pp 281–300

Özsoy E, Di Iorio D, Gregg M, Backhaus J (2001) Mixing in the Bosphorus Strait and the Black Sea Continental Shelf: Observations and a Model of the Dense Water Outflow. J Mar Sys 31: 99–135

Roether W, Manca BB, Klein B, Bregant D, Georgopoulos D, Beitzel V, Kovacevich V, Lucchetta A (1996) Recent changes in Eastern Mediterranean deep waters. Science 271: 333–335

Ryan, WBF, Pitman III WC, Major CO, Shimkus K, Maskalenko V, Jones GA, Dimitrov P, Görür N, Sakinç M, and Yüce H (1997) An abrupt drowning of the Black Sea shelf. Mar Geol 138: 119–126

Schilman B, Almogi-Labin A, Bar-Matthews M, Luz B (2001) Late Holocene productivity and hydrographic variability in the eastern Mediterranean inferred from benthic foraminiferal stable isotopes. Paleoceanography 18 (3): 1064, doi:10.1029/2002PA000813

Sur Hİ, Özsoy E, Ünlüata Ü (1992) Simultaneous Deep and Intermediate Depth Convection in the Northern Levantine Sea, Winter 1992. Ocean Acta 16: 33–43

Stanev EV, Peneva EL (2002) Regional sea level response to global climatic change: Black Sea examples. Global and Planetary Changes 32: 33–47

Zervakis V, Georgopoulos D, Drakopoulos PG (2000) The role of the North Aegean Sea in triggering the recent Eastern Mediterranean climatic changes. Journal of Geo-physical Research, 105 (C11): 26103-26116