IV-7 Mediterranean Sea: LME #26

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The Mediterranean Sea LME, located between Southwestern Europe and Northern Africa, is bordered by a large number of countries. It has a narrow continental shelf and covers a surface area of about 2.5 million km^2, of which 1.43% is protected, with 0.4% of the world's sea mounts (Sea Around Us 2007). A warm-temperate climate and several distinct biogeographical sub-units characterise this LME. For the origin and history of the Mediterranean and Adriatic Seas, see Bombace (1993). Book chapters and articles pertaining to this LME include Bombace (1993), Caddy (1993) and UNEP (1997). A new strategic partnership for the Mediterranean has been formed by the GEF, UNEP, and the World Bank to implement the Strategic Action Plan (SAP) agreed upon by the participating countries to reduce pollution impacts on environment and human health, to address pollution from land-based activities, reach sustainable fisheries, and protect coastal-marine biodiversity and communities (see www.medsp.org).

I. Productivity

Overall, the Mediterranean Sea LME is considered a Class III, low productivity ecosystem (<150 $gCm^{-2}yr^{-1}$). For an oceanographic overview of the Mediterranean Sea and its hydrographic inputs and primary production, see Caddy (1993). Temperature stratification can occur during extended periods of calm seas, high temperatures, and inflows of fresh water. This separates the warmer, less saline surface water from the deeper, colder and more saline water, resulting in autumnal algal blooms and extended hypoxia or anoxia. The LME presents a composite structure of environmental conditions, with local areas of upwelling, wind-driven currents, high water temperatures at least in some periods of the year, and nutrient inputs from rivers and human activities (see Caddy 1993). The major inflow into the Mediterranean is nutrient-poor, oxygenated Atlantic surface water through the Strait of Gibraltar, resulting in generally well-oxygenated bottom waters. Gyres and upwellings contribute to the Adriatic Sea's phytoplankton productivity. The highest levels of productivity occur along the coasts, near major cities and at estuaries, while the lowest levels occur in the southeastern Mediterranean (Darmouli 1988; Stergiou *et al.* 1997).

Oceanic Fronts (after Belkin et al. 2009): Western Mediterranean fronts include the North Balearic Front between France and Corsica, along 42°N; gyre fronts of the western Alboran Sea; Almeria-Oran Front of the eastern Alboran Sea; Sardinia-Sicily Front; North Adriatic Front (winter); Albanian Upwelling Front (19°E; fall and winter only); a zonal front south of Golfo di Taranto and Strait of Otranto; 395°N; fall and winter) and Libyan Front (Figure IV-7.1).

Eastern Mediterranean fronts include the Mid-Mediterranean Jet Front, a permanent feature south of Crete, as well as some smaller fronts of local scale. Inter-annual variability of the Mediterranean fronts is very substantial, as shown by a comparison of the frontal map here with, for example, Philippe & Harang (1982). "Winter cooling, which extends deeper than the density-criterion mixed layer, is very brief so the pycnocline lies within the photic zone from March to November.
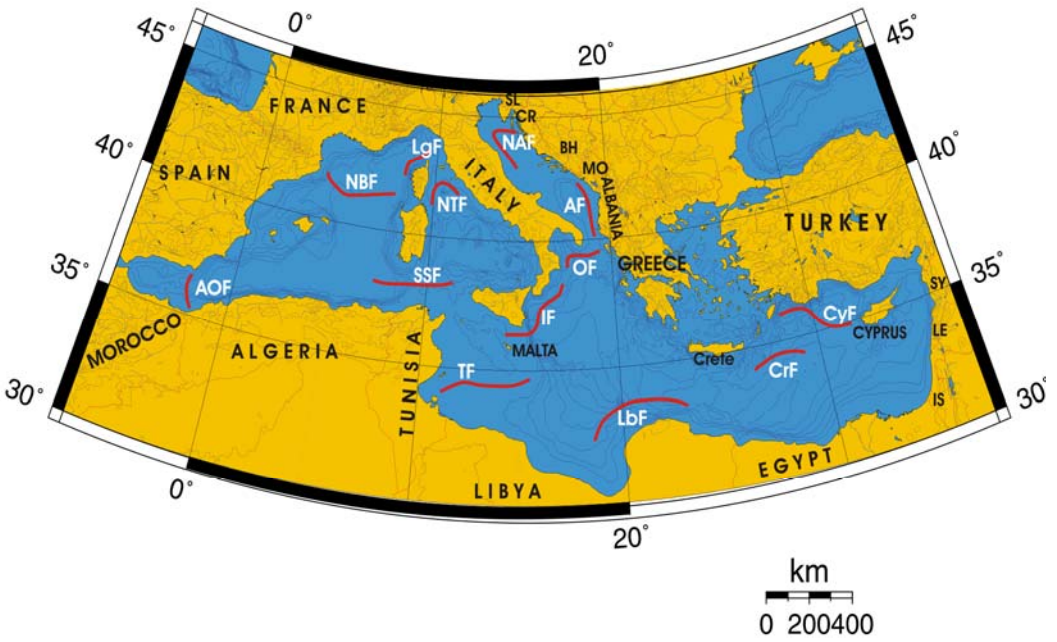
Figure IV-7.1. Fronts of the Mediterranean Sea LME. AF, Albanian Front; AOF, Almeria-Oran Front; CrF, Crete Front; CyF, Cyprus Front; LbF, Libyan Front; LgF, Ligurian Front; NAF, North Adriatic Front; NBF, North Balearic Front; NTF, North Tyrrhenian Front; OF, Otranto Front; SSF, Sardinia-Sicily Front; TF, Tunisian Front. Countries: BH, Bosnia-Herzegovina; CR, Croatia; IS, Israel; LE, Lebanon; MO, Montenegro; SL, Slovenia; SY, Syria. After Belkin et al. 2009).

The primary production rate is minimal in late summer, and increases when the mixed layer deepens in autumn. Chlorophyll accumulation is rapidly overtaken by loss in spring as herbivore consumption builds up to balance production" (Longhurst 1998). Belkin and O'Reilly (2008) have put forward an algorithm for oceanic front detection in chlorophyll and SST satellite imagery.

Mediterranean Sea SST (after Belkin 2009)
Linear SST trend since 1957: 0.43°C.
Linear SST trend since 1982: 0.71°C.

The thermal history of the Mediterranean Sea since 1957 has consisted of two major periods: (1) cooling until the all-time minimum in 1978; (2) warming until the present at a very fast rate of 1.2°C in 28 years. This rate is roughly consistent with the warming rate of 0.067°C per year based on satellite data from 1990-2006 (Del Rio Vera et al., 2006). High-resolution regional ocean models predict a 3°C SST rise in the Mediterranean Sea by 2100 (Somot et al., 2006), a rather conservative estimate given the current SST warming rate of approximately 0.5°C to 0.7°C per decade. The present warming was accentuated by the all-time maximum of 20.5°C in 2003, a result of an exceptional heat wave caused by a blocking anticyclone situated over Western Europe for >20 days in summer.

Most climate studies consider separately two major basins, Western and Eastern. Long-term variability of the Western Basin is linked to the North Atlantic Oscillation, whereas the Eastern Basin variability is linked to the Indian monsoon (CIESM, 2002). Lascaratos

et al. (2002) used the COADS (Comprehensive Atmosphere-Ocean Data Set) data from 1945-1994 to study long-term variability of SST and atmospheric parameters over the Mediterranean Sea after removal of seasonal signal and quasi-biannual oscillation by a digital filter. Their SST time series is similar to ours, except for a different dating of the all-time minimum (1975 instead of 1978) likely caused by the digital filter. During the 15-year warming period of 1975-1990, they found SST increases of 0.8°C, 0.5°C and nearly zero in the Western Basin, Ionian and Levantine Seas respectively. The strong eastward diminishing trend is suggestive of eastward advection (Lascaratos et al., 2002). Alternatively, this trend reflects a diminishing influence of the North Atlantic toward east.
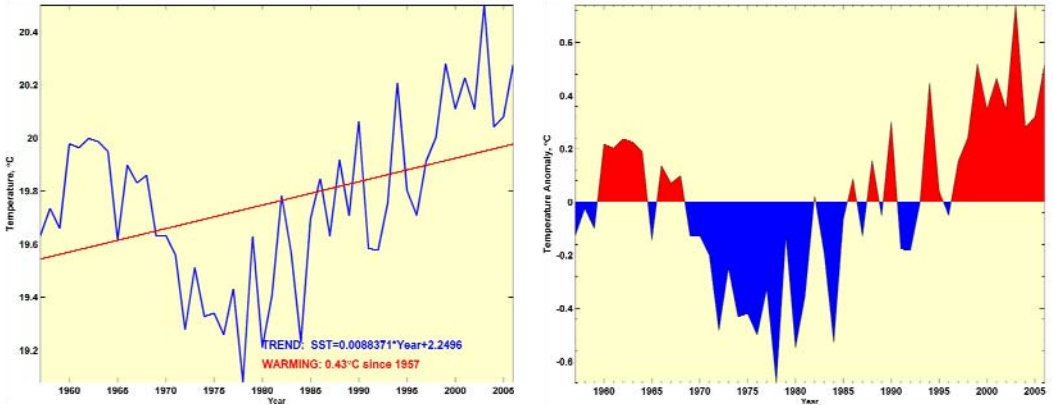

Figure IV-7.2. Mediterranean Sea LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

Mediterranean Sea LME Trends in Chlorophyll and Primary Productivity: Overall, the Mediterranean Sea LME is considered a Class III, low productivity ecosystem (<150 $gCm^{-2}yr^{-1}$), but that natural productivity is augmented by increased nutrient input from human induced activities.
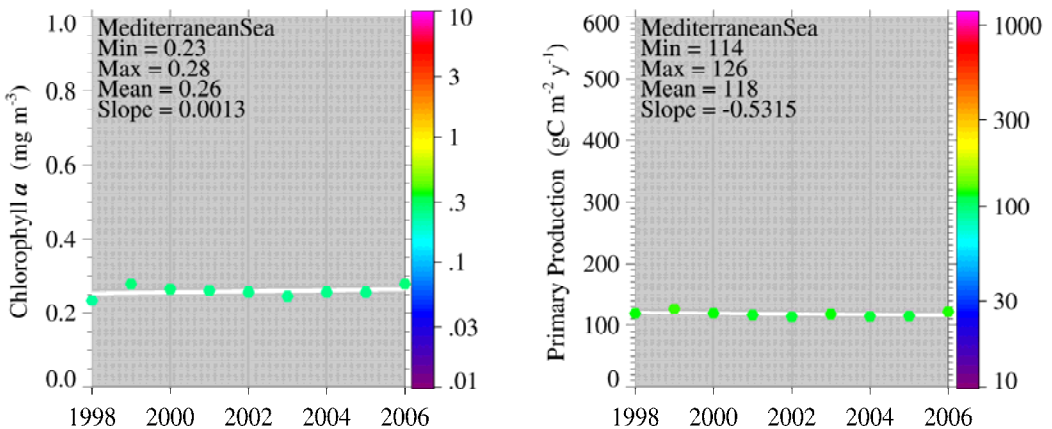

Figure IV-7.3. Mediterranean Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2007. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The Mediterranean Sea LME is one of the most diverse and stable LMEs in terms of species groupings and their share in the total catch (Garibaldi and Limongelli 2003). For

more information on primary production and fisheries, as well as a historical perspective on fisheries in the Mediterranean Sea, see Caddy (1993). For a study on ecology and fisheries in the Adriatic Sea, see Bombace (1993).

Total reported landings in the LME, consisting largely of clupeoids (pilchard, anchovy & sardinella), increased from 1950 to the mid 1980s, levelling off at around 900,000 tonnes in the 1990s, with landings over 1 million tonnes recorded in 1994 and 1995 (Figure IV-7.4). The value of the reported landings has peaked at about 2.4 billion US$ (in 2000 real US$) in 1988 (Figure IV-7.5).
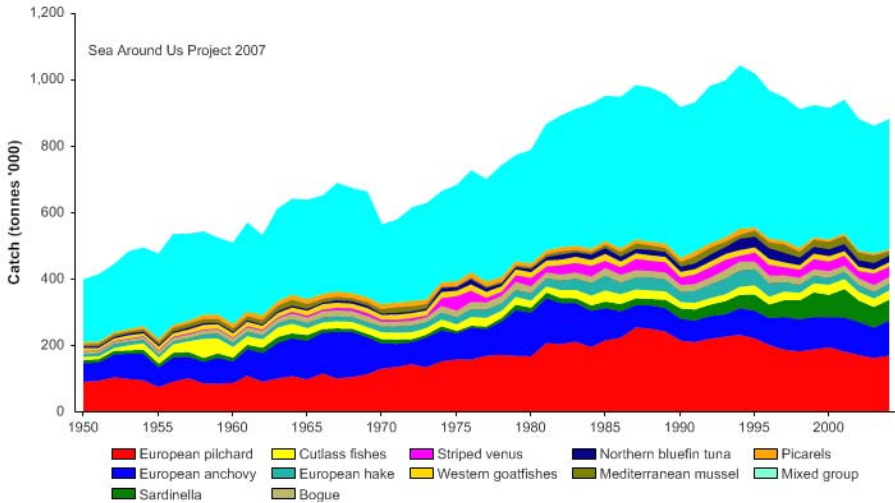

Figure IV-7.4. Total reported landings in Mediterranean Sea LME by species (Sea Around Us 2007).
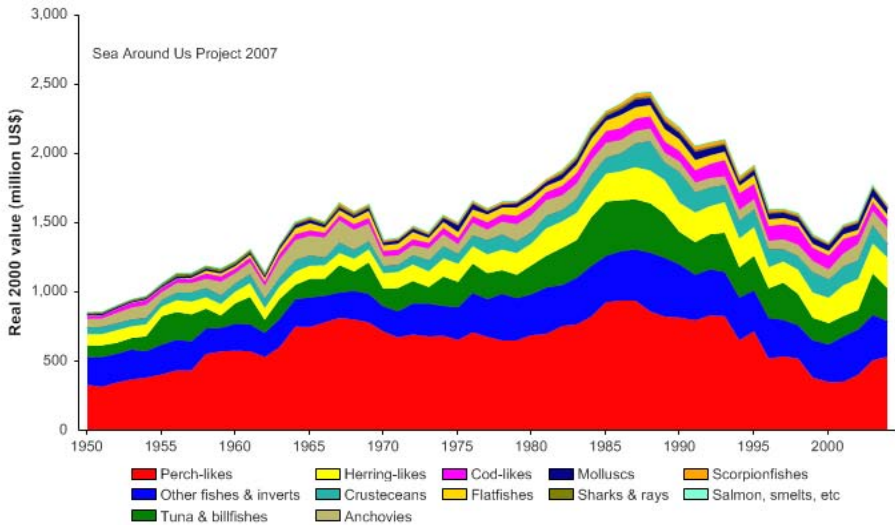

Figure IV-7.5. Value of reported landings in the Mediterranean Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 20% of the observed primary production in 1994, but has

since declined to 15% (Figure IV-7.6). Italy has the largest footprint, but overall, the PPR is evenly distributed amongst the Mediterranean countries.
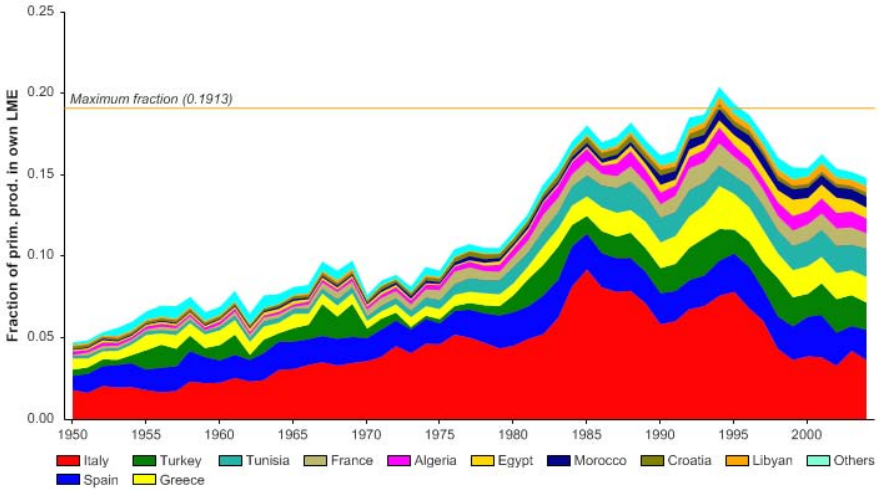

Figure IV-7.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Mediterranean Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) has increased until the mid 1980s and has declined since the mid 1990s, when the expansion of the fisheries, particularly offshore, ceased, as suggested by the increase of the FiB index from 1950 to the mid 1980s. Since the mid 1980s, the FiB has stabilized and began to decline in the late 1990s (Figure IV-7.7 bottom), an indication of decline in both the MTI and catch (Pauly & Watson 2005).
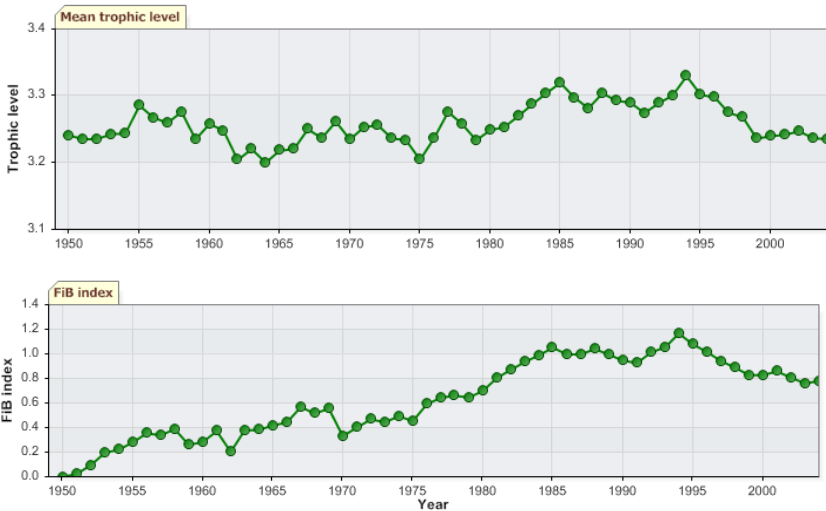

Figure 1V-7.7. trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Mediterranean Sea LME (Sea Around Us 2007).

These trends confirm, along with the contributions by Durand (2000), that substantial 'fishing down' has occurred in the Mediterranean, as originally suggested by Pauly *et al.*

(1998). Demersal fish populations are constantly overfished: shallow areas (within the 3-miles coastal limit or on bottom less than 50 m deep) are illegally trawled and small, illegal mesh sizes are used (UNEP, RAC/SPA 2003). It should also be noted that the 'fishing down' is not a result of an increase in the production of low-trophic, farmed organisms (e.g., mussels) being included in the valuation of mean trophic level, as suggested by Pinnegar *et al.* (2003). In fact, if the production from the Mediterranean aquaculture were included in the valuation, the mean trophic level would be higher, because it is, increasingly, high-trophic level fishes (e.g., bluefin tuna) that are being farmed in the Mediterranean (Stergiou *et al.* 2007).   In recent years, aquaculture production in the Mediterranean increased from 19,997 tonnes in 1970 to 339,185 tonnes in 2002 (FAO FISHSTAT 2002). The Stock-Catch Status Plots suggest that, based on reported landings statistics, very few stocks have collapsed (Figure IV-7.8, top), and that over 80% of the reported landings originate from fully exploited stocks (Figure IV-7.8, bottom).

Technological improvements in fishing fleets and their increased fishing capabilities in the LME have resulted in a decline in the catch per boat (Caddy 1993), while fishing effort has increased in response to high fish prices. By the 1970s, a substantial portion of the less productive southern shelves was being fished for demersal resources.   In the Adriatic Sea sub-area, coastal pollution and eutrophication have been the principal factors driving change in fisheries yields. Fish kills have also occurred in the northern Adriatic from noxious phytoplankton blooms and anoxic conditions. For more information on demersal and pelagic fish and molluscs in the Adriatic, see Bombace (1993).
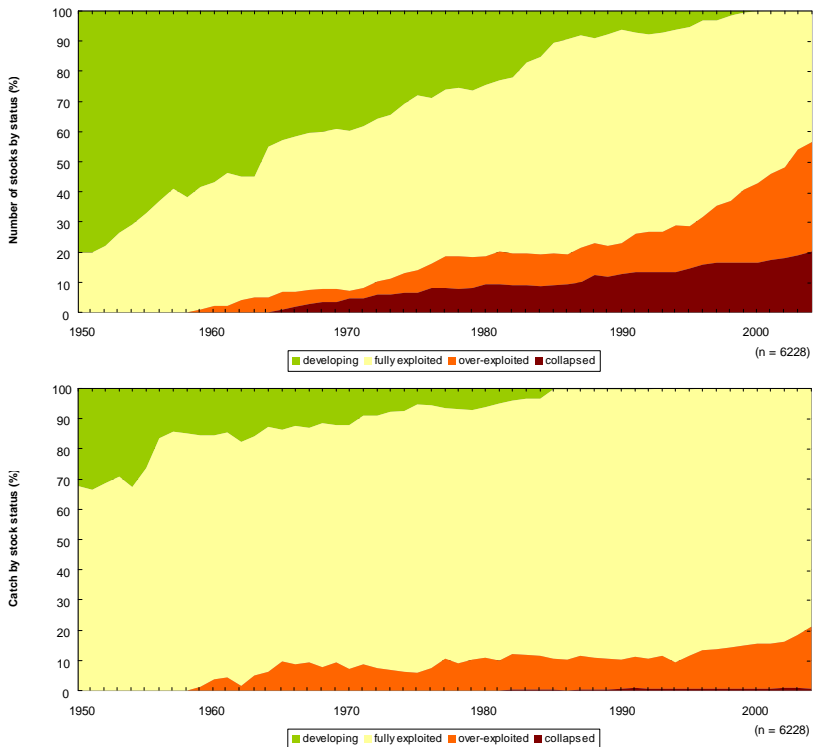
Figure IV-7.8. Stock-Catch Status Plots in the Mediterranean LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', 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).

III. Pollution and Ecosystem Health

Anthropogenic pressures on the Mediterranean marine environment include agricultural wastes, airborne particles and river run-off that carries nutrients, pathogens, heavy metals, persistent organic pollutants, oil and radioactive substances. All these pollution sources affect the most productive areas of the Mediterranean marine environment, including estuaries and shallow coastal waters. At the same time, physical changes to its 46,000 Km coastline from human activities are threatening Mediterranean coastal and marine habitats of vital importance in maintaining a healthy ecosystem. Focusing on human activities, 131 "pollution hot spots" have been identified by the countries in the frame of the Strategic Action Programme (SAP) of UNEP. These pollution hot spots are point pollution sources or coastal areas, which may affect human health, ecosystems, biodiversity, sustainability, or economy. Of these hot spots, 26% are urban, 18% industrial and 56% mixed (urban and industrial) (UNEP/WHO 2003). Additionally to the pressures from land based pollution sources and off-shore and shipping activities, biological invasions of alien species and the increasing appearance of Harmful Algal Blooms (HABs) are considered as emerging issues threatening the marine environment of the Mediterranean (EEA 2006). The atmosphere also contributes nitrogenous compounds, contaminants and heavy metals (see Caddy 1993, UNEP 1989).

The Mediterranean Sea LME's 46,000 km of coast supports an estimated population of 150 million inhabitants along the coast of the LME. Note that this population produces 3.8 billion cubic metres of wastewater each year (www.unepmap.org). Along the Mediterranean coast, 69% of the 601 cities with population above 10,000 (total resident population 58.7 million) operate a wastewater treatment plant, mostly using secondary treatment (56% of the operating plants) (UNEP/MAP/MEDPOL/WHO 2004). However, the distribution of treatment plants is not uniform along the Mediterranean region, the northern coast having a much greater part of its population served by treatment plants than the southern coast. Furthermore, due to increasing population in the cities, poor rate of sewerage connections and failures in treatment plant operation, an important part of the generated municipal effluents is still discharged untreated into the Mediterranean. A further 2.5 million cubic metres of waste water are produced by the 220 million tourists visiting the Mediterranean region every year, especially in summer. Blooms of phytoplankton and benthic diatoms have resulted in local fish kills caused by anoxia. Planktonic blooms and sewage contamination of coastal waters have also caused human health problems associated with the ingestion of contaminated shellfish (see UNEP/FAO 1990, Caddy 1993, UNEP/MAP 2004).

Agriculture is the largest non-point contributor of pollutants to the Mediterranean (UNEP/MAP 2001). The EEA reported in 2001 that the large river basins like the Rhone and Po basins are subjected to heavy agricultural pressures. "The first six drainage regions, following a tentative ranking of the risk of soil erosion and nutrient losses, are found in peninsula Italy, Sicily, Sardinia, Greece, Turkey and Spain (EEA, 1999c) with an estimated annual minimum agricultural load (excluding Croatia, Egypt, Libya, Malta land Slovenia) to the Mediterranean Sea of 1.6 million tonnes nitrogen, 0.8 million tonnes phosphorus and 1.7 million tonnes TOC" (reports.eea.europa.eu). Intensive aquaculture is undoubtedly a matter of concern for the Mediterranean marine coastal environment, since it can induce pollution and can lead to conflicts with other users (UNEP/MAP/MEDPOL 2004).

Rivers are important conveyors of industrial pollutants to the Mediterranean, especially the Po, Ebro and Rhône rivers (UNEP/MAP 2003). Industrial wastewater is either discharged directly to the sea or through municipal sewerage systems, outfalls, uncontrolled disposal sites and rivers. There are more than 200 petrochemical and energy installations, basic chemical industries and chlorine plants located along the

narrow Mediterranean coast and catchment basins of rivers, including at least 40 major oil refineries, in addition to cement plants, steel mills, tanneries, food processing plants, textile mills and pulp and paper mills (UNEP/MAP 2001). Petrol refineries are dumping 20,000 tonnes of petrol per year into the sea. Discharges during routine unloading account for 60% to 70% of the oil pollution in the Mediterranean. EEA estimates that 50% of the land area is at risk of erosion (reports.eea.europa.eu, 2001). A recent survey carried out by MAP through the MED POL Programme resulted in the preparation of the National Baseline Budget of emissions and releases in the Mediterranean region. The database showed that the sectoral contribution to the overall industrial loads (e.g. 86.1% of biological oxygen demand (BOD) comes from food processing, farming and oil refining; 97.3% of lead in effluents comes from inorganic chemical plants and fertilizers manufacturing (UNEP/MAP 2006).

IV. Socioeconomic Conditions

UNEP/MAP.org predicts the population of the coastal states of the Mediterranean will reach 600 million by 2050. Urban growth rates are high for the Mediterranean and it is likely that in 50 years the population will shift from essentially rural to urban (www.unepmap.org). In terms of wealth, the EU countries have 90% of the GDP for the Mediterranean, with GDP per capita values twelve times higher than in north African countries (www.unepmap.org). Anthropogenic nutrient enrichment and eutrophication caused by runoff and polluted river discharges are a major concern both for fisheries and tourism revenues. In 1998, the Barcelona Declaration of the Mediterranean NGOs for Sustainable Development attested that the Mediterranean was at that time the site of 35% of the world's trade in hydrocarbons, of 15% of the chemicals trade, and of 17% of world trade. The UNEP/Mediterranean Action Plan (www.unepmap.org) reports that 42% of the coastal zone is under artificial land cover and that by 2025, half the coastal zone will be covered by roads, ports, airports and industrial and power facilities.

Fisheries production has increased in many areas and is of major economic importance. Mariculture production of mussels and oysters has also increased. Production from aquaculture increased from 78,000 ty^{-1} in 1984 to 248,000 ty^{-1} in 1996, according to the EEA (http://reports.eea.europa.eu).

V. Governance

Governance of the Mediterranean Sea LME involves 21 countries and the European Union. The countries differ in their stages of economic and institutional development and in their capacities to address biodiversity issues in the context of sustainable development. The Mediterranean became the first region to adopt an Action Plan – the Mediterranean Action Plan (MAP) in 1975, under the UNEP Regional Seas Programme. This was followed by the adoption of the Convention for the Protection of the Mediterranean Sea against Pollution (Barcelona Convention) in 1976, which entered into force in 1978, and a succession of six landmark protocols (www.unepmap.org/ html/homeeng.asp). The MED POL Programme and six Regional Activity Centres are responsible for the implementation of respective components of the MAP. In 1996 the Mediterranean Commission on Sustainable Development was set up as an advisory body for defining a regional sustainable development strategy for the Mediterranean Sea. The Action Plan and Convention have since been amended to reflect the emphasis on sustainable development and biodiversity conservation (see Caddy 1993, UNEP 1989). MEDPOL is a pollution monitoring and assessment programme that began in the mid-1970s.

GEF is supporting an LME project to help the Mediterranean countries jointly address critical threats to the coastal and marine environment, and to promote ecosystem-based

management of coastal and marine resources (Lascaratos 2006). GEF projects involve the conservation of wetlands and coastal ecosystems, and the building of country capacity. Through a TDA adopted by the Contracting Parties to the Barcelona Convention in 2004, the participating countries have analysed factual and scientific information on transboundary concerns and their root causes, and have set priorities for action (see Mediterranean Action Plan 1999). Decline in biodiversity, fisheries, and seawater quality, along with human health risks and the loss of groundwater dependent coastal ecosystems were identified as the major environmental concerns of the basin. In addition, they are determining national and regional policy, legal and institutional reforms and investments needed to address the priorities within the LME. They have also committed to pollution reduction for specific pollutants with specific timetables and targets. Two SAPs were prepared and adopted in 1997 and 2003 respectively: SAP-MED for land-based sources of marine pollution and SAP-BIO, the Strategic Action Programme for the conservation of Mediterranean Marine and Coastal Biological Diversity. The SAP-MED has now formed the basis for the National Action Plans of each country, finalized and endorsed by the Contracting Parties in 2005.

A new Strategic Partnership for the Mediterranean Sea Large Marine Ecosystem supported by GEF, UNEP, the World Bank and a large number of additional national and international donors, has recently been adopted by the GEF Council and will be implemented as from 2008. The strategic partnership is addressed to all the countries of the Mediterranean and to all international cooperation Agencies and donors. The Partnership will serve as a catalyst in leveraging policy/ legal/ institutional reforms as well as additional investments for reversing degradation of this damaged large marine ecosystem, its contributing freshwater basins, its habitats and coastal aquifers. The major threats to be collectively addressed are environmental challenges including climate change; population growth, tourism and urbanization; loss of biodiversity and the unsustainable use of fisheries. Programmes have been developed in conjunction with a review of the European Union's Common Fisheries Policy and illustrate increasing international coordination of scientific studies of fisheries resources and the biological and oceanographic environment. In 2006 the 10th anniversary Euro-Med Summit in Barcelona adopted an initiative, Horizon 2020, to reduce and control, with the help of a coalition of partners, major Mediterranean pollution "hot spots" by the year 2020.

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