XII-35 Baltic Sea: LME #23

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The Baltic Sea LME is the world's largest brackish water body, covering an area of about 390,000 km^2, of which 2.21% is protected (Sea Around Us 2007). The LME catchment area is four times larger than its surface area (Jansson 2003), comprising about 1.7 million km^2, nearly 93% of which belongs to the nine riparian countries: Denmark, Estonia, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. The non-coastal countries in the catchment area include Belarus, the Czech Republic, Slovakia and Ukraine. The LME receives freshwater from a number of large and small rivers, while saltwater enters from the North Sea along the bottom of the narrow straits between Denmark and Sweden. This creates a salinity gradient from southwest to northeast and a water circulation characterised by the inflow of saline bottom water and an outflowing surface current of brackish water. It is estimated that a renewal of the total water mass of the Baltic Sea would take about 25-35 years. A permanent stratification layer exists between the upper layer of low salinity and a deeper layer of more saline water (Stigebrandt & Wulff 1987). Book chapters on this LME have been published by Kullenberg (1986), Jansson (2003) and UNEP (2005).

I. Productivity

The Baltic Sea LME is a Class I, highly productive ecosystem (>300 $gCm^{-2}yr^{-1}$). This LME is characterised by its temperate climate. Large-scale meteorological conditions cause long-term fluctuations of salinity and temperature in the deep and bottom waters. Periodic inflows of North Sea water drive changes between oxic and anoxic conditions in deeper waters (Jansson 2003). The diversity, composition and distribution of the Baltic Sea biota are influenced by its brackish-water character, the two-layered water mass and variable environmental conditions. Primary production exhibits large seasonal and interannual variability (Jansson 2003, HELCOM 2002); downward trends were found for diatoms in spring and summer, whereas dinoflagellates generally increased in the Baltic proper, but decreased in the Kattegat. The phytoplankton community is represented by only a very small fraction of the world species total and approximately 10 species of zooplankton account for most of the biomass and production.

The species composition of the zooplankton reflects the salinity, with more marine species (e.g., *Pseudocalanus* sp.) in the southern areas and brackish species (e.g., *Eurytemora affinis* and *Bosmina longispina maritima*) in the northern areas. As a result of the declining salinity, the relative abundance of small plankton species has increased in some parts of the Baltic Sea LME (Viitasalo *et al*. 1995). Since the 1980s, the abundance of *Pseudocalanus* sp. has declined in the central Baltic, whereas the abundance in spring of *Temora longicornis* and *Acartia* spp. increased (Möllmann *et al*. 2000, 2003). This change is unfavourable for cod recruitment (Hinrichsen *et al*. 2002) and herring growth (Möllmann *et al*. 2003, Rönkkonen *et al*. 2004), whereas it favours sprat, currently the dominant fish species in the Baltic Sea.

Changes have been documented in the productivity of the near coastal as well as offshore waters due to eutrophication as a consequence of increased nutrient inputs (Jansson 2003). Eutrophication is the secondary driving force of biomass change in this LME (Sherman 2003). Changes in community structure of the phytoplankton have occurred, e.g., the former dominance of diatoms, especially in the spring bloom, has switched to dinoflagellates and increased blooms of cyanobacteria (Kahru *et al*. 1994). Among the marine mammals in the LME are grey seal (*Halichoerus grypus*), ringed seal (*Phoca hispida*) and harbour seal (*P*. *vitulina*), and a small population of harbour porpoise (*Phocaena phocaena*).

Oceanic fronts (after Belkin et al. 2009): Several fronts (Figure XII-35.1) exist within the Baltic Sea LME (Belkin. 2004), namely the Bothnian Bay Front (BBF), Bothnian Sea Front (BSF), North Baltic Proper Front (NBPF), South Baltic Proper Front (SBPF), Gotland Front (GF), Irbe Strait Front (ISF), and Arkona Front (AF). Most fronts are topographically controlled: BBF and BSF encircle the respective depressions, while NBPF, SBPF, and GF extend along 100-m isobath that outlines the Baltic Proper basin. The ISF is situated over the outer edge of a sill that separates the Gulf of Riga from the Baltic Proper. Some fronts are distinct year-round - BSF, NBPF and SBPF- while others emerge and persist seasonally.

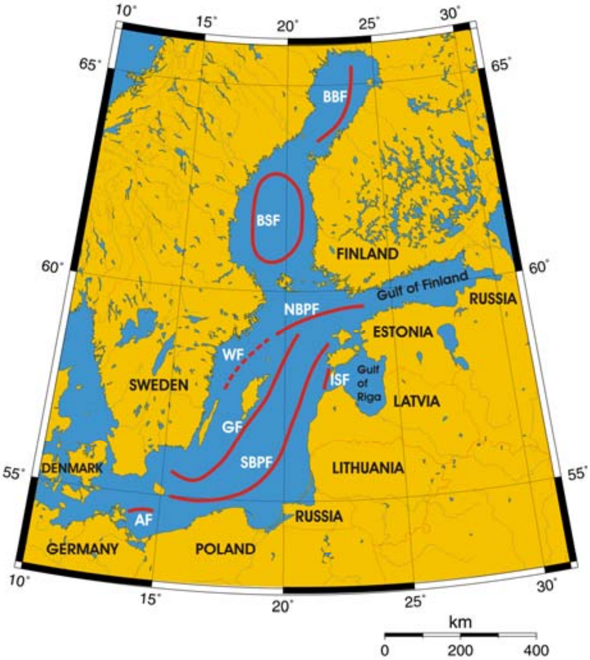

Figure XII-35.1. Fronts of the Baltic Sea LME. AF, Arkona Front; BBF, Bothnian Bay Front; BSF, Bothnian Sea Front; GF, Gotland Front; ISF, Irbe Strait Front; NBPF, North Baltic Proper Front; SBPF, South Baltic Proper Front; WF, Western Front (most probable location). After Belkin et al. 2009.

Baltic Sea LME SST (Belkin, 2009)
Linear SST trend since 1957: 0.75°C.
Linear SST trend since 1982: 1.35°C.

The long-term 50-year warming (Figure XII-35.2) was interrupted in 1976 by an abrupt cooling of nearly 2°C over just three years. After a partial rebound, SST dropped again, by >1°C in a year, and by 1987 reached the all-time minimum of 6.4°C, more than 2°C below the previous all-time maximum of 8.7°C in 1975. The exceptionally cold spell of 1985-87 was followed by a spectacular 2.3°C rebound in just two years. This is probably the most abrupt warming observed in any LME to date. The extremely rapid warming rate of 1.5°C/year in 1986-87 provided a test of the Baltic Sea LME resilience with regard to rapid climate warming. According to HELCOM (2007), from 1861–2000 the trend for the Baltic Sea basin has been 0.08°C/decade (cf. global SST trend of 0.038°C/decade between 1850-2005, according to the IPCC Fourth Assessment in 2007). Our analysis shows that the Baltic Sea warming accelerated over the last 50 years, with the average SST warming rate of 0.15°C/decade. The post-1987 warming was dramatic compared with previous years, with the average SST warming rate well over 1.0°C/decade. These results are confirmed by daily monitoring surface data (Mackenzie and Schiedek 2007): since 1985, summer SST increased three times faster than the global warming rate, and two to five times faster than other seasons' SST. "The recent warming event is exceeding the ability of local species to adapt and is consequently leading to major changes in the structure, function and services of these ecosystems" (Mackenzie and Schiedek 2007, p.1335). As the Baltic Sea becomes warmer and fresher, "marine-tolerant species will be disadvantaged and their distributions will partially contract from the Baltic Sea; habitats of freshwater species will likely expand" (Mackenzie et al. 2007, p.1348).

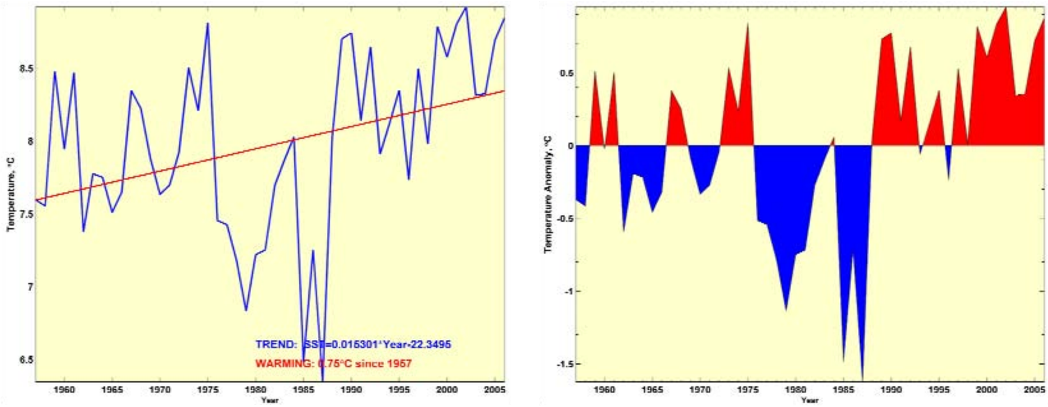

Figure XII-35.2. Baltic Sea LME annual mean SST (left) and SST anomaly (right), 1957-2006, based on Hadley climatology. After Belkin (2009).

***Baltic Sea LME Chlorophyll and Primary Productivity*:** The Baltic Sea LME is a Class I, highly productive ecosystem (>300 $gCm^{-2}yr^{-1}$).

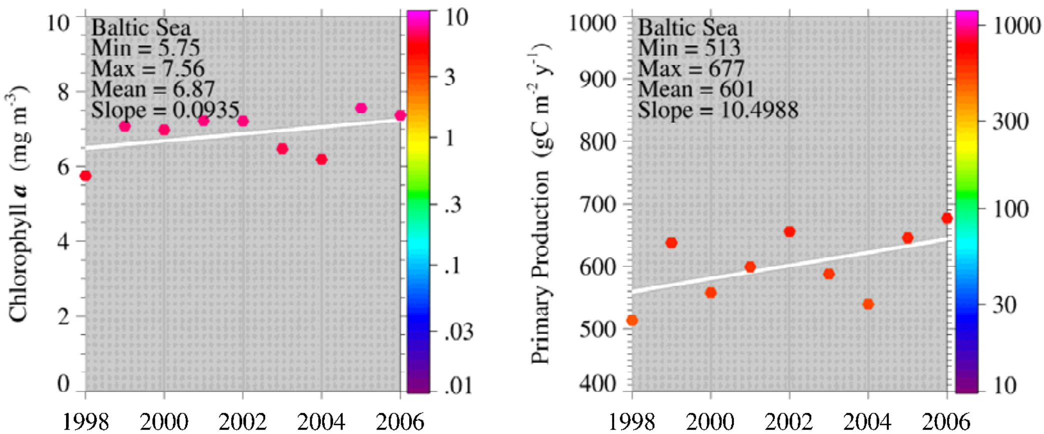

Figure XII-35.3. Baltic Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, Valuesare colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

In the Baltic Sea LME, cod (*Gadus morhua*), herring (*Clupea harengus*) and sprat (*Strattus sprattus*) dominate the fish community in terms of numbers and biomass. Commercially important marine species are sprat, herring, cod, various flatfish and salmon (*Salmo salar*). Other important target species are sea trout (*Salmo trutta*), pike-perch (*Stizostedion lucioperca*), whitefish (*Coregonus lavaretus*), eel (*Anguilla anguilla*), bream (*Abramis brama*), perch (*Perca fluviatilis*) and pike (*Esox lucius*). Total reported landings in this LME showed a steady increase from the 1950s to the 1970s and the early 1980s when the landings of over 900,000 tonnes were recorded (Figure Xii-35.4). A decline in the landings was recorded in the late 1980s, down to 560,000 tonnes in 1992 due to diminished landings of Atlantic cod. This was followed by record landings in 1997 with 975,000 tonnes, almost half of which was that of European sprat (Figure XII-35.4). The landings have since declined again, with 670,000 tonnes reported for 2004. The value of the reported landings peaked in the late 1960s and the early 1970s, estimated at US$960 million (in 2000 US dollars) in 1969 (Figure XII-35.5).

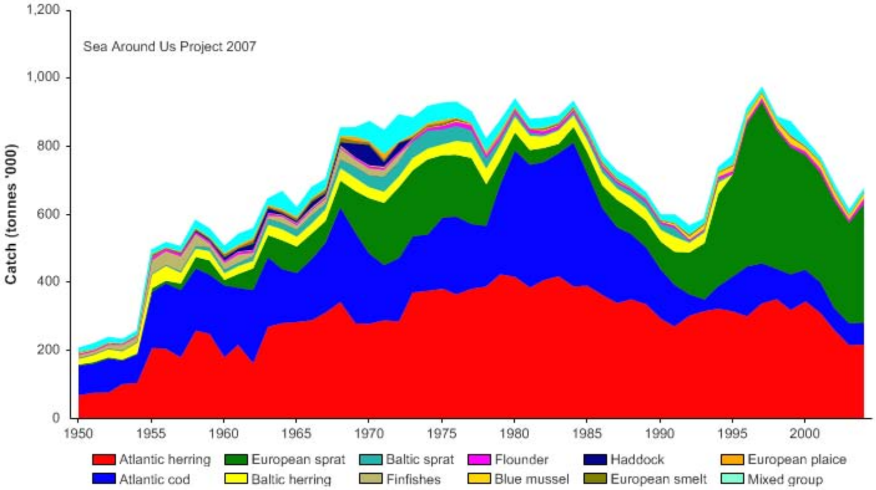

Figure XII-35.4. Total reported landings in the Baltic Sea LME by species (Sea Around Us 2007).

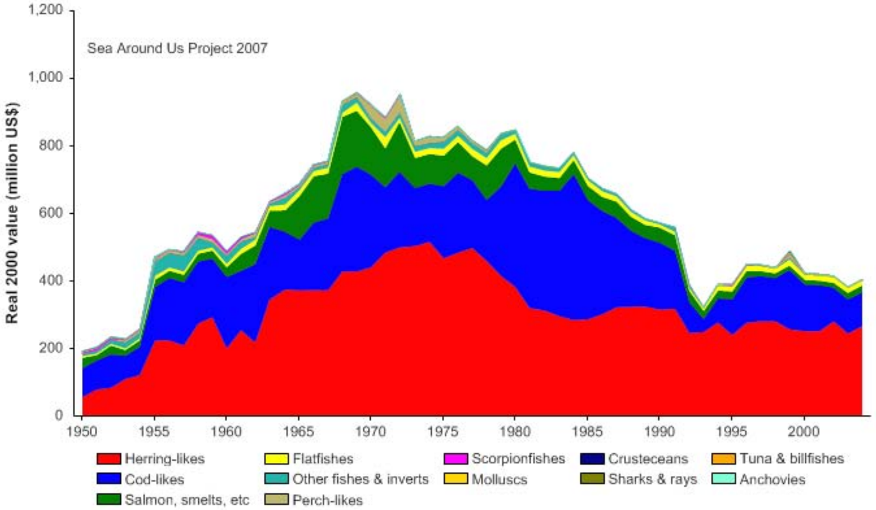

Figure XII-35.5. Value of reported landings in the Baltic Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 25% of the observed primary production in the mid-1980s, but has declined to less than 10% in recent years (Figure XII-35.6). The countries bordering the LME account for most of the ecological footprints, roughly corresponding to the extent of their coastlines.

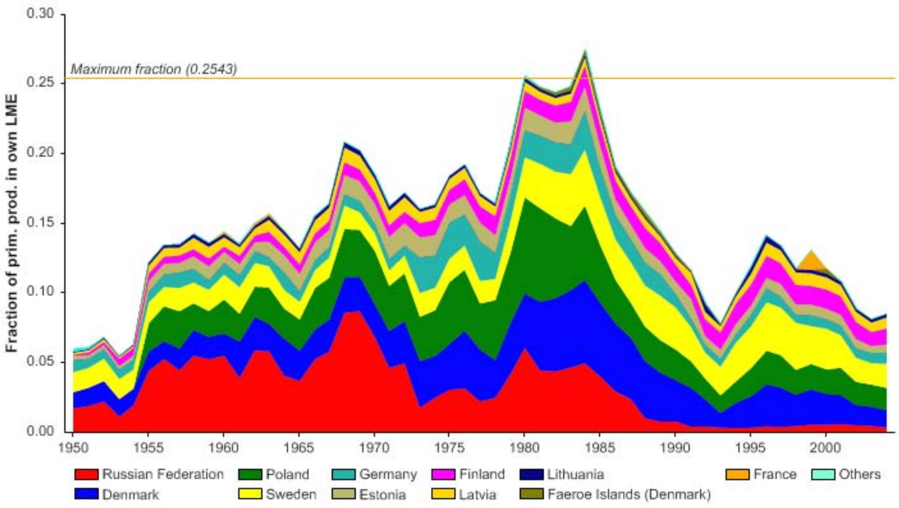

Figure XII-35.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Baltic Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) shows a significant decline from the mid 1980s to 2004 (Figure XII-35.7, top), likely due to the increased sprat landings. However, as a notable decline in Atlantic cod landings is also evident (Figure XII-35.4), and together with the decline in the mean trophic level, constitutes a case of a 'fishing down' of the local food webs (Pauly *et al.* 1998). The rapid decline in the FiB index also supports this interpretation (Figure XII-35.7, bottom).

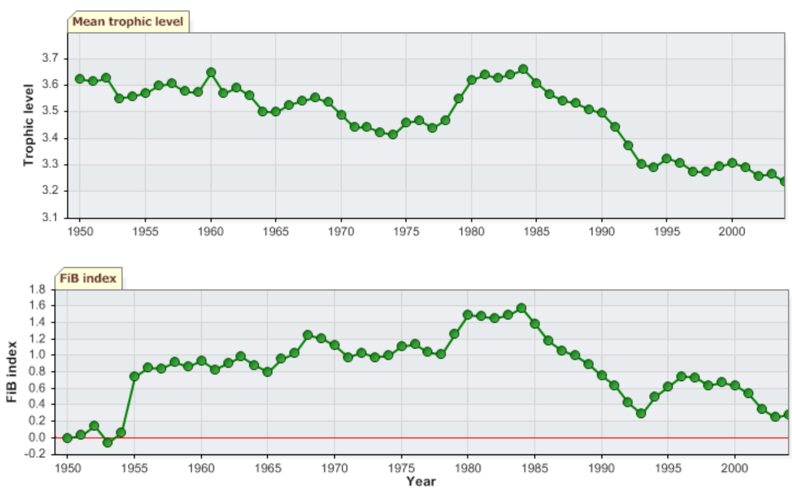

Figure XII-35.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Baltic Sea LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that over 60% of the fished stocks in the LME have collapsed (Figure XII-35.8, top), but that the majority of the catch is supplied by fully exploited stocks (Figure XII-35.8, bottom), likely due to the large European sprat catch.

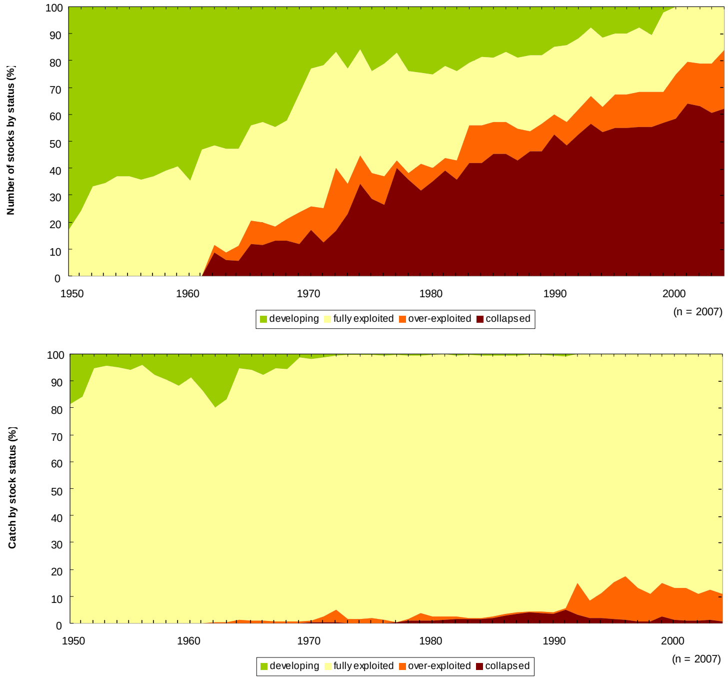

Figure XII-35.8. Stock-Catch Status Plot for the Baltic Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', 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).

Overexploitation was found to be severe in the Baltic Sea LME (UNEP 2005), with intense fishing the primary driving force of biomass change (Sherman 2003). The stocks have been exploited at levels beyond those advised by ICES. Fleet capacity as well as fishing effort have not been reduced, with fishing mortality continuing to increase during stock decline (Baltic 21 1998). The fisheries for cod, herring, salmon and eel are unsustainable (Jansson 2003). High cod exploitation rates since the early 1980s resulted in a decline in its abundance (Baltic 21 1998). Cod landings were 3.5 times smaller during the 1990s (ICES 1994, 1999a, 1999b) and a number of actions to address this situation were taken by the IBSFC up to 2006. In September 2007 the EC agreed on a new management plan for cod in the Baltic Sea. Between 1984 and 1992, a decline in spawning stock size was also observed (Baltic 21 2000). During the last years ICES advice for the eastern cod stock have been a zero advice. However, the latest (May 2008) advice was placed at the level of 48,000 ton which must be considered being a trend brake. The improvement of the cod stock is mainly due to the management plans but also to the fact that the new advice is based on the ecosystem-based approach to management. A continuous decreasing trend in mean weight-at-age has been observed in most of the herring stocks since the mid-1980s. Population sizes of sea trout and eel have declined significantly, while sturgeons, once common in the Baltic Sea LME and its large rivers, are now extinct from the area. As a result of damming, pollution and fishing, wild salmon is another species of great concern to the IBSFC (Baltic 21 1998). The wild component has declined to some 10% of the total stock. A Salmon Action Plan, implemented to safeguard and increase the present wild populations, has been adopted by the IBSFC. Large-scale rearing and stocking of smolt has been undertaken to compensate for the decline of wild salmon stocks.

Excessive bycatch and discards and destructive fishing practices were considered to be slight (UNEP 2005), although their impacts are still unknown and unexplored to a large extent. The EU has supported several studies of bycatch, the results of which have been compiled by ICES (2000). These studies primarily concern the major fisheries for cod, herring, and sprat, which have low bycatches. The less important smaller fisheries can have a high proportion of bycatch (HELCOM 2002), for example, in the roe fishery (vendace, *Coregonus alba*). Bycatch of harbour porpoises has been reported in the fisheries in Danish and German waters. Seals are also taken as bycatch, but this added mortality does not seem to threaten the population since their numbers are increasing (HELCOM 2002).

A slight improvement in the fisheries of this LME is anticipated due the implementation of appropriate regulations, and the improvement of the eastern cod stock seems to be a good example of this. However, the impacts on fisheries of long-term natural environmental variability and anthropogenic pressures on the Baltic Sea ecosystem have not been fully explored, making it difficult to predict future trends in the fisheries.

III. Pollution and Ecosystem Health

Pollution: The ecosystem of the Baltic Sea LME is very sensitive to pollution, as a result of the limited water exchange and run-off from the vast catchment area (HELCOM 2003). The increasing human population after the year 1800, estimated at 85 million now living in the catchment area (HELCOM 2007) as well as intense industrialisation after the two World Wars have led to increasing emissions of contaminants into the LME (Jansson 2003). These include point sources from industries and municipalities and non-point source agricultural pollutants. Pollution is generally severe, with eutrophication being the most pressing environmental issue (UNEP 2005). The most striking changes in this LME since World War II are due to severe eutrophication from increased nutrient inputs (Jansson 2003), principally from agricultural discharges via rivers. Evidence of eutrophication includes hypoxic conditions in deep water over widespread areas, increased occurrence of HABs and significant biological changes in the littoral communities (HELCOM 2002). The occurrence of HABs increased between 1994 and 1998, with several large phytoplankton blooms in the Baltic Proper, the adjacent gulfs as well as the Kattegat and Belt Sea. About 30 phytoplankton species have been proved to be harmful. Toxic events such as outbreaks of fish kills as well as marine mammal and seabird mortalities caused by blue-green algae have been documented since the early 1960s (Baltic 21 1998). Addressing the problem of eutrophication requires an urgent, substantial reduction in nutrients from the agricultural sector (Lääne *et al*. 2002).

Microbiological pollution is often a local problem mainly related to discharges of untreated wastewater. During the last decade, the construction of biological wastewater treatment plants in the coastal and catchment areas has reduced the concentration of microbes in wastewater. Pollution from suspended solids results from the increased amounts of phytoplankton in eutrophic areas and increased coastal erosion in southern and eastern areas of the LME.

Mercury concentration in sediments was found to be highest in the Bay of Bothnia as well as the eastern Gulf of Finland, while the concentration of cadmium, zinc and copper was highest in the central basin of the Baltic Sea. Lead, however, seems to be evenly distributed (HELCOM 2002). The health of many birds of prey and mammals has improved but some species still experience reproductive problems. The concentrations of most heavy metals monitored in mussels, fish and in bird eggs have decreased or remained stable. An exception is cadmium, the concentration of which increased in fish during the 1990s. Metal concentrations at appreciable levels were found in fish in the southern part of the Gulf of Bothnia, in the eastern end of the Gulf of Finland, in the Kattegat and in the Gulf of Riga (Baltic Sea Environment 2004).

Despite the implementation of recommendations by HELCOM to reduce discharges of pollutants into the Baltic Sea LME and the steady decrease of organochlorine compounds throughout the region during the past 30 years, inputs of chlorinated compounds and other toxicants such as pesticides and polychlorinated compounds still occur. The concentration of dioxins in herring and salmon varies regionally, with the highest levels found in herring in the Bothnian Sea and salmon in the Bothnian Bay. According to HELCOM (2003), the transfer of dioxins up the marine food chain is observed in fish-eating birds and their eggs. The concentration of dioxins in guillemots' eggs decreased rapidly until the mid 1980s, but has since remained at roughly the same level. Dioxin concentrations in sediments peaked in the 1970s then began to decrease (HELCOM 2003). Evidence has been found of moderate levels of decreased viability of stocks in the Baltic Sea ecosystem caused by pollution and diseases. Examples of diseases include the mouth disease of pike, crayfish disease, salmon M-74 disease, bacterial skin ulcer in cod and diseases in eel as well as flatfish (Walday & Kroglund 2002).

Despite the designation of the Baltic Sea as a 'special area' under MARPOL 73/78, many illegal oil discharges are observed in the region. Between 1969 and 1995, about 40 major oil spills greater than 100 tonnes were registered and an average of about three accidents occur each year. However, this is not entirely surprising for an area where 7,000 voyages involving the transport of oil take place annually. The number of accidents may rise during the next decade as seaborne oil transport is expected to increase from its current level of 77 to 177 million tonnes per year (HELCOM 2002). While spills from vessels and offshore platforms contribute the most conspicuous input of oil, these account for only a small part of the total marine oil pollution in the Baltic Sea LME (Baltic Sea Environment 2004). Most of the oil input into the Baltic Sea comes from dilute but persistent land-based sources.

One major growing concern in the Baltic Sea area is the introduction of invasive/alien species, mainly by the release of ballast water from oil tankers. During the last decades over one hundred invasive species have been detected and established, and several of these have had detrimental effects on the habitat. Two of the potentially most harmful invaders are the round goby (Neogobius melanostomus), well established in the southern Baltic and the ctenophore Mnemiopsis leidyi. HELCOM and the BSRP have supported the establishment of an on-line data-base for continuous information about alien species (Baltic Sea Alien Species Database, 2007: www.corpi.ku.lt/nemo/).

Habitat and Community Modification: The coastal and marine habitats of the Baltic Sea LME are under considerable pressure mainly from human settlements, pollution and coastal construction. Habitat and community modification were found to be moderate (UNEP 2005). Approximately 90% of the marine and coastal biotopes in the LME are threatened to some degree, either by loss of area or reduction in quality (HELCOM 2001, 1998). According to HELCOM (1998), 88% of the 133 marine biotopes and 13 biotope complexes are exposed to some kind of anthropogenic threat (e.g. eutrophication, contamination, fisheries or human settlements) and are considered to be endangered or highly endangered. Out of 66 pelagic and benthic marine biotopes assessed, two were classified as heavily endangered, 58 as endangered and four as potentially endangered (HELCOM 1998).

Sandy foreshores (intertidal zone; wet-sand area) have been affected by tourism, pollution and construction. Lagoons are threatened by pollution, urbanization, industry, agriculture, and dredging, while estuaries suffer from land-based pollution and construction. Muddy and rocky foreshores in Sweden and Finland have been affected by dredging and the construction of harbours, respectively. Sea grass and *Fucus* meadows have been moderately impacted by pollution. The long-term changes in the Baltic ecosystem are described by Kullenberg (1986).

Improvements in the health of this LME are occurring as a result of several ongoing activities and the implementation of environmental protection legislation. The significant reduction in the discharge of hazardous and biogenic substances at the end of the 20th century was an important step towards reducing the pollution load of the LME. Since 1992 about 50 hot spots have been cleaned up. However, as a consequence of the slow water exchange and the accumulation of large quantities of pollutants, it may be a long time before a significant improvement in water quality is achieved (UNEP 2005). Greater public awareness of the impact of human activities on sensitive habitats is needed, although in many instances it may be too late to rehabilitate the modified ecosystems.

IV. Socioeconomic Conditions

Economically, the Baltic Sea states can be divided into two groups: old market economy countries (Denmark, Finland, Germany and Sweden), and countries in economic transition (Estonia, Latvia, Lithuania, and Poland, which acceded to the EU in 2004) and Russia. A fairly stable and largely urbanised population of nearly 85 million people of many ethnic groups lives within the catchment area, about half of them in Poland.

The fishing industry makes a significant contribution to the regional as well as local economies, with subsistence fishing critical to the social and economic welfare of the coastal communities in the eastern Baltic Sea. Fisheries traditionally play an important role in food supply, especially in Estonia, Latvia and Lithuania. The economic impact of unsustainable exploitation of fish and other living resources is moderate, although in some areas the impact is severe (UNEP 2005), for example in Poland (EU Enlargement 1998) and in Kaliningrad, Russia (Dvornyakov 2000), where fisheries are significant in the national economy. The market for fish is affected as fish landings become more variable and uncertain. Reduced landings also increase unemployment in the fisheries sector and subsequently jeopardise income growth. Worsening unemployment as well as loss of livelihood among fishermen is a growing concern especially in the recently EU-acceded countries and Russia. The unemployment level in Russian fisheries is estimated to be 1.5 to 3.5 times higher than in other sectors (Dvornyakov 2000). Declining returns from fisheries could also lead to higher demands for subsidies and other governmental fishing support. Moreover, severe protection measures to help fish stock recovery may, in the short term, further exacerbate the economic impact (Baltic 21 1998, FAO 1999).

The socioeconomic impacts of pollution include possible health risks from consuming contaminated fish (UNEP 2005). However, the potential health impacts of pollution will be reduced with the implementation of EU Directives to limit the use of fish with high dioxin levels. The recreational value of coastal areas may be affected as a consequence of pollution. Generally, the socioeconomic impacts of habitat and community modification are slight in relation to human needs for food as well as aesthetic and recreational values. Nevertheless, the loss and modification of habitats will have serious economic impacts in the future, requiring considerable investments to restore damaged habitats.

V. Governance

Water protection in the Baltic Sea region is regulated by several international conventions ratified by the Baltic Sea states. ICES is one of the main organisations coordinating and promoting marine research in the North Atlantic, including its marginal seas such as the Baltic and North Seas. The Baltic Sea Regional Seas Programme is an independent programme (not established under UNEP), but participates in the global meetings of UNEP Regional Seas and supports the developing Regional Seas Programmes.

The two most important conventions regulating the protection of the environment and living resources of the Baltic Sea LME up to 2006 were the Convention on Fishing and Conservation of the Living Resources in the Baltic Sea and the Belts, signed in Gdansk in September 1973 (Gdansk Convention)(implementing unit: IBSFC), followed by the Convention on the Protection of the Marine Environment of the Baltic Sea Area, signed in Helsinki in March 1974 (Helsinki Convention)(implementing unit: HELCOM). Each year, on the basis of recommendations from ICES, the IBSFC, and after 2006 the EU, sets total allowable catches for the four main commercial species: cod, salmon, herring and sprat. HELCOM, which is responsible for the implementation of the Convention, coordinated a joint monitoring programme of the Baltic The countries in the drainage basin initiated a Joint Comprehensive Environmental Action Programme for the Baltic Sea (JCP). This programme, was adopted in 1992 and strengthened and updated in 1998, constituted a 'Strategic Action Plan' for the Baltic Sea region. HELCOM is now finalising a new Baltic Sea Action Plan which, like the JCP, will provide an environmental management framework for the long-term restoration of the ecological balance of the Baltic Sea, recognizing the linkages between freshwater, coastal and marine resources.

Baltic 21 is a regional multi-stakeholder process for sustainable development initiated in 1996 by the Prime Ministers of the eleven member states of the Council of the Baltic Sea States. The Mission of Baltic 21 is to pursue sustainable development in the Baltic Sea Region by regional multi-stakeholder cooperation. Accordingly, Baltic 21 provides a regional network to implement the globally agreed Agenda 21 and World Summit on Sustainable Development activities, while focusing on the regional context of sustainable development (Baltic 21 2004).

The GEF supported the Baltic Sea Regional Project, the basis for which was provided by the JCP, until several of the participating countries became members of the EU. Proposals for assisting the Russian Federation with Baltic Sea LME projects are underway. A long-term objective of these projects is to introduce ecosystem-based assessments to strengthen the management of Baltic Sea coastal and marine environments through regional cooperation as well as targeted transboundary coastal, marine and watershed activities. A major objective is to develop an array of ecosystem management tools to manage the whole Baltic Sea ecosystem. Agencies collaborating in the GEF project include HELCOM, the IBSFC and ICES. Eight of the nine states surrounding the Baltic Sea are now members of the EU as of May 1, 2004. There is a need to develop the technical, scientific and local capacity of the eastern Baltic countries to enable them to fully participate with western Baltic countries in improving the long-term sustainability and socioeconomic benefits of this LME.

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