XIII NORTH EAST ATLANTIC

XIII-36 Barents Sea LME
XIII-37 Celtic-Biscay Shelf LME
XIII-38 Faroe Plateau LME
XIII-39 East Greenland Shelf LME
XIII-40 Iberian Coastal LME
XIII-41 Iceland Shelf LME
XIII-42 North Sea LME
XIII-43 Norwegian Sea LME

XIII-36 Barents Sea LME

S. Heileman

The Barents Sea LME is situated within the European part of the Arctic shelf and to the north of the Polar Circle (Matishov *et al*. 2003). It is a relatively shallow sea with a surface area of about 1.7 million km^2, of which 4.32% is protected (Sea Around Us 2007), a large shelf, and an extensive polar front. Among its river systems and estuaries are the Dvinskaya Guba and Pechorskaya Guba. This LME is a transition zone where relatively warm inflowing Atlantic water is cooled and transformed into Arctic as well as Polar water (Blindheim & Skjoldal 1993). Arctic continental shelves show a complex density circulation, behaving as 'salt-wedge estuaries' in summer and, by the deep export of salt-rejection brine produced as the sea freezes, 'negative estuaries' in winter (Longhurst 1998). The surface water is more dilute and shows greater seasonal variation in salinity than the central part of the Arctic Ocean (Carmack 1990). The climate of this LME shows high spatial and temporal variability that depends mainly on the activity and temperature of the inflowing Atlantic water. A notable feature is the extreme environment with considerable annual and inter-annual variations in ice cover, which extends over one- to two-thirds of the sea with maximum extension during winter (Blindheim & Skjoldal 1993). Book chapters and reports pertaining to this LME include Blindheim & Skjoldal (1993), Dalpadado *et al*. (2002), Matishov *et al*. (2003) and UNEP (2004).

I. Productivity

The Barents Sea LME can be considered a Class II, moderately productive ecosystem (150-300 gCm^{-2}yr^{-1}). Biological activity in the Arctic seas is determined mainly by seasonal changes in the temperature and light regimes, advection and ice cover (Matishov *et al*. 2003). Many biological processes are strongly influenced by the formation of the seasonal thermocline and convective mixing (Terziev 1990). In addition, the drifting and fixed ice masses have a significant influence on the dynamics as well as seasonality of plankton communities and consequently, the higher trophic levels (Matishov *et al*. 2003). The ice-edge zones are distinguished by increased primary production in spring and early summer in response to the melting of ice (Blindheim & Skjoldal 1993, Matishov *et al*. 2003). The total annual primary production from in situ data is estimated to be 38.4 million tonnes of carbon (Vetrov and Romankevich 2004).

More than 310 species of pelagic microalgae belonging to the Diatomea, Bacilloriophyta, Dinophyta, Chrysophyta, and Chlorophyta, among others, have been identified in the phytoplankton of the Barents Sea LME. Approximately 40% of these can be characterised as Arctic species, more than 20% as boreal species and the rest as cosmopolitan or with an undesignated geographic distribution (Biological Atlas of Arctic Seas 2000). Phytoplankton blooms in the surface water masses are dominated by *Chaetoceros* spp. and *Phaeocystis pouchetii*. Ice algae such as *Melosira arctica* and loosely attached mats of diatoms are a feature of the ice-covered portions of the Arctic seas. Algal macrophytes include *Ascophyllum nodosum*, *Fucus distichus* and blade-kelps *Laminaria saccharina* and *L. digitata* (Matishov 1998).

Boreal, arctic, and transitional species constitute the zooplankton (Biological Atlas of Arctic Seas 2000). In the Barents Sea and elsewhere in the Arctic, copepods are the dominant group of zooplankton followed by amphipods, decapods, ostracods, pteropods and chaetognaths (Melnikov 1997). The water column below the ice is inhabited by a sparse but permanent zooplankton community, its biomass dominated by calanoid copepods such as *Calanus glacialis* (*C*. *finmarchicus* in the south) and *C*. *hyperboreus* and larger numbers but smaller biomass of species such as *Pseudocalanus*, *Oithona*, and *Microcalanus* (Longhurst 1998). Dalpadado et al. 2002) have shown the richness of the zooplankton community in the northern Barents Sea.

The Arctic trophic links vary significantly according to the environmental conditions (Matishov *et al*. 2003). For example, in the Atlantic water mass, each level of the food web contains one dominant, central species or group of species on which the rest of the biota depends. These dominant groups include pelagic crustaceans (*Calanus finmarchicus* and Euphausids), herring (*Clupea harengus*), capelin (*Mallotus villosus*), polar cod (*Boreogadus saida*) (in the NE) and cod (*Gadus morhua*). Marine birds and mammals (e.g., seals, polar bears and whales) are among the top consumers in the pelagic realm. Biological activity is also closely connected with the ice cover. The Arctic sea ice biocenoses are described by Melnikov (1997). The biota within the sea ice is small (<1mm) and dominated by bacteria, unicellular plants and animals and small multi-cellular animals. Protozoans, turbellarians, nematodes, crustaceans and rotifers can be abundant in the ice year-round. A partially endemic fauna comprised mainly of gammaridean amphipods thrive on the underside of ice floes with up to several hundred individuals m^{-2}. The amphipods are a prey of cod, which in turn are preyed upon by marine mammals (e.g., seals) and birds. The polar bear (*Ursus maritimus*) and the Arctic fox (*Alopex lagopus*) are the top consumers on the drifting sea ice.

Oceanic fronts: The Atlantic flow enters the Barents Sea LME along the Norwegian coast and continues along Russia’s coast, carrying warm and salty waters that form distinct TS-fronts at the contact with coastal waters and resident waters of the Barents Sea proper (Belkin *et al*. 2008). North of Tromsø and Nordkapp two fronts are distinguished: a coastal front just a few miles off the coast and an offshore front farther out to sea (Figure XIII-36.1). The Polar Front (PF) south of Bear Island follows the Spitsbergen (Svalbard) continental slope, which provides bathymetric steering to the front and ensures its stability. In the absence of topographic steering elsewhere within the Barents Sea LME, the Polar Front’s location is variable and depends largely on the intensity of the Atlantic inflow to the Barents Sea.

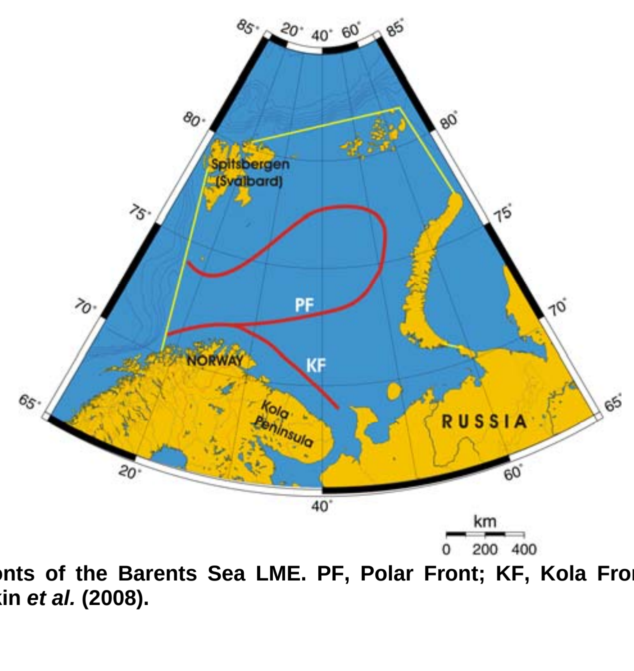

Figure XIII-36.1. Fronts of the Barents Sea LME. PF, Polar Front; KF, Kola Front. Yellow line, LME boundary. After Belkin *et al.* (2008).

Barents Sea LME (Belkin 2008)(Figure XIII-36.2):
Linear SST trend since 1957: -0.04°C.
Linear SST trend since 1982: 0.12°C.

In the long-term, the Barents Sea LME appears relatively stable, although its interannual variability is substantial, having a magnitude of 1°C. The timing of cold events of 1978-79, 1987, and 1997-99 is consistent with passages of decadal-scale "Great Salinity Anomalies" (Dickson et al., 1988; Belkin et al., 1998; Belkin, 2004) of the 1970s, 1980s, and 1990s through the Barents Sea. The double-pronged cold event of 1966-68, which resulted in the all-time low of 2.6°C in 1966, must have had a different origin. The well-defined warming events that peaked in 1973 and 2000 also need to be explained. The last warming event, of 2000, was concurrent with a sharp maximum in the Norwegian Sea, consistent with large-scale atmospheric forcing and also with oceanic advection. The previous peak of 1974 in the Norwegian Sea may have been related to the Barents Sea maximum of 1973.

One has to be cautious while trying to determine long-term trends in the Barents Sea. Depending on choice of end points, trends could be increasing or decreasing. Most recent reports of a dramatic three-degree warming of the Barents Sea over the last 26 years are based on satellite data from 1982 on. Note that the year of 1982 was one of the coldest years on record in this area. Therefore, selection of this year as an end-point would yield a rapidly increasing SST trend.

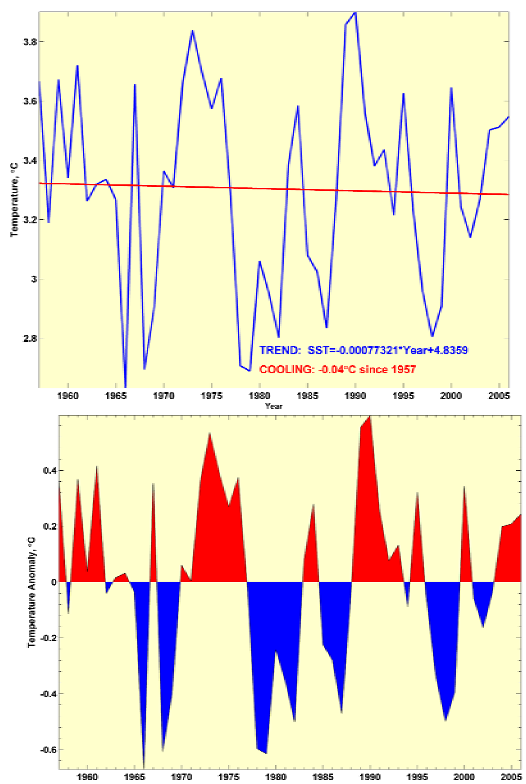

Figure XIII-36.2. Barents Sea LME annual mean SST (top) and SST anomalies (bottom), 1957-2006, based on Hadley climatology. After Belkin (2008).

Barents Sea LME Chlorophyll and Primary Productivity

The Barents Sea LME is a Class II, moderately productive ecosystem (150-300 gCm^{-2}yr^{-1})(Figure XIII-36.3).

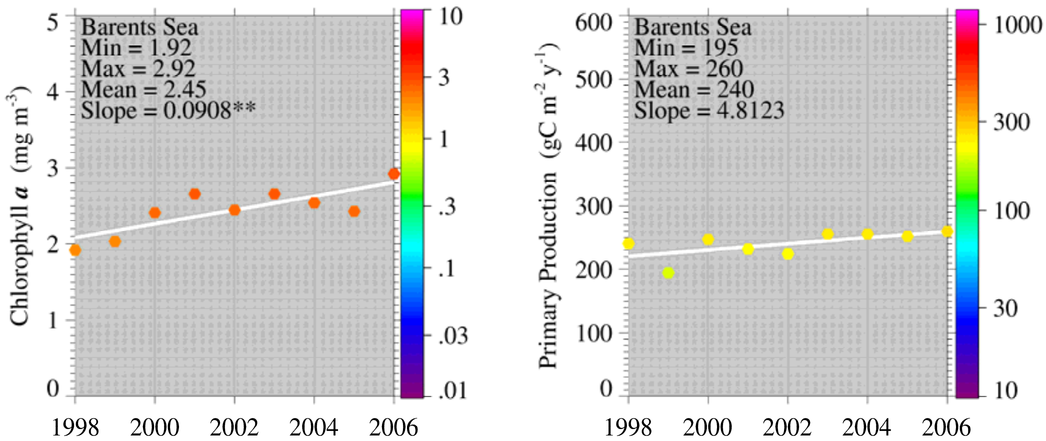

Figure XIII-36.3. Barents Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998 – 2006, from satellite ocean colour imagery; courtesy of K. Hyde.

II. Fish and Fisheries

The major species fished in the Barents Sea LME are capelin, Atlantic cod and herring, with capelin and herring being the major prey of cod (Blindheim & Skjoldal 1993). The LME is one of the world's most intensively exploited ecosystems, with severe overexploitation of the major fish stocks such as cod and haddock (UNEP 2004).Note that the Norwegian Polar Institute reports a reduction in overfishing in 2008. During the last decades, the biomass yield of the major species has fluctuated significantly because of high fishing mortality and variation in the natural environment (Skjoldal 1990, Blindheim & Skjoldal 1993, Matishov *et al*. 2003).

Total reported landings show marked fluctuations and reached a peak of 3.3 million tonnes in 1977, with capelin accounting for 70% of these landings, followed by a precipitous decline to 340,000 tonnes in 1990 (Figure XIII-36.4). Cod landings have decreased considerably from the early 1970s, possibly as a result of the temperature-salinity anomaly (indicated by cooling and reduced salinity) that occurred in the northern North Atlantic during the 1960s and the 1970s (Blindheim & Skjoldal 1993). By the beginning of 2000, the commercial cod stock was estimated at 1.5 million tonnes and its spawning stock at 300,000 tonnes, significantly lower than the average long-term values of 2.5 million and 600,000 tonnes, respectively (Borovkov *et al*. 2001). The total value of the reported landings also peaked in 1977, estimated at more than US$2.1 billion (in 2000 US dollars; Figure XIII-36.5). In her 2006 address to the North Atlantic Conference in Tromsø, Minister of Environment Helen Bjørnøy expressed strong concern for illegal, unregulated and unreported fisheries (IUU-fisheries) in the Barents Sea, stating that more than 100.000 tonnes of Arctic cod and 30–40,000 tonnes of haddock are estimated to be illegally fished there each year.

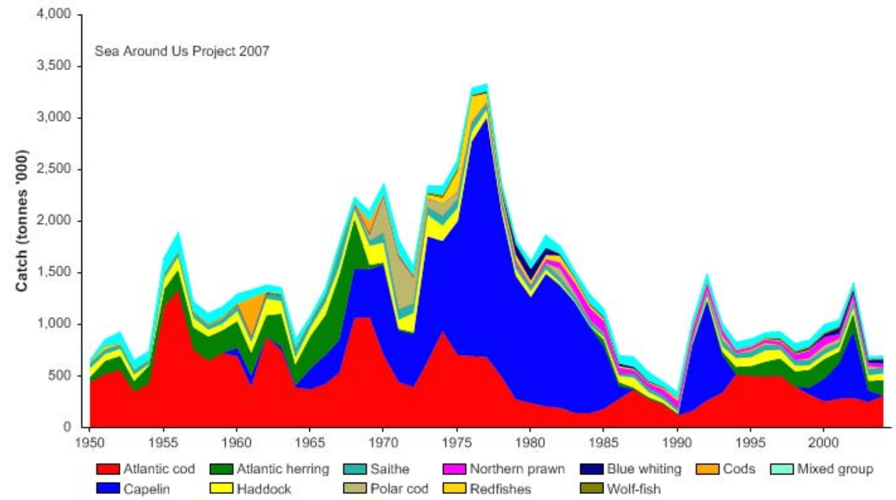

Figure XIII-36.4. Total reported landings in the Barents Sea LME by species (Sea Around Us 2007).

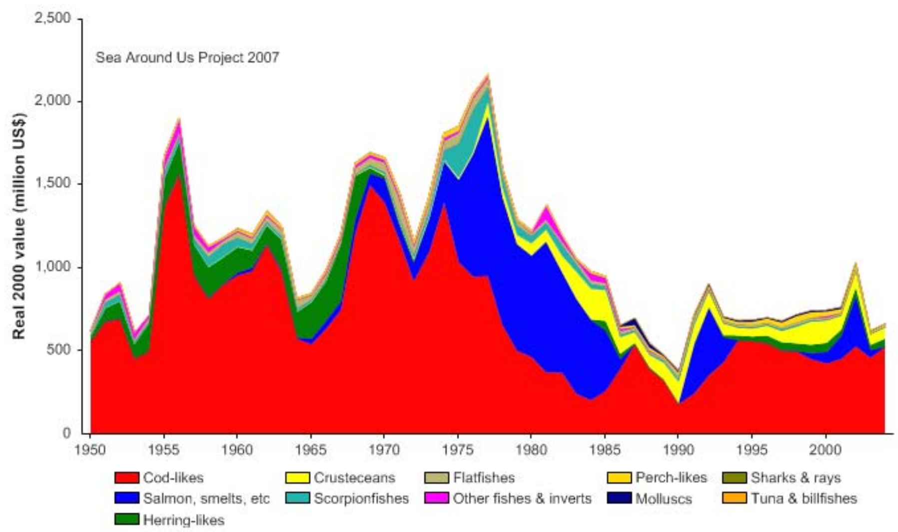

Figure XIII-36.5. Value of reported landings in the Barents Sea LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 70% of the observed primary production in 1955 and recorded similarly high levels in mid 1970s, before declining to less than 30% in recent years (Figure XIII-36.6). The high PPR level achieved in 1955 is probably a result of the large landings of accumulated cod biomass, not of annual surplus production, whilst the levels achieved in the mid 1970s is likely due to the expansion of capelin distribution beyond the LME boundary which led to possible misreporting of capelin caught outside the LME as being caught within the LME. Russia and Norway have the largest share of the ecological footprint in this LME.

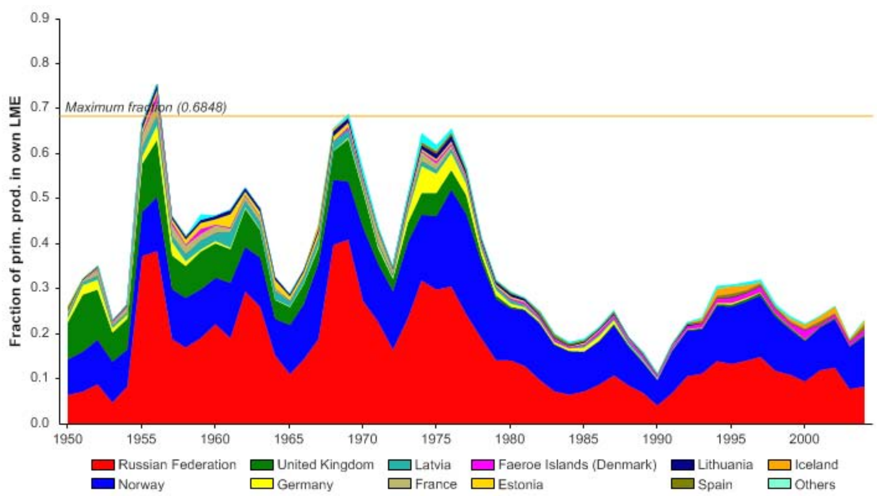

Figure XIII-36.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Barents Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the fisheries catch (i.e., the MTI; Pauly & Watson 2005) underwent a decline from 1950s to the mid-1980s, suggesting a 'fishing down' of the food web (Pauly *et al*. 1998); it then increased in a fluctuating manner (Figure XIII-36.7, top), reflecting the relative abundance of cod and capelin in the reported landings during the 1990s and the 2000s (Figure XIII-36.4). During the same period, the FiB index fluctuated without any observable trend (Figure XIII-36.7, bottom). The Nordic Council of Ministers is initiating a study on indicators for sustainable fisheries for the Barents and Norwegian Seas LMEs that is expected to shed new light on the fish abundance in these areas. Note that he Mare cognitum programme in the Norwegian Sea concluded that the food chains were short (phytoplankton – zooplankton – fish) with high trophic efficiency (20 % rather than 10%).

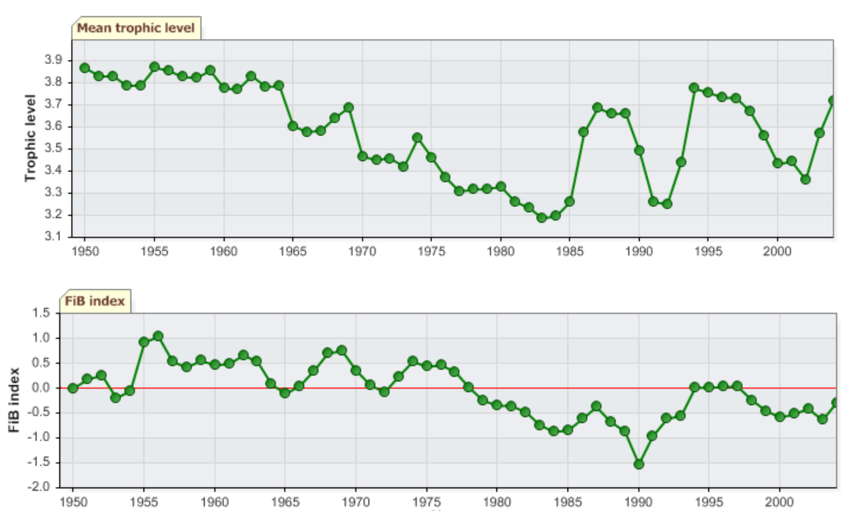

Figure XIII-36.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Barents Sea LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that the number of collapsed stocks has been rapidly increasing, to about 80% of the commercially exploited stocks, with the remainder classed as overexploited (Figure XIII-36.8, top). The contribution to the reported landings biomass by these two stock categories is roughly equal (Figure XIII-36.8, bottom).

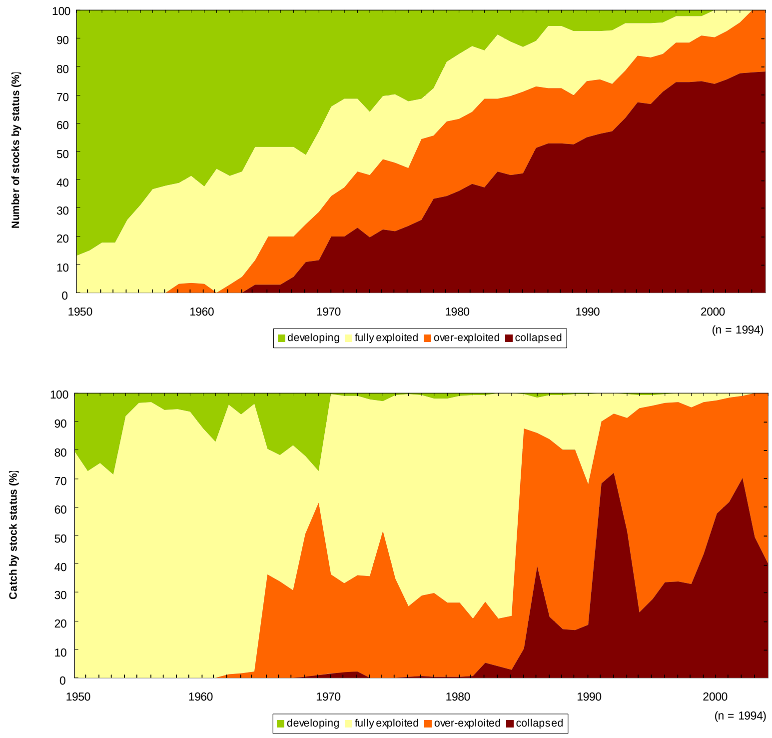

Figure XIII-36.8. Stock-Catch Status Plots for the Barents Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', 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).

Over the past several decades, capelin biomass has declined significantly, falling from about 2.5 million tonnes in the late 1970s to almost zero during the late 1980s-1990s (Dalpadado *et al*. 2001, ICES 2003, Matishov *et al*. 2003). Predation on capelin larvae by young herring as well as on immature capelin by cod can have a marked impact on the capelin stock (Blindheim & Skjoldal 1993) and the formation of strong year classes of cod and herring in 1983 is thought to have contributed to the collapse of the capelin stock in 1986 (Blindheim & Skjoldal 1993). As capelin plays an important intermediate link in the food web, a decline in its biomass can have serious effects on other components of the regional ecosystem and may have led to the poor growth of local cod stocks (Monstad & Gjoesaeter 1987), high seabird mortality and massive seal invasions along the Norwegian coast (Skjoldal 1990). The capelin biomass has since increased to nearly three million tonnes in 1999-2000 (Matishov *et al*. 2003). The editors and Norwegian reviewer caution that management policies for reduction of catch for some stocks has caused an appearance of reduced amounts of fish available.

Bycatch and discards are considered to be small in the LME (UNEP 2004), but the available data are highly uncertain. These issues could, therefore, be serious (Matishov *et al*. 2003). Bycatch in the cod fishery consists mainly of under-sized cod and haddock.

According to studies by the Murmansk Marine Biological Institute and other unofficial assessments, discards of under-sized fish could be as high as 30% for several species, despite a number of regulations requiring that all bycatch must be landed. Moreover, lack of reliable data on the level of discards could be detrimental to fisheries management as it often leads to uncertainty in assessments of stock sizes (PINRO 2000). Destruction of the bottom habitat by trawling also has a negative impact on cod and bottom fish, such as catfish, perch, plaice, Greenland halibut and American plaice, which already suffer from relatively small stock sizes (UNEP 2004).

Mitigation of overfishing can be expected, as a series of management measures continue to be implemented in the LME. In fact, the total catch has shown some signs of recovery over the past decade. However, effective management and sustainable use of the LME's fisheries resources must also take into consideration the impact of environmental variability on these resources.

III. Pollution and Ecosystem Health

Pollution: The two main sources of pollution are water mass and atmospheric advection from external sources as well as industrial activities within the basin (Matishov *et al*. 2003). Water and ice exchange with adjacent areas has a significant role in the pollution of this LME, which is a sink for the Atlantic Ocean currents. However, information on the bulk of pollutants discharged into the LME is limited (Matishov *et al*. 2003). The authoritative source is the AMAP (2002) report on POPs, heavy metals, radioactivity, and other aspects affecting ecosystem health.

The overall slight level of pollution (UNEP 2004) is possibly related to the Barents Sea's high assimilating capacity and being open towards the north and the west (Matishov *et al*. 2003). Microbiological pollution, eutrophication and suspended solids are not of general concern (UNEP 2004), although elevated levels of microbiological pollution have been observed in some localised areas. Pollution by solid waste is due mainly to timber and municipal waste in localised areas.

The coastal areas are most exposed to chemical pollution. However, in these areas, the levels of chemical pollutants, such as chlorinated hydrocarbons and heavy metals and their compounds as well as organic compounds such as DDT are lower than the Maximum Allowable Concentrations, the standard set by Russian regulations and Norwegian Pollution Control Authority environmental quality assessment criteria (Molvaer *et al*. 1997). These levels are also lower than in other parts of Russia or in the European Seas (Matishov *et al*. 2003). An exception to this, however, is Kola Bay, which has high levels of contamination in the water and sediments. There are eutrophication hotspots in the estuarine zone of the Kola River (UNEP 2004). The areas adjacent to the port of Murmansk as well as the port centre of Severomorsk have extremely high levels of practically all metals. Elevated levels of POPs such as toxaphene and brominated flame retardant have been found in bottom sediments in some areas of the Kola Bay (Savinov *et al*. 2000).

Low accumulation of contaminants in the tissues and organs of the most important commercial species of fish and invertebrates has been reported (Matishov *et al*. 2003). On the other hand, elevated levels were detected in animals at higher trophic levels (seabirds, marine mammals and polar bear) due to food web bio-accumulation (Muir *et al*. 2003, Savinov *et al*. 2003).

There is concern over possible radioactive contamination. The main sources of artificial radionuclides in the marine environment include atmospheric fallout, river runoff, discharges from West-European nuclear reprocessing plants entering the region with the Gulf Stream Current, discharges of liquid radioactive wastes from sources on the Kola

Peninsula as well as a result of nuclear tests (mostly, on nearby Novaya Zemlya) and accidents such as occurred in Chernobyl (Matishov & Matishov 2001).

The oil, gas and shipping industries are potentially dangerous to the health of the LME, with the chronic pollution of the marine environment and biota from petroleum products being a serious environmental threat (UNEP 2004). The LME is covered with numerous navigation routes, including the Northern Sea Route and thousands of vessels, including oil tankers, pass through the Barents Sea year round. The presence of drifting and packed ice increases the threat of pollution because of the accumulation of concentrated oil products and other toxic substances in ice and their release into the marine environment during ice-melting in summer. Elevated hydrocarbon levels have been reported in some areas. For instance, levels of oil products higher than MAC are routinely recorded in the convergence zones and fishing grounds (Matishov *et al*. 2003). A spreading oil film covering a relatively large area has been observed in the vicinity of Kolguev Island where oil is extracted (Ivanov 2002). Pollution from petroleum products may worsen with the intensification of hydrocarbon extraction on the Arctic shelf and increased oil transport as well as shipping in the region. The Norwegian government has petitioned the UN's International Maritime Organization, IMO, to establish mandatory shipping routes, 30 nautical miles off the coast, between Vardø and Røst (Norwegian Ministry of Fisheries and Coastal Affairs 31 March 2006 press release).

Habitat and community modification: There are no records of serious habitat modification in the LME, but there is evidence of slight degradation and loss of some habitats (UNEP 2004). An important issue is the introduction of humpback salmon, snow crab (Kuzmin 2000) and red king crab into the LME (Orlov 1977). These species have caused serious changes in the faunal composition of benthic communities in localised areas. For example, sea urchin biomass in Zelenetskaya Bay decreased by a factor of five following the introduction of the red king crab (UNEP 2004). These might be natural changes in abundances, but similar changes in a number of areas may provide evidence for the impact of the crab on benthic communities. Distribution of the red king crab along the warm Atlantic water masses and its expansion into new warm water habitats has been observed (UNEP 2004). The introduction and rapid population growth of this species, which is a large mobile predator and polyphage, has limited the food resources for itself as well as for other benthic organisms including fish fry. The king crab is also an intermediate host for a cod fry parasite and an increased infection rate and potential decrease in cod abundance are expected in the coming years. The majority of the Barents Sea whales are rare or protected species and are included in the IUCN Red List.

At present the health of the Barents Sea LME is in relatively good condition. This may change, however, as a result of the rapid development of the oil and gas industry on the Arctic shelf, increased volume of oil and gas transport as well as the accidental introduction of alien species with ship ballast water. In addition, the potential threat from radionuclides may increase in the future (UNEP 2004). Therefore, regional authorities should be increasingly focused on radiological protection activities and prepared for any eventualities related to nuclear reactors, storage of radioactive waste and spent nuclear fuel.

IV. Socioeconomic Conditions

The total human population in the catchment area of the Barents Sea LME is about five million, composed partly of indigenous peoples (Nenets, Lapps, Karelians and Vepsians). About 1.5 million people live in the coastal zone (Matishov *et al*. 2003). The average population densities in the Russian and Norwegian parts of this LME are significantly below the national averages. This is a consequence of population decrease, including migration from these regions, during the last two decades (Demographic Annual

Book 2002). The countries' economies and populations are partly dependent on the Barents Sea LME and its resources, directly or indirectly through fisheries, oil and gas extraction and marine transportation. The economic development of the Russian coast of the LME is based on the exploitation of natural resources. Tourism is growing in importance in this region, with the opening of the Russian borders.

Overexploitation has had severe social and economic consequences, in terms of employment, incomes, investment activity and population growth, particularly in the coastal settlements that depend on fisheries (UNEP 2004). During the 1990s, fishing outside the LME was stopped and coastal fish processing reduced, which resulted in a significant increase in unemployment in the fisheries sector. Unemployment in Finnmark, Norway is two times higher than the Norwegian average and is principally caused by the reduction in employment in the fisheries sector. Overexploitation has also resulted in the loss of human and animal food sources, increase in poaching and conflicts over access to the resources. Fish consumption in the north of Russia declined by 50% from 1990 to 2001 (UNEP 2004).

The socioeconomic impacts of pollution can be moderate. The large metallurgy, pulp and paper, mining as well as chemical enterprises are the main source of contaminants potentially impacting human health in the neighbouring territories. The high cost of radiological protection is of particular concern.

In general, habitat and community modification have slight socioeconomic impacts, which include the cost of managing the number of intentionally introduced species, especially the red king crab, monitoring programmes, research and international agreements on management and quotas. Potentially the most damaging alien species in Norway are toxic phytoplankton, which have caused losses in the aquaculture industry of some US$5 - 8 million , and parasites and pathogens which have caused damage of at least US$630 million to farmed and wild Atlantic salmon in Norway over the last 15 years.

V. Governance

Environmental protection activities are regulated by and carried out through a number of international programmes and instruments. Among these is the Oslo Convention, adopted in 1972 to prevent the dumping of hazardous substances at sea, which was followed by the 1974 Paris Convention dealing with land-based sources of pollution. These legal instruments have now been merged into the present Convention for the Protection of the Marine Environment of the North-East Atlantic of 1992 (OSPAR Convention), which entered into force in 1998. This Convention contains a number of supporting legislative and policy instruments regarding the Northeast Atlantic. See the OSPAR website for more information on the protection and conservation of ecosystems and biological diversity, and for the optimum utilisation of the fisheries of the Northeast Atlantic (www.ospar.org/). OSPAR is a regional body for international cooperation on the prevention and elimination of pollution from land-based and off-shore sources, dumping or incineration, and assessment of the quality of the marine environment. The OSPAR Commission site has information on the 1992 Convention, ministerial declarations and statements, and the use of the ecosystem approach to the management of human activities (www.ospar.org/). Other relevant international conventions include MARPOL and the United Nations Economic Commission for Europe Protocol of the European Commission on Strategic Environmental Assessments (the UNECE SEA Protocol).

The Arctic Council is one of the main international organisations dealing with environmental issues in the Arctic and Barents Sea Region. At least three of its five programmes deal with the protection of the marine environment: Protection of the Arctic Marine Environment (PAME) addresses policy and non-emergency response measures related to protection from land and sea-based activites, the Arctic Monitoring and

Assessment Programme (AMAP) has responsibilities to monitor the levels of and assess the effects of pollutants in all components of the Arctic marine environment, as well as in humans and the Emergency Prevention, Preparedness and Response, which is responsible for emergency preparedness in the region. The countries have adopted the Rovaniemi Initiative on the Protection of the Arctic Environment, through which the Arctic Environmental Protection Strategy was launched in 1991.

The Arctic Council is an intergovernmental forum addressing many of the common concerns and challenges faced by Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the USA. Arctic Council Ministers, in a 2002 declaration, recognised that 'existing and emerging activities in the Arctic warrant a more coordinated and strategic approach to address the challenges of the Arctic coastal and marine environment'. The Council has agreed to develop a strategic plan for protection of the Arctic marine environment under the leadership of PAME, one of the five working group of the Arctic Council. PAME is an independent partner of UNEP Regional Seas Programme. Its international secretariat has been located in Iceland since 1999. More than 20 treaties and agreements cover the Arctic area. Several countries and groups of countries, including Norway, are engaged in scientifically-driven management of marine ecosystems, with an integrated approach similar to the LME approach.

Finland, Sweden and Norway all have bilateral environmental programmes and projects under-way with Russia in the Barents Sea LME region. Norway and Russia share stocks of cod, capelin and haddock, and close cooperation is needed in the management of these transboundary resources. These two countries manage their shared fish stocks through the Joint Norwegian-Russian Fishery Commission, established in 1975. The Commission sets total allowable catches (TAC) for shared fish stocks throughout their transboundary migratory routes. Fish quotas are also allocated to third-parties with historical rights to the Barents Sea fisheries. The TAC's are based on scientific advice from ICES and national research institutions. ICES formulates scientific advice to fisheries authorities in the North Atlantic region, and is one of the main organisations coordinating and promoting marine research in the North Atlantic, including in adjacent seas such as the Baltic and North Seas (www.ices.dk/indexnofla.asp). The Barents Euro-Arctic Council (BEAC) encourages economic intergovernmental cooperation in trade, investment, energy transport and information technology, on the environment and nuclear safety, and on human and social development. The Council has a rotating chairmanship among the 13 member countries.

Cooperation in control, enforcement and marine research is being strengthened. A GEF-supported project (Support to the National Programme of Action for the Protection of the Arctic Marine Environment) is being conducted in the region. The main objectives are: to ensure a coherent basis for the identification of priorities associated with the adverse effects of land-based activities, to meet Russia's obligations under the GPA as well as other international agreements and to prepare the ground for environmentally sustainable development of the Arctic. Project outcomes will include an agreed SAP to address damage and threats to the Arctic environment from land-based activities in the Russian Federation, a regulatory framework complemented by adequate infrastructural and technical capacities and prepared ground for substantial investments in remediation/prevention of damage to the Arctic environment.

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XIII-37 Celtic-Biscay Shelf LME

M.C. Aquarone, S. Adams and L. Valdés

The Celtic-Biscay Shelf LME is situated in the Northeast Atlantic Ocean, and covers an area of 756,000 km^2, of which 0.98% is protected, with 0.01% of the world's sea mounts (Sea Around Us 2007). At its southern limit the shelf is steep and narrow, but it widens steadily along the west coast of France, merging with the broad continental shelf surrounding Ireland and Great Britain. Three countries, Ireland, Great Britain, and France border this LME. Spain is not part of this LME. However Spain has fishing rights in both the French Biscay and in the Celtic Shelf (e.g. the Great Sole Bank, a major fishing ground).The Celtic-Biscay Shelf is characterised by a strong interdependence of human impact and biological and climate cycles (see Koutsikopoulos & Le Cann 1996). River systems and estuaries include the Seine, Gironde (Garonne River), Bristol Channel and Firth of Clyde. Two important book chapters pertaining to this LME are Valdés & Lavin (2002) and Lavin et al. (2006), both on the Bay of Biscay. The OSPAR reports provide information on the geography, hydrography and climate of Regions 3 and 4 that together cover the Celtic-Biscay Shelf LME, (www.ospar.org). See also the ICES working group WGRED annual report at http://www.ices.dk/iceswork/wgdetailacfm.asp?wg=WGRED

I. Productivity

The Celtic-Biscay Shelf LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$). This LME is influenced by the North Atlantic Drift in the north, and by the Azores Current in the south. For information on circulation and currents, see Koutsikopoulos & Le Cann (1996). The region undergoes a seasonal climatic cycle that strongly affects the pelagic ecosystem through forcing factors: sunlight exposure, heat input, and mechanical forcing on the surface by wind. For more information on seasonal variability, the vertical structure of coastal and oceanic waters, river plumes, coastal runoff and tidal fronts, see Valdes & Lavin (2002) who also describe the coastal upwelling in the Bay of Biscay that affects mainly Iberian coast, being very weak and only occasional along the French coast; they also describe the warm and salty Navidad Current. Living marine resources include a wide range of organisms. The LME is a region of transition that is rich in floral and faunal species. It is difficult to determine the states of equilibrium of species and communities, since natural variability occurs on a wide range of space and time scales (seasonal, inter-annual, decadal and centennial cycles). This LME is positioned in the eastern North Atlantic, in the cyclical North Atlantic Oscillation.

Oceanic fronts (Belkin et al. 2008): The most important front within this LME is the Shelf-Slope Front (SSF) that extends along the shelf break/upper continental slope from the Bay of Biscay around the British Isles up to the Faroe-Shetland Channel where it joins the North Atlantic Current Front (Figure XIII-37.1). This front is distinct year-round but is best defined in fall when its separation from the Mid-Shelf Front (MSF) becomes evident. The SSF is associated with the Shelf Edge Current, believed to be continuous all the way up to the Faroe-Shetland Channel. The SSF, however, does not appear continuous, suggesting that the Shelf Edge Current is likely not always continuous. The areas where the SSF is broken most often are near Goban Spur and Porcupine Bank; these bathymetric features are clearly responsible for the front's instabilities in these areas. The Mid-Shelf Front (MSF) is located between the SSF and the coasts of France, United Kingdom and Ireland. Tidal mixing fronts exist off Ushant Island, south of the Irish Sea, south of Ireland, and over the Malin Shelf.

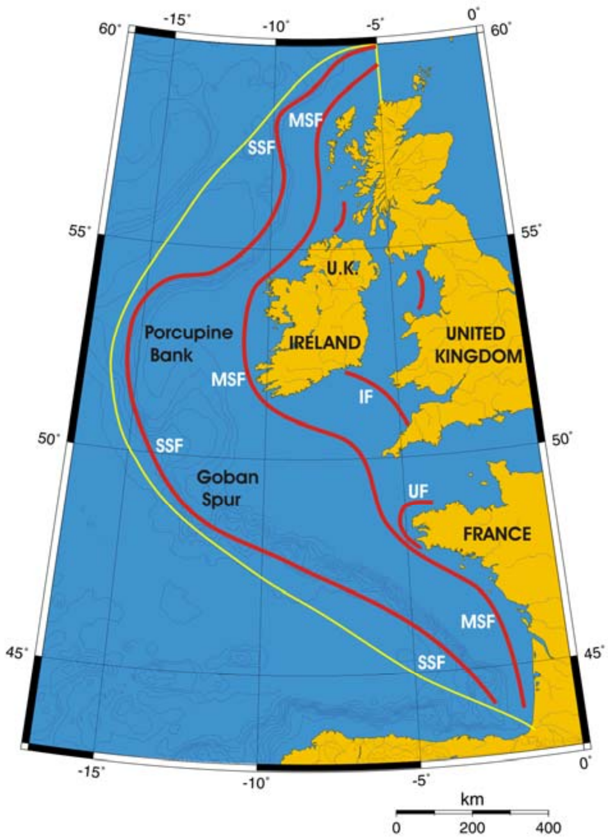


Figure XIII-37.1. Fronts of the Celtic-Biscay Shelf LME. IF, Irish Front; MSF, Mid-Shelf Front; SSF, Shelf-Slope Front; UF, Ushant Front. Yellow line, LME boundary. After Belkin et al. (2008).

Celtic-Biscay Shelf LME SST (Belkin 2008)(Figure XIII-37.2)
Linear SST trend since 1957: 0.41°C.
Linear SST trend since 1982: 0.72°C.

The thermal history of the Celtic-Biscay Shelf included (1) abrupt cooling in 1959-1963; (2) cold period until the all-time minimum in 1986; (3) very fast warming at a rate of 1.3°C over 20 years, accentuated by a major warming peaked in 1989 and interrupted by a cold spell in 1991-94.

The sequence of alternating, well-defined extremums in 1986 (cold), 1989 (warm), and 1991-94 (cold) is strongly correlated with similar events in the adjacent Iberian Coastal LME. The latter is oceanographically connected to the Celtic-Biscay Shelf by the Iberian Poleward Current and its extension off northern Spain dubbed "Navidad" (e.g. Garcia-Soto et al., 2002) flowing from the Iberian LME onto the Celtic-Biscay Shelf. Given the short distance between the two LMEs, all three events occurred nearly simultaneously in both LMEs. The same sequence of three alternating cold-warm-cold events of 1986, 1989, and 1991-94 in the Celtic-Biscay Shelf LME can be tentatively correlated with a similar cold-warm-cold event sequence of 1986, 1990, and 1995 in the Norwegian Sea LME located downstream of the Celtic-Biscay Shelf and connected to the latter by the Slope Current and North Atlantic Current. The less conspicuous minimum of 1972 on the Celtic-Biscay Shelf was likely related to the all-time minimum of 1972 in the Iberian LME. The previous minimum of 1963 was also simultaneous in both LMEs. The near-all-time maximum of 1959 on the Celtic-Biscay Shelf can be tenuously linked to the all-time maximum of 1961 in the Norwegian Sea. The above correlations suggest a dominant role of oceanic advection in transporting thermal signals across the Northeast Atlantic. The ongoing warming has already significantly affected this LME. For example, in the southern Bay of Biscay (43°–47°N), cold-water species of fish and sea birds declined; two species (puffin and killer whale) disappeared; populations of warm-water species increased; all these changes could amount to a regime shift in this LME (Hemery et al., 2007).

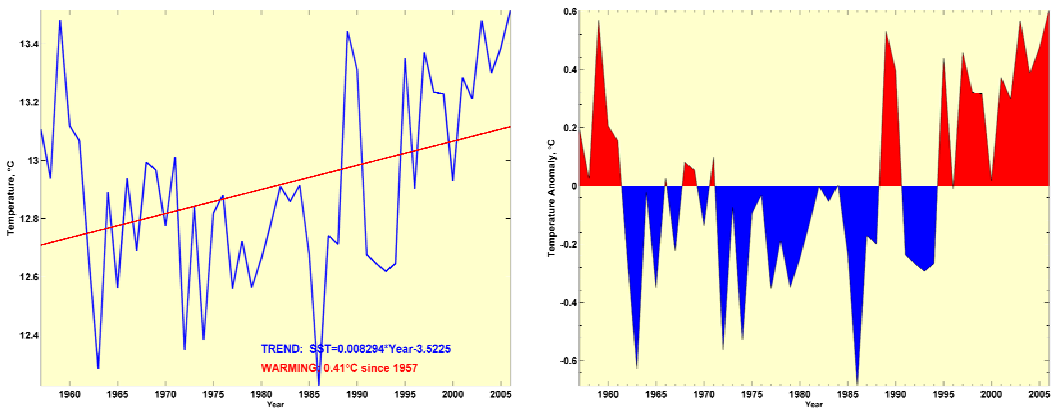


Figure XIII-37.2. Celtic-Biscay Shelf LME annual mean SST (left) and annual SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

***Celtic-Biscay Shelf LME Chlorophyll and Primary Productivity*:** This LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$)(Figure XIII-37.3).

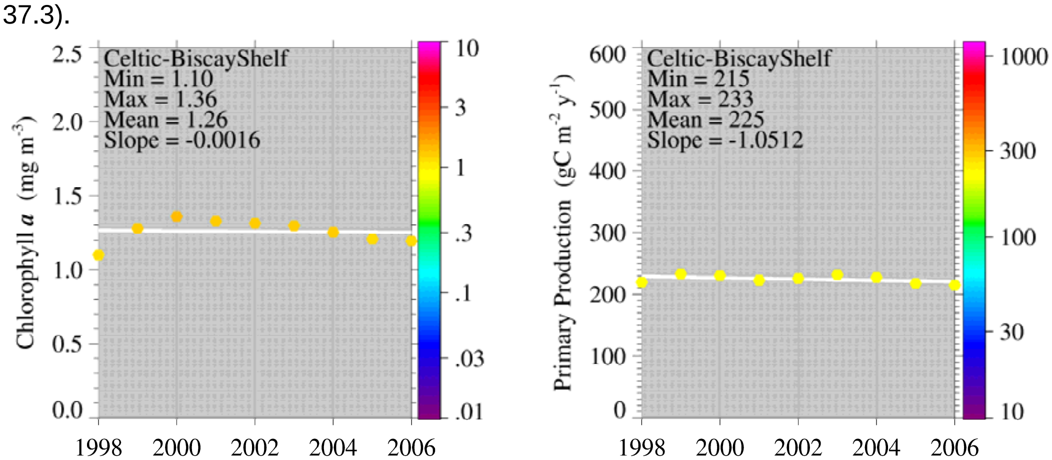


Figure XIII-37.3. Celtic-Biscay shelf LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The natural environmental variability in this LME adds a high degree of uncertainty to the management of marine resources. Cyclical oscillations, such as the North Atlantic Oscillation, have been linked to fluctuations in the abundance of albacore and bluefin tuna (see Ortiz de Zarate *et al*. 1997 and Santiago 1997). Many stocks in the LME are intensively exploited or depleted and TAC-based regulations have been implemented for anchovy, hake and blue whiting. ICES provides general information on fisheries and other topics pertaining to the LME, while OSPAR reports on biodiversity and evolution of catches of same depleted stocks, but not with an intention of doing any management.. The main marine resources exploited in the LME include molluscs, seaweed, herring, redfish, sand eel and mackerel. The most important fish caught in its shelf waters include various pelagic fish species, as well as cod and hake. Sardine is not as important a resource in this LME as in the Iberian Coastal LME. For more on sardine recruitment, see Valdés & Lavin (2002).

Total reported landings in this LME show changes in biomass and catch composition (Figure XIII-37.4). The landings recorded a peak of 1.4 million tonnes in 1998, and declined to 1 million tonnes in 2004. The value of the reported landings reached US$1.6 billion (in 2000 US dollars) in 1976 (Figure XIII-37.5).

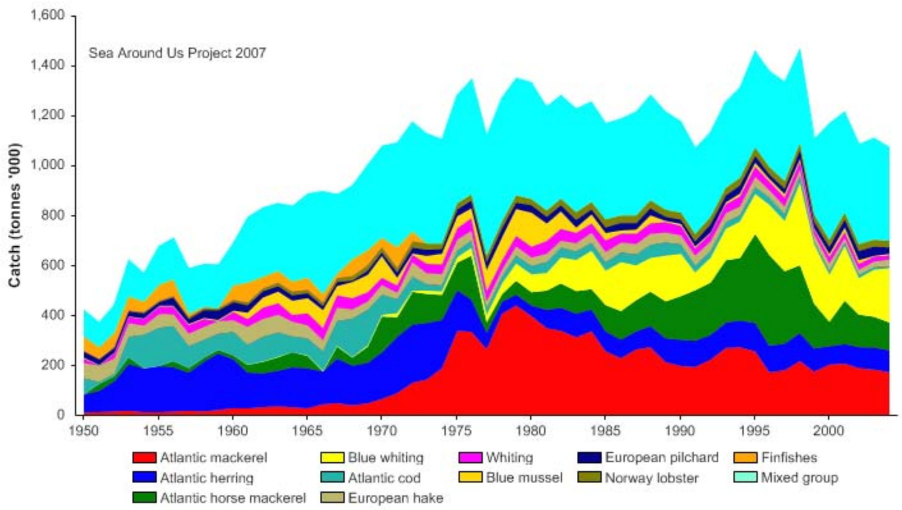


Figure XIII-37.4. Total reported landings in the Celtic-Biscay Shelf LME by species (Sea Around Us 2007).

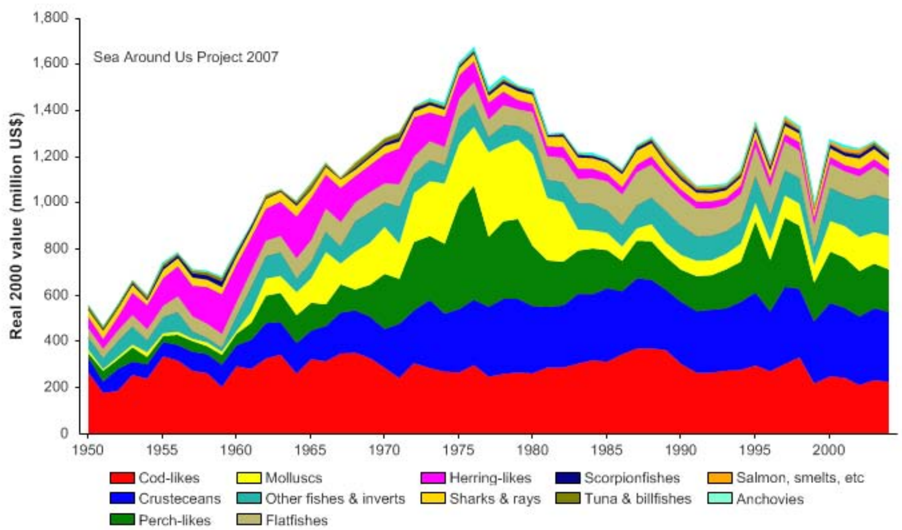
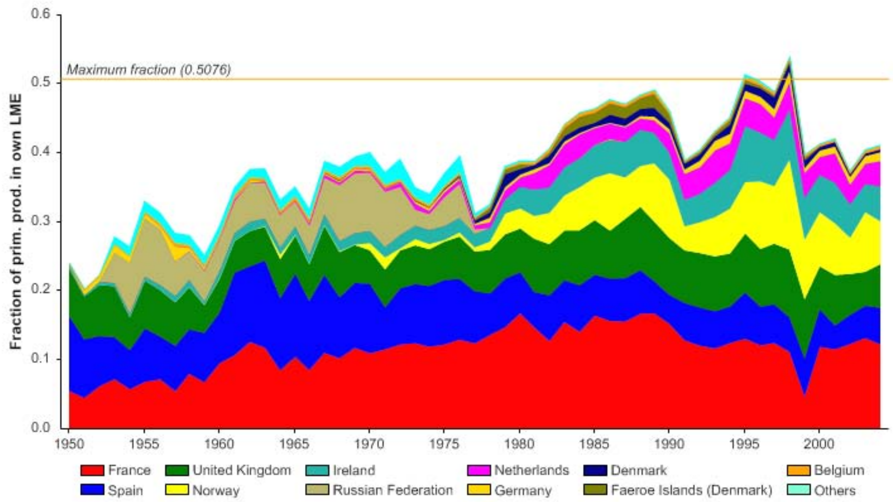


Figure XIII-37.5. Value of reported landings in the Celtic-Biscay Shelf LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached 50% of the observed primary production in the mid-1990s, but has declined to 40% in recent years (Figure XIII-37.6). France and the UK account for the largest share of the ecological footprint in this LME.



FigureXIII-37.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Celtic-Biscay Shelf LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of fisheries catches (i.e., to the MTI; Pauly and Watson 2005) declined over the three decades from 1950 to 1980. In the early 1980s, however, it underwent a strong increase (Figure XIII-37.7, top) while the FiB index reached a new plateau (Figure XIII-37.7, bottom). These trends indicate that a 'fishing down' of the food web occurred from 1950 to the 1980s (Pauly *et al.* 1998), after which the effect was masked by expansion of the fisheries into new stocks (e.g., blue whiting, Figure XIII-37.4). This also confirms the results of Pinnegar *et al*. (2002), who, using fine-resolution data, concluded "there has been [in the Celtic Sea - ICES divisions VII f–j] a significant decline in the mean trophic level of survey catches from 1982 to 2000 and a decline in the trophic level of landings from 1946 to 1998."

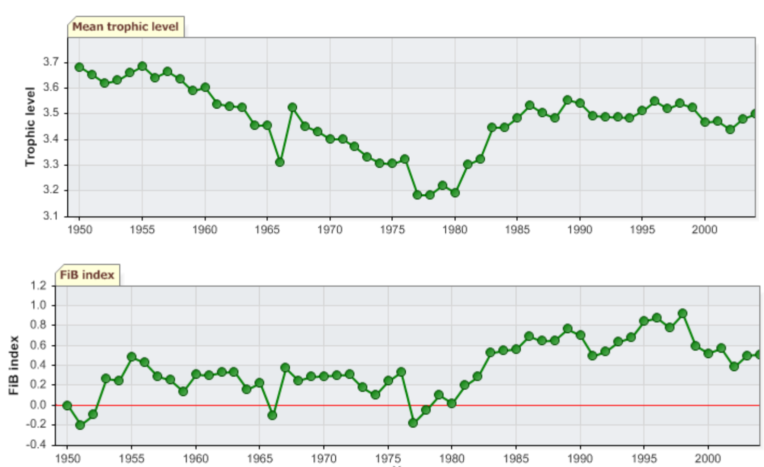


Figure XIII-37.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Celtic-Biscay Shelf LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate that collapsed stocks make up half of all stocks exploited in the LME (Figure XIII-37.8, top), but that fully exploited stocks contribute almost 60% of the reported landings biomass (Figure XIII-37.8, bottom).

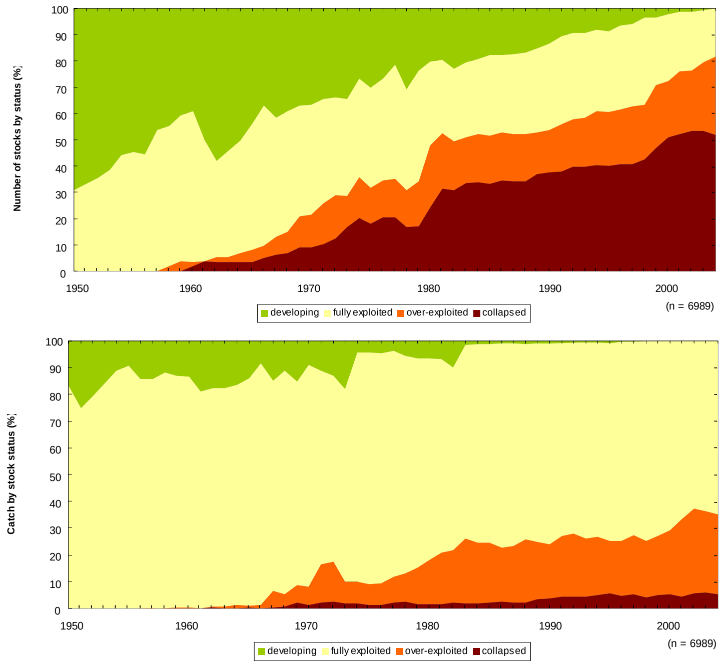


Figure XIII-37.8. Stock-Catch Status Plots for the Celtic-Biscay Shelf LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number 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

The Celtic-Biscay Shelf LME has experienced ecological disturbances of target fish species, with alterations in the abundance, distribution and diversity of fish and marine mammals. Pollution and global change are impacting the coastal habitats (estuaries, coastal lagoons, rocky cliffs, rocky shores, sandy and muddy shores). Estuaries and coastal lagoons receive most of the impact of microbiological contamination of urban origin. Effects of ecosystem variability and human impact on species and habitats of the Bay of Biscay are described by Valdés & Lavin (2002). The ecosystem is affected by alterations to the seabed, the introduction of non-indigenous species, agriculture and sewage (Valdés & Lavin 2002). Introduced species are naturally transported by currents or are human-induced, caused by an intensification of fisheries and by transport in ballast water of commercial vessels. The use of DDT in agriculture has now been banned. There is pressure on the coastal margins from urban sources and from industrial activities, such as paper mills, petroleum refineries, iron and steel works and chemical plants.

Industrial discharges, inorganic and organic compounds, mercury (associated with paper mill industries), and PAHs (linked to human activities such as marine oil extraction, industry and oil traffic), are described by Valdés & Lavin (2002). Major oil spills have occurred in the area, listed at the EEA's website <epaedia.eea.europa.eu>, for example Torrey Canyon off Cornwall in 1967, the Ammoco Cadiz off Brittany, France in 1978, and the Sea Empress off Wales in 1992. In December 1999, the supertanker *Erika* spilled

10,000 tonnes of oil in shallow waters off the coast of France. Due to the strong wind in the area, the ‘black tide’ moved to the coast of the Bay of Biscay and large expanses of French beaches were contaminated by oil. The EEA reports that the remains of this ecological disaster can still be seen.

OSPAR provides information on the chemical aspects of the North-East Atlantic, the inputs of contaminants and nutrients, and their concentrations in different environments (www.ospar.org). It identifies pollution trends, the effectiveness of measures, the major causes of environmental degradation within the area and the managerial and scientific actions needed to redress this. The OSPAR Integrated Report on Eutrophication (2003) points out that in all participating countries many coastal areas, fjords and estuaries showed increased riverine N and P inputs, and some fjords and offshore sedimentation areas received increased transboundary nutrient inputs. Also reported were elevated levels of winter DIN and DIP concentrations, elevated levels in winter N/P ratios, elevated levels of chlorophyll *a* and elevated “nuisance bloom” or toxic assessment levels.

IV. Socioeconomic Conditions

Traditionally, the LME has been a region of intense fishing activity. Whale hunting began along the Spanish coast in the Middle Ages. Human activities in the coastal areas also include aquaculture and farming. Population densities at the coastal edges of the Celtic-Biscay Shelf LME are increasing. OSPAR estimates that 47.2 million people live in the catchment areas draining into the Bay of Biscay and Iberian coastal waters. In Brittany in France, more than 90% of the entire population lives on the coast, according to the EEA SOE report 2005 Part A, Ireland (together with the Mediterranean coast of Spain) has one of the two fastest growing coastal area populations in Europe, with increases of up to 50% in the past decade (http://epaedia.eea.europa.eu). Rapid population growth and socioeconomic development have resulted in environmental imbalances. EEA cites as principal threats to the Celtic Sea, Bay of Biscay and Iberian coast, eutrophication from sewage, agriculture, and fish farming; threats to fishing from overfishing, bottom trawling, discards and catch of non-targeted species; threats from industry in the form of chemicals and radionuclides; and threats from shipping accidents, pollution and oil spills. Additional pressure comes from tourism, urbanisation of coastal areas, transportation and recreational uses of beaches and shores.

V. Governance

A new Marine Strategy Framework Directive was recently enacted which promotes and integrates environmental considerations into all relevant policies areas and which forms the basis for a future Maritime Policy for the EU. The countries bordering this LME are all members of the European Union. The use of natural marine resources is governed by a number of conventions, declarations and regulations, including the European Commission directives and regulations within the Common Fisheries Policies. A large number of instruments from international bodies, such as the UN, the International Maritime Organisation and the European Union, exist to conserve natural resources, protect the environment and ensure health and safety standards. The European Community laws protect the environment in terms of air and noise, chemicals and industrial risks, nature conservation, waste and water. The EEA online summary for the Northeast Atlantic Ocean, lists the major political instruments as OSPAR, ICES, EU Birds and Habitats Directives, North Atlantic Marine Mammal Commission (NAMMCO), the Bern convention and other conventions covering part of the area including Ramsar for wetland protection, the Bonn convention for migratory species, MARPOL73/78IMO convention of marine pollution from ships in additional to national laws, and NGO organisations such as WWF are working to accelerate the establishment of no-fishing zones and offshore marine protected areas (www.eea.org).

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XIII-38 Faroe Plateau LME

M.C. Aquarone, S. Adams and E. Gaard

The Faroe Plateau LME surrounds the Faroe Islands in the northeast Atlantic Ocean. It is a high latitude environment characterised by a sub-arctic climate that affects productivity through changes in temperature, currents, tides and seasonal oscillations. The Faroe Plateau is a well-defined and geographically uniform LME, with a surface area of 150,000 km^2 (Sea Around Us 2007). The islands have a relatively broad shelf and are surrounded by a persistent tidal front that separates shelf waters from the open ocean. The circulation of water masses is anticyclonic, with a branch of the North Atlantic Drift current flowing north. Gaard *et al*. (2002) and UNEP (2004) have described this LME.

I. Productivity

For a map of the Faroe Islands and surrounding LME, with a typical position of the tidal front that separates the shelf water from the ocean water, see Gaard *et al*. (2002, p. 246). Climate (e.g., temperature) is the primary force driving the LME, with intensive fishing the secondary driving force. The dynamic system of ocean currents in the area, in particular the inflow of warm Atlantic waters to the Nordic seas, is an important feature. Currents, tides and seasonal oscillations affect productivity. The shallow parts of the shelf are well mixed by extreme tidal currents, with no stratification occurring during the summer. For a map of salinity at 50 m depth, see Gaard *et al*. (2002, p. 248).

The Faroe Plateau LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$). Primary productivity and phytoplankton biomass are very low during winter, but increase during spring and summer. Neritic phytoplankton and zooplankton communities are found on the shelf, and are somewhat separated from the offshore areas while receiving variable influence from the offshore environment. The shelf production of plankton is the basis for production in the higher trophic levels. The LME also serves as an important feeding ground for pilot whales and other marine mammals. Monitoring data show simultaneous fluctuations in several trophic levels in the ecosystem. Plankton production, fish recruitment, seabird recruitment and growth, and ultimately fish landings, vary inter-annually. For more information on trophic interactions, and on the large numbers of seabirds, see Gaard *et al*. (2002).

Oceanic Fronts: The Faroe Plateau LME is surrounded by tidal mixing fronts (Belkin *et al*. 2008). These fronts (Figure XIII-38.1) define the ecosystem and its important fishery grounds, especially of herring and cod (Hamilton *et al*. 2004). Unlike their counterparts around the British Isles, the Faroese tidal mixing fronts have not been studied in detail. A large-scale water mass front between the Plateau waters and the North Atlantic waters exists at the boundary of this LME, running along the Faroe-Shetland Channel (Sherwin *et al*. 2001).

Faroe Plateau LME SST (after Belkin (2008)
Linear SST trend since 1957: -0.14°C.
Linear SST trend since 1982: 0.75°C.

Like the Iceland Sea, the Faroe Plateau experienced long-term cooling of 1.2°C from 1960 through 1993, followed by rapid warming (1.3°C in 10 years) by 2003. All major extremums – maxima of 1960 and 2003, and minimum of 1993-1995– were also observed in the Iceland Shelf LME.

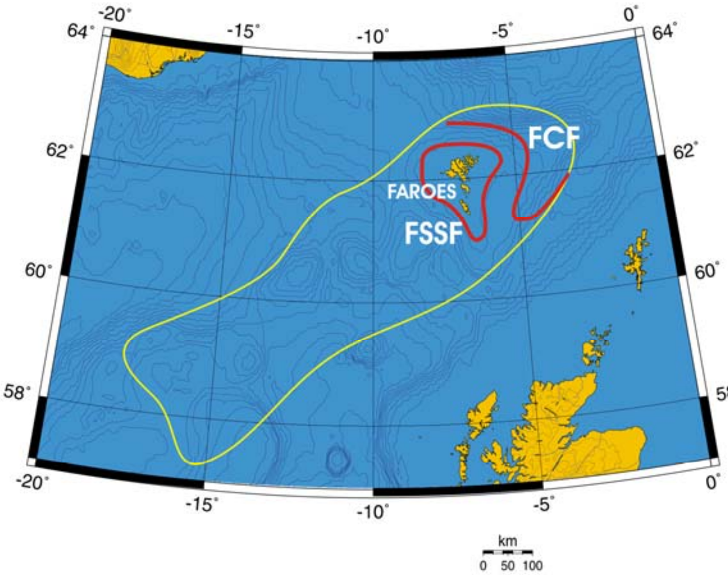


Figure XIII-38.1. Fronts of the Faroe Plateau LME. FCF, Faroe Channel Front; FSSF, Faroes Shelf-Slope Front. Yellow line, LME boundary. After Belkin et al. (2008).

The observed synchronism between Iceland Shelf and Faroe Plateau can be explained by the prevalence of northward transport, of various branches of the NAC. Therefore any SST anomaly transported by them would reach both LMEs at approximately the same time. Ocean circulation around the Faroes also effectively protects the islands from being directly affected by cold waters from the Nordic Seas. Subarctic cold waters could only reach the Faroes with easternmost branches of the North Atlantic Current, particularly the Irminger Current and Rockall Trough branch, after completing a rather circuitous journey around the Subarctic Gyre (Orvik and Niiler, 2002; Arhan, M. 1990.).

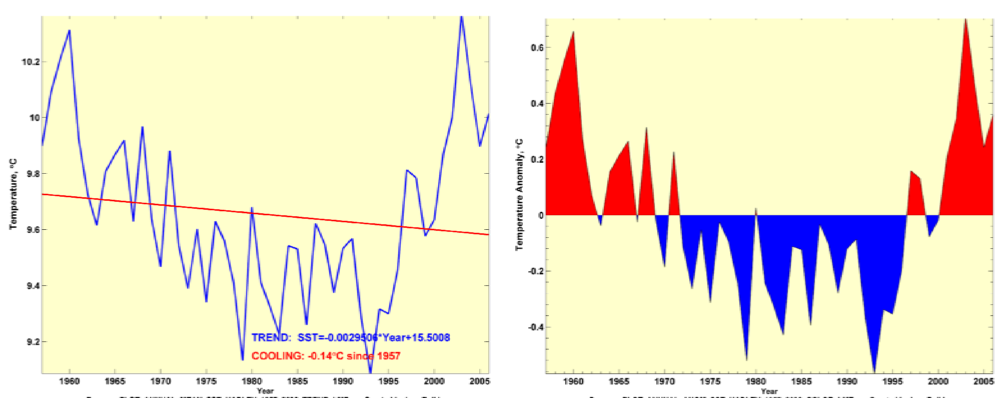


Figure XIII-38.2. Faroe Plateau LME Annual Mean SST and annual SST anomalies, 1957-2006, after Belkin (2008).

***Faroe Plateau LME Chlorophyll and Primary Productivity*:** The Faroe Plateau LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$).

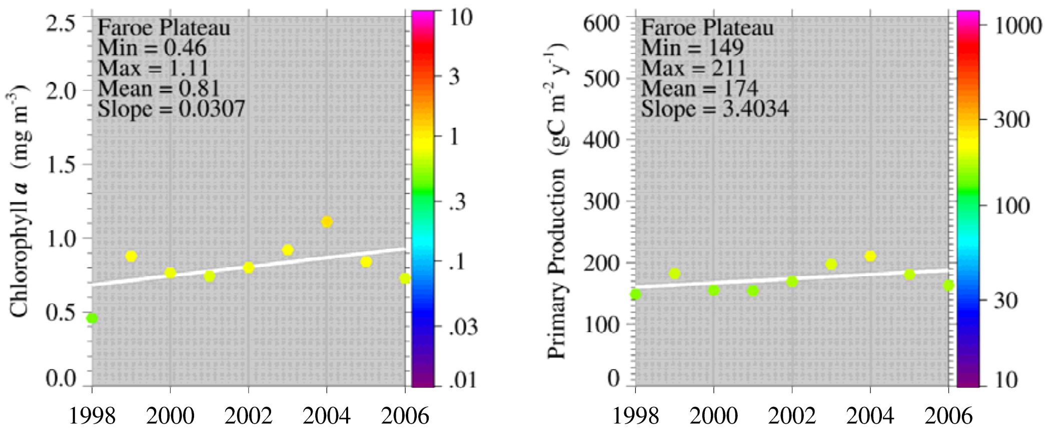


Figure XIII-38.3. Faroe Plateau LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Climatic variability has a major impact on fish landings in the LME. The most important species group is pelagic fish, representing on average 52% of the total catch, and cod, saithe and haddock, representing more than 30% of the catch. For landings of cod and haddock between 1903 and 1998, see Gaard *et al*. (2002, p. 247). The long-term average of annual landings of cod fluctuates between 20,000 and 40,000 tonnes. Landings of haddock fluctuate between 15,000 and 25,000 tonnes per year. In the early 1990s, cod and haddock annual landings reached the lowest values recorded. Cod and haddock do not always fluctuate simultaneously due to their different reproductive strategies. Other important species are saithe, halibut and the Norway pout. The latter is not caught commercially but serves as a food supply for fish (mainly cod and haddock), seabirds and grey seals. A marked increase in fishing effort has not resulted in an increase in fish landings.

Total reported landings have been on a rise, recording about 450,000 tonnes in recent years (Figure XIII-38.4). Blue whiting account for the largest share of the landings since the late 1970s, with 75% of the total landings in 2004. From 1986 to 1994, landings of Norway pout were also significant, averaging between 14,000 and 27,000 tonnes per year. The value of the reported landings recorded 355 million US$ (in 2000 real US$) in 2003 (Figure XII-38.5).

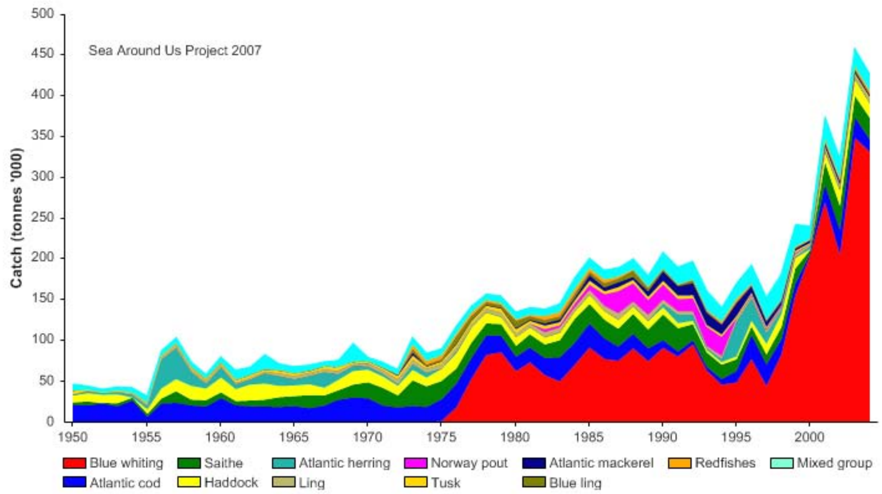


Figure XIII-38.4. Total reported landings in the Faroe Plateau LME by species (Sea Around Us 2007).

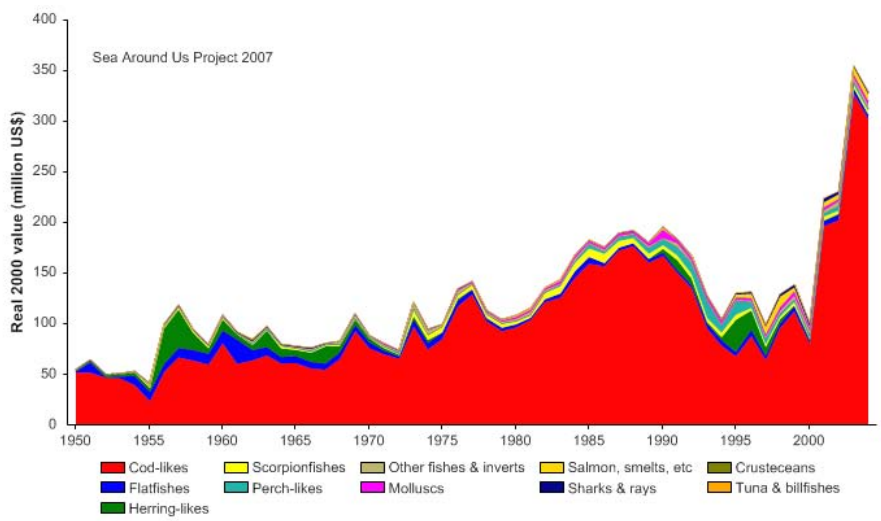


Figure XIII-38.5. Value of reported landings in the Faroe Plateau LME by commercial groups (Sea Around Us 2007).

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME has reached a level that far exceeds the observed primary production of the region (Figure XIII-38.6). While there might be other causes (e.g., problems with the landings statistics, and/or with the primary production estimate used here), it is probably due to fish being caught in the LME recruiting from and/or feeding outside the LME, which thus subsidize the productivity of the Faroe Plateau LME. Faroe Islands, Russia and Norway account for the largest share of the ecological footprint in this LME.

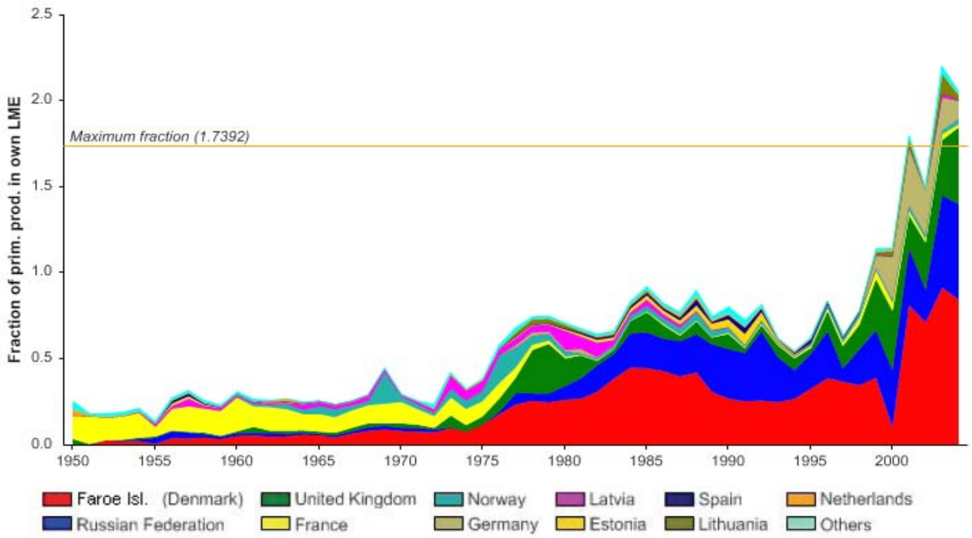


Figure XIII-38.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Faroe Plateau LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

No clear trend can be observed in the mean trophic level of fisheries landings (i.e., the MTI; Pauly & Watson 2005) until mid-1990 (Figure XIII-38.7 top). Since then, however, the level appears to increase, presumably due to the almost exclusive, and increasing landings of blue whiting (Figure XIII-38.4), which could be masking any possible 'fishing down' effect in the LME (Pauly *et al.* 1998). The expansion of the blue whiting fisheries is also evident in the FiB index (Figure XIII-38.7 bottom).

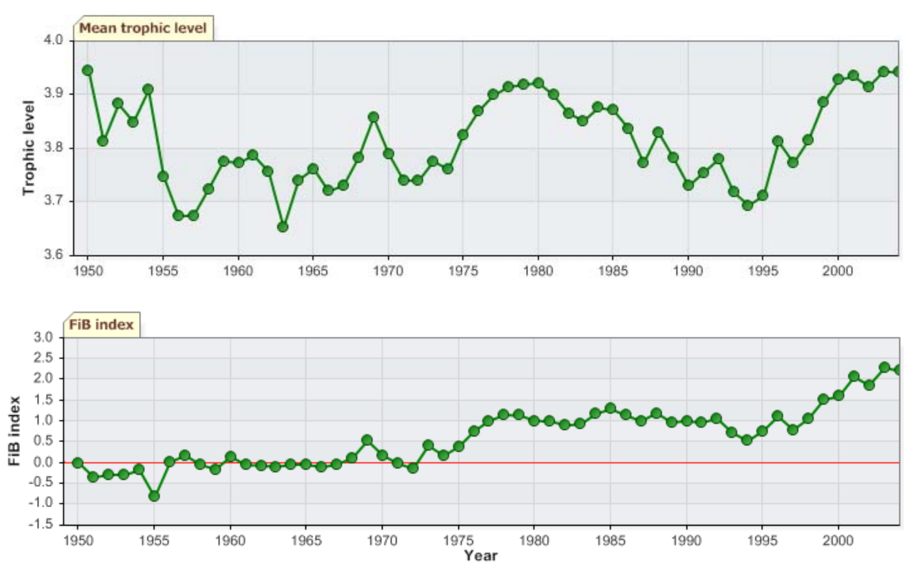
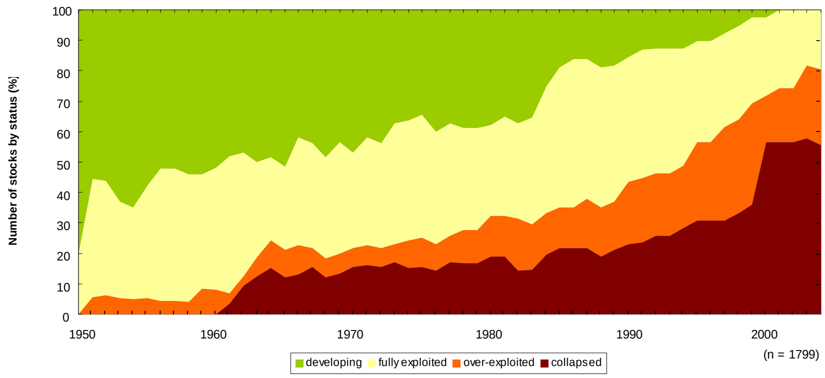


Figure XIII-38.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Faroe Plateau LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate the high proportion of stocks defined as 'collapsed' in the LME (Figure XIII-38.8, top). However, fully exploited stocks contribute almost 90% of the reported landings biomass (Figure XIII-38.8, bottom), a result of the increase in the blue whiting landings.



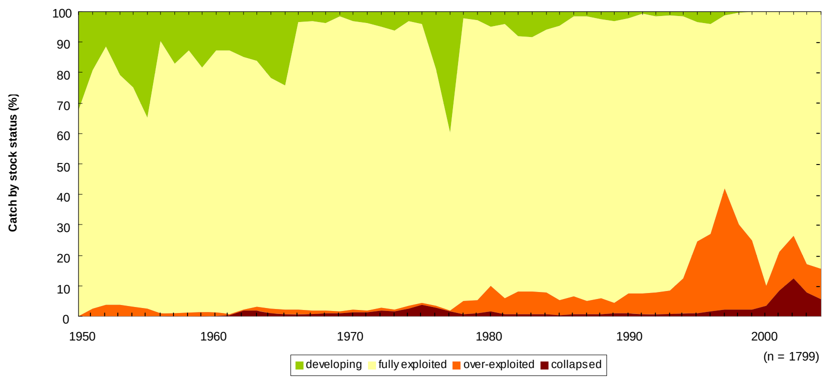


Figure XIII-38.8. Stock-Catch Status Plots for the Faroe Plateau LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of '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).

The commercial fishing fleet of the Faroe Plateau is comprised mainly of coastal vessels, long-liners and ocean trawlers. The Faroese fisheries management system with restrictions on fishing-days was adopted in 1996. The fishing-day system manages fishing capacity and effort rather than allocating specific quotas for species and stocks and was put in place for the management of demersal fisheries in the 200-mile fisheries zone around the Faroe. Vessels are grouped according to size and gear type, and each group is allocated a set number of fishing days per year, which are allocated among the vessels. This scheme is combined with gear restrictions designed to protect juvenile fish, as well as closures of extensive areas to active gear such as trawls in order to protect nursery and spawning stocks (Zeller & Reinert 2004).

III. Pollution and Ecosystem Health

Fisheries are totally dependent on a sound and healthy marine ecosystem. Safeguarding the marine environment and ensuring the sustainable use of its valuable resources is a necessity, in view of the dependence of the population on these resources. Monitoring of environmental parameters of the Faroe Shelf LME was initiated in the mid 1990s. International conventions are the basis for Faroese national legislation to protect the marine environment, mainly the MARPOL convention for the Prevention of Pollution from Ships and the OSPAR Convention for the Protection of the Marine Environment in the North-East Atlantic, which, amongst others, lays down rules for the discharge from offshore installations. The 2004 GIWA assessment of the marine waters around the Faroes reports that toxic contamination of the tissue of marine mammals is causing human health problems and may also affect the economically important fisheries sector (www.giwa.net/publications/r13.phtml). The report cites long distance transport of pollutants by ocean currents and air from industrial areas in Europe, North America and Asia among the sources of the contamination. The traditional consumption of whale meat has occasioned concern that elevated levels of mercury might be found among pregnant women (Booth & Zeller 2005).

IV. Socioeconomic Conditions

In 1998, the Faroe Islands had an estimated population of 44,000 persons who are almost totally dependent on fisheries and on fish farming, which began in the 1980s. Fishery is the main industry: fishery products, including farmed salmon, represent more than 95% of total Faroese exports and nearly half of the GDP. Bioaccumulation of mercury in whales, pelagic fish, and seabirds has already warranted warnings regarding human consumption of them (online at www.giwa.net/publications/r13.phtml, causal chain analysis chapter; Booth & Zeller (2005). The phasing out of government subsidies to the fisheries sector has been a major factor in reducing over-capacity and stimulating more effective, market-driven approaches to fisheries.

The challenge for the future is to ensure that fisheries management can continue to be flexible and adaptive to changes in the resource base and the industry, in order to ensure both biological and economic sustainability. As pollution in the Faroe Islands is largely caused by long-distance transport of the pollutants by ocean and atmospheric currents from the highly industrialized countries, solutions will be international in scope. Petroleum production is being explored in areas close to the Faroe Islands, and between the Faroe and Shetland Islands.

V. Governance

The Faroe Islands are a self-governing overseas administrative division of Denmark, a major fishing nation that is attempting to integrate fisheries and environmental policies. An ecosystem approach was used officially for the first time in 1995 at the international level with the Convention on Biological Diversity. Denmark participates in ICES. The Faroe Islands participate in the NEAFC (Northeast Atlantic Fisheries Commission, see http://www.neafc.org); NAFO (North-west Atlantic Fisheries Organisation, see http://www.nafo.ca); NASCO (North Atlantic Salmon Conservation Organisation, see http://www.nasco.org.uk); and NAMMCO (the North Atlantic Marine Mammal Commission, see http://www.nammco.no). Greenland participates in the Arctic Council as part of Denmark and the Faroe Islands (see the Barents Sea LME).

The Faroese Parliament adopted UNCLOS in 2003 and the UN Agreement for the Implementation of the Provisions of the Convention relating to the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks in 1995. Information on the Faroe Islands is available at: www.faroeislands.org.uk.

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Zeller, D. and Reinert, J. (2004). Modelling spatial closures and fishing effort restrictions in the Faroe Islands marine ecosystem. Ecological Modeling 172: 403-420.

XIII-39 East Greenland Shelf LME

M.C. Aquarone and S. Adams, D. Mikkelsen and T.J. Pedersen

The East Greenland Shelf LME extends along Greenland's east coast to the Eirik Ridge, covering an area of about 319,000 km^2, of which 13.34% is protected (Sea Around Us 2007). It is influenced by the cold East Greenland Current, which flows south along the coast from the polar area. A sub-arctic climate, seasonal ice cover and marked fluctuations in salinity, temperature and phytoplankton characterise this LME. The continental shelf varies in width, from 750 km in the north to 75 km in the south, and a large number of fiords are found. LME book chapters, articles and reports pertaining to this LME include Prescott (1989), Skjoldal *et al*. (1993) and UNEP (2004).

I. Productivity

Changes in sea and air temperature are the principal physical driving forces of this LME. Climatic variability causes large inter-annual variability in ice and hydrographic conditions. This, in turn, affects plankton production and fish recruitment, and can contribute to variations in annual catches of cod and small pelagics. Due to the cover of ice for most of the year, which inhibits the penetration of light, the East Greenland Shelf is considered a Class III, low productivity ecosystem (<150 gCm^{-2}yr^{-1}). The melting of sea ice in the summer has significant effects on ecological conditions, causing large amounts of nutrient salts to be transported into the waters around East Greenland. Owing to these climatic factors and to the high latitude of the region, the seasonal phytoplankton production is of short duration and of limited extent. Primary production is conveyed efficiently to higher trophic levels and supports large populations of fish, marine mammals and seabirds.

Oceanic fronts (Belkin *et al.* 2008): The East Greenland Polar Front (EGPF) (Figure XIII-39.1) hugs the shelf break and the Greenland continental slope, and serves as the offshore boundary of this LME. The EGPF waters originate in the Arctic Ocean, which explains their extremely low temperature and salinity. A complicated pattern is formed by the EGPF over the broad Ammassalik Shelf between 63° N and 65° N, where three separate branches of the EGPF are observed. This shelf is known as a major spawning area of cod. Therefore the multiple frontal structure discovered from satellite data is important to the local cod fishery. South of the Denmark Strait, the EGPF is joined by the Irminger Current Front that carries warm and salty waters originated in the North Atlantic Current.

East Greenland Shelf LME SST (Belkin 2008)(Figure XIII-39.2):
Linear SST trend since 1957: 0.51°C.
Linear SST trend since 1982: 0.73°C.

Like many other boreal LMEs, the East Greenland Shelf cooled down in the 1950s-1960s until it reached the all-time minimum of just 0.5°C in 1971 during the passage of the Great Salinity Anomaly (GSA) of the 1970s (Dickson et al. 1988; Belkin et al. 1998). The passage of the GSA'70s is believed to have contributed to the collapse of cod fisheries downstream, off West Greenland and Newfoundland, in the 1980s (Hamilton et al. 2003). Later on, the GSAs of the 1980s and of the 1990s were absent over the East Greenland Shelf, consistent with their local formation in the Labrador Sea (Belkin et al., 1998; Belkin, 2004).

After a quick recovery in 1972, SST rose steadily until present. The all-time maximum SST in 2003 exceeded 2.6°C. The record-breaking SST is consistent with the all-time maximum near-surface air temperature of 1.5°C recorded in Ammassalik on the east coast of Greenland in 2003. The SST maximum of 2003 correlates with the all-time SST maximum of 2004-2005 in the downstream-located West Greenland Shelf LME. In the two nearby LMEs, Iceland Shelf and Faroe Plateau, SST also reached all-time maxima in 2003. Perhaps, it is not accidental that all these anomalies peaked right after El Niño 2002-2003.

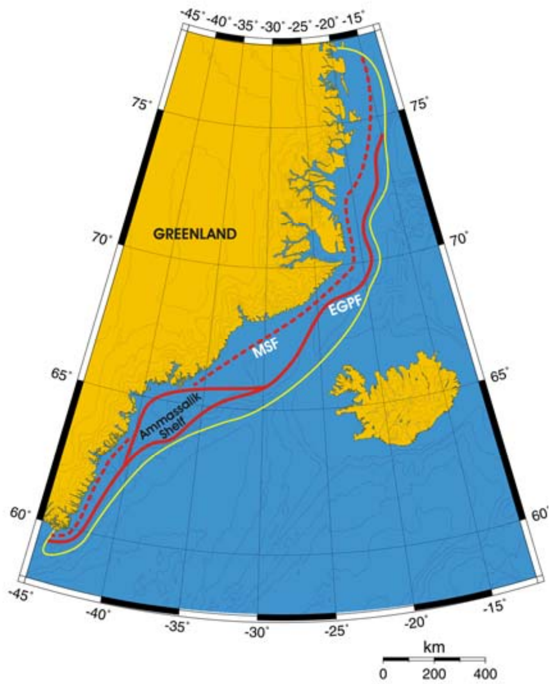

Figure XIII-39.1. Fronts of the East Greenland Shelf LME. EGPF, East Greenland Polar Front; MSF, Mid-Shelf Front (most probable location). Yellow line, LME boundary. After Belkin *et al.* (2008).

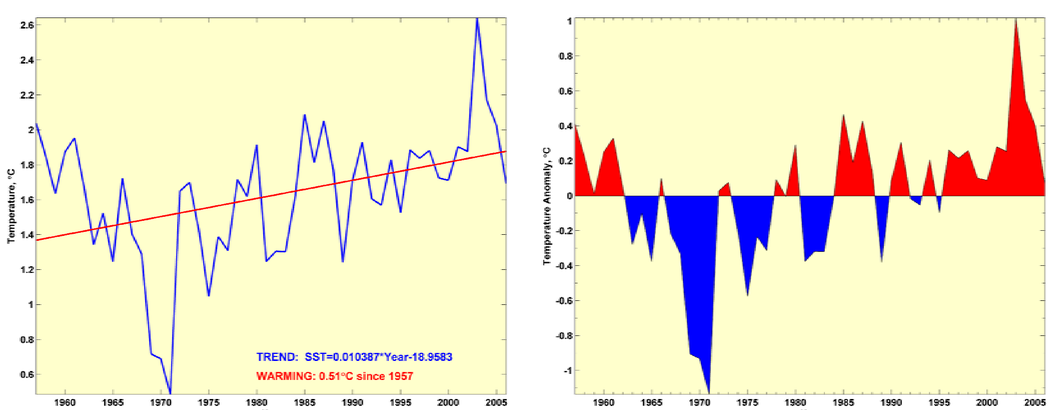

Figure XIII-39.2 East Greenland Shelf annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

East Greenland Shelf LME Chlorophyll and Primary Productivity

The East Greenland Shelf LME is a Class III, low productivity ecosystem (<150 $gCm^{-2}yr^{-1}$)(Figure XIII-39.3).

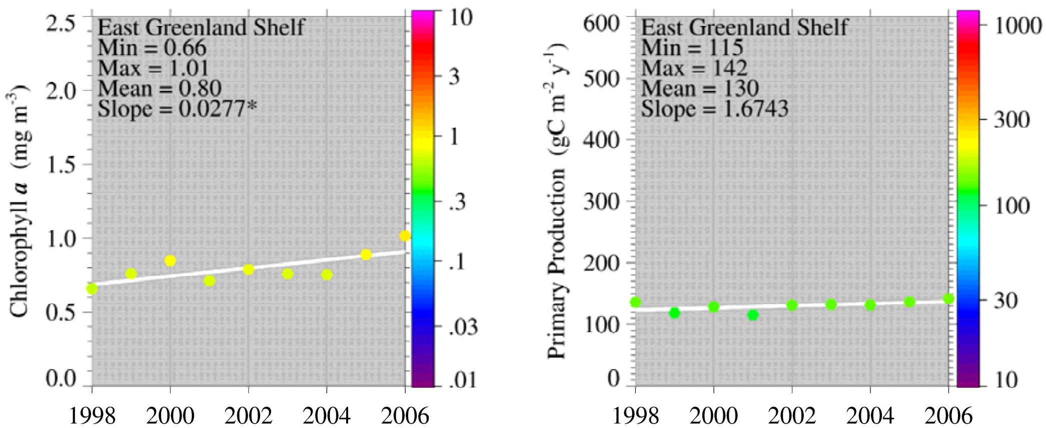

Figure XIII-39.3. East Greenland Shelf trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Total reported landings[1] from 1950 to 2003 show a series of peaks and troughs (Figure XIII-39.4). Reported landings have fluctuated from a low of 11,000 tonnes in 1983 to a high of 225,000 tonnes in 1996. While historically cod dominated reported landings, in more recent years pelagic fish, notably capelin dominate (Figure XIII-39.4)[2]

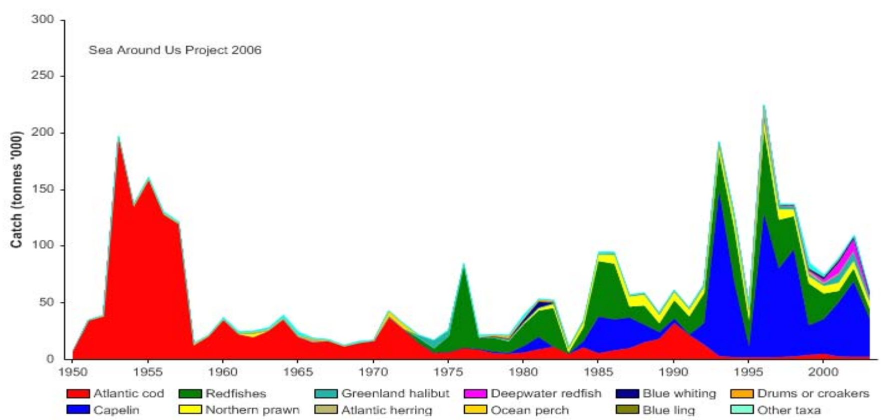

Figure XIII-39.4. Total reported landings in the East Greenland Shelf LME by species (Sea Around Us 2007).

[1] Due to a recent adjustment to the boundaries of the East Greenland Shelf LME, the landings data presented here are based on the 1950-2003 data, computed using the boundaries defined in Figure XIII-39.1. Data for 1950-2004, based on the new LME boundaries, will be available online at www.seaaroundus.org.

[2] Information on the value of reported landings cannot be provided at this stage, due to the recent adjustments in LME boundaries (see note 1 above). Data for values using the newly adjusted boundaries will be available at www.seaaroundus.org.

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached to 35% of the observed primary production in the mid 1950s, but this relatively high value has not been achieved in recent years, and has remained mostly under 10% (Figure XIII-39.5). The countries with the largest share of the ecological footprint in this LME have changed frequently over the years, with Iceland accounting for the largest footprint in recent years.

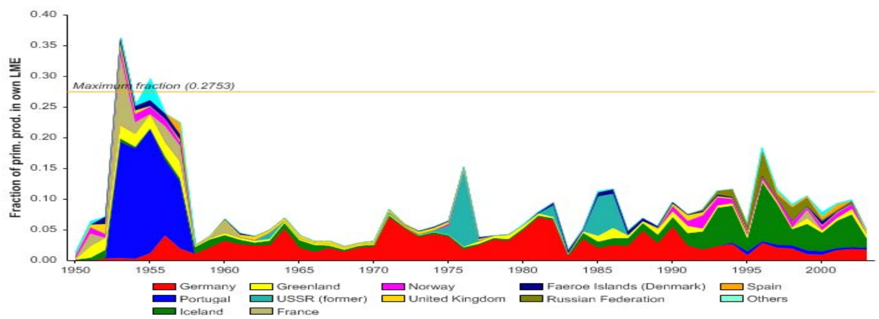

Figure XIII-39.5. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the East Greenland Shelf LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

Until the early 1970s, the reported landings from this LME and the mean trophic level of the entire fisheries in the region were dominated by cod (i.e., the MTI; Pauly & Watson 2005). With new species coming under exploitation, and the gradual decline of cod landings, a classical 'fishing down' scenario ensued (Pauly *et al.* 1998), with trophic levels declining (Figure XIII-39.6, top), and some compensation through higher landings of species from lower trophic levels (e.g. capelin), the reason for the stability in the FiB index (Figure XIII-35.6, bottom).

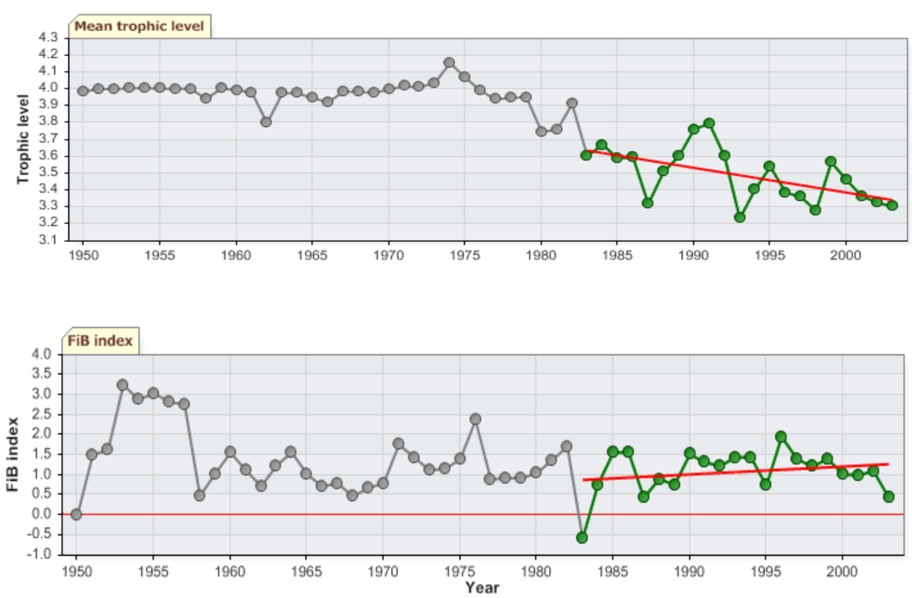

Figure XIII-39.6. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the East Greenland Shelf LME (Sea Around Us 2007).

The Stock-Catch Status Plots indicate a high proportion of collapsed stocks in this LME (Figure XIII-39.7, top), and a high contribution of these stocks to the reported landings biomass (Figure XIII-39.8, bottom). The jagged appearance of the latter plot reflects fluctuations in the reported landings (Figure XIII-39.4).

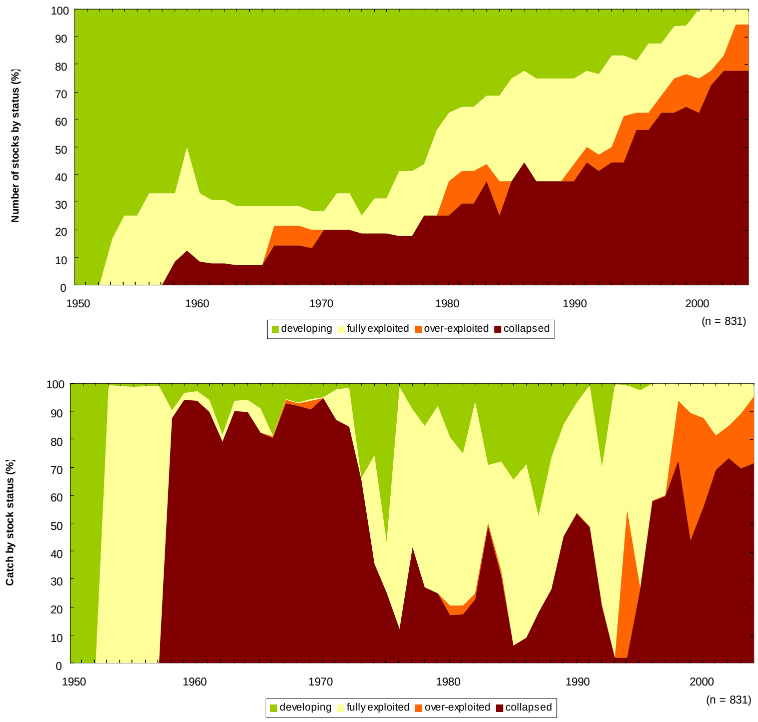

Figure XII-39.7. Stock-Catch Status Plot for the East Greenland Shelf LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number 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).

A stock of some commercial significance was cod, once central to Greenland's economy. This stock collapsed in the early 1990s, with landings falling from about 13,000 tonnes in 1992 to below 4,000 tonnes in the following years. The fluctuations of cod stocks have been linked to changes in sea temperature (see Buch *et al*.1994). Overfishing and its effects on stock size and stock interactions appear to coincide with climatically-driven variability. Atlantic herring was a major species fished in the 1950s and 1960s but it has also almost entirely disappeared in the catch statistics. Today, species landed are mostly capelin, shrimp and redfish. Shrimp (*Pandalus borealis*) is exported. Greenland halibut, Norway haddock, catfish, Atlantic halibut, salmon and char are important to the local economy. Greenland's fishing industry tries to balance the possibilities offered by modern fishing technology with the need to sustain this LME's natural resources. The near-shore quota system differs from the off-shore system for shrimp, cod and Greenland halibut. Marine mammals (five species of seal, walruses and whales) are essential for the survival of the traditional hunting communities, and the meat is traded locally. The whaling industry led to the decimation of several whale species in the region. While the recovery of the overexploited right whale has been very slow, the fin and minke whales have recovered well. Legal measures protect a number of marine species.

III. Pollution and Ecosystem Health

The International Cod and Climate Change Programme studies the response of different cod populations to climate change in various regions of the cod's North Atlantic range. A report by the OSPAR Commission describes the main human pressures in a region of the Arctic Ocean that includes the east coast of Greenland. Owing to this LME's remoteness and low population density, environmental conditions within it are generally good. However, certain activities such as fisheries give cause for concern. In terms of oil pollution, the difficulties associated with taking remedial actions in a cold environment such as this are also of concern. Levels of PCB and DDT are quite high in both biotic and abiotic media around eastern Greenland. For more information about pollutants in the Arctic region including Greenland, the AMAP website (www.amap.no) makes recent reports available. The measurement of 'new' chemicals, in particular brominated and fluorinated compounds in the Arctic environment and evidence of the biological effects of OCs (Organochlorines) in polar bears, glaucous gulls, and northern fur seals are highlights of recent research carried out on POPs in the Arctic (AMAP 2002 Report on POPs). These compounds can adversely affect immune, endocrine and reproductive systems.

The PAME Working Group is involved in assessing changing states of Arctic environments (see also the Governance module). The PAME work plan (2004-2006) will identify indicators of ecosystem health and ecosystem objectives for the Arctic LMEs. In the Arctic, the average extent of sea-ice cover in the summer has declined by 15-20% over the past 30 years. This decline is expected to accelerate, with the near total loss of sea ice in the summer projected for late this century (ACIA 2004). The OSPAR website has information on the protection and conservation of marine biodiversity and ecosystems, eutrophication, hazardous and radioactive substances (www.ospar.org).

IV. Socioeconomic Conditions

The first Europeans arrived in Ammassalik only about 100 years ago. The human population in the region is extremely small, with about 3,500 people living in the 2 towns and 9 settlements of Greenland's east coast. Many are from the traditional Inuit culture, which continues to play an important role in everyday life. The Inuit dependence on fishing and on the harvesting of wildlife formed the basis of their society, culture and economy. Today, the local population continues to be highly dependent on the fish, crustaceans and mussels obtained from the sea, and on the hunting of seals, whales, polar bears and other prey. Fishing accounts for 95% of total exports. Certain mineral deposits may be of future economic interest, including the oil fields near Jameson Island in East Greenland. Diamond, gold, niobium, tantalite, uranium and iron deposits are found on the island.

The PAME Working Group has information on the indigenous and non-indigenous communities living in the Arctic who are heavily dependent on the Arctic living marine resources. All of these groups are represented in the Arctic Council. OSPAR provides information on the offshore oil and gas industry, and the use of the ecosystem approach to the management of human activities (www.ospar.org).

V. Governance

For centuries Greenland belonged to Denmark, but since 1979 has moved towards independence. The Greenland Institute of Natural Resources is responsible for providing scientifically sound management advice to the Greenland government. Investigations on selected fish larvae and zooplankton in relation to hydrographic features is currently undertaken as part of the monitoring programme NuukBasic. The marine component of the monitoring program was initiated in 2005, and is managed by the Center of Marine

Ecology and Climate Effects at Greenland Institute of Natural Resources. Results from the monitoring programme are published in annual reports, as well as peer-reviewed scientific papers when appropriate. Issues that have been identified as important for the management of this LME include the need to improve the scientific basis for linking climatic variability and climate change to the chemical and biological processes and fishing pressure. Greenland participates in the Arctic Council and OSPAR as part of Denmark and the Faroe Islands.

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XIII-40 Iberian Coastal LME

M.C. Aquarone ,S. Adams and L. Valdés

The Iberian Coastal LME is a continental shelf region of the Eastern Atlantic Ocean lying between approximately 36° N (Gulf of Cadiz) and 44° N (Cantabrian Sea), and bordered by Spain and Portugal. A temperate climate characterises this western boundary current ecosystem. The continental shelf in this region varies from 12 to 50 km, being the narrowest in the Northeast Atlantic margin. The LME has an area of about 300,000 km^2, of which 0.45% is protected, and contains about 0.07% of the world's sea mounts (Sea Around Us 2007). One of the main geomorphological features of the Iberian Coastal LME is a series of extremely steep and deep marine canyons. The coast of Asturias has the canyons of Avilés, Lastres and Llanes; these are so abrupt that in only 7 km from the coastline the depth reaches 4500 m, making these features the steepest and deepest near-shore canyons in the world. It seems that these canyons are the refuges of giant squids (Architeuthis dux and Taningea danae) which are found here quite often (usually in October) dead on the beaches. Off Portugal there is a remarkable canyon Nazaré. Other interesting features in this LME are the seamounts or relic shelves offshore, such as the Bank of Galicia and the Bank of Le Danois (known in Spain as El Cachucho), which has been recently protected as an AMP in the Northern Spain. The Iberian seaboard has a highly convoluted coastline indented with drowned river valleys called *ria*. Book chapters and articles pertaining to this LME include Wyatt & Perez-Gandaras (1989) and Wyatt & Porteiro (2002). This LME together with the Bay of Biscay is included in OSPAR as Region 4. This is the same regionalization that the EU has done in the recently published Directive on Marine Strategy (25/06/08). ICES is supporting a Working Group named WGRED which had done quite extensive regional descriptions, including Iberian shelf. The report of last year can be found at: www.ices.dk/iceswork/wg detailacfm.asp?wg=WGRED. Additional general information on this region can be found in Valdes and Lavín (2002) and Lavín et al. (2006).

I. Productivity

Productivity and resource abundance in the Iberian Coastal LME are driven by climate and upwelling, with intensive fishing being the secondary driving force. The importance of climate is suggested by the link between sardine catches and Ekman drift, and by the link between anchovy catches in this LME and biological changes in the Western English Channel (see Wyatt & Perez-Gandaras 1989). The coastal upwelling is the most important feature in terms of natural variability in the entire LME. Upwelling takes place in late spring and summer along the coast of Portugal, Western Galicia up to the Cape Peñas in the North Spanish coast (mid-Cantabrian Sea). For more on changes in oceanographic conditions in this LME, see Wyatt & Porteiro (2002).

The Iberian Coastal LME is considered a Class II, moderately productive ecosystem (150-300 gCm^{-2}yr^{-1}). Margalef (1956) identified marked changes in the phytoplankton composition of Galician waters during the 1950s sardine crisis. The LME is characterised by favorable conditions for the production of clupeoids and other small pelagic fishes. For biomass changes in sardine, see Wyatt & Perez-Gandaras (1989). Changes in the upwelling regime affected the sardine stock. There were changes in the phytoplankton composition and in the patterns of water exchange between the rias and the open sea. Major changes in sardine abundance were accompanied by equally radical changes in other trophic levels. Good sardine productivity is linked with the presence of the diatom *Melosira (Paralia) sulcata*, and poor productivity with *Thalassiosira rotula* invasions. There are marked changes in the abundance of certain dinoflagellate species. See the ocean triads model for an explanation of upwelling, concentration of larval food brought about by convergences, and mesoscale circulation patterns that help to maintain larval retention (Wyatt & Porteiro 2002). Galicia is the most important region in the world in terms of production of mussels cultured in rafts (extensive culture in the rias), with annual average rates of ~250,000 tons.

Oceanic Fronts (Belkin et al. 2008): The frontal pattern off Iberia (Figure XIII-40.1) is fairly complicated and variable, especially on the seasonal and interannual scales. Most fronts are caused by coastal wind-induced upwelling, which is similar to the Northwest African coastal upwelling (Barton 1998) and also broadly similar to the California Current upwelling (Haynes *et al*. 1993). The upwelled water is entrained into large filaments that extend hundreds of kilometres offshore. SST fronts are most pronounced during the peak of the upwelling season, from July through September. The wintertime frontal pattern is quite variable from one year to another and depends, at least partially, on the poleward coastal warm current that emerges once the trade winds collapse (e.g. Garcia-Soto et al 2002); this current is, however, confined to a very narrow near-coastal band, 25-40 km wide; its thermal signature is just 1.0-1.5°C.

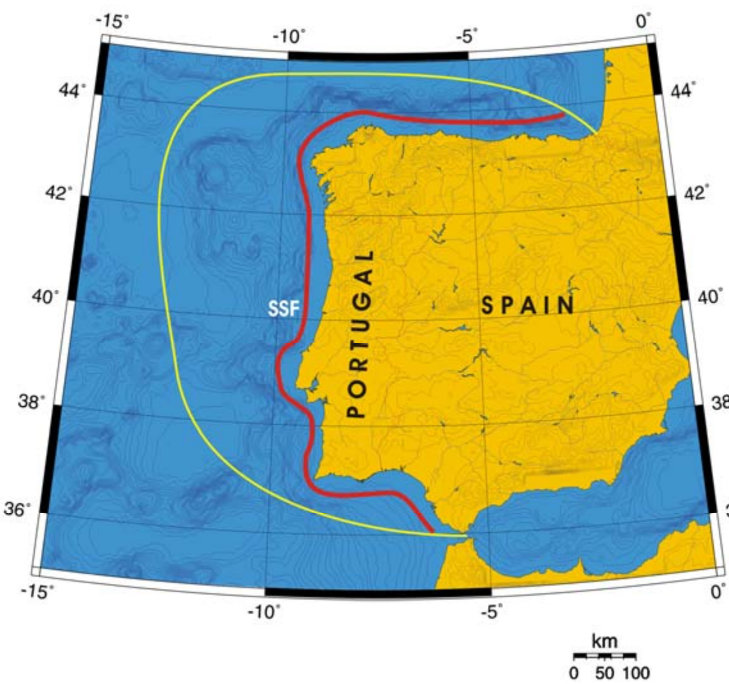

Figure XIII-40.1. Fronts of the Iberian Coastal LME. SSF, Shelf-Slope Front. Yellow line, LME boundary. After Belkin et al. (2008)..

Iberian Coastal LME SST (Belkin 2008):
Linear SST trend since 1957: 0.80°C.
Linear SST trend since 1982: 0.68°C.

Since 1957, the Iberian Coastal LME went through a cooling until the all-time minimum of 1972, followed by a rapid warming, 1.7°C over 34 years (Figure XIII-40.2). Several major events in the Iberian Coastal LME occurred practically simultaneously – within a year – with similar events in the adjacent Celtic-Biscay Shelf LME located downstream of the Iberian Coastal LME and connected to the latter by the Iberian Poleward Current and its extension off northern Spain dubbed "Navidad" (e.g. Garcia-Soto et al., 2002) flowing from the Iberian LME onto the Celtic-Biscay Shelf. These events include three minima of

1963, 1972, and 1986; a maximum of 1989; and a minimum of 1991-94. The observed synchronism between both LMEs may be more appearance than reality since annual mean data does not allow for a study of anomaly propagation over short distances where propagation time is a few months, not years. The very fast post-1972 warming by 1.7°C over 34 years has already profoundly affected this LME. Observations in the southern Gulf of Biscay in 1974-2000 revealed substantial restructuring of local ecosystems caused by the ongoing warming: cold-water fish and sea bird species dwindled, whilst two species – puffin and killer whale – disappeared completely; whereas warm-water species proliferated; taken together, these changes likely manifest a regime shift (Hemery et al., 2007).

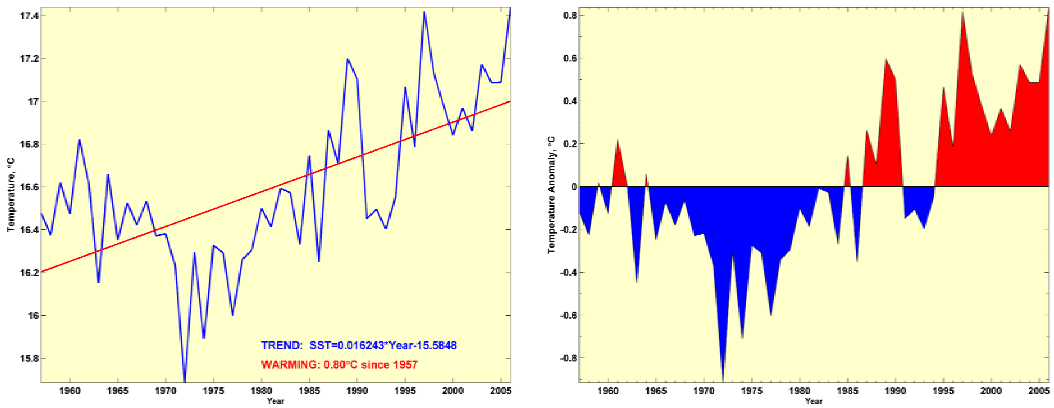

Figure XIII-40.2. Iberian Coastal LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

Iberian Coastal LME Chlorophyll and Primary Productivity: This LME is considered a Class II, moderately productive ecosystem (150- 300 $gCm^{-2}yr^{-1}$)(Figure XIII-40.3).

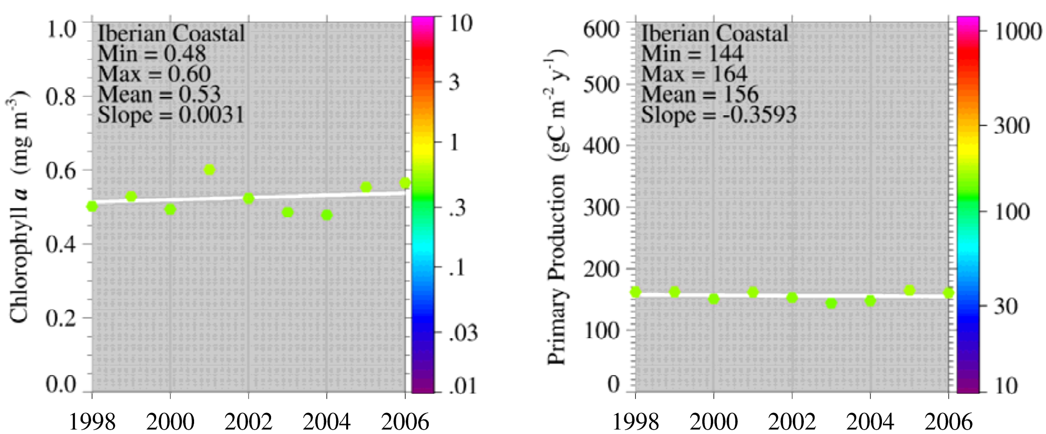

Figure XIII-40.3. Iberian Coastal LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

The catch in the Iberian Coastal LME is essentially composed of three groups: herring, sardine and anchovy (42%), other pelagic fish (28%), and cod, hake and haddock. Coastal species harvested are anchovy, sardine, mackerel and horse mackerel. Hake, blue whiting, bream, bogue, pilchard, sprat and tuna are also caught. For examples of biomass changes in sardine, sprat, anchovy and other species, as well as for landings of fish in 1981, and for a description of fisheries geography and Iberian sardine fisheries in crisis in the 1940s and 1950s, see Wyatt & Porteiro (2002). Total reported landings in the LME peaked at 575,000 tonnes in 1972, but in general have fluctuated between 250,000 to 350,000 tonnes (Figure XIII-40.4). The value of the reported landings reached almost US$700 million (in 2000 real US dollars) in 1972, after which it dropped precipitously and fluctuated between US$200 million and US$500 million ever since (Figure XIII-40.5).

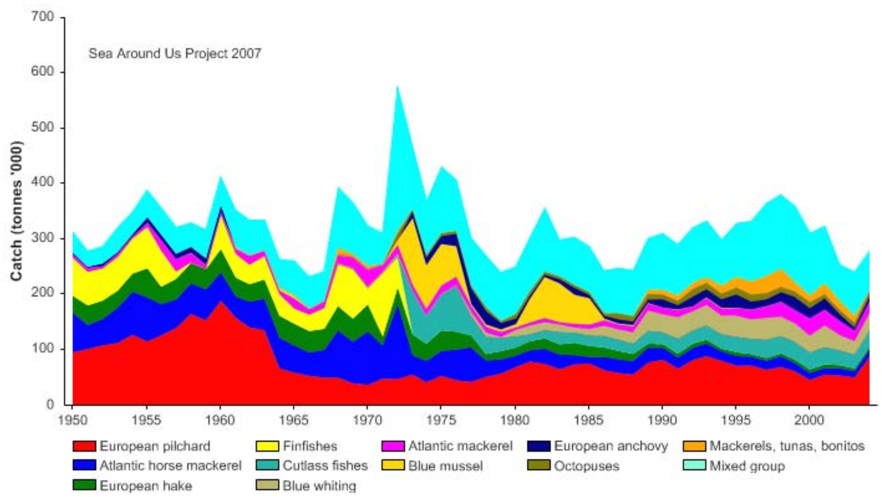

Figure XIII-40.4. Total reported landings in the Iberian Coastal LME by species (Sea Around Us 2007)

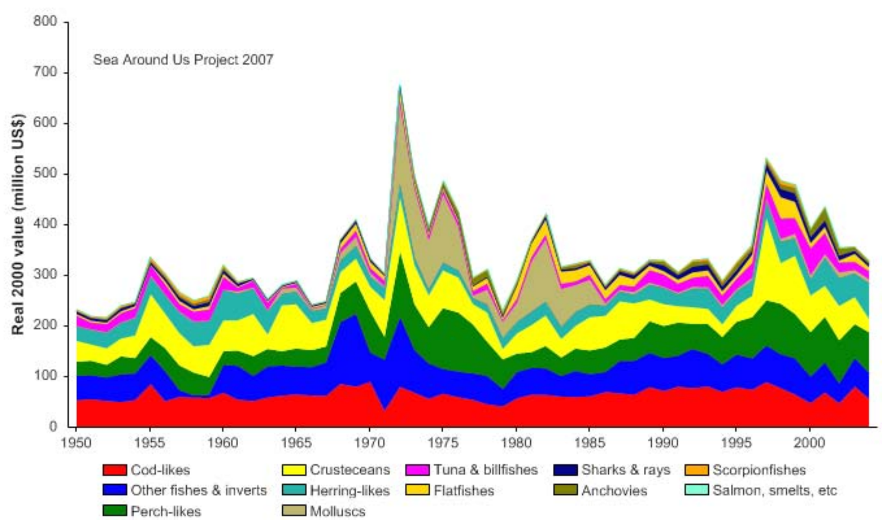

Figure XIII-40.5. Value of reported landings in the Iberian Coastal LME by commercial groups (Sea Around Us 2007)

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached extremely high level in the mid 1970s, but has declined to 30% by 2004 (Figure XIII-40.6). Spain and Portugal account for most of the ecological footprint in this LME.

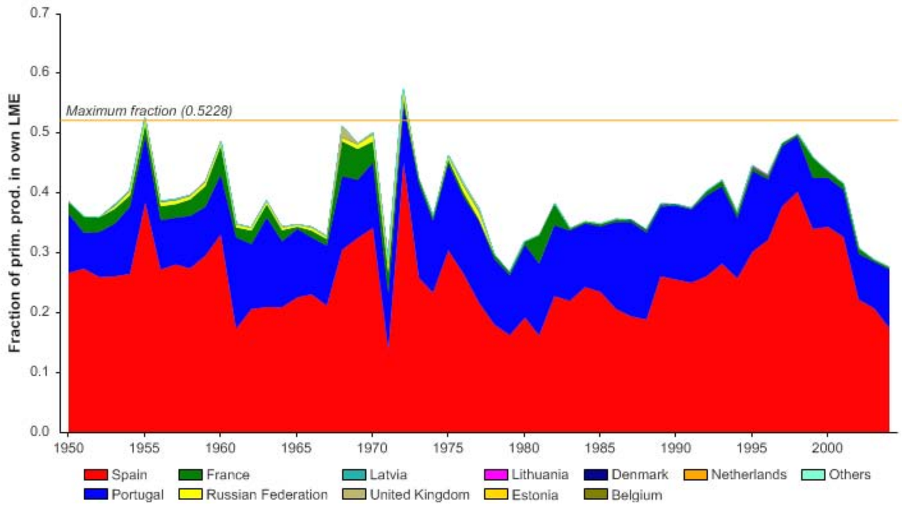

Figure XIII-40.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Iberian Coastal LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) remained more or less even, except for two 'dips' in 1973 and 1983, likely associated with the high landings of (possibly farmed) mussels (XIII-40.7, top). The FiB index is also rather uninformative, except for the very last years, which reflects the decline in the landings (XIII-40.7, bottom). The sustainable mussel farming here (established in the 1950's) stably produced ~250,000 tonnes/year since 1970's, making it one of the most important farming cultures in the world..

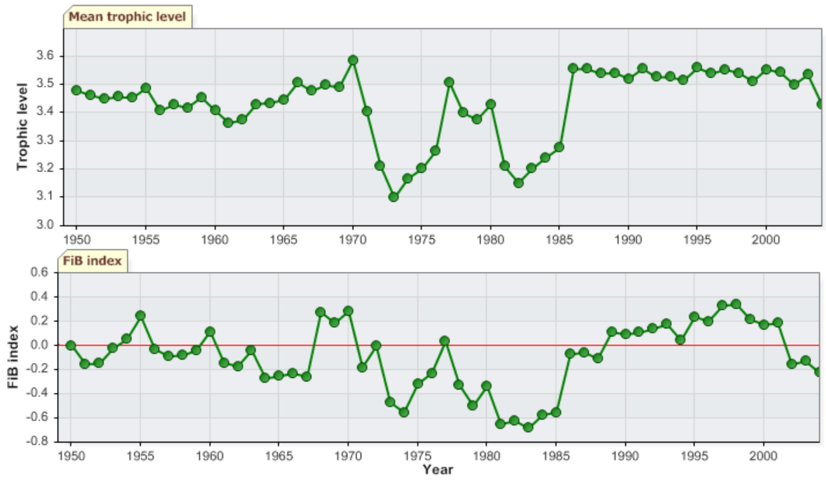

Figure XIII-40.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Iberian Coastal LME (Sea Around Us 2007)

The Stock-Catch Status Plots indicate that the number of collapsed stocks has been increasing, accounting for over 60% of the commercially exploited stocks in the LME (Figure XIII-40.8, top), while the majority of the reported landings biomass is supplied by overexploited stocks (Figure XIII-40.8, bottom).

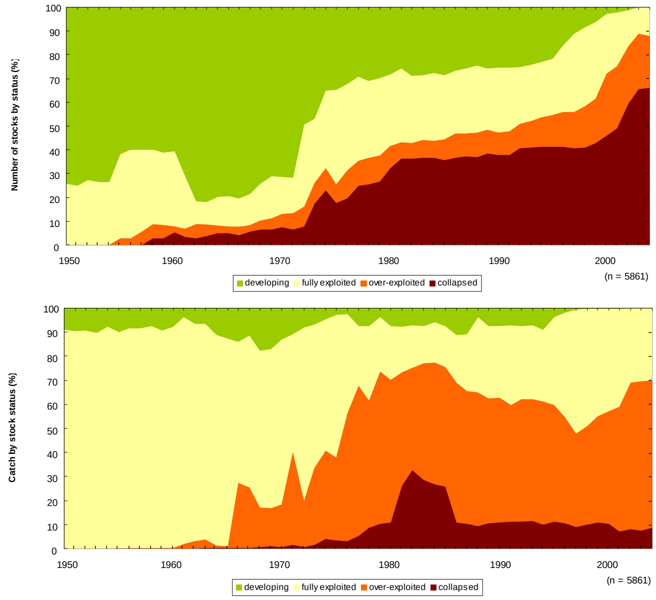

Figure XIII-40.8. Stock-Catch Status Plot for the Iberian Coast LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of '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

Red tides were a more or less annual occurrence in the Rias Bajas from the beginning of the 20th Century until the 1950s. These were almost always due to the dinoflagellate *Gonyaulax*, and sometimes to the ciliate *Mesodinium*. Since the 1970s, *Gonyaulax* blooms have not been reported in the Rias Bajas. Instead, there have been occasional blooms of the toxic dinoflagellates *Alexandrium tamarense, A. minutum* and *Gymnodinium catenatum*. These phytoplankton changes are seen as part of a worldwide increase in the frequency and intensity of harmful algal blooms, and are attributed to various causes including eutrophication and ballast water transport. Perez *et al*. (2004) report that under strong insolation and weak synoptic forcing, typically in the summer, sea breezes and mountain-induced winds develop to create re-circulations of pollutants along the eastern Iberian coast. According to Wyatt & Porteiro (2002), on the whole, pollution is not of major importance in the Iberian LME, except in a few localised areas. OSPAR lists ballast water, mariculture itself; coastal installations intensifying stratification. Anthropogenic inputs and fluxes of nitrogen into areas susceptible to eutrophication; unbalanced nutrient ratios in N: P and N:Si for example; hydroelectric power plant exceptional discharges; and increasing inputs of humic substances from rivers are threats to mariculture (OSPAR 2000). The EEA in "Eutrophication in Europe's Coastal Waters" reports in July 2001 that the Bay of Biscay and Iberian coast eutrophication problems are restricted to estuaries and coastal lagoons, especially Ria Formosa and Huelva. The concentration in this region of ship transport towards Northern Europe requires special regulation to prevent and control pollution. The waters around

Finisterre are regulated to avoid collisions of tankers and carriers. This region has seen a high number of oil spills from wrecks such as the recent Aegean Sea (1992) and Prestige (2002). A map with the location of events can be found in Lavin et al 2006.

IV. Socioeconomic Conditions

In its reports for 2000, OSPAR estimates population in the "Atlantic arc," the coastal regions of France, Spain and Portugal, at 36.6 million inhabitants or 106 inhabitants per km^2. In Spain, the three northern coastal regions are densely populated: Pais Vasco (>110 inh/km^2), Cantabria (100 inh/km^2) and Asturias (104 inh/km^2). Population is concentrated in the coastal areas as are most of the economic activities and industries.

Spain and Portugal are important fishing nations in the European Union, with Spain having the largest distant water fleet of any European country. The total number of vessels in the Spanish fishing fleet decreased during the 1990s and is currently around 9000, and only part of it operates in this LME. Spanish artisanal vessels fish for hake and mackerel in the winter, anchovy in spring, and sardine and albacore in summer and autumn. Sardine is one of the most important species in both landings and price. The focus of the Spanish anchovy fishery has moved eastwards, resulting in almost the entire catch being landed in Basque ports. Technical changes in the Basque fishery accounted for part of the increase in landings after the 1960s (Igelmo *et al*. 1984). Spain is gradually being excluded from several of its traditional extraterritorial fishing grounds, and will need to focus on the management of its local resources. A blue mussel farming industry, initiated in the 1950s in the Rias Bajas, produces about 250,000 tonnes annually. In the main area of raft cultivation, the Ria de Arosa, the standing stock of mussels is near or above carrying capacity of phytoplankton production.

Coastal erosion is a major concern, with subsequent salt water intrusion into estuaries, coastal lagoons, wetlands and groundwater as sea level rises likely (OSPAR 2000). The quality of farmed shellfish, particularly near outfalls discharging domestic wastewater, is also a major concern. HABS that affect the human consumer, episodes of acute shellfish toxicity, coastal development including urban expansion, and sea invasion of important agricultural areas, present a number of environmental issues to this coastal population. Compared to its Mediterranean coast, Spain's Atlantic coast is not a frequent destination for tourists; the total number of overnight stays in local hotels on the Atlantic coast represents 6% of overnight stays in Spain and 87% of the visitors are Spanish (OSPAR 2000) (the French Atlantic Coast represents 24%). Tourism that adds pressure to existing marine ecosystems is also a force for maintaining clean beaches, potable water and uncontaminated fish and shellfish. Currently there is no sewage sludge dumped at sea along the Atlantic coast by France, Spain or Portugal, either from land or ships.

V. Governance

Spain and Portugal are both members of the EU. Being relatively small, the LME can be surveyed with the resources already available in the two countries. Both countries collaborate effectively in various fisheries contexts. The exploitation of the natural marine resources of the Iberian Coastal LME follows a number of conventions, declarations and regulations, including the European Commission directives and regulations within the Common Fisheries Policies. All in all, a large number of instruments from international bodies, such as the UN, ICES, OSPAR, International Maritime Organisation (IMO) and the EU, exist to conserve natural resources, protect the environment and ensure health and safety standards. The European Community laws protect the environment in terms of air and noise, chemicals and industrial risks, nature conservation, waste and water. See the OSPAR website for more information (www.ospar.org).

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XIII-41 Iceland Shelf LME

M.C. Aquarone and S. Adams

The Iceland Shelf LME surrounds the island-nation of Iceland in the northeast Atlantic Ocean. It is characterised by a sub-arctic climate and environment, with seasonal ice cover and marked fluctuations in salinity and temperature off the north coast. Temperature, currents, tides and seasonal oscillations affect productivity in this LME. The area of this LME is 315,500 km^2, of which 0.06% is protected (Sea Around Us 2007). In this highly active geological region, the divergence of two tectonic plates causes the formation of oceanic crust and the crest of the Mid-Atlantic Ridge. LME book chapters and articles pertaining to this LME include Prescott (1989) and Astthorsson & Vilhjalmsson (2002).

I. Productivity

Iceland has a wide volcanic margin marked by broad valleys and a sharply defined slope. For a map of bottom topography around Iceland, see Astthorsson & Vilhjalmsson (2002, p. 220). Three ocean currents (the North Icelandic Irminger Current, the East Icelandic Current, and the Coastal Current move in a clockwise gyre around the island. For a map of ocean currents, see Astthorsson & Vilhjalmsson (2002, p. 221). A complex system of transverse ridges is oceanographically important because it separates the relatively warm and saline waters of the Atlantic from the cold, fresh Arctic waters of the Iceland Sea and Norwegian Sea to the north and northeast.

The Iceland Shelf LME is considered a Class II, moderately high productivity ecosystem (150-300 $gCm^{-2}yr^{-1}$). Extensive primary productivity measurements have been carried out annually in the waters around Iceland for more than four decades (see Thordardottir 1984). For a map of average primary production in Icelandic waters based on data from the period 1958-1982, see Astthorsson & Vilhjalmsson (2002). Climate is the primary force driving the LME. There are marked interannual changes in the spring development of phytoplankton (Gudmundsson, 1998). Studies on zooplankton biomass and species composition have been carried out on standard transects during late May-June in Icelandic waters. The highest biomass is found in the front area between the coastal and the Atlantic water off Iceland's south coast and in the Arctic waters of the East Icelandic Current off the northeast coast. Changes in hydrography impact the food chain through influences on primary production, zooplankton, and the capelin and cod stocks. For a conceptual model of how climatic conditions in Icelandic waters may affect production at lower trophic levels and eventually the yield from the Icelandic cod stock, see Astthorsson & Vilhjalmsson (2002, p. 240).

Oceanic fronts (Belkin et al. 2008). The Irminger Current warm and salty waters arrive on the Iceland Shelf from the south and circulate anticyclonically around Iceland. The Polar and Arctic waters, both relatively fresh and cold, arrive from the north along the North Iceland Front to meet the Irminger waters (carried by the North Icelandic Irminger Current along the Irminger Current-West Iceland Front) over the northwest, north and northeast Iceland Shelf where two major fronts form (Figure XIII-41.1). The western front is located where the Irminger waters meet the western branch of cold, fresh waters headed toward the Denmark Strait. The eastern front is located north and northeast of Iceland where the East Icelandic Current meets the North Icelandic Irminger Current. The eastern front appears to be connected to the Iceland-Faroes Front observed farther east, although this connection is rather tenuous.

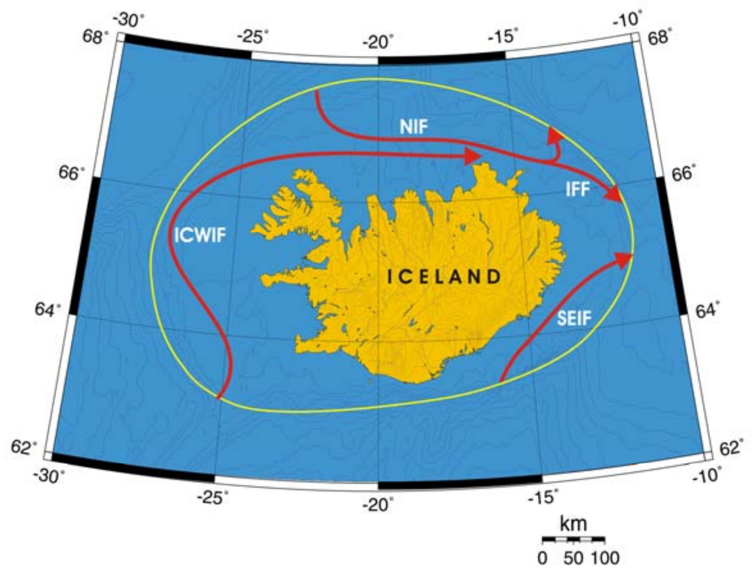

Figure XIII-41.1. Fronts of the Iceland Shelf LME. IFF, Iceland-Faroes Front (located mostly outside this LME; the link between NIF and IFF is rather tenuous); ICWIF, Irminger Current-West Iceland Front; NIF, North Iceland Front; SEIF, Southeast Iceland Front. Yellow line, LME boundary. After Belkin et al. 2008.

Iceland Shelf LME (Belkin, 2008)

Linear SST trend since 1957: -0.11°C.
Linear SST trend since 1982: 0.86°C.

The Iceland Shelf experienced a dramatic cooling from the all-time maximum of 7.2°C in 1958 down to the all-time minimum of 5.4°C in 1967 (Figure XIII-41.2). This event heralded the arrival of the Great Salinity Anomaly (GSA) of the 1960s-1970s (GSA'70s; Dickson et al., 1988; Belkin et al., 1998), which had a lasting effect on this ecosystem. This cold anomaly was associated with low salinities and with increased export of sea ice. Ocean currents transported the GSA'70s from the Greenland Sea southward past Iceland, then around the Subarctic Gyre, and eventually back to Iceland and past Iceland into the Norwegian Sea. A map of the circulation in the northern North Atlantic is shown at www.ospar.org.

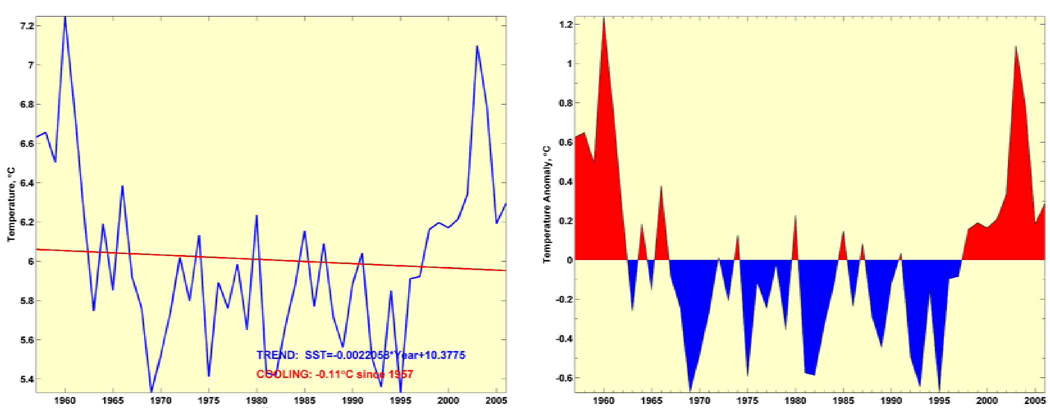

Figure XIII-41.2. Iceland Shelf LME annual mean SST (left) and SST anomaly (right), 1957-2006. After Belkin (2008).

The SST remained low through 1995, the year when SST was as cold as in 1969 (<5.4°C). Then SST abruptly rose through 2003, when it peaked at 7.1°C, a 1.7°C rise in 8 years, thereby posting an average annual warming rate of >0.2°C/year, one of the fastest warming rates observed in the world's oceans.

Iceland Shelf LME Chlorophyll and Primary Productivity: The Iceland Shelf LME is considered a Class II, moderately high productivity ecosystem (150-300 $gCm^{-2}yr^{-1}$).

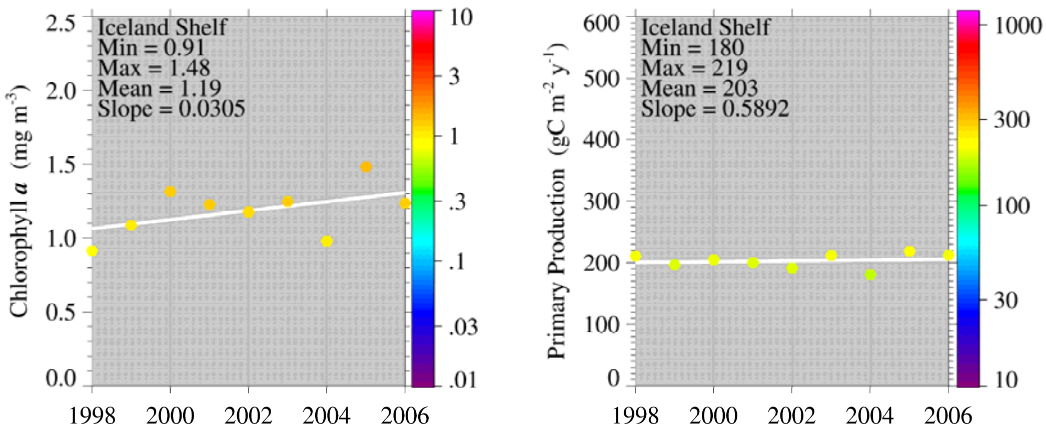

Figure XIII-41-3. Iceland Shelf LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume.

II. Fish and Fisheries

Total reported landings[1] have increased since 1950, with occasional considerable variation mainly driven by fluctuations in capelin landings, and total reported landings peaked in 1997 at 1.6 million tonnes (Figure XIII-41.4). Landings were driven primarily by Atlantic cod before the 1970s and by herring and especially capelin afterwards (Figure XIII-41.4). Capelin, which in 1997 accounted for over 60% of the total landings, are linked to cod through a tight predator-prey relationship (Jakobsson & Stefansson, 1998). The herring catch peaked at about 615,000 tonnes in 1962, before collapsing in the late 1960s and early 1970s. An important fishery for northern shrimp developed during the 1970s to the 1990s, with landings in the mid-1990s of over 60,000 tonnes[2]. This declined has been attributed to higher predatory pressure by cod and reduced recruitment related to recent warming (Astthorsson et al., 2007)

[1] Due to a recent adjustment to the boundaries of the Iceland Shelf LME, the landings data presented here are based on the 1950-2003 data, computed using the boundaries defined in Figure XIII-41.1. Data for 1950-2004, based on the new LME boundaries, will be available online at www.seaaroundus.org.

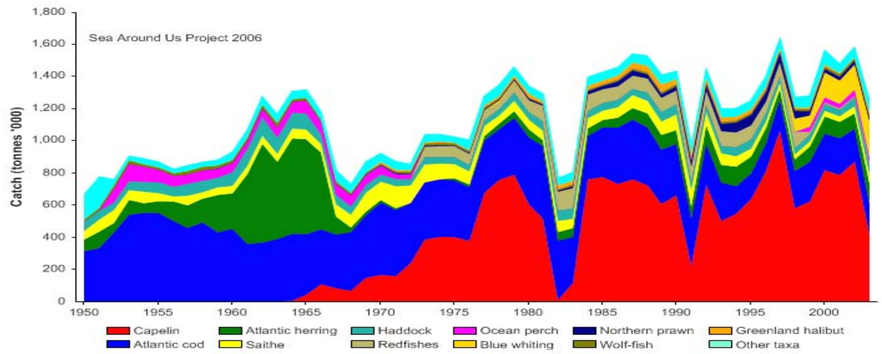

Figure XIII-41.4. Total reported landings in the Iceland Shelf LME by species (Sea Around Us 2007)

No Figure XIII-41.5. Information on the value of reported landings cannot be provided at this stage, due to the recent adjustments in LME boundaries (see note 1 above). Data for values using the newly adjusted boundaries will be available at www.seaaroundus.org.**.**

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in the LME exceed the observed primary production (Figure XIII-41.6). Such unrealistically high PPR likely imply that the large portion of the reported landings are supported by primary production from neighbouring marine ecosystems, i.e., large groups of exploited stocks are feeding outside of the Iceland Shelf LME and migrating in (see e.g. FAO 1981). Iceland accounts for almost the entire ecological footprint in the LME since the late 1970s, following a long, well-documented struggle against the exploitation of its shelf area by distant-water fleets (Bonfil *et al.* 1998).

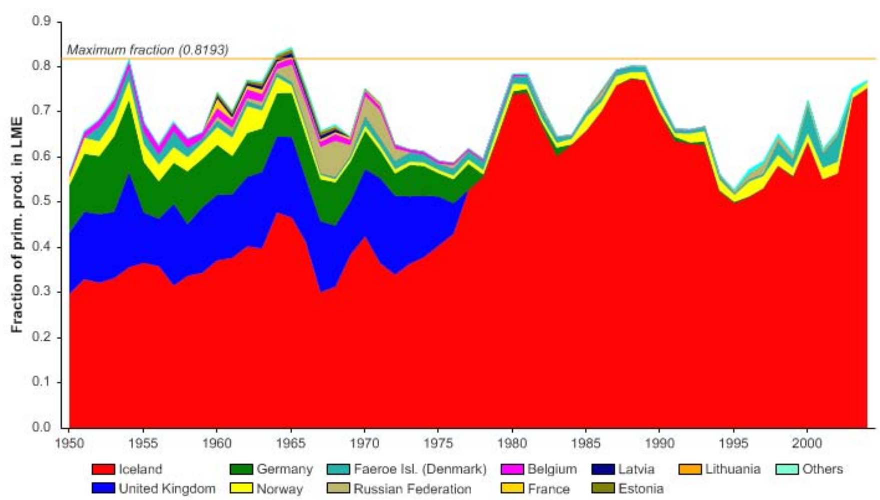

Figure XIII-41.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Iceland Shelf LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

Both the mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) and the FiB index have declined over the reported period (Figure XIII-41.7). In a detailed analysis on the state of the fisheries in the Iceland shelf LME Valtysson & Pauly (2003) stated that the declining TL level reflected increasing interest in pelagic species and invertebrates due to new fishing technology, fish processing technology and marketing, and was also driven by restrictions in groundfish catches due to declining stocks. Note that capelin and herring were never historically harvested simultaneously until the 1980s. Furthermore, the lower trophic level blue whiting has migrated into Icelandic waters because of the warming climate in recent years. These factors help create the appearance of, but not the fact of, 'fishing down the food web'.

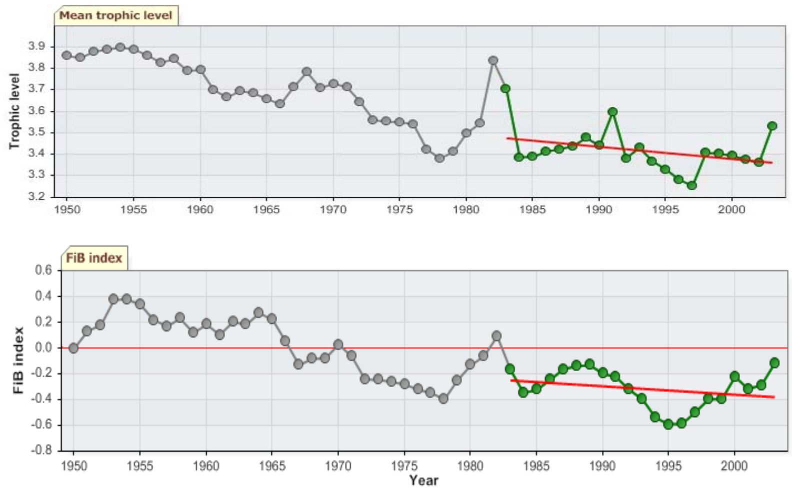

Figure XIII-41.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Iceland Shelf LME (Sea Around Us 2007)

The Stock-Catch Status Plots indicate that the number of overexploited stocks has been increasing over the years, accounting for nearly 90% of the commercially exploited stocks in the region (Figure XIII-41.8, top) with the majority of the reported landings biomass supplied by overexploited stocks (Figure XIII-41.8, bottom).

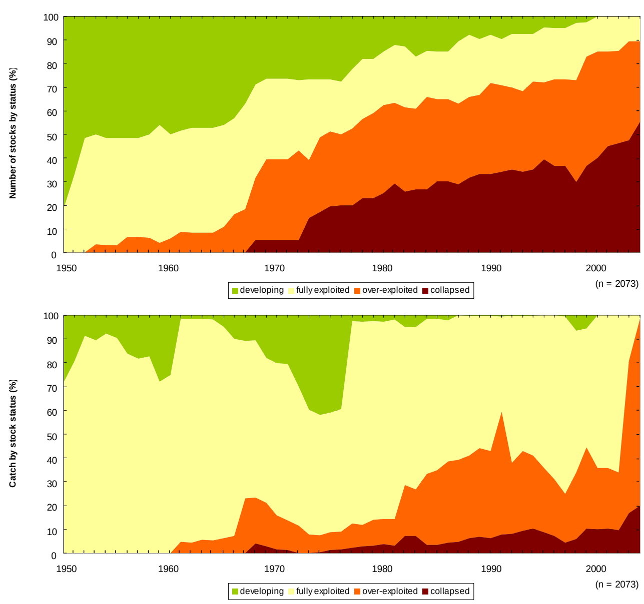

Figure XIII-41.8. The Stock-Catch Status Plots for the Iceland Shelf LME showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number 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).

Fluctuations in salinity, temperature and phytoplankton contribute to variations in annual catches of cod and small pelagics. Actions are underway in Iceland to reduce overexploitation in a joint government-industry effort for achieving long term sustainability in fish stock yields. Intensive fishing is a secondary force, after climate, driving this LME. Changes in fisheries technology have also impacted the total catch from this LME. At the turn of the last century, the fishing industry gradually became more mechanised, which led to a catch increase. See Astthorsson & Vilhjalmsson (2002) for the following: information on fish yields; a graph of demersal fish catches (cod, haddock, saithe, redfish) in 1950-1998; the inshore and offshore shrimp catch in 1964-1998; a graph of the huge fluctuations of herring and capelin from 1950- 1995 (p. 232); the spawning stock biomass and total catch of the Icelandic cod stock from 1955- 1998 (p. 233); a map of feeding areas and spawning grounds of the Icelandic capelin (p. 236); and for a conceptual model of how climatic factors may affect the yield of cod through the food chain. The simplicity of the main trophic links and oscillations between warm and cold climatic regimes dramatically influence fish yield in this LME. For further information on the impact of climate on the Icelandic Shelf LME see Astthorsson *et al*., (2007) and for occurrence of new and rare species in recent years see Astthorsson & Palsson (2006). Fluctuations in temperature and salinity can be related to large-scale changes in the atmospheric circulation over the North Atlantic Ocean (Malmberg *et al*., 1999). See Dickson *et al*. (1988), Belkin et al. (1998) and Belkin (2004) for information on the 'Great Salinity Anomalies' in the Northern North Atlantic. Near shore, hydrographic conditions may vary considerably from year to year mainly due to timing and variations of fresh water runoff.

III. Pollution and Ecosystem Health

Marine pollution appears to be negligible in the fishing grounds of the Iceland Shelf LME. However, the Iceland's Ministry of the Environment reports that in some seasons of the year, the quantity of persistent organic pollutants has been measured above the EU's established critical limits in fish products such as fish oil and fish meal for animal feed. (Report on the Implementation of the GPA 2001-2006 in Iceland, p.11). Although the proportion of inhabitants with sewage treatment has risen from 40% in 1992 to almost 70% in 2005, measurements of faecal bacteria have revealed occasional contamination in the vicinity of Reykjavik. The OSPAR 2005 report reveals that in Iceland the concentration of arsenic in the vicinity of Álftafijord northwest and cadmium in the Hvalfjord southwest has increased since the last measurements and efforts are underway to determine why. Yet, heavy metal contamination in living organisms does not appear to be a problem in the sea around Iceland, largely because of the lack of heavy industry. The concentration of mercury is among the lowest measured in the Northeast Atlantic and has not increased since measurements began. The Ministry recounts that regular warnings concerning shellfish consumption had to be released in the July 2006 when in the west in Hvalfjord and Breiõafjord and in Eyjafjord in the north, the levels of Dinophysis species and the Pseudo-nizschia pseudodelcatissima both measured far above reference limits. Causes are being investigated. Of particular concern is the effect of the toxins on humans and on the farmed fish and cultivated shellfish. Nitrogen and phosphorous released into the ocean from Iceland's rivers are routinely measured. Recent legislation requires ship owners to remove ships that run aground within six months following the incident. Iceland's environment laws and their monitoring and assessments, demonstrate their intent to remain one of the cleanest places on earth.

IV. Socioeconomic Conditions

Iceland has a population of nearly 313,000 as of October 2007 according to Statistics Iceland (www.statice.is). Icelanders enjoy a per capita income among the highest in Europe and remain quite dependent on the fishing industry. Foreign fleets, specifically

British, began fishing these waters at the beginning of the 15^{th} Century (Jonsson, 1994). Fishing by foreign fleets (particularly German and British) played an important role in the cod fisheries during the 20^{th} Century (Schopka, 1994) but foreign investment in the fishing industry is no longer allowed. Iceland is one of the few nations in the world today that has been able to build a modern society upon the exploitation of the resources of its surrounding waters. Seafood products constitute about 60% of Iceland's exports. To address fisheries overexploitation, Iceland has successfully introduced a management system to allow stocks to recover (country profiles at <www.fco.gov.uk>). Iceland has diversified its economy away from fishing into other investments: i.e. aluminium smelting, finance and overseas investment—with some 60% of bank profits now coming from overseas operations. The country is self-sufficient in meat and dairy products. Tourism is now a major foreign exchange earner with some 400,000 visitors in 2005-2006. Whale-watching attracts some 20% of visitors to Iceland. In 2006, 70,000-80,000 visitors from Britain alone came to Iceland. Major industries today in Iceland are fish processing, aluminium smelting, ferrosilicon production, geothermal power, tourism, and pharmaceuticals (country profiles at <www.fco.gov.uk>).

V. Governance

Iceland has played a pioneering role in international Law of the Sea. The competition of foreign fishing fleets prompted Iceland to protect its fisheries by extending its territorial limits. The territorial sea was three miles in 1901, and was extended to four miles in 1952. These extensions were early and bold moves for that time. In 1958, the territorial sea was extended to 12 miles, then in 1972, to 50 miles. British protests against these extensions took the form of three 'cod wars' (in 1961, 1972 and 1975). In an arbitration opposing Iceland and Great Britain, the International Court of Justice ruled in favour of Iceland. Finally, in 1975, Iceland extended its limits to 200 miles. The Ministry of Foreign Affairs has information on Iceland's international relations (http://www.mfa.is/). Iceland has at least 8 pieces of legislation for marine conservation and is about to establish its first major marine conservation area. Iceland works closely with ICES to monitor the size of fish stocks (www.ices.dk/indexnofla.asp). There are various restrictions on fisheries. The most common methods are TAC, mesh size and gear restrictions, restrictions on season length and timing and area closures. Often all methods are used in combination but depending on species some may be more important for one species than another. The main aim is to secure sustainable fishing.. The management of Icelandic capelin has been approached in a multi-species context since 1980 (Astthorsson & Vilhjalmsson 2002). The immature stock is specifically protected from fishing and the needs of cod, the main predator, are taken into account prior to the final decision on total allowable catch. Steps have been taken to obtain a better understanding of multi-species interactions in this LME (Anon. 1997). The EEA (European Economic Area) Agreement is legally binding for Iceland to harmonize their legislation and regulatory framework with EU environmental legislation. Iceland is party to UNCLOS and the OSPAR Convention. The LRTAP agreement on Long-range Transboundary Air Pollution of POPs has not been ratified by Iceland, but Iceland is party to its protocols on POPs and PAHs. Iceland is party to MARPOL for prevention of pollution from ships, the London Dumping Agreement, the Copenhagen Convention on international Nordic country cooperation on dealing with accidents caused by oils and other hazardous substances, and the Basel convention to control transboundary movement of hazardous wastes and their disposal. Iceland is working with the Arctic Council and with PAME to protect the Arctic marine environment (Iceland, Ministry for the Environment, 2006) and chaired the Arctic Council 2002-2004.

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XIII-42 North Sea LME

M.C. Aquarone and S. Adams

The North Sea LME is situated on the continental shelf of northwestern Europe. It covers an area of 694,000 km², of which 1.94% is protected (Sea Around Us 2007). Besides the North Sea with an area of 575,000 km^2 and average depth of 94 m, this LME includes a part of the deep-water basin between the Faroes and Shetland Islands. The North Sea LME includes one of the most diverse coastal regions in the world, with a great variety of habitats (fjords, estuaries, deltas, banks, beaches, sandbanks and mudflats, marshes, rocks and islands). Among its many river systems and estuaries are the Thames, Rhine, Elbe, Sheldt and Ems. A temperate climate and four seasons characterise this LME. Great Britain, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium and France are the countries bordering the North Sea. LME book chapters and articles pertaining to this LME include Daan (1986, 1993) and McGlade (2002). There is a wealth of data on the North Sea. Information on climatology, and physical, chemical and biological oceanography was published by McGlade in 2002. ICES issued a report on the fisheries and fish of this region in August 2008.

I. Productivity

The North Sea LME is a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$). Primary production varies considerably across the LME. The highest primary productivity occurs in the coastal regions, influenced by terrestrial inputs of nutrients, and in areas such as the Dogger Bank and tidal fronts. For more information on plankton communities, benthic, fish and shellfish communities, as well as for food web dynamics and information about bird communities and marine mammals see McGlade (2002). The Sir Alister Hardy Foundation for Ocean Science has been conducting Continuous Plankton Recorder surveys, collecting data from the North Atlantic and the North Sea on biogeography and ecology of plankton since 1931. The Foundation website reports on plankton abundance in the North Sea (www.**sahfos**.ac.uk/).

Oceanic fronts: Up to ten fronts have been distinguished in the North Sea LME from satellite data (Belkin *et al*. 2008) (Figure XIII-42.1). The North Atlantic Current enters the North Sea from the north. Its branches are associated with the Fair Isle Front (FIF) and Shetland Front (ShF). The Norwegian Coastal Current Front (NCCF) extends along the Norwegian Coast and separates the low-salinity near-shore waters from Atlantic waters. Tidal mixing fronts form around Dogger Bank (DBF) and off Flamborough Head (FHF). The Atlantic waters entering the North Sea via the English Channel form two fronts, western (WECF) and eastern (EECF) fronts at their contact with resident waters; these fronts flank the Atlantic inflow. The Frisian Front (FF) origin is related to the fresh outflow from the Rhein River and Scheldt River. The Skagerrak Front (SkF) is located at the boundary with the Baltic Sea waters.

North Sea LME SST (Belkin, 2008)(Figure XIII-42.2)
Linear SST trend since 1957: 0.88°C.
Linear SST trend since 1982: 1.31°C.

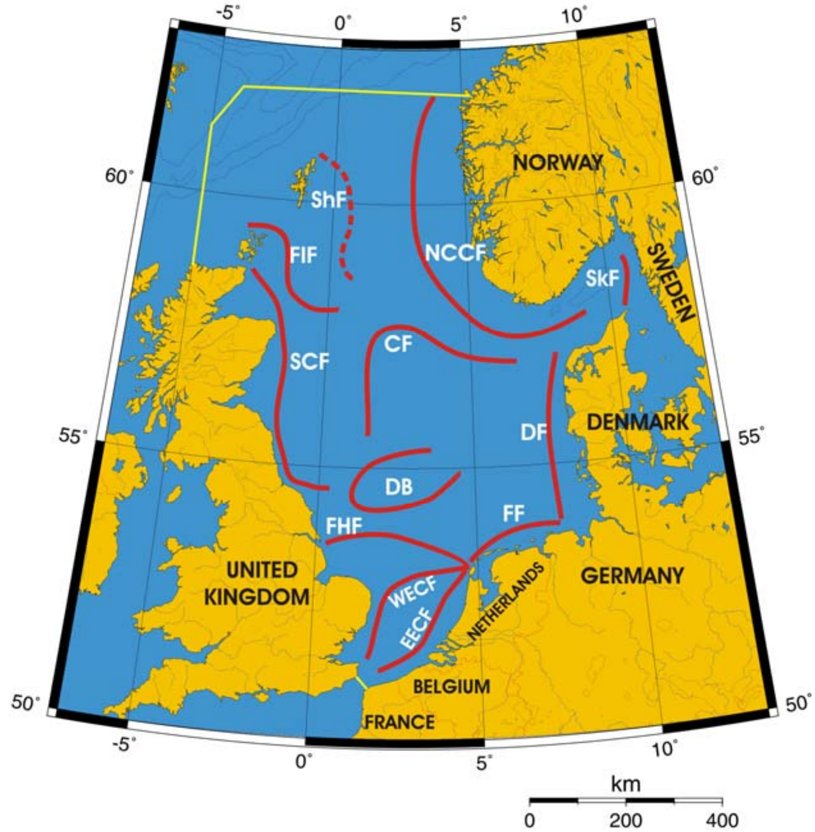

Figure XIII-42.1. Fronts of the North Sea LME. CF, Central Front; DBF, Dogger Bank Front; EECF, East English Channel Front; FF, Frisian Front; FHF, Flamborough Head Front; FIF, Fair Isle Front; NCCF, Norwegian Coastal Current Front; ShF, Shetland Front; SkF, Skagerrak Front; WECF, West English Channel Front. Yellow line, LME boundary. After Belkin et al. (2008).

The 50-year long-term warming of this LME was not uniform. In fact, the North Sea cooled in 1957-1986; this cooling culminated in two cold events of 1979 and 1986 linked to two consecutive Great Salinity Anomalies, GSAs (Dickson et al., 1988; Belkin et 1998). The cold event of 1986 was followed by a dramatic rebound by 1.3°C over the next three years. The third cold event of 1996 was linked to the GSA of the 1990s (Belkin, 2004). The above decadal-scale events were likely associated with the North Atlantic Oscillation, NAO. The cold event of 1962-63 may have been associated with a previous GSA, which is not fully documented because of scarce hydrographic data. The post-1982 warming of 1.31°C makes the North Sea the 2nd fastest warming LME of the last 25 years (after the Baltic Sea LME).

The ongoing rapid warming of the North Sea will likely have an adverse effect on recruitment and catches of boreal fish species (Stenevik and Sundby, 2007). In particular, water temperature in coastal areas of the North Sea is inversely correlated with cod recruitment and catches (Hannesson, 2007). At the same time, warm-water species are expected to become more abundant (Stenevik and Sundby, 2007).

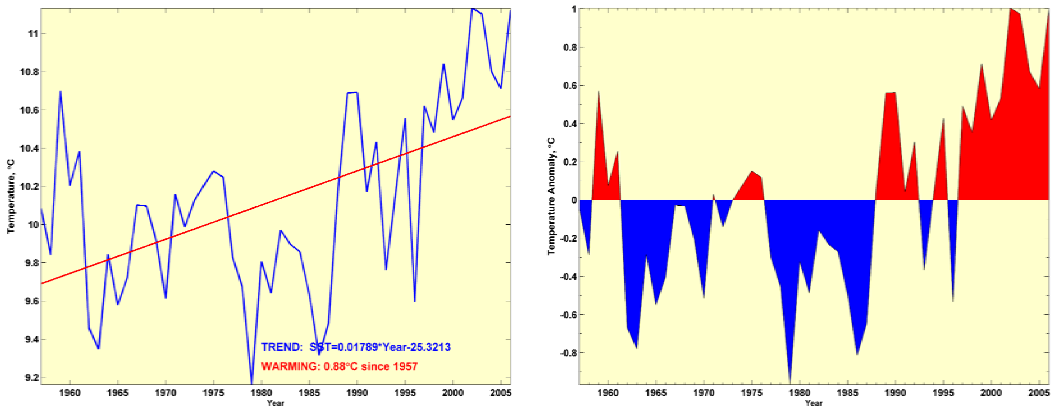

Figure XIII-42.2. North Sea LME annual mean SST (left) and SST anomalies (right), 1957-2006, based on Hadley climatology. After Belkin (2008).

North Sea LME Chlorophyll and Primary Productivity: The North Sea LME is a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$) (Figure XIII-42.3).

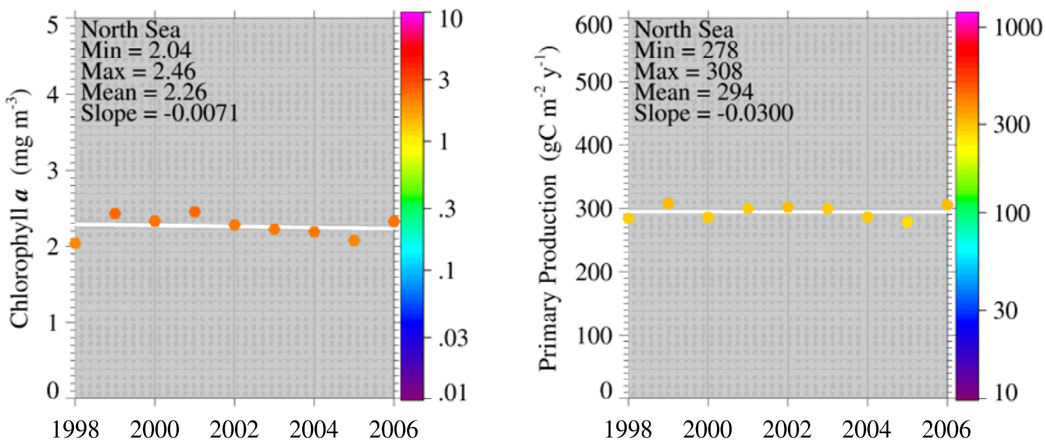

Figure XIII-42.3. North Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery; courtesy of K. Hyde.

II. Fish and Fisheries

Fishing is a long-established activity in the North Sea LME and there is a wealth of fisheries data. The most important species for human consumption represented in the catch are cod-like fishes (cod, saithe, haddock, etc.), herring, sprat and flatfishes. For more information on North Sea fishing fleets, see McGlade (2002). Landings from the industrial fishery consist mainly of sandeels, Norway pout and sprat. There are several commercially important shellfish species of molluscs and crustaceans, including shrimp, crab, lobster, oysters, mussels and scallops. The North Sea, on average, supported total reported landings of over 3 million tonnes per year from the mid 1960s to the early 1990s, with a peak landing of 4.4 million tonnes in 1968 (Figure XIII-42.4). However, reported landings have declined consistently since the early 1990s. The value of the reported landings reached US$3.5 billion (in 2000 US dollars) in 1968, following which it steadily declined (Figure XIII-42.5).

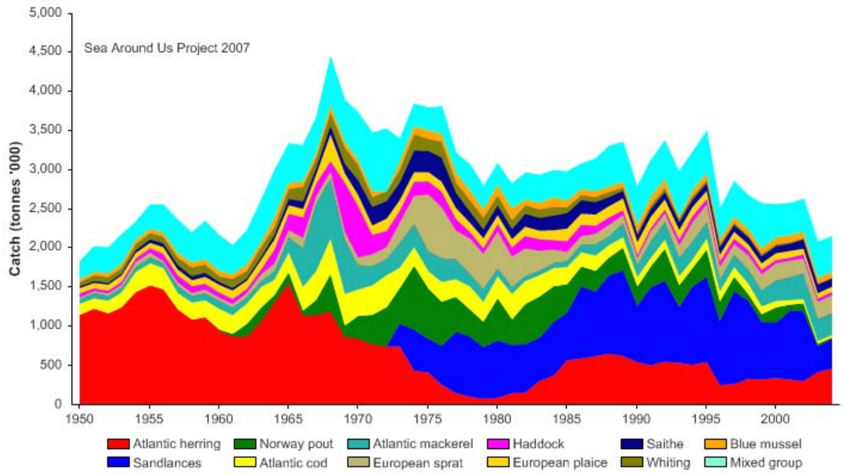

Figure XIII-42.4. Total reported landings in the North Sea LME by species (Sea Around Us 2007)

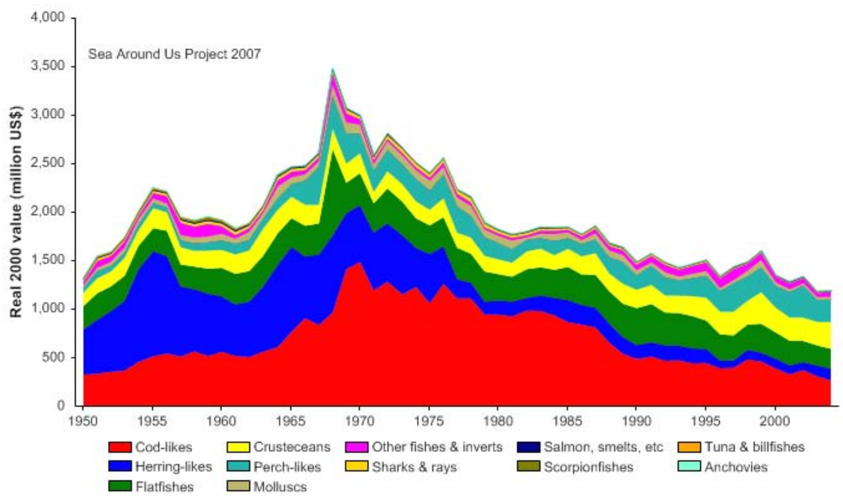

Figure XIII-42.5. Value of reported landings in the North Sea LME by commercial groups (Sea Around Us 2007)

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached extremely high level, over 70% of the observed primary production in the late 1960s, but has declined to less than 40% in recent years (Figure XIII-42.6). Denmark, Norway and the United Kingdom account for the highest share of the ecological footprint in this LME. The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) has shown a steady decline since 1970 (Figure XIII-42.7, top), an indication of a 'fishing down' of the food web in the LME (Pauly et al. 1998). The FiB index has been on a similar decline over the past three decades (Figure XIII-42.7, bottom). Both indices thus correspond with the detailed analysis by Froese & Pauly (2003), which was based on catch data starting in 1903. The Stock-Catch Status Plots, based on the first analysis of an LME using such plot (Froese and Pauly 2003), indicate that the numbers of collapsed and overexploited stocks have been increasing, accounting for close to 80% of all commercially exploited stocks in the LME (Figure XIII-42.8, top). A majority of the reported landings biomass, particularly in recent years, is supplied by overexploited stocks (Figure XIII-36.8, bottom).

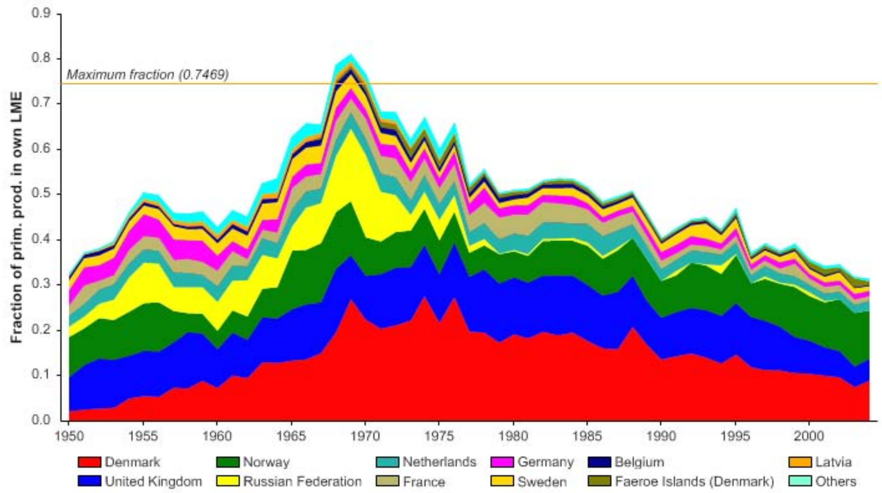

Figure XIII-42.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the North Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

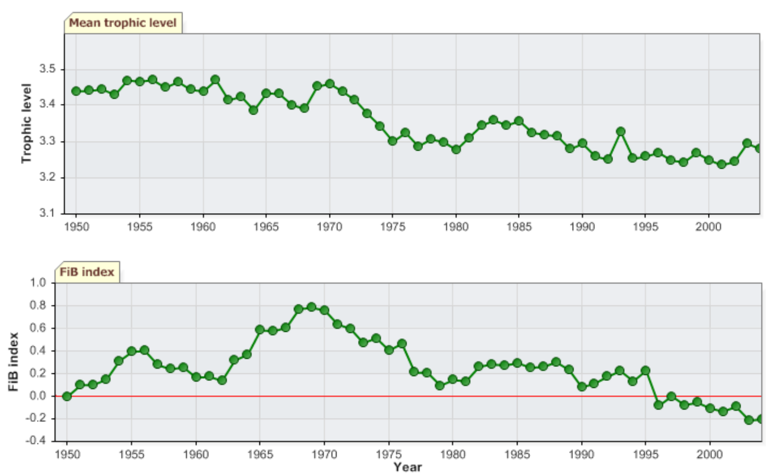

Figure XIII-42.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the North Sea LME (Sea Around Us 2007).

The LME is not stable with regard to individual fish species. Changes in the abundance of commercially important fish stocks have been monitored since the 1950s. All are heavily exploited and the majority of those exploited for human consumption are considered to be seriously depleted. In fact, intensive fishing is the primary force driving the LME. Analytical assessments of all commercially important species are carried out by ICES (www.ices.dk). Improvements in fishing equipment (more powerful engines, hydroacoustic equipment, and the purse-seine net in the mid 1960s) have changed the nature of the fisheries. Various management measures (closures, restrictions on the number of vessels, fishing gear and time) have been enacted to try to control fishing mortality, but these are not systematic throughout the LME. The inclusion in the EU of all riparian countries except Norway led to the development of the Common Fisheries Policy, the results of which are mixed.

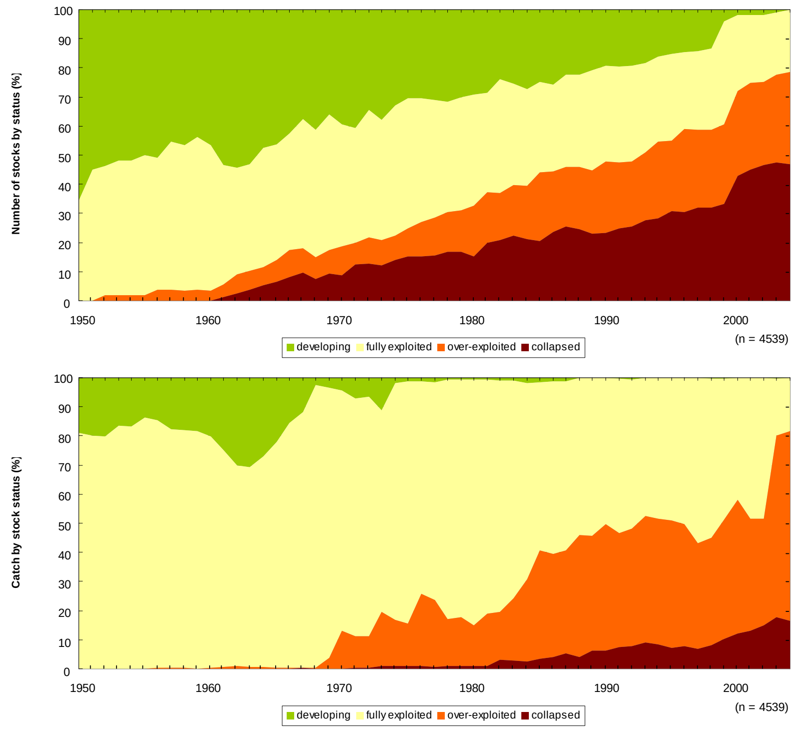

Figure XIII42.8. Stock-Catch Status Plots for the North Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of 'stocks', 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).

III. Pollution and Ecosystem Health

Both offshore and land-based activities have a significant effect on the North Sea LME. Eutrophication is now a major environmental issue arising from the general increase in nutrient discharges from rivers, land run-off and the atmosphere, largely resulting from sewage effluents, leaching from agricultural land, contributions from rural populations and atmospheric nitrogen deposition. Hazardous substances, oily wastes and slicks are a problem for birds and marine mammals. Alien species have been introduced into the North Sea ecosystem through ballast water and shipping. For more information on the impacts of non-indigenous species, coastal habitats, the ecological impacts of pollution and the effects of marine industries (hazardous and radioactive substances, oil and oily wastes, litter and dumping), see McGlade (2002). An assessment of the health of the North Sea LME was initiated in 1987 as part of the international ministerial activities to address concerns over the impact of human activities and climate change on the ecosystem. In 2000, ICES reviewed the effects of different types of fisheries on North Sea benthic ecosystems. Effective on 11 August 2007, the EU Directive 2005/33/EC on the North Sea SECA (Sulphur Emission Control Area) came into force to regulate sulphur emissions from all ship fuels not to exceed 1.50% m/m/ (www.imo.org and www1.veristar.com).

IV. Socioeconomic Conditions

The North Sea LME plays a key role in one of the world's major economic regions. Approximately 185 million people live in highly industrialised countries, the United Kingdom, Norway, Sweden, Denmark, Germany, the Netherlands, Belgium, France, the Czech and Slovak Republics, Switzerland, and Austria, which have part or the totality of their territory in the catchment area of the North Sea (Ducrotoy 2003). The fishing sector is important in terms of employment, with about 260,000 fishers directly involved in fishing. Currently, the European Union fishing industry comprises 97,000 vessels. The industry supports additional significant numbers of jobs in processing, packing, transportation, marketing, ship-building, fishing gear manufacture and servicing. The LME is also a source of economic resources other than fisheries. The North Sea supports highly productive extractive industries of hydrocarbons, sand and gravel. It is a transport highway as well as a sink for waste and pollution. The Straits of Dover and the North Sea itself are among the most heavily-used sea routes in the world, and are serviced by large commercial ports. Recreation and tourism are important activities in the LME. Large wind parks are in advanced planning stages.

In 2000, the EEA reported that approximately 164 million people lived in the North Sea catchment area, and use the coastline and the marine environment. Due to increased population growth and industrial activity, many of its resources are close to over-exploitation. The fisheries sector is under increasing pressure to allow fish stocks to recover. The northern seaboard will continue to supply at least 50% of the total energy requirements of the European Union, with increases in natural oil and gas production from the North Sea and off Scotland.

V. Governance

A new Marine Strategy Framework Directive was recently enacted which promotes and integrates environmental considerations into all relevant policies areas and which forms the basis for a future Maritime Policy for the EU. The exploitation of natural marine resources in the North Sea is governed by a number of conventions, declarations and regulations. These include the Geneva Convention on the Continental Shelf (1958), the joint declaration of the EU Commission on the coordinated extension of jurisdiction in the North Sea through the establishment of EEZs (1992), and European Commission directives and regulations within the Common Fisheries Policies. All in all, a large number of instruments from international bodies, such as the UN, IMO and the EU, exist to conserve natural resources, protect the environment and ensure health and safety standards. The European Community laws protect the environment in terms of air and noise, chemicals and industrial risks, nature conservation, waste and water. The European Union "North Sea Programme Progress Report" (2006) offers insight into social and environmental activities calculated to build capacity to enable sustainable management of existing resources in rural and urban areas around the North Sea. The OSPAR Commission has information on the 1992 Convention and ministerial declarations on the ecosystem approach (www.ospar.org/eng/html/ welcome.html). The Oslo and Paris Conventions (OSPARCOM) contain a number of supporting legislative and policy instruments. The Esbjerg Conference in 1995 enlarged the focus of protection to wildlife beyond territorial waters, promoted sustainable fishery management, and pushed for more research on the effects of chemicals on reproductive systems. It is expected that future conferences will be held at 5-year intervals (see Reid 1999). The principle of precautionary management has been successfully introduced in the North Sea fisheries, particularly for herring. For more information on governance of European fisheries, and on political and legal regimes, see McGlade (2002).

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XIII-43 Norwegian Sea LME

M.C. Aquarone and S. Adams

The Norwegian Sea LME is a western boundary ecosystem situated off the West Coast of Norway. It covers about 1.12 million km^2, of which 0.08% is protected, and contains about 0.13% of the world's sea mounts (Sea Around Us 2007). A sub-arctic climate characterises this LME. The Iceland-Faroe Ridge separates the relatively warm waters of the Northeast North Atlantic from the cold Arctic deep water of the Norwegian Sea. A boundary current flows along the edge of the Norwegian Shelf into the Arctic region. The cold and low salinity East Icelandic Current flows southeast towards the Norwegian Basin. LME book chapters and articles pertaining to this LME include Ellertsen *et al*. (1990), Blindheim & Skjoldal (1993) and Skjoldal et al. (2004).

I. Productivity

The Norwegian Sea LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$). All the major marine phytoplankton groups are represented in the Norwegian Sea. Significant temporal and spatial variations in phytoplankton distribution and productivity in the open waters of the Norwegian Sea are described by F. Rey (2004). Winter is characterised by very low phytoplankton biomass ,0.05 mg m^{-3}. The end of the winter period is marked by the appearance of small diatoms (e.g. *Fragiliaropsis pseudonana* and *Thalassiosira binoculata* var. *raripora* (Dale *et al.* 1999) that become important components of the spring bloom. The dominant species during this pre-bloom period advect to the area with Atlantic water from the south, or overwinter in the water column above the permanent pycnocline (Rey 2004). The spring bloom occurs when increased light warms the upper layer, producing a deep seasonal pycnocline and an upper mixed layer. The spring bloom is dominated by early diatom production and later by small flagellates, especially *Phaeocystis pouchetii*, that can dominate the phytoplankton community after the diatom spring bloom (Rey 2004).

There is a tight coupling of primary with secondary production, especially during the spring bloom, in the Norwegian Sea. The reproductive activity of the main copepod in the Norwegian Sea, *Calanus finmarchicus*, is closely related to, and exerts grazing pressure on, the spring phytoplankton bloom (Niehoff and Hirche 2000). In the post-bloom period, coccolithophorids, dinoflagellates and other flagellates dominate the phytoplankton community while the proportion of diatoms falls. Heterotrophic flagellates such as *Leucocryptos marina* appear at this time (Rey 2004). In the Autumn, one or more secondary but smaller blooms occurs, together with a reduction in zooplankton grazing pressure. Despite an increase in nutrients by October, diminished light inhibits production to less than 100 mg C m^{-2} day^{-1} in September and decreasing into winter (Rey 2004).

Oceanic fronts (Belkin *et al.* 2008)(Figure XIII-43.1): The North Atlantic Current Front (NACF) exists year-round between warm and salty Atlantic waters transported by the current into the Norwegian Sea, and resident waters of the Norwegian Sea (Belkin *et al*. 2008, Kostianoy *et al*. 2005) (Figure XIII-43.1). The Norwegian Coastal Current Front (NCCF) hugs Norway's coast. This current carries northward low-salinity waters from the North Sea with an admixture of the Baltic Sea waters. The Arctic Front (AF) follows the Mid-Atlantic Ridge meridionally up to Jan Mayen, turns NE along Mohns Ridge, then turns NNW along Knipovich Trough. The Iceland-Faroes Front (IFF) runs near the LME's southern boundary, spawning warm and cold eddies responsible for the bulk of crossfrontal exchange of heat, salt and nutrients. Decadal-scale 'Great Salinity Anomalies' travelled across this LME in the 1970s, 1980s and 1990s (Belkin *et al*.1998, Belkin 2004).

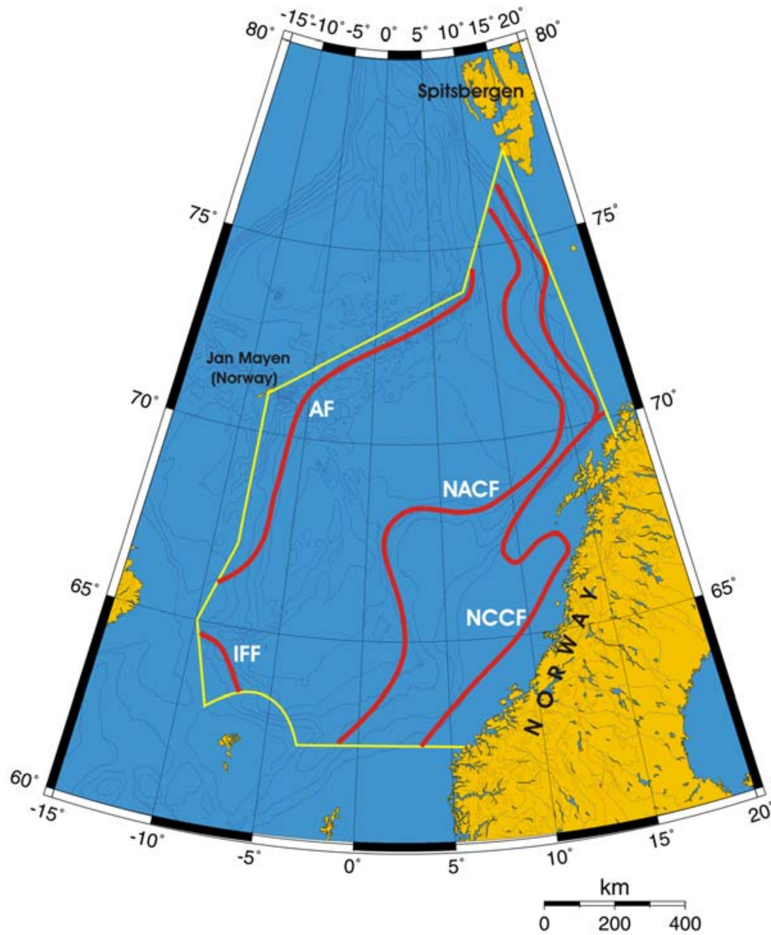

Figure XIII-43.1. Fronts of the Norwegian Sea LME. AF, Arctic Front; IFF, Iceland-Faroes Front; NACF, North Atlantic Current Front; NCCF, Norwegian Coastal Current Front. Yellow line, LME boundary (after Belkin et al. 2008).

Norwegian Sea LME (after Belkin 2008)
Linear SST trend since 1957: 0.22°C.
Linear SST trend since 1982: 0.85°C.

The thermal record of the Norwegian Sea since 1957 was non-monotonous and consisted of (1) cooling until the breakpoint of the all-time minimum in 1979, followed by (2) warming until present, during which SST rose by 1.3°C over 27 years. This is a relatively fast warming rate, consistent with other fast-warming LMEs that surround Europe. The SST maxima of 1961, 1974 and 1990 seem to correspond to the SST maxima of 1961, 1973 and 1989-90 in the Barents Sea LME, which is not surprising given links between circulations in these seas. Thermal manifestations of the Great Salinity Anomalies, GSA (Dickson et al., 1988; Belkin et al., 1998; Belkin, 2004), are not evident here, apparently obscured by larger thermal signals, although salinity manifestations are distinct. Year-to-year variability in the Norwegian Sea is relatively small compared to sub-decadal and decadal variability, which strongly modulates long-term trends. The recent warming of the Norwegian Sea is expected to benefit cod fisheries owing to a positive correlation between temperature and cod recruitment and catches, in this area (Hannesson, 2007). Under the present warming conditions, the optimum temperature for fish is shifting north, from the northern part of West Norway towards the Helgeland coast (Stenevik and Sundby, 2007).

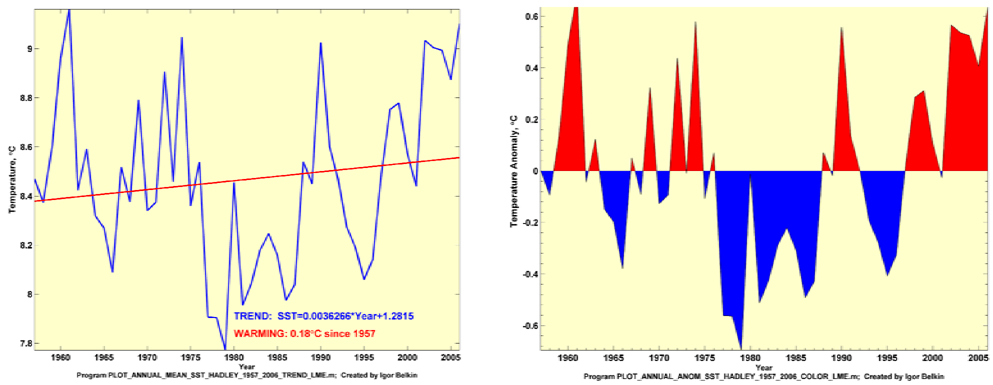

Figure XIII-43 2. Norwegian Sea LME annual mean SST (left) and annual SST anomalies (right), 1957-2006 from Hadley climatology. After Belkin (2008).

Norwegian Shelf LME Chlorophyll and Primary Productivity: The Norwegian Sea LME is considered a Class II, moderately productive ecosystem (150-300 $gCm^{-2}yr^{-1}$).

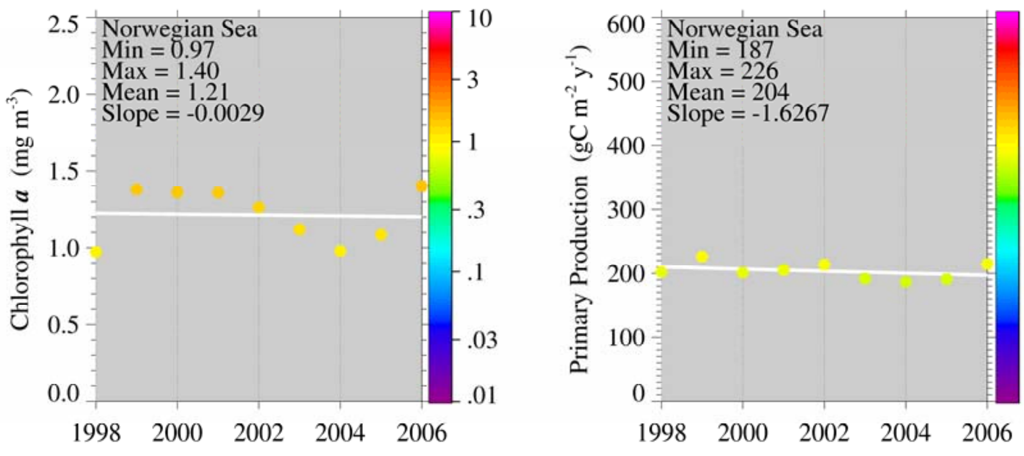

Figure XIII-43-3. Norwegian Sea LME trends in chlorophyll *a* (left) and primary productivity (right), 1998-2006, from satellite ocean colour imagery. Values are colour coded to the right hand ordinate. Figure courtesy of J. O'Reilly and K. Hyde. Sources discussed p. 15 this volume..

II. Fish and Fisheries

The Norwegian Sea LME has a complex fishery history with concomitant influences of ecological anomalies, high fishing mortality and early implementation of management measures. Reported landings in the LME include Atlantic herring, capelin Atlantic cod, saithe and blue whiting. While Capelin does not occur in the Norwegian Sea, Norway has agreed that the use of resources in Norway's neighbouring Arctic seas shall not cause species to become endangered or extinct. Populations of species that are currently believed to be endangered or adversely affected by land use, harvesting or pollution shall be conserved and if possible restored. According to the Norwegian Polar Institute brief of 30 May 2008, capelin quotas are in place in accordance with the recommendation from the International Council for the Exploration of the Sea (ICES). Reported landings show significant fluctuations in both total landed biomass and composition, particularly for herring and capelin (Figure XIII-43.4). In recent years, the total landings increased from less than half a million tonnes in 1990 to 1.5 million tonnes in 2004. The value of the reported landings peaked in 1980 at US$ 1.2 billion (in 2000 real US dollars), mainly due to the high blue whiting landings (Figure XIII-43.5).

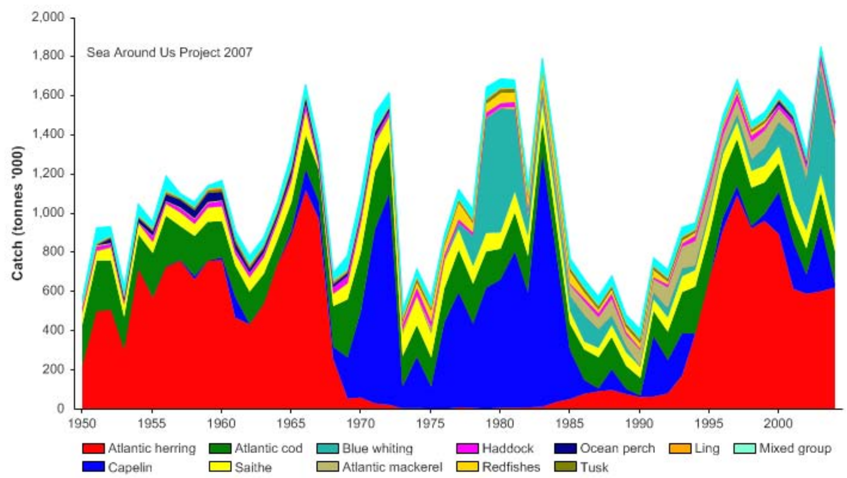

Figure XIII-43.4. Total reported landings in the Norwegian Sea LME by species (Sea Around Us 2007)

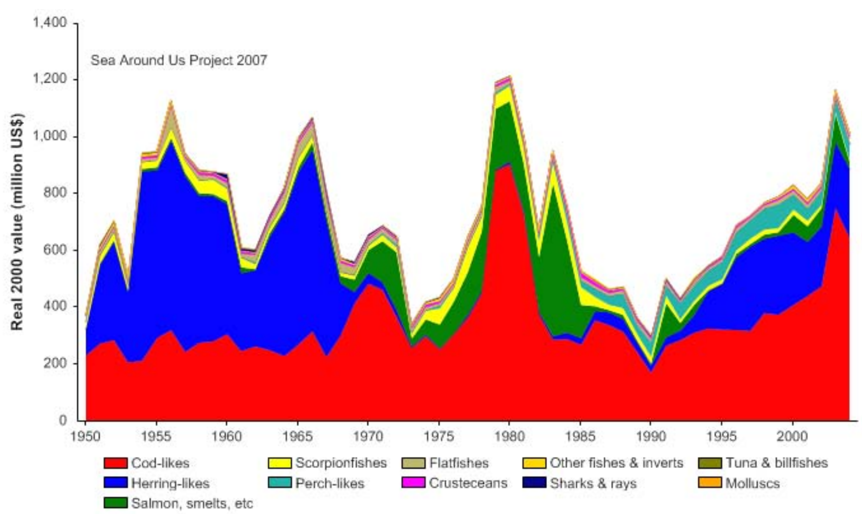

Figure XIII-43. 5. Value of reported landings in Norwegian Sea LME by commercial groups (Sea Around Us 2007)

The primary production required (PPR; Pauly & Christensen 1995) to sustain the reported landings in this LME reached above 60% of the observed primary production in the late 1970s and again in the 2000s (Figure XIII-43.6). Norway and Russia account for the largest share of the ecological footprint in this LME.

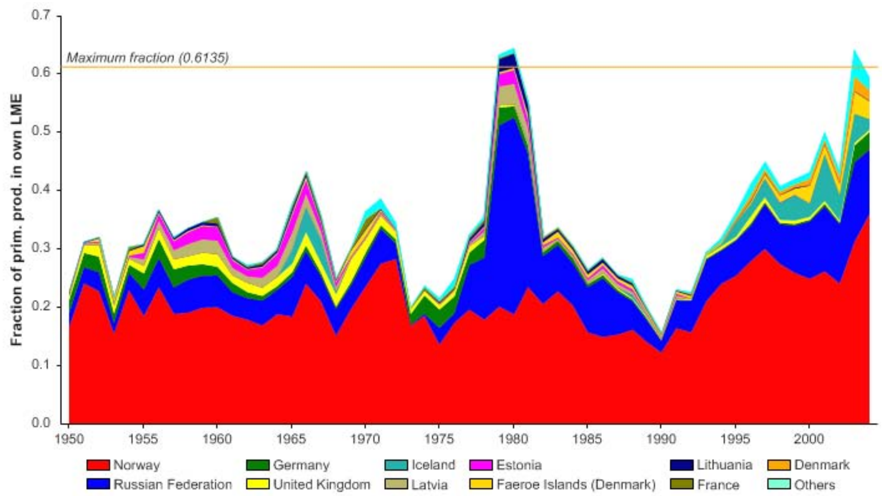

Figure XIII-43.6. Primary production required to support reported landings (i.e., ecological footprint) as fraction of the observed primary production in the Norwegian Sea LME (Sea Around Us 2007). The 'Maximum fraction' denotes the mean of the 5 highest values.

The mean trophic level of the reported landings (i.e., the MTI; Pauly & Watson 2005) and the FiB index remained roughly stable (albeit with considerable year-to-year fluctuation) over the reported period (Figure XIII-43.7), which may seen as surprising, given the strong fluctuation of species composition in the landings. One possible explanation may be that the key species in the ecosystem are fluctuating in such a way that a balance is maintained in terms of feeding guilds (zooplanktivores, piscivores, etc).

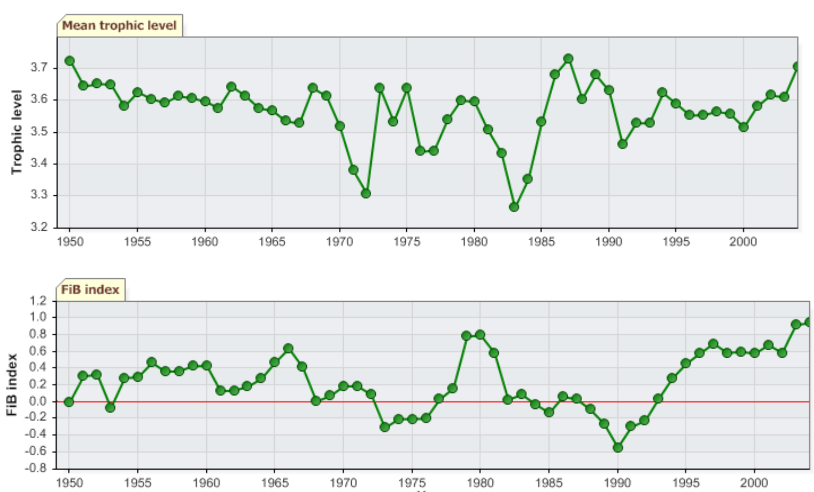

Figure XIII-43.7. Mean trophic level (i.e., Marine Trophic Index) (top) and Fishing-in-Balance Index (bottom) in the Norwegian Sea LME (Sea Around Us 2007).

The fluctuations in species composition of the reported landings strongly affect the Stock-Catch Status Plots, which show that the number of collapsed stocks have been consistently increasing, to about 80% of the commercially exploited stocks, in the LME (Figure XIII-43.8, top). A majority of the catch is also supplied by collapsed stocks (Figure XIII-43.8, bottom).

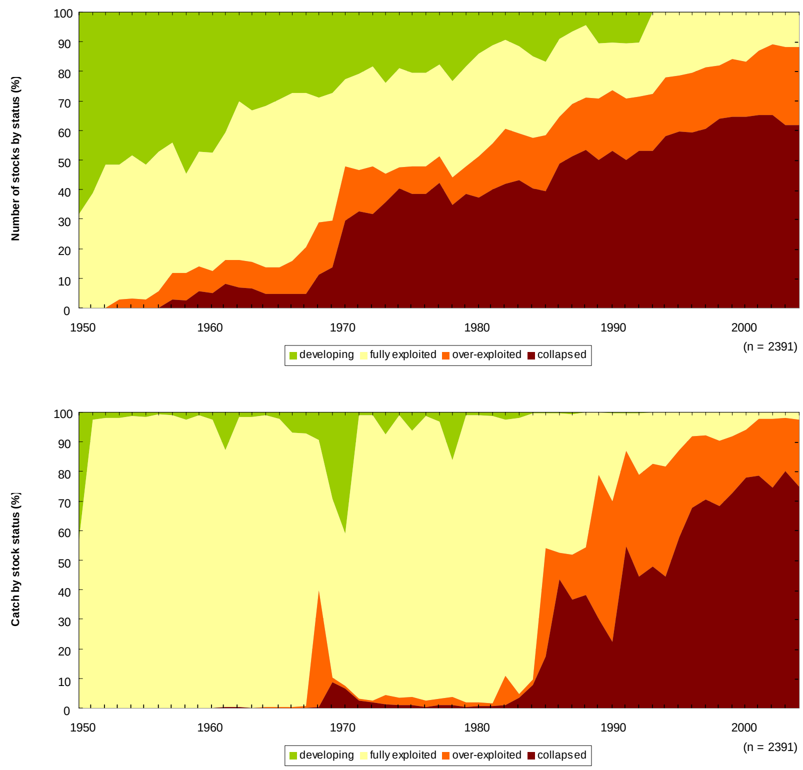

Figure XIII-43.8. Stock-Catch Status Plots for the Norwegian Sea LME, showing the proportion of developing (green), fully exploited (yellow), overexploited (orange) and collapsed (purple) fisheries by number of stocks (top) and by catch biomass (bottom) from 1950 to 2004. Note that (n), the number of '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).

In the 1960s and 1970s, fishing pressure increased as a result of purse seining technology. Herring was depleted, which eventually led to its collapse. After two decades of very low abundance, the herring stock has recovered to a total biomass of over 10 millions tonnes. The herring stock overwinters in the Vestfjord and feeds throughout the Norwegian Sea in summer. The main spawning grounds are off Møre, with smaller populations spawning off of Iceland and southern Norway. For a map of the distribution of the Arcto-Norwegian cod, see Ellertsen *et al*. (1990, p. 20). The spawning areas of cod are located in the Norwegian coastal current, in coastal bays and near offshore banks (see Ellertsen *et al*. 1989). Temperature is an important factor affecting cod recruitment. The data strongly suggests that a high temperature is a necessary condition for the formation of a strong year-class. Capelin migrates out of the Barents Sea into the Norwegian Sea. For more information on the influence of the marine environment on fish recruitment and biomass yields, see Ellertsen *et al*. (1990).

III. Pollution and Ecosystem Health

Some pollution issues in this LME stem from Norway's offshore oil industry, and the risk of oil spills in Norwegian waters. Poor weather and substandard ships have caused groundings and losses. In Norway, the Norwegian Pollution Control Authority is placed under the Ministry of the Environment. This agency aims to promote sustainable development. For more information about pollutants in the Arctic region including the Norwegian Sea, see AMAP (see the Barents Sea LME). The PAME Working Group of the Arctic Council is involved in assessing changing states of Arctic environments (see also Governance). The PAME work plan (2004-2006) will identify indicators of ecosystem health and ecosystem objectives for the Arctic LMEs including the Norwegian Sea. For information on the protection and conservation of marine biodiversity and ecosystems, eutrophication, hazardous and radioactive substances see the OSPAR website at www.ospar.org/.

IV. Socioeconomic Conditions

The fisheries industry is important to coastal Norway's economy. Norway exports fish and fish products to more than 150 countries world-wide. The fishing industry in Norway is divided into a marine and an aquaculture sector. The former employs some 15,000 fishermen at sea and 12,000 people in 500 fish plants along the coast. The aquaculture industry employs some 6,000 people, with fish farms all along the Norwegian north coast. PAME Working Group has information on the small indigenous and non-indigenous communities living in the Arctic that are heavily dependent on the Arctic living marine resources (see the Barents Sea LME). Lidunn Mosaker reports in Fiskeriforskning of 6-08-2007 that since 2000, almost 4,000 jobs in the fishing industry have disappeared. The OSPAR Commission has information on the offshore oil and gas industry, and the ecosystem approach to the management of human activities (www.ospar.org/). Rigzone.com, oil and gas industry news, reports on 4 December 2007 that StatoilHydro secured 6 seismic vessels for work offshore Norway. This deal valued at NOK 1.8 billion, Bjarte Ydstebø, VP for drilling and well acquisitions for StatoilHydro, says will give the company a better foundation for finding drilling targets on the NCS.

V. Governance

More than 20 treaties and agreements cover the Arctic area. Norway established an EEZ in 1977 and recently introduced protective measures for the reefs of cold water corals on the continental slope. It has negotiated a series of agreements with neighbouring countries, including Russia, to decide on management measures and allocation of quotas on shared fish stocks. Several national measures for the management of the Norwegian Sea LME have been implemented in Norway in accord with Norway's activities in the Arctic Council, ICES and OSPAR. The ICES symposium on the changing states of LMEs in the North Atlantic was held in Norway in 1999.

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