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Contents

1 Executive Summary

Ecosystem overviews are presented for nine ICES Advisory Regions:

East Greenland and Iceland

Barents Sea

Norwegian Sea

Faroe Plateau

Celtic Seas

North Sea

Baltic Sea

Iberian Seas

Deep-sea Atlantic

All the overviews follow a common structure, addressing:

Bathymetry, substrate, and currents

Physical Oceanography

Primary Production

Zooplankton and Secondary Production

Benthos and large Invertebrates

Fish and Fish Communities

Seabirds and Marine Mammals

Effects of the ecosystem on fisheries

Effects of the fisheries on the ecosystem

In a few cases additional sections were added to bring out ecosystem features of particular importance to a specific region.

The second section of the report considers ecosystem events in the past year that may be particularly important to dynamics of exploited fish stocks in a particular region, and warrant explicit consideration 2006 assessments and/or advice. The three events which were identified were:

The continued low abundance and restricted distribution of capelin around Iceland. The consequences of low food availability should be taken into account in weights-at-age and other estimates of productivity used in short-term and medium-term projections.

The very warm conditions in Barents Sea in 2005, combined with the high abundance of young herring, suggest that the predator-prey relationships currently included in the analytical assessment models for cod and capelin should be scrutinized carefully, and 2005 data examined for evidence of anomalous predation rates.

The very low abundance of Norway pout and low abundance of sand eel in many parts of the North Sea suggest that the prey base for higher predators might be anomalously limited in 2005 and 2006. The most recent possible data should be used for weights at age in the projections, and survey data should be examined carefully for anomalous distributions.

In addition, it was noted that the NAO has changed from strongly positive to near neutral in 2005. It is too soon to know if this change has important ecosystem consequences, and it is considered premature to speculate than another regime shift has occurred in the Iberian Seas.

In Section 4 of the report, the very slow uptake of ecosystem information by assessment working groups is documented. Three illustrations are provided for why such information is important for assessments, and particularly for evaluation and application harvest control rules. The illustrations include:

> Climate change, global warming and fish population and community dynamics and distributions
>
> Regime shifts and sustainable harvesting strategies
>
> Recovery strategies and ecological niche theory

The concluding portion of the paper proposed a new role for WGRED within ICES. It is proposed that WGRED review major reports from EU projects, ICES expert groups, and other major science initiatives, in the context of current assessment practice. The goal would be to identify relevant findings in these reports, and make specific recommendations for improvement in practice of appropriate assessment groups, to ensure practice kept pace with advances in knowledge. The report lays out four potential test cases for the 2007 meeting, where this approach would be explored. These include:

A harvest control rule for a planktivorous pelagic fish

The harvest control rule for Barents Sea cod.

Harvest control rules for Canadian cod which consider changing productivity

The Russia-Norway harvest control rule for ecosystem-based advice

2 Advisory Region Overviews

2.1 Iceland & East Greenland

2.1.1 Ecosystem Components

2.1.1.1 Bottom topography, substrates, and circulation

The bottom topography of this region is generally irregular, with hard rocky bottom prevailing in most areas. The shelf around Iceland extends out often over 150 km in some areas, but is cut by many sub-sea canyons. Beyond the shelf the seafloor falls away to over 1000 m, although sub-sea ridges extend to the north (Jan Mayen and Kolbeinsey Ridges) and southwest (Reykjanes Ridge).

The seafloor drops rapidly from the Greenland coast to depths over 1000 m. In the areas seasonally ice free, the Shelf area is rarely more than 75 km wide. The coastline and sub-sea topography are heavily serrated with canyons, and bottom topography is generally rough with hard bottom types.

The Polar Front extends between Greenland and Iceland. It separates the cold and relatively less saline south-flowing East Greenland Current from the Irminger Current, the westernmost branch of the warmer and more saline North Atlantic Current (Figure 2.1.1). To the south and east of Iceland the North Atlantic Current flows towards the Norwegian Sea, dominating the water mass properties between Iceland and the Faroes and Norway. The Irminger Current flows north-easterly to the west of the Reykjanes Ridge, before splitting into an arm which flows eastward to the north of Iceland and an arm which flows south-westward parallel to the East Greenland Current. Further north of Iceland the cold East Icelandic Current (an arm of the East Greenland Current) forms a counter-clockwise gyre around the Iceland Sea.

The strong, cold East Greenland Current dominates the hydrographic conditions along the coast of Greenland. In some years the warmer Irminger Current extends somewhat further west, transporting heat and biological organisms from Iceland into Greenland waters.

2.1.1.2 Physical and Chemical Oceanography (temperature, salinity, nutrients)

Icelandic waters are relatively warm due to Atlantic influence and generally ice free under normal circumstances. Infrequently for short periods in late winter and spring drift ice may come close inshore and even become landlocked off the north and east coasts. Waters to the south and east of Iceland are usually within the range of 6-10°C whereas on the North-Icelandic shelf mixing of Atlantic and Arctic waters means temperatures cool from west (~4-6 °C) to East (<4 °C). The water masses of the Iceland Sea are much colder than those of the Icelandic shelf.

Hydrobiological conditions are quite stable in the domain of Atlantic water south and west of Iceland, whereas there may be large seasonal as well as inter-annual variations of hydrography in the mixed waters on the N- and E-Icelandic shelf. On longer timescales changes in the strength and position of major currents and water masses probably tied to NAO regime shifts combine to have a large influence on the marine ecosystem of the north Icelandic shelf (Figure 2.1.2) (Malmburg *et al.* 1999).

East Greenlandic waters are much colder than those surrounding Iceland. The surface layer is dominated by cold polar water, while relatively warm mixed water of Atlantic origin is found at depths between 150 and 800 m north to about 64°N. Mixing and diffusion of heat between these two layers, as well as changes of the relative strength of flow of these two main water components are fundamental in determining physical marine climatic conditions as well as primary and secondary production off W-Greenland. Large changes in water temperature regimes have been documented on time-scales of decades or longer in both East and West Greenlandic waters.

In 2005 Greenlandic waters were warmer than long-term average, continuing a trend started earlier in this decade. The warming was stronger in West Greenland than East Greenland, where a strong inflow of Irminger Sea water was present as far north as Fylla Bank, resulting in temperatures that were the warmest in more than 50 years. However, in the last quarter of 2005 there was a marked cooling of waters around Greenland, declining to near long-term average surface temperatures. There was also much greater than average melting of glaciers and snow on both coasts of Greenland, increasing the input of freshwater runoff to coastal areas.

Broad-scale climate & Oceanographic features & drivers

The NAO has a strong effect on ocean climate and water mass distributions in these waters, and environmental regimes are thought have altered several times over the past decades. These regimes are thought to have affected the productivity of many exploited fish stocks, as well as the fish and zooplankton on which they feed. In 2005 the NAO was in a condition of transition. After being strongly positive for several years, in the past year or slightly more it has changed to near average conditions. The position and strength of the Icelandic Low appears to be without a clear trend towards a state that is either strongly negative or positive.

The deep Greenland Basin is an important area for deep sea convection of heat in the ocean. The nature and timing of water mass formation in the Greenland Basin plays a significant role in global climate change.

2.1.1.3 Phytoplankton – timing, biomass/abundance, and major taxonomic composition

The Iceland Shelf is a moderately high (150-300 gC/m2-yr) productivity ecosystem based on SeaWiFS global primary productivity estimates. Productivity is higher in the southwest regions than to the northeast and higher on the shelf areas than in the oceanic regions (Gudmundsson 1998). There are marked changes in the spring development of phytoplankton from one year to another, depending on local atmospheric conditions, but spring blooms may start as early as mid-March rather than the more usual mid-April. Particularly on the shelf primary productivity appears to have been trending upward since the 1970s, but year to year variation has been as much as 3 to 4-fold during that period. This variation has corresponded with substantial variability of year-classes in a number of fish stocks during that period. “Cold” years, with less influence of North Atlantic Current waters tend to have lower primary productivity than warmer years.

The East Greenland Shelf is a low productivity (<150 gC/m^2-yr) ecosystem based on SeaWiFS global primary productivity estimates. The melting of the ice in the summer has significant effects on ecological conditions, causing large amounts of nutrients 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. The plankton bloom is dominated by diatoms, but in some years the flagellate *Phaeocyctis* may also contribute. http://na.nefsc.noaa.gov/lme/text/lme19.htm.

2.1.1.4 Zooplankton

Collectively, the Iceland Sea water fosters such arctic types of zooplankton as *Calanus finmarchicus, C. hyperboreus* and *C. glacialis, Metridia longa,* amphipods and others, with *C. finbmarchicus* commonly comprising 60-80% of the spring zooplankton bloom. Zooplankton productivity is highest along the frontal area to the south and East of Iceland, along the North Atlantic Current, and lowest to the west and north of Iceland. Zooplankton production has shown a trend interannually, although with different patterns in the Arctic, the Atlantic, and the mixed Arctic/Atlantic waters. Zooplankton production tended to increase in all three water masses throughout the 1990s (Astthorsson and Vilhalsson 2002). Monitoring series indicate that in the early part of this decade zooplankton biomass was relatively high both north and south of Iceland but began to decline in 2002 in both areas. Zooplankton biomass was near historic lows in the north by 2003 and in the south in 2004 (WGZE report 2005).

Zooplankton biomass is generally much lower in East Greenland than in Icelandic waters, but has varied extensively over the historic period. Zooplankton production in East Greenlandic waters is dominated by *Calanus*, but late in summer, smaller plankton species may become common. http://na.nefsc.noaa.gov/lme/text/GIWAGreenlandreport.pdf.

These zooplankton, particularly calanoid copepods and krill, are eaten by adult herring and capelin, juvenile stages of numerous other fish species as well as by baleen whales. The larvae of both pelagic and demersal fish also feed on eggs and juvenile stages of the zooplankton. In the pelagic ecosystem off Greenland and Iceland the population dynamics of calanoid copepods and to some extent krill are considered to play a key role in the food web as a direct link to fish stocks, baleen whales (*Mysticeti*) and some important seabirds, such as little auk (*Alle alle*) and Brünnitch's guillemot (*Uria lomvia*).

2.1.1.5 Benthos, larger invertebrates (cephalopods, crustaceans etc), biogenic habitat taxa

The Greenland-Scotland Ridge represents a biogeographical boundary between the North Atlantic Boreal Region and the Arctic Region and major faunistic changes around Iceland are mainly associated with the ridge. The Nordic Seas, i.e. the Norwegian, Greenland and Iceland Sea, are relatively low in species diversity, at the least for some benthic groups, compared with areas south of the Greenland-Scotland Ridge (e.g. Weisshappel 2000) . This has been explained partly by a short evolutionary time of the fauna within this environment, but in particular due to isolation caused by the Greenland-Scotland Ridge, which acts as a barrier against the immigration of species into the Nordic Seas (Svavarsson *et al.* 1993). Studies, based on material from the BIOICE programme , indicate that in the Iceland Sea and the western part of the Norwegian Sea, the benthic diversity increases with depth to about 320 to 1100 m (shelf slope), below which the diversity again decreased (Svavarsson 1997). South of the Ridge the species diversity has been shown to increase with depth (Weisshappel and Svavarsson 1998).

The underlying features which appear to determine the structures of benthic communities around Iceland are salinity (as indicator of water masses) and sediment types. Accordingly, the distribution of benthic communities is closely related to existing water masses and, on smaller scale, with bottom topography. Also, it has been shown that large differences occur in species composition around the Kolbeinsey Ridge, in the Iceland Sea, with greater abundances and diversity of benthos on the western slope of the ridge, compared with the east slope (Brandt and Piepenburg, 1994). This will indicate that benthos abundance and diversity is determined by differences in bottom topography and food supply (largely pelagic primary production).

Biogenic habitat taxa

Lophelia pertusa was known to occur in 39 places in Icelandic waters (Carlgren 1939, Copley *et al.* 1996). The distribution was mainly confined to the Reykjanes Ridge and near the shelf break off the South coast of Iceland. The depth range was from 114 to 875 m with most occurrences between 500 and 600 m depth.

Based on information from fishermen (questionnaires), eleven coral areas were known to exist close to the shelf break off NW- and SE- Iceland at around 1970. Since then more coral areas have been found, reflecting the development of the bottom trawling fisheries extending into deeper waters in the 70s and 80s. At present considerably large coral areas exist on the Reykjanes Ridge and off SE-Iceland (Hornafjarðardjúp deep and Lónsdjúp deep). Other known coral areas are small (Steingrímsson and Einarsson 2004).

In 2004 a research project was started on mapping coral areas off Iceland (using a Remote Operated Vehicle, ROV), based on the results from questionnaires to fishermen on occurrence of such areas. The aim of the project is to assess the species composition (including L. pertusa), diversity and the status of coral areas in relation to potential damages by fishing practices. In the first survey, intact Lophelia reefs were located in two places on the shelf slope off the south coast off Iceland. Evidence on bottom trawling activities in these areas was not observed.

The database of the BIOICE programme provides information on the distribution of soft corals, based on sampling at 579 locations within the territorial waters of Iceland. The results show that gorgonian corals occur all around Iceland. They were relatively uncommon on the shelf (< 500 m depth) but are generally found in relatively high numbers in deep waters (> 500 m) off the South, West and North Iceland. Similar patterns were observed in the distribution of pennatulaceans off Iceland. Pennatulaceans are relatively rare in waters shallower than 500 m but more common in deep waters, especially off South Iceland.

Aggregation of large sponges ("ostur" or sponge grounds) is known to occur off Iceland (Klittgard and Tendal 2004). North of Iceland, particularly in the Denmark Strait, "ostur" was found at several locations at depths of 300-750 m, which some are classified as sponge grounds. Comprehensive "ostur" and sponge grounds occur off south Iceland, especially around the Reykjanes Ridge.

Survey measurements indicate that shrimp biomass in Icelandic waters, both in inshore and offshore waters, has been declining in recent year. Consequently the shrimp fishery has been reduced and is now banned in most inshore areas. The decline in the shrimp biomass is in part considered to be environmentally driven, both due to increasing water temperature north of Iceland and due to increasing biomass of younger cod.

Shrimp biomass off East Greenland and Denmark Strait has been relative stable in the last years considering standardized CPUE data, which include most but not all fleets participating in the fishery (see e.g. NAFO SCS Doc. 04/20). Other information, e.g. survey based results on shrimp/cod interaction, do not exist for this area.

2.1.1.6 Fish Community

Icelandic waters are comparatively rich in species and contain over 25 commercially exploited stocks of fish and marine invertebrates. Main species include cod, capelin, haddock, wolffish, tusk *(Brosme brosme)*,ling *(Molva molva)*, Greenland halibut and various other flatfish, plus Polar cod *(Boreogadus saida)* and sand eel which are not exploited commercially. Most fish species spawn in the warm Atlantic water off the south and southwest coasts. Fish larvae and 0-group drift west and then north from the spawning grounds to nursery areas on the shelf off NW-, N- and E-Iceland, where they grow in a mixture of Atlantic and arctic water.

Capelin is important in the diet of cod as well as a number of other fish stocks, marine mammals and seabirds. Unlike other commercial stocks, adult capelins undertake extensive feeding migrations north into the cold waters of the Denmark Strait and Iceland Sea during summer. Capelin abundance has been oscillating on roughly a decadal period since the 1970s, producing a yield of >1600 Kt at the most recent peak. Herring were very abundant in the early 1960s, collapsed and then have increased only slowly since 1970. Abundance of demersal species has been trending downward irregularly since the 1950s, with aggregate catches dropping from over 800 Kt to under 500 Kt in the early 2000s.

A number of species of sharks and skates are known to be taken in the Icelandic fisheries, but information on catches is incomplete, and the status of these species is not known. Information on status and trends of non-commercial species, including species considered to be rare or vulnerable, and their catches in fisheries, is not available.

The Greenlandic commercial fish and invertebrate fauna counts fewer species and is characterized by coldwater ones such as Greenland halibut *(Hippoglossoides Reinhardtius)*, northern shrimp *(Pandalus borealis)*, capelin and snow crab *(Chionoecetes opilio)*. Redfish *(Sebastes spp.)* are also found, but mainly in Atlantic waters outside the cold waters of the E-Greenland continental shelf. Greenlandic waters also contain capelin populations that spawn at the heads of numerous fjords on the west and east coasts.

Cod can be plentiful at W-Greenland in warm periods, when larvae are though to drift from Iceland to Greenland. The drift of larval and 0-group cod from Iceland waters to Greenland was especially extensive during the warm period of the 1920s and 1940s; however, such drift occurred intermittently on a smaller scale until 1984. The fishable and spawning components of the West Greenland cod are believed to have reached more than 3 and 4 million tonnes respectively in their heyday in the 1940s (Figure 2.1.3), but many of the cod returned to spawn at Iceland. The Greenland cod stock collapsed in the 1970s because of worsening climatic conditions and overfishing. After 1970, all year classes of cod of any importance at East Greenland have been of Icelandic origin.

Warm conditions returned since the mid 1990 and, in particular off East Greenland, some increase in the abundance of juvenile cod has been observed since the early 2000s. However, recruitment, although improved, has remained below what has seen at comparable hydrographic conditions before, suggesting that other factors might have become more prominent. Possible contributing factors include as the younger age structure of the cod spawning stock at Iceland (reduced egg quality and changed location and timing of larval hatch) and the by-catch of small cod in the increased fishery for northern shrimp. However the year-classes from 2002 and possibly more recently are beginning to support substantial increases in cod biomass off Greenland. Management of this biomass, including decisions on when, where, and how much cod and shrimp to harvest, must take into account the potential for rebuilding spawning biomass off Greenland, the consequences of increased shrimp for the shrimp fishery, and the possibility that as the cof year-classes mature they will return to Icelandic waters.

2.1.1.7 Birds & Mammals: Dominant species composition, productivity (esp. seabirds), spatial distribution (esp. mammals)

The seabird community in Icelandic waters is composed of relatively few but abundant species, accounting for roughly ¼ of total number and biomass of seabirds within the ICES area (ICES 2002). Auks and petrel are most important groups comprising almost 3/5 and ¼ of both abundance and biomass in the area, respectively. The most abundant species are Atlantic puffin, northern fulmar, Common and Brunnich’s guillemot, black-legget kittiwake and common eider. The estimated annual food consumption is on the order of 1.5 million tonnes.

At least 12 species of cetaceans occur regularly in Icelandic waters, and additional 10 species have been recorded more sporadically. Reliable abundance estimates exist for most species of large whales while such estimates are not available for small cetaceans. In the continental shelf area minke whales (*Balaenoptera acutorostrata*) probably have the largest biomass. According to a 2001 sightings survey, 67 000 minke whales were estimated in the Central North Atlantic stock region, with 44 000 animals in Icelandic coastal waters (NAMMCO 2004, Borchers *et al.* 2003, Gunnlaugsson 2003). Minke whales have opportunistic feeding habits, their diet ranging from planktonic crustaceans (krill) to large (> 80cm) cod. Little information is available on the diet composition of minke whales in Icelandic and adjacent waters, but their annual consumption has been estimated to be of the same order of magnitude as the total catch of the Icelandic fishing fleet (2M tons). Fin whales (*Balaenoptera physalus*) are mainly distributed along the continental slope and further offshore. The abundance of the East Greenland - Iceland Stock of fin whales was estimated around 23 thousand animals in 2001 (Pike *et al.* 2003). This stock has been increasing during the last 20 years, mainly in the waters between Iceland and East Greenland. The diet of Icelandic fin whales is known only from the whaling grounds west of Iceland where it consists overwhelmingly of krill, mainly Meganychtiphanes norwegica.

Sei whale (*Balaenoptera borealis*) abundance is estimated around 10 thousand animals. The species has similar distribution and diet in Icelandic waters as fin whales.

Humpback whale (*Megaptera novaeangliae*) abundance was estimated as around 14 thousand animals in 2001 (Pike *et al.* 2002). The abundance of this species has been increasing rapidly (10-14% per year) during the last 30 years, but the species was previously very rare. Feeding habits of humpback whales off Iceland are virtually unknown but the species seems to be closely related to the distribution of capelin at certain times of the year. Humpback whales are primarily distributed on the continental shelf area in Icelandic waters.

Sperm whales (*Physeter macrocephalus*) are a deep water species, feeding on cephalopods and various fish species. They are relatively common in Icelandic waters, but no reliable absolute abundance estimate is available because of the long diving habits of the species.

Blue whale (*Balaenoptear musculus*) is the least abundant of the large whales with estimated stock size of 1-2 thousand animals. This species feeds exclusively on krill.

As mentioned above, no reliable estimates are available for most species of medium sized and small cetaceans. The exceptions are long-finned pilot whales (*Globicephala melas*) with estimated abundance of around 800 thousand animals in the Icelandic-Faroes area, and northern bottlenose whales (40 thousand in the NE Atlantic). Some of these small cetaceans (e.g. white -beaked dolphins (*Lagenorhynchus albirostris*) and harbour porpoises (*Phocoena phocoena*) are piscivorous and mainly distributed in coastal waters and may thus have significant interactions with fisheries.

2.1.2 Environmental Forcing on Fish Stock Dynamics and Fisheries

The environmental conditions particularly to the North and West of Iceland have a major effect on the biology and distribution of many key species. In the most recent two years, these areas have been anomalously warm, and capelin has largely relocated from the south and east of Iceland to the waters to the north of Iceland. This resulted in a low availability of capelin for feeding by the Icelandic cod stock in late 2003 and early 2004, and consequently some impact on cod growth. However cod were able to increase their feeding on shrimp. In 2004 and 2005 the warm anomaly strengthened ever further, and both capelin and shrimp now appear to be distributed outside the range of foraging cod. There is evidence that this may be leading to an even more marked detrimental impact on cod growth.

The transport of cod larvae from Iceland to East Greenland has been a major ecological feature of this region. Its strong decadal signal, tied to climatic regimes, has significant impacts on stock sizes in both areas, but particularly in East Greenland. The strong influence of cod eggs and larvae transported from Iceland on the dynamics of the East Greenland cod (and in some periods return migration of adult cod to Iceland has an impact of the cod fisheries in Iceland), has both medium and longer term implications for management strategies. In the near future decisions must be made on when, where and how much yield to take from cod in east (and west) Greenland. There are a number of policy considerations in these decisions, but clear science advice needs to be available on the possible consequences of various harvesting scenarios on the future productivity dynamics of both east Greenlandic and Icelandic cod. In the longer term ICES needs to develop and test management strategies designed for stocks whose dynamics are not determined by local biomass, and for stocks where environmental conditions cannot be counted on to ensure sustainable populations, whether harvested or not. The scientific community should give priority to development of sustainable management strategies for fisheries on stocks whose dynamics are not primarily determined by stock sizes and environmental conditions in the local management area.

2.1.3 Ecosystem Effects of the Fisheries

Many of the demersal fisheries use mobile gears and fish on hard bottoms. This presents an opportunity for substantial impacts on seafloor structural habitats and benthos. If the recent changes in distribution of major fish stocks continue, there may be incentives for these fisheries to relocate to new fishing grounds. This, in turn could potentially increase the amount of habitat altered by these gears, and should be discouraged until information is available on the nature and vulnerability of any new areas to be fished.

The ITQ system used in Icelandic fisheries is widely thought to have resulted in substantial high-grading of target species. This is undesirable even from the context of sustainable use of the target species. Moreover, the underscores the need for reliable information on non-target species taken as bycatch in these fisheries.

2.1.4 References:

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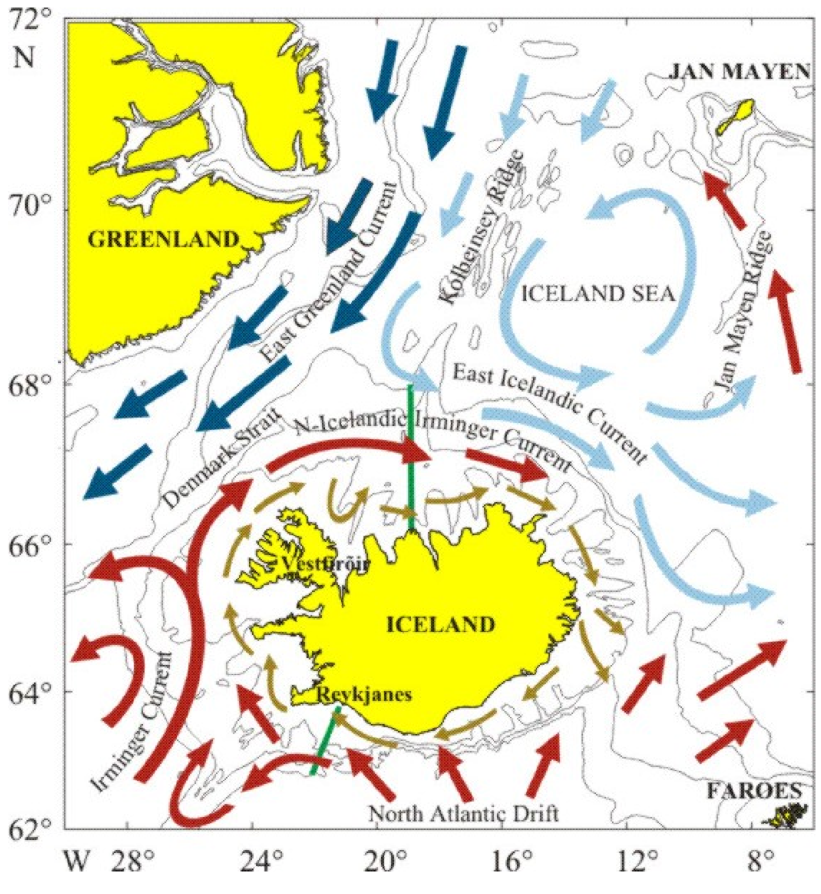

Figure 2.1.1. The system of ocean currents around Iceland and in the Iceland Sea

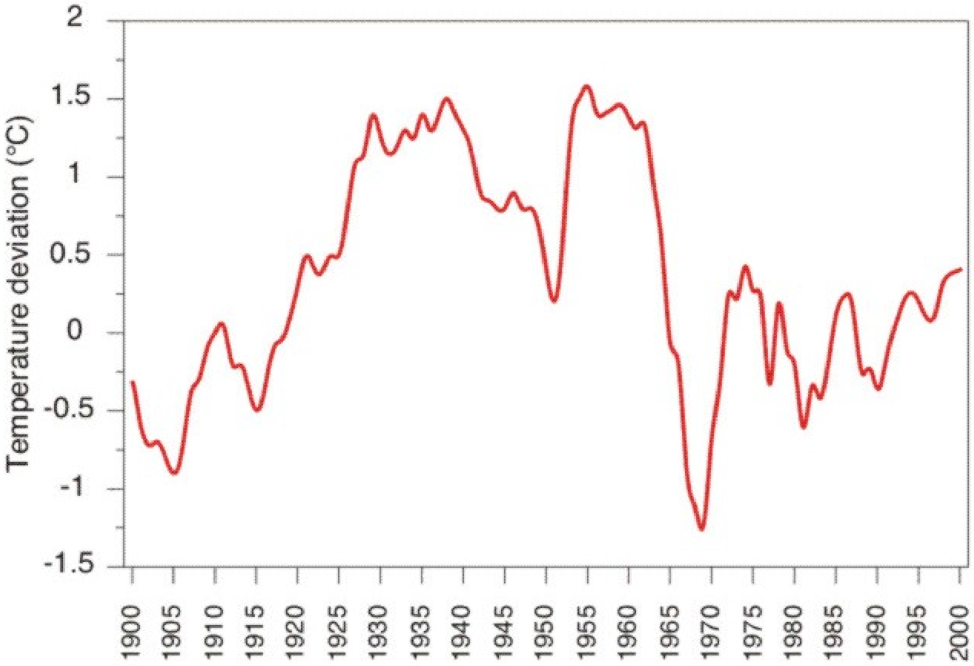

Figure 2.1.2. Temperature deviations north of Iceland 1900-200, five year running averages.

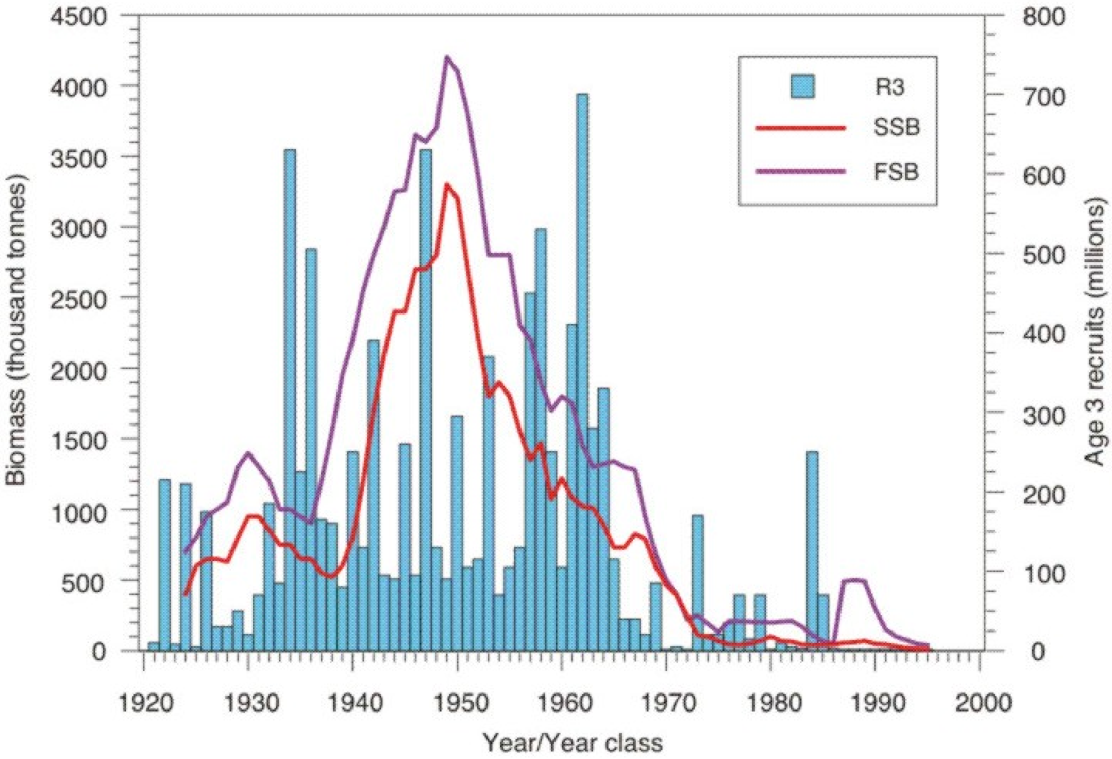

Figure 2.1.3. Recruitment at age 3, spawning biomass and fishable biomass of cod off West Greenland.

2.2 The Barents Sea

2.2.1 Ecosystem Components

2.2.1.1 General geography

The Barents Sea is a shelf area of approx. 1.4 million km2, which borders to the Norwegian Sea in the west and the Arctic Ocean in the north, and is part of the continental shelf area surrounding the Arctic Ocean. The extent of the Barents Sea are limited by the continental slope between Norway and Spitsbergen in west, the continental slope towards the Arctic Ocean in north, Novaja Zemlya in east and the coast of Norway and Russia in the south (Figure 2.2.1). The average depth is 230 m, with a maximum depth of about 500 m at the western entrance. There are several bank areas, with depths around 50-200 m.

2.2.1.2 General oceanography

The general circulation pattern is strongly influenced by topography. Warm Atlantic waters from the Norwegian Atlantic Current with a salinity of approx. 35 flow in through the western entrance. This current divides into two branches, one southern branch, which follows the coast eastwards against Novaja Zemlya and one northern branch, which flow into the Hopen Trench. The relative strength of these two branches depends on the local wind conditions in the Barents Sea, South of the Norwegian Atlantic Current and along the coastline flows the Norwegian Coastal Current. The Coastal Water is fresher than the Atlantic water, and has a stronger seasonal temperature signal. In the northern part of the Barents Sea fresh and cold Arctic water flows from northeast to southwest. The Atlantic and Arctic water masses are separated by the Polar Front, which is characterised by strong gradients in both temperature and salinity. In the western Barents Sea the position of the front is relatively stable, but in the eastern part the position of this front has large seasonal, as well as year- to-year variations. Ice conditions show also large seasonal and year-to year variations. In the winter the ice can cover most of the Barents Sea, while in the summer the whole Sea may be ice-free. In general, the Barents Sea is characterised by large year-to-year variations in both heat content and ice conditions. The most important cause of this is variation in the amount and temperature of the Atlantic water that enters the Barents Sea.

The water temperatures in the Barents Sea have been relatively high during most of the 1990s, with a continuous warm period from 1989-1995. During 1996.1997, the temperature was just below the long-term average before it turned warm again at the end of the decade, and has remained warm until present. 2005 was one of the warmest years recorded and with a record salinity (Figure 2.2.2).

2.2.1.3 Phytoplankton

The Barents Sea is a spring bloom system and during winter the primary production is close to zero. The timing of the phytoplankton bloom is variable throughout the Barents Sea, and has also high interannual variability. In early spring, the water is mixed but even though there are nutrients and light enough for production, the main bloom does not appear until the water becomes stratified. The stratification of the water masses in the different parts of the Barents Sea may occur in different ways: Through fresh surface water along the marginal ice zone due to ice melting, through solar heating of the surface waters in the Atlantic water masses, and through lateral spreading of coastal water in the southern coastal (Rey 1981). The dominating algal group in the Barents Sea is diatoms like in many other areas (Rey 1993). Particularly, diatoms dominate the first spring bloom, and the most abundant species is *Chaetoceros socialis*. The concentrations of diatoms can reach up to several million cells per liter. The diatoms require silicate and when this is consumed other algal groups such as flagellates take over. The most important flagellate species in the Barents Sea is *Phaeocyctis pouchetii*. However, in individual years other species may dominate the spring bloom.

2.2.1.4 Zooplankton

Zooplankton biomass has shown large variation among years in the Barents Sea. Crustaceans form the most important group of zooplankton, among which the copepods of the genus Calanus play a key role in the Barents Sea ecosystem. *Calanus finmarchicus*, which is the most abundant in the Atlantic waters, is the main contributor to the zooplankton biomass. *Calanus glacialis* is the dominant contributor to zooplankton biomass of the Arctic region of the Barents Sea. The Calanus species are predominantly herbivorous, feeding especially on diatoms (Mauchlin 1998). Krill (euphausiids) is another group of crustaceans playing a significant role in the Barents Sea ecosystem as food for both fish and sea mammals. The Barents Sea community of euphausiids is represented by four abundant species: neritic shelf boreal *Meganyctiphanes norvegica*, oceanic arcto-boreal *Thysanoessa longicaudata*, neritic shelf arcto-boreal *Th. inermis* and neritic coastal arcto-boreal *Th. raschii* (Drobysheva 1994). The two latter species make up 80-98% of the total euphausiids abundance. Species ratio in the Barents Sea euphausiid community is characterized by year-to-year variability, most probably due to climatic changes (Drobysheva 1994). The observations showed that after cooling the abundance of *Th. raschii* increases and of *Th. inermis* decreases, while after the number of warm years, on the contrary, the abundance of *Th. inermis* grows and the number of cold-water species becomes smaller (Drobysheva, 1967). The advection of species brought from the Norwegian Sea is determined by the intensity of the Atlantic water inflow (Drobysheva 1967, Drobysheva *et al*. 2003). Three abundant amphipod species are found in the Barents Sea; *Themisto abyssorum* and *T. libellula* are common in the western and central Barents Sea, while *T. compressa* is less common in the central and northern parts of the Barents Sea. *T. abyssorum* is predominant in the sub-arctic waters. In contrast, the largest of the Themisto species, *T. libellula*, is mainly restricted to the mixed Atlantic and Arctic water masses. A very high abundance of *T. libellula* is recorded close to the Polar Front.

2.2.1.5 Benthic habitats in the Barents Sea

Benthic organisms (benthos) are found on or buried in the seabed, but their composition is highly dependent on the predominating type of water (Arctic or Atlantic water, or at their convergence), the bottom substrate and the depth. The richest communities of benthic animals are found along the Norwegian coast and the coast of Svalbard, where the hard-bottom communities display an unusually high richness of species. Among these, kelp is a key species along the Norwegian coast, whereas other species of seaweeds dominate in Svalbard. The kelp forests are extremely valuable biotopes and home to a large number of invertebrates and fish that spawn and grow up here. Sea urchins, *Strongylocentrotus droebachiensis*, are attached to this biotope and graze on the kelp stalks. Another example of a biotope containing a particularly large number of species is the deep-water coral reefs, especially those with the stone coral, *Lophelia pertusa*. These reefs have been mapped in recent years, and large ones have been discovered off Røst. Reefs are also known on the shelf off Finnmark. Just as the coral reefs offer space for an associated abundance of animal life, the occurrences of sponges in the Barents Sea are valuable for the species diversity. Large aggregations of sponges (for example *Geodia*) have been found on Tromsøflaket, and these are currently being mapped. The deeper parts of the Barents Sea are covered by fine-grained sediment, sand and mud, and the infauna (benthic animals living in the sediment) are dominated by polychaetes (bristleworms). The echinoderms, brittle stars and sea urchins, are important constituents of the bottom fauna. On the shallower banks, the sediment is coarser due to current activity, and there are larger numbers of bivalves here, such as the Iceland scallop, *Chlamys islandica*. This species has been fished quite extensively.

A relationship has been found between the biomass of benthic animals and the ice edge in the Barents Sea. This increase in the biomass is correlated, among other things, with the high seasonal pulse in the growth of algae during the short, intense spring, and with processes in the water that cause the food to sink to the bottom. However, as the ice margin may vary by several hundred kilometres from year to year, the benthic animals must also tolerate large fluctuations in the accessibility of food.

Red king crab (*Paralithodes camtschatica*) was introduced to the Barents Sea in the 1960s (Jørgensen and Hop). The stock is growing and expanding eastwards and along the Norwegian coast westwards. Adult red king crabs are opportunistic omnivores.

Northern shrimp (*Pandalus borealis)* is an important prey for several fish species, especially cod, but also other fish stocks like blue whiting (ICES 2005). Consumption by cod significantly influences shrimp population dynamics. The estimated amount of shrimp consumed by cod is on average much higher than shrimp landings. Shrimp is most abundant in central parts of the Barents Sea and close to Svalbard, mostly on 200 – 350 meter depths (Aschan, 2000). It is common close to the sea floor, preferably silt or fine-grained sand. Shrimp in the southern parts of the Barents Sea grow and mature faster than shrimp in the central or northern parts.

2.2.1.6 Fish community in the Barents Sea

The Barents Sea is a relatively simple ecosystem with few fish species of potentially high abundance. These are Northeast Arctic cod, haddock, Barents Sea capelin, polar cod and immature Norwegian Spring-Spawning herring. The last few years there has in addition been an increase of blue whiting migrating into the Barents Sea. The composition and distribution of species in the Barents Sea depends considerably on the position of the polar front. Variation in the recruitment of some species, including cod and herring, has been associated with changes in the influx of Atlantic waters into the Barents Sea.

Capelin (*Mallotus* villosus) plays a major role in the Barents Sea ecology, even though the stock has fluctuated greatly in recent years. In summer, they migrate northwards and feed on the zooplankton as the ice margin retreats. Here, they have continuous access to new food resources in the productive zone that has just become ice-free. In September-October, the capelin may have reached 80ºN before they migrate southwards again to spawn on the coasts of north Norway and Russia. In the central and southern Barents Sea, the capelin become prey for cod. Some marine mammals and seabirds also have a strong preference for capelin. Their feeding migration means that capelin function as transporters of biomass from the ice margin to the Norwegian coast, and that the production from areas covered by ice in winter is available for the cod. The capelin were heavily fished in the 1970s and the first half of the 1980s at a time when there were few herring in the area. In the mid-1980s, the stock collapsed and has since varied greatly. Fishing is permitted when the stock is both strong enough for good recruitment and to cover the consumption by cod.

Polar cod (*Boreogadus saida*) are adapted to cold water and live mainly in the eastern and northern Barents Sea. They are an important prey for many marine mammals and seabirds, but have little commercial significance.

Cod (*Gadus morhua*) are the most important predator fish in the Barents Sea and take a variety of prey. They spawn along the Norwegian coast from Møre to Finnmark, and after hatching they are dependent on *Calanus finmarchicus* nauplii in the initial phase of their growth before they begin to take larger plankton and small fish. In addition to capelin, shrimps and amphipods are important prey.

Haddock (*Melanogrammus aeglefinus*) feed on somewhat smaller prey, especially among the benthic fauna. The stock has substantial natural fluctuations, but is currently strong.

Saithe (*Pollachius virens*) are the third large member of the cod family with substantial economic importance, and occurs in comparatively warm, coastal waters. Like cod, saithe fry depend upon zooplankton, but saithe subsequently become important predators on other fish.

Blue whiting (M*icromesistius poutassou*) are a smaller member of the cod family, and has its main distribution in the southern part of the northeast Atlantic. It mostly eats plankton, but larger individuals also take small fish. It can enter the southern Barents Sea in warm years.

Norwegian spring-spawning herring (*Clupea harengus*) spawn along the Norwegian coast from Lindesnes in the south to Vesterålen, grow up in the Barents Sea and feed in the Norwegian Sea as adults. In years when recruitment is good, most of the 0-group individuals drift passively into the Barents Sea, where they remain until they are around three years old. The young herring are predators on capelin larvae, and when there are many herring in the Barents Sea the capelin recruitment and the capelin stock will be depleted. This has great consequences for the balance between the species of fish in the area and for the ecosystem in general. A depleted capelin stock means less transport of production from the northern to the southern Barents Sea, and less supply of capelin for cod and other predators. It appears as though herring only to a limited extent replace capelin as prey for cod; hence, there will also be less production of species that depend upon capelin. Young herring are not fished in the Barents Sea, but some catches of adult herring are taken in the southwestern part of the management area.

Deep-water redfish (*Sebastes mentella*) and golden redfish (*Sebastes marinus*) are slow-growing, deep-water species that have been heavily fished, and their fishing is now strictly regulated to rebuild the stocks. Redfish fry eat plankton, whereas larger individuals take larger prey, including fish.

Greenland halibut (*Reinhardtius hippoglossoides*) have an extensive distribution in deep water along the continental slope between the Barents Sea and the Norwegian Sea. It is also found in the deeper parts of the Barents Sea and north of Spitsbergen. Juveniles live in the northern parts of the Barents Sea. Fish, squids, octopi and crustaceans are the most important food of the Greenland halibut. The Greenland halibut stock is depleted at present, and fishing is strictly regulated.

2.2.1.7 Seabirds

The Barents Sea holds one of the largest concentrations of seabirds in the world (Norderhaug *et al.* 1977; Anker-Nilssen *et al.* 2000). About 20 million seabirds harvest approximately 1.2 million tonnes of biomass annually from the area (Barrett *et al.* 2002). About 40 species are thought to breed regularly around the northern part of the Norwegian Sea and the Barents Sea. The most typical species belong to the auk and gull families, and some of them are listed below.

There are about 1 750 000 breeding pairs of Brünnich’s guillemot (*Uria lomvia*) in the Barents region. They live on fish, particularly polar cod, and ice fauna.

The population of common guillemots (*Uria aalge*) is about 140 000 breeding pairs. Capelin is the most important food source all the year round.

There are thought to be more than 1.3 million pairs of little auk (*Alle alle*) in the Barents Sea. It is found in the area throughout most of the year and many probably winter along the ice margin between Greenland and Svalbard and in the Barents Sea. Small pelagic crustaceans are the main food for this species, but they may also feed on small fish.

The black-legged kittiwake (*Rissa tridactyla*) breeds around the whole of Svalbard, but like the Brünnich’s guillemot it is most common on Bjørnøya, Hopen and around Storfjorden. Its most important food items in the Barents Sea are capelin, polar cod and crustaceans. The breeding population seems stable, comprising 850 000 pairs in the Barents region.

The northern fulmar (*Fulmarus glacialis*) is an abundant Arctic and sub-Arctic species living far out to sea except in the breeding season. It lives on plankton and small fish taken from the surface. The population estimates are uncertain, but high (100 000 - 1 000 000 pairs).

The Atlantic puffin (*Fratercula arctica*) is the most abundant seabird on the mainland and in the Norwegian Sea, but may also breed on Bjørnøya and on Svalbard.

2.2.1.8 Marine mammals

About 24 species of marine mammals regularly occur in the Barents Sea, comprising 7 pinnipeds (seals), 12 large cetaceans (large whales) and 5 small cetaceans (porpoises and dolphins). Some of these species (including all the baleen whales) have temperate/tropical mating and calving areas and feeding areas in the Barents Sea (*e.g.* minke whale *Balaenoptera acutorostrata*), others reside in the Barents Sea all year round (*e.g.* white-beaked dolphin *Lagenorhynchus albirostris* and harbour porpoise *Phocoena phocoena*). Only the beluga whale (*Delphinapterus leucas*), the bowhead whale (*Balaena mysticetus*) and the narwhal (*Monodon monoceros*) remain in the area throughout the year.

The currently available abundance estimates of the most abundant cetaceans in the north-east Atlantic (*i.e.* comprising the North, Norwegian, Greenland and Barents Seas) are: minke whales 107,205; fin whales *B. physalus* 5,400; humpback whales *Megaptera novaeangliae* 1,200; sperm whales *Physeter macrocephalus* 4,300 (Skaug *et al.* 2002, Øien 2003, Skaug *et al.* 2004).

Lagenorhyncus dolphins are the most numerous smaller cetaceans, with an abundance of 130,000 individuals (Øien 1996). The population of harbour porpoises (*Phocoena phocoena*) has been estimated to 11 000 (Bjørge and Øien, 1995) in the Barents Sea, mostly along the coast.

Beluga whales may occur in groups varying from a few individuals to more than 1000. It is one of the most commonly observed whales off Svalbard. It may feed on everything from benthic invertebrates, octopi and squids to fish.

The bowhead whale is an arctic species closely attached to the sea ice, but is rarely observed in the Barents Sea. No estimates of the Barents Sea population exist but it is agreed that it is small, maybe in the tens. Before it was decimated by whaling, the bowhead whale was very numerous in the fjords and along the coast of Spitsbergen. It feeds on various species of zooplankton.

The killer whale also enters the Barents Sea, but its life cycle presently is tightly connected to the migrations of the Norwegian spring spawning herring.

Harp seals are the most numerous seal in the Barents Sea with approximately 2.2 million individuals. The Norwegian coast has experienced periodical invasions of harp seals.

Ringed seals are abundant in the Svalbard area and the ice-covered parts of the Barents Sea. They mostly live solitarily and take polar cod, shrimps and amphipods beneath the ice.

The bearded seal is another common, solitary species. It lives in the ice-covered parts of the Barents Sea and the fjords around Svalbard taking benthic organisms like shells, crabs and shrimps, which it finds in shallow water.

The harbour seal mainly lives in colonies along the Norwegian coast and in other coastal areas. In 1994-1998, close to 1300 individuals were recorded along the Norwegian coast. In addition, there is a small population off Svalbard.

Marine mammals are significant ecosystem components. In the Barents Sea the marine mammals may eat 1.5 times the amount of fish caught by the fisheries. Minke whales and harp seals may consume 1.8 million and 3-5 million tonnes of prey per year, respectively (*e.g.*, crustaceans, capelin, herring, polar cod and gadoid fish; Folkow *et al.* 2000, Nilssen *et al.* 2000). Functional relationships between marine mammals and their prey seem closely related to fluctuations in the marine systems. Both minke whales and harp seals are thought to switch between krill, capelin and herring depending on the availability of the different prey species (Lindstrøm *et al.* 1998, Haug *et al.* 1995, Nilssen *et al.* 2000).

2.2.2 Fisheries effects on the ecosystem

In order to conclude on the total impact of trawling, an extensive mapping of fishing effort and bottom habitat would be necessary. However, its qualitative effects have been studied to some degree (ICES 2000). The most serious effects of otter trawling have been demonstrated for hard-bottom habitats dominated by large sessile fauna, where erected organisms such as sponges, anthozoans and corals have been shown to decrease considerably in abundance in the pass of the ground gear. In sandy bottoms of high seas fishing grounds trawling disturbances have not produced large changes in the benthic assemblages, as these habitats may be resistant to trawling due to natural disturbances and large natural variability. Studies on impacts of shrimp trawling on clay-silt bottoms have not demonstrated clear and consistent effects, but potential changes may be masked by the more pronounced temporal variability in these habitats (Løkkeborg, 2004). The impacts of experimental trawling have been studied on a high seas fishing ground in the Barents Sea (Kutti *et al.*, 2005). Trawling seems to affect the benthic assemblage mainly through resuspension of surface sediment and through relocation of shallow burrowing infaunal species to the surface of the seafloor. Lost gears such as gillnets may continue to fish for a long time (ghost fishing). The catching efficiency of lost gillnets has been examined for some species and areas, but at present no estimate of the total effect is available. Other types of fishery-induced mortality include burst nets, and mortality caused by contact with active fishing gear such as escape mortality. Some small-scale effects are demonstrated, but the population effect is not known. The harbour porpoise (*Phocoena phocoena*) is common in the Barents Sea region south of the polar front and is most abundant in coastal waters. The harbour porpoise is subject to by-catches in gillnet fisheries (Bjørge and Kovacs 2005). In 2004 Norway initiated a monitoring program on by-catches of marine mammals in fisheries. Several bird scaring devices has been tested for long-lining, and a simple one, the bird-scaring line (Løkkeborg 2003), not only reduces significantly bird by-catch, but also increases fish catch, as bait loss is reduced. This way there is an economic incentive for the fishermen, and where bird by-catch is a problem, the bird scaring line is used without any forced regulation.

Fishing on capelin has the potential to disrupt the food chain between zooplankton and predators like cod, harp seals, minke whales and some birds. However, fishing on capelin is only permitted when the stock is sufficiently large enough both to sustain the predation by cod and to allow good recruitment.

Estimates on unreported catches on cod the last years indicate that this is a considerable problem; at least 20% in addition to official catches (ICES, 2005b).

2.2.2.1 Knowledge Gaps

Inflow of water from the Norwegian Sea to the Barents Sea brings with it populations of phyto- and zoo-plankton which become part of the Barents Sea production system. A study of the volume and timing of inflow events and plankton production in the Barents Sea would be helpful in understanding this part of the production system.

Gjøsæter et al. (2002) showed that there is a connection between measured zooplankton biomass and capelin growth during the following year. Further work on the connection between zooplankton production and the production of pelagic forage fishes (capelin, polar cod, herring and possibly blue whiting) would be important in understanding the mechanisms of food supply for cod and larger predators like harp seals and minke whales.

Data about stomach contents and prey consumption for cod is available for a number of years and is used by AFWG. Information about predator/prey relationships is needed for more of the quantitatively important consumer species and groups.

Fisheries statistics from the Barents Sea does not fully reflect landings and discards, as has been described for cod in AFWG reports.

More information on these points would improve the qualitatative and quantitative understanding of the production system being harvested through fishing, and the effects of fishing on the ecosystem.

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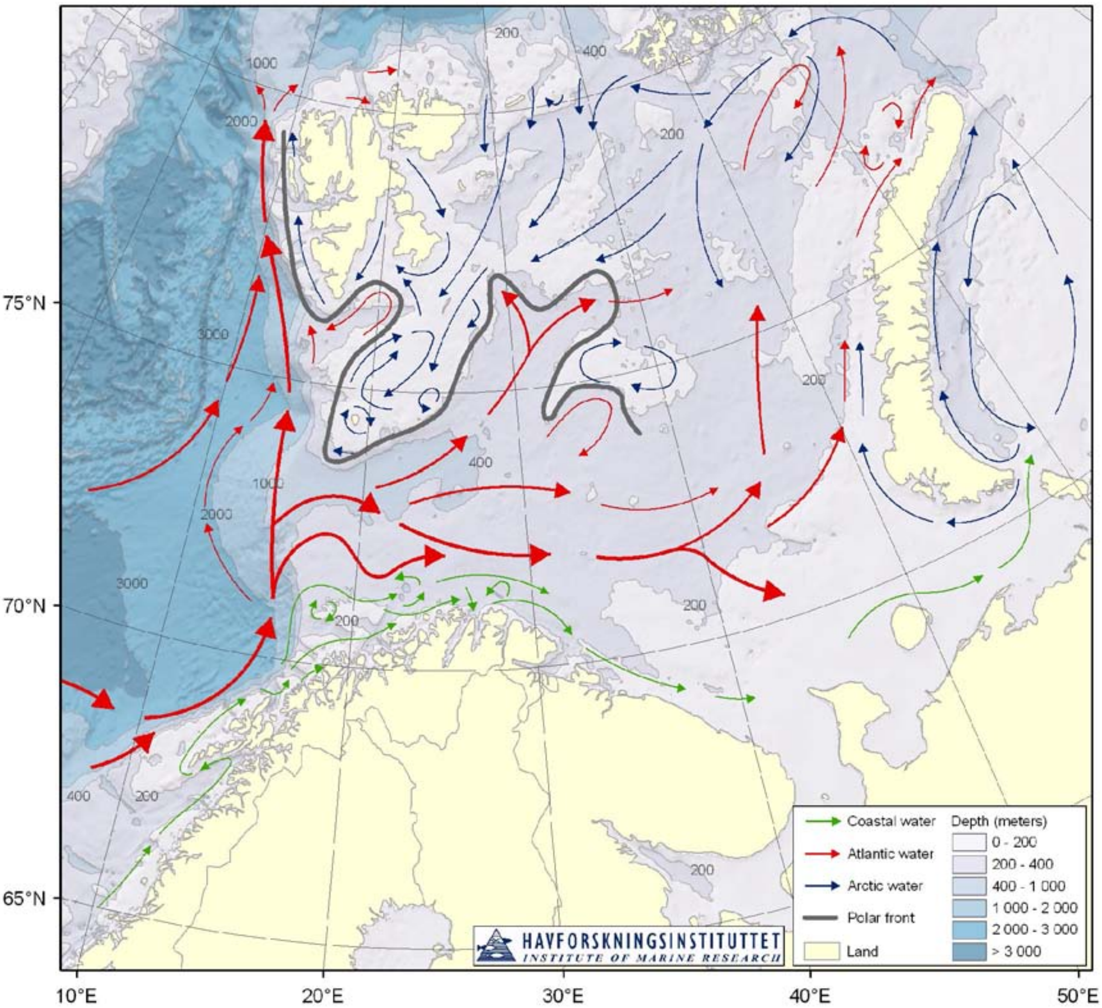

Figure 2.2.1 Bottom contours and current systems in the Barents Sea.

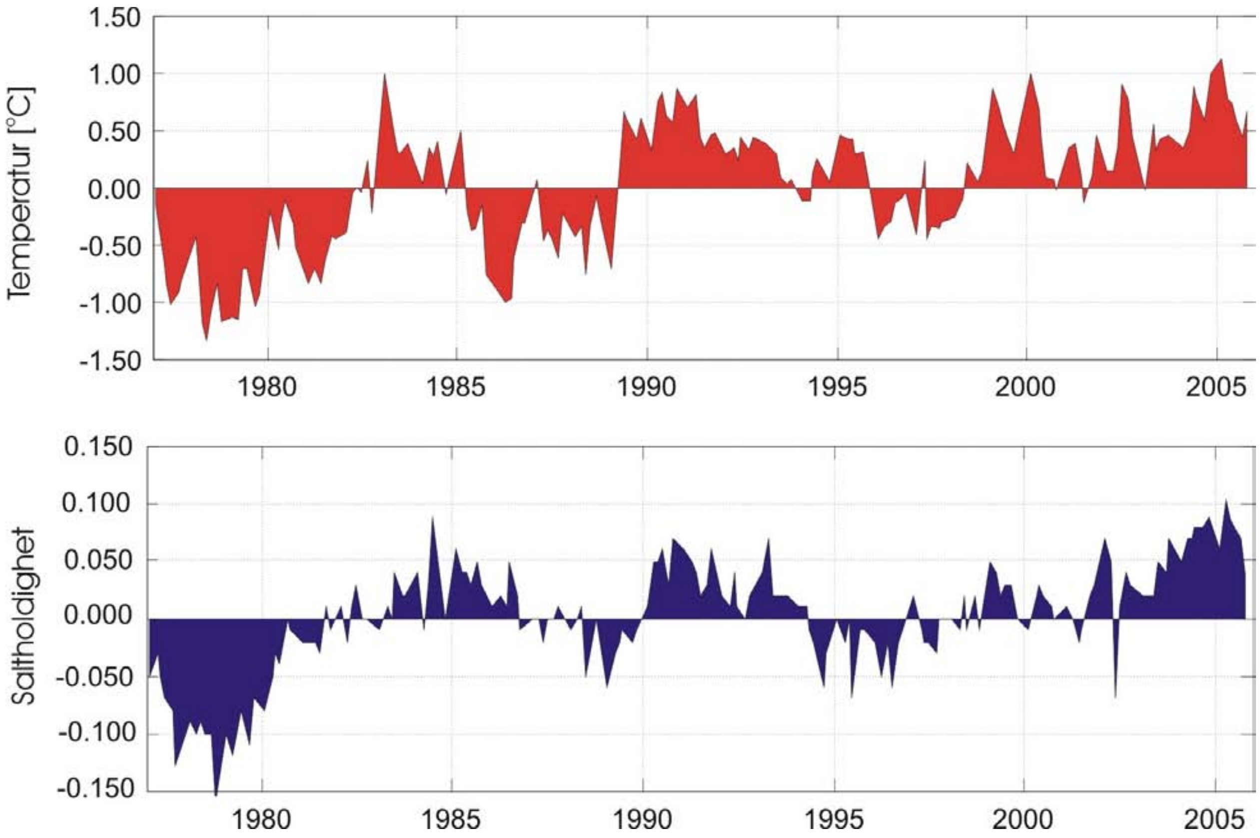

Figure 2.2.2. Temperature (upper graph) and salinity (lower graph) anomalies in the Fugløya - Bjørnøya transect during the period 1977 - 2005.

2.3 Norwegian Sea

2.3.1 Ecosystem Components

2.3.1.1 General geography

The Norwegian Sea is traditionally defined as the ocean bounded by a line drawn from the Norwegian Coast at about 61°N to Shetland, further to the Faroes-East Iceland-Jan Mayen-the southern tip of Spitsbergen-the Vesterålen at the Norwegian coast and the along the coast. In addition a wedge shaped strip along the western coast of Spitsbergen is included in area D. The offshore boundaries follow in large part the mid Atlantic subsurface ridges.

The Norwegian Sea has an area 1,1 million km^2 and a volume of more than 2 million km^3, i.e. an average depth of about 2000m. The Norwegian Sea is divided into two separate basins with 3000m to 4000m depth, with maximum depth 4020m. Along the Norwegian coast there is a relatively narrow continental shelf, between 40 and 200 km wide and with varied topography and geology. It has a relatively level sea bottom with depths between 100 and 400 m. The shelf is crossed by several troughs deeper than 300. Moraine deposits dominate the bottom substratum on the shelf, but soft layered clay is commonly found in the deeper parts. Gravelly and sandy bottoms are found near the shelf break and on ridges where the currents are strong and the sedimentation rates low.

2.3.1.2 General Oceanography

The circulation in the Norwegian Sea (Figure 2.1.3) is strongly affected by the topography. On the continental shelf at the eastern margin of the area flows the low salinity Norwegian Coastal Current. It enters the area from the North Sea in the south and exits to the Barents Sea in the north east. The inflow of water from the north Atlantic to the Norwegian Sea takes place through the Faroe-Shetland Channel and flow over the Iceland-Faroe Ridge. At the northern slope of the ridge the warm Atlantic water meets the cold Arctic water and the boundary between these waters are called the Iceland Faroe Front. The major part of the warm and high salinity Atlantic Water continues northward as the Norwegian Atlantic Current along the Norwegian shelf, but parts of it branches into the North Sea and also to the more central parts of the Norwegian Sea. At the western boundary of the Barents Sea, the Norwegian Atlantic Current further bifurcates into the North Cape Current flowing eastwards into the Barents Sea and the West Spitsbergen Current flowing northwards into the Fram Strait (Furevik 2001).

The border zones between the domains of the Norwegian Atlantic Current and the Arctic waters to the west are known as the Arctic and Jan Mayen Fronts, located north and south of Jan Mayen, respectively. Cold and low salinity Arctic Water flows into the southern Norwegian Sea in the East Icelandic Current. At the northern flank of the Iceland Faroe Ridge the East Icelandic Current meets the warm Atlantic Water that crosses the ridge into the Norwegian Sea and this boundary is called the Iceland Faroe Front. The front has a clear surface signature, but a part of the Arctic Water submerges under the Atlantic Water and thus becomes Arctic Intermediate Water.

With respect to the underlying waters, there is evidence that the Arctic Intermediate Water has been expanding in volume in recent decades (Blindheim, 1990; Blindheim et al., 2000). The Arctic Intermediate water manifests itself as a salinity minimum in the water column and it blankets the entire Norwegian Sea and thus precludes direct contact between the warm surface waters and the dense deep waters (T<-0.5°C) whose properties are defined by inflows from the Greenland Sea. The circulation in the deep waters is topographically influenced and clockwise in the two basins. Cold deep water flows out of the Norwegian Sea through the Faroe Bank channel, the deepest connection to the North Atlantic.

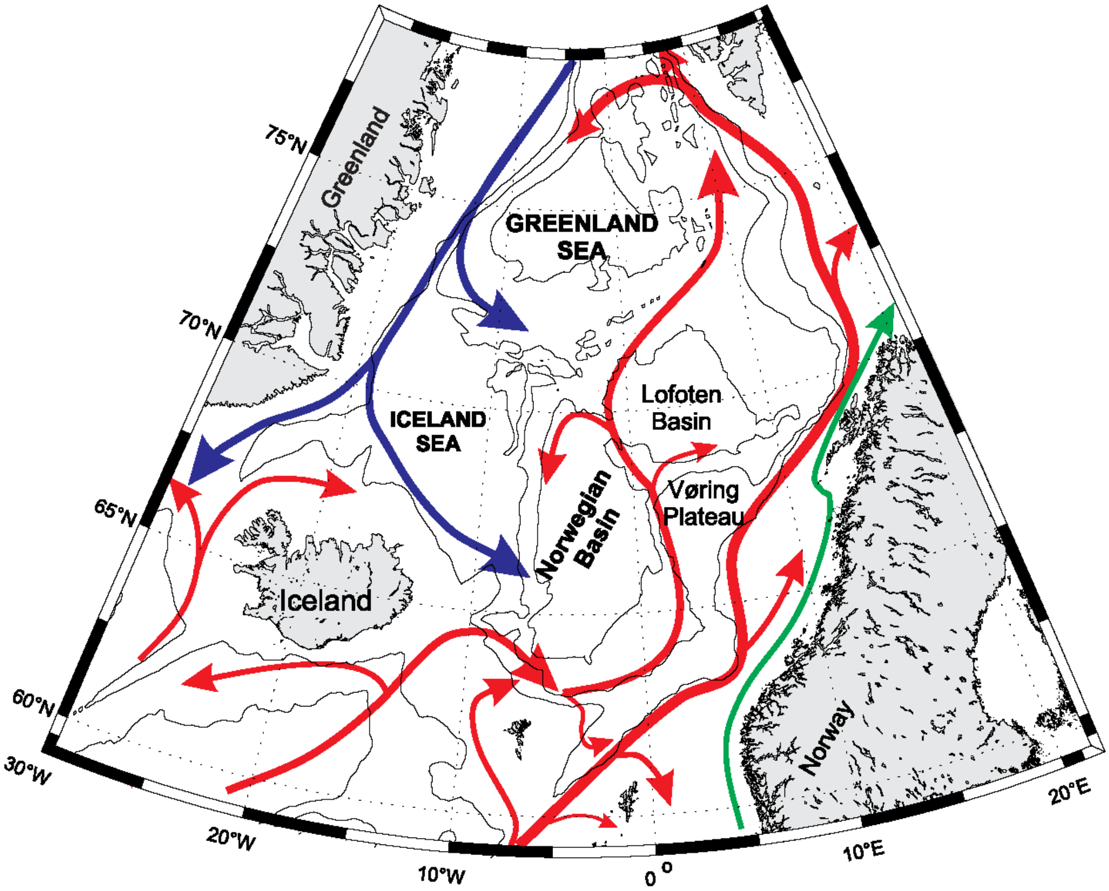

Figure 2.2.3. Norwegian Sea main circulation pattern. Red lines indicate warm currents, blue lines indicate cold currents and green lines show low salinity coastal water.

2.3.1.3 Climate variability

Between Iceland and Jan Mayen variations in the volume of Arctic waters carried by the East Icelandic Current (EIC) may result in relatively large shifts of the front between the cold Arctic waters and the warm Atlantic water. Fluctuations in fluxes and water-mass properties in the two major current systems are therefore of decisive importance for the structure and distribution of the water masses in the Nordic Seas. A high NAO index with strong westerly winds results in increased transport in the EIC. E.g. in the early 1990s the NAO index was high and the Arctic water occupied a larger portion of the Norwegian Sea. The volume of and properties of the Arctic water carried directly into the Norwegian Sea by the EIC play a larger role than previously believed in the creation of variability in the distribution of water masses and their properties in the Nordic Seas (Blindheim et al. 2000).

2.3.1.4 Phytoplankton

The annual rate of primary production in the Atlantic Water has been estimated to be about 80 g C m^{-2} $year^{-1}$ (Rey 2004). Of this production about 60% is new production, i.e. the remainder 40% of the production is assumed to be based on regenerated nutrients. The new production represents the potential for harvest in the ocean. The spring bloom, defined as the time of the maximum chlorophyll concentration, occurs in the mean around 20th of May, but may occur a month earlier or later. The most important group of phytoplankton is the diatoms, with most of the species belonging to the Order Centralis, and the most important representatives are species of the genus *Thalassiosira* and *Chaetoceros*. After the diatom spring bloom the phytoplankton community is often dominated by the flagellate *Phaeocystis pouchetii*. In the Norwegian Coastal Current the primary production varies from 90-120 g C m^{-2} $year^{-1}$.

2.3.1.5 Zooplankton

The zooplankton community of the Norwegian Sea is dominated by copepods and euphausids. The main copepod is *Calanus finmarchicus* in the Atlantic water while *Calanus hyperboreus* is the dominant species in the arctic watermasses. The main euphausids are *Meganychthiphanes norvegica*, *Thysanoessa inermis* and *Thysanoessa longicaudata*. Other important zooplankton are the hyperids *Themisto libellula* and *Themisto abyssorum*. The plankton community show varying productivity with concentrations of the most important species *Calanus finmarchicus* varying for instance between about 8 g/m^2 dryweight in 1997 to 28 g/m^2 dryweight in 1995. The highly variable availability of zooplankton is an important factor for fish stocks productivity.

2.3.1.6 Benthic habitats in the Norwegian Sea

Coral reefs formed by the cold-water coral *Lophelia pertusa* are quite common in the eastern shelf area of the Norwegian Sea. Nowhere else in the world similar densities and sizes of such reefs have been found. The largest reef, or reef complex (comprising several closely situated individual reefs) known as the Røst Reef, is situated south west of Lofoten. *Lophelia* reefs offers habitats (microhabitats) for a great diversity of other species. Redfish (*Sebastes* spp.) are common on the reefs. The great abundances of this fish has been known by local fishers for a long time. More recent fishery practice employing rock hopper trawl gear close to or directly on these reefs has led to severe damages. Other corals such as gorgonians also form habitats utilised by fish and other organisms. These habitats are often called “gorgonian forests”, and are common in some fjords and along the shelf break.

2.3.1.7 Fish community of the Norwegian Sea

The Norwegian Sea fish community is characterised by a number of large stocks of medium sized highly migratory pelagic species exploiting the pelagic zone of the vast areas with large bottom depths, smaller mesopelagic species exploiting the same areas and several demersal and pelagic stocks exploiting and/or spawning in the marginal eastern continental shelf areas. The large stocks exploiting the area for feeding must be regarded key species in the ecosystem. The main pelagic stocks feeding in the area are the blue whiting *Micromesistius poutassou*, NE Atlantic mackerel *Scomber scombrus* and Norwegian spring spawning herring *Clupea harengus*. The herring also spawns in the eastern shelf areas. With regard to horizontal distribution in the feeding areas the herring is the most northern one, mackerel more southern while the blue whiting seems distributed over most of the area. With regard to vertical distribution during the feeding season the mackerel is closest to the surface, the herring somewhat deeper, while the blue whiting as a mesopelagic species with the deepest mean depth distribution. Other important mesopelagic species in the area are redfish *Sebastes sp.*, pearlsides *Maurolicus muelleri* and lanternfishes *Benthosema glaciale*. The open Norwegian Sea all way into the polar front is an important nursery areas for the lumpsucker *Cyclopterus lumpus* and the northeastern shelf areas are important spawning grounds. Local stocks of herring exist in many fjords along the Norwegian coastline. The stocks make limited migration out in to the open waters for feeding.

None of the main pelagic species has its entire life cycle within the Norwegian Sea ecosystem. The blue whiting spawns west of the British Isles and perform a northerly and westerly feeding migration into the Faroes ecosystem and the Norwegian Sea ecosystem. The mackerel spawns west of the British Isles and in the North Sea and performs northerly feeding migrations into the Norwegian Sea. The Norwegian spring spawning herring has its main spawning and feeding areas in the Norwegian Sea while the main nursery and young fish area is in the neighbouring Barents Sea ecosystem.

As pelagic feeders all the three stocks must be expected to have major influences on the ecosystem. Studies on this subject have only been carried out to a limited degree and are mainly of descriptive character. For instance was the highest catches of salmon ever (1970'ies) taken during a period when the herring stock was at a record low level. This has been suggested to be a potential effect of reduced competition beneficial for salmon stock productivity (Hansen et al., 2000).

The NE Arctic cod *Gadus morhua* and haddock *Melanogrammus aeglefinnus* have their main adult feeding and nursery areas in the Barents Sea while the main spawning areas are along the eastern shelf areas of the Norwegian Sea and into the SE parts of the Barents Sea ecosystem. There are local cod stocks connected to the coast and only doing limited migrations from the coast for feeding. The NE Arctic saithe also spawns along the eastern shelf areas of the Norwegian Sea and has important nursery areas on this coastline and into the Barents Sea on the Finmark coast. The migration of older and mature saithe are to a large degree linked with those of the Norwegian spring spawning herring out into the high seas areas of the Norwegian Sea. There are also stocks of ling *Molva molva* and tusk *Bromse brosme* along the eastern shelf region. Greenland halibut *Reinhardtius hippoglossoides* is found along the eastern shelf and also in the shelf areas of Jan Mayen Island. Other important species inhabiting the hydrographic transition zone include roughead grenadier *Macrourus berglax*, several species of eelpouts *zoarcids* and the rajiids *Raja hyperborean, R. radiata* and *Bathyraja spinicauda* (Bergstad et al., 1999).

The demersal species are in general connected to the eastern shelf area and the presence of the largest stocks are connected to spawning. The fishes then migrate back to the Barents Sea for feeding. The fry also in general drift out of the Norwegian Sea and into the Barents Sea. As compared to the pelagic species the demersal stocks must accordingly be regarded as less significant for the Norwegian Sea ecosystem as a whole.

2.3.1.8 Seabirds

No information was provided

2.3.1.9 Seals in the Norwegian Sea

There are two seal stocks of particular importance in the Norwegian Sea: Harp and hooded seals. Both species are mainly connected to the Norwegian Sea through feeding. They show opportunistic feeding patterns in that different species are consumed in different areas and at different times of the year.

2.3.1.10 Whales in the Norwegian Sea

Due to topographical and hydrographic characteristics beneficial for production the Norwegian Sea has abundant stocks of whales feeding on plankton, pelagic fishes and Cephalopods. Besides minke whale, fin whale, blue whale, sperm whale, humpback and killer whales are important species in the area. All except the killer whale are seasonal migrators visiting the Norwegian Sea for feeding during the summer.

The minke whale *Balaenoptera acutorostrata* is the smallest in size and most numerous in stock size of the baleen whales in the Norwegian Sea. It is found throughout the area, in particular along the eastern shelf area and in the Jan Mayen area. The species is an opportunistic feeder with special preference for herring in the Norwegian Sea ecosystem.

The killer whale *Orcinus orca* in the area is closely linked to the yearly migrations of the Norwegian spring spawning herring. In the present wintering area of the herring, the Vestfjord, Tysford and Ofotfjord an estimated 500 killer whales have been feeding on herring during the winter months. A total estimate of killer whales for the Norwegian Sea and the Barents Sea it is at some few thousands individuals.

2.3.2 Fisheries effects on the ecosystem

Destruction of deepwater coral reefs has been documented in the eastern shelf areas. These descriptions have resulted in management measures like area closures for bottom trawling. Effects on bottom fauna could be expected from bottom trawling activities in the eastern shelf areas.

Work is carried out within the framework of ICES in order to sort out the scale of unintentional bycatch of salmon in the pelagic fisheries in the Norwegian Sea (SGBYSAL) but no such major effects have been documented so far.

Mortality of seabirds occurs in longline fisheries. Magnitude and species composition is unknown.

Bycatch of harbour porpoise is routinely observed in net fisheries. In episodes of coastal invasion of arctic seals large mortality of seals has been observed in net fisheries. This mortality has not been regarded as problematic for the state of the seal stocks due to the general good condition and low harvesting level of the stocks.

Mortality of large marine mammals due to bycatch has not been described and is probably low.

Ghost fishing has been documented through dredging of lost gear along the eastern shelf area. A programme for retrieval of such gears is in effect along the Norwegian coast towards the Norwegian Sea, and a high number of ghost fishing nets are retrieved yearly. The need for such activity is probably larger than what is currently carried out, given the fish mortality observed in retrieved nets.

A major collapse in the herring stock was observed during the late 1960'ies. Various analyses have shown that the fisheries were a major factor driving the collapse.

2.3.3 Major significant ecological events and trends in the Norwegian Sea in 2005

Generally warming climate during the last 20 years with about 0.7ºC increase since 1978 in the Atlantic Water on the Svinøy section. The years 2002-2005 are all warm years, but there was a small drop in temperature from 2004 till 2005. The salinity, however, has continued to increase and was record high in 2005 in the Atlantic Water on the Svinøy section.

In 2005, there was an increased influence of Arctic water, from the East Icelandic Current, in the southern Norwegian Sea compared to 2004, and thus lower temperatures. Otherwise no major hydrographic events in 2005.

Generally low zooplankton in the central Norwegian Sea for several years.

Large stocks of all major pelagic stocks. The total stock of highly migratory plankton feeders is high at ~20-25 million tonnes.

Changes in herring feeding migration occurred during the summers 2004 and 2005 when increasing amounts of herring started to feed in the southwestern Norwegian Sea. At the same time we observed that increasing numbers of herring were not wintering in the fjords of northern Norway, but in the deep waters off the shelf. This winter (2005/2006) the main wintering area was off the shelf north of Vesterålen to 72ºN.

Reduced herring growth since 2001. Continued poor growth conditions could be expected unless major migration or productivity changes occur.

2.4 Area c – Faroe Plateau Ecosystem

2.4.1 Ecosystem Components

2.4.1.1 Topography, water masses and circulation

The upper layers of the waters surrounding the Faroes are dominated by 'Modified North Atlantic Water' which derives from the North Atlantic Current flowing towards the east and north-east (Hansen and Østerhus, 2000) (Figure 1, upper left panel). This water is typically around 8°C with salinities around 35.25. Deeper than 500-600 m (Figure 2.4.1 lower left panel), the water in most areas is dominated by cold water (T<0°C) with salinities close to 34.9, flowing out of the Nordic Seas through the deepest passages.

In shallow regions, there are strong tidal currents, which mix the shelf water very efficiently. This results in homogeneous water masses in the shallow shelf areas. The well-mixed shelf water is separated relatively well from the offshore water by a persistent tidal front, which surrounds the shelf at about the 100-130 m bottom depth. In addition, residual currents have a persistent clockwise circulation around the islands (Figure 2.4.1, right panel).

The Shelf-front provides a fair, although variable, degree of isolation between the on-shelf and the off-shelf areas. This allows the on-shelf areas to support a relatively uniform shelf ecosystem, which in many ways is distinct from off-shelf waters. This ecosystem has distinct planktonic communities, benthic fauna, and several fish stocks. Furthermore, about 1.7 million pairs of seabirds breed on the Faroe Islands and take most of their food from the shelf water.

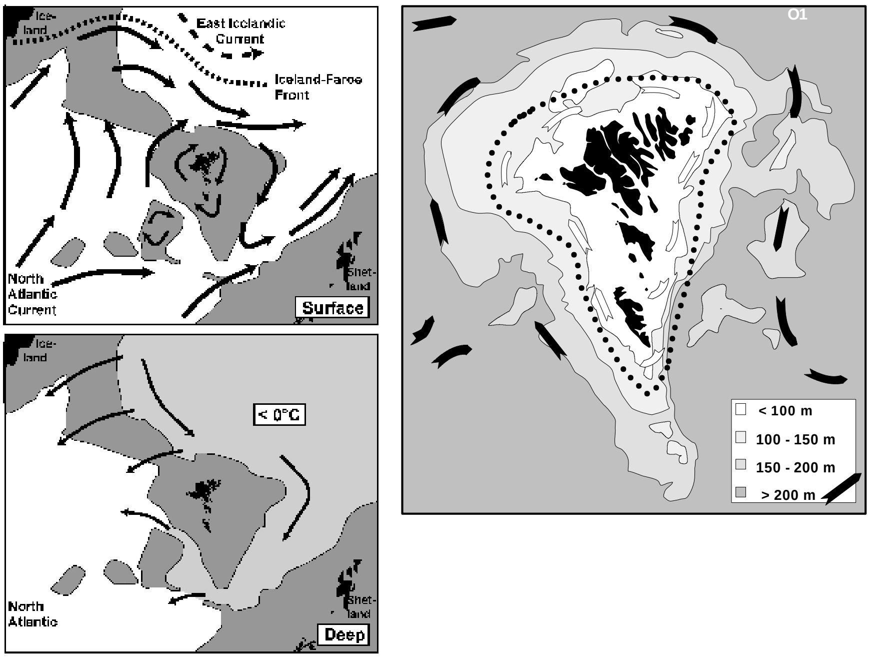

Figure 2.4.1. Bottom topography, circulation and water masses at the surface (top left panel), at depth greater than about 500 m (bottom left panel) in the area around the Faroes and on the Faroe shelf (right panel). Dashed lines indicate fronts.

2.4.1.2 Phytoplankton

The three oceanographic regimes (well-mixed shelf, frontal and stratified off-shelf) give different conditions for primary production. While the shallow well-mixed part is relatively well studied, little is known about production cycles, and their dependence on the variable weather conditions in the two other regimes in the region.

One distinguishing feature is a typical earlier establishment of the spring bloom on the shelf than offshelf. However, timing and intensity of the bloom can vary very much from one year to another. This variability has pronounced effects on the ecosystem.

Most of the primary production usually is from May to August. Timing of the onset of primary production in spring is, however, highly variably between years (Figure 2.4.2). This variability affects production of food for fish larvae in spring (Gaard 2000, 2003, Debes et al. 2005), which mainly consists of copepod eggs and nauplii and small copepodites (Gaard and Steingrund 2001).

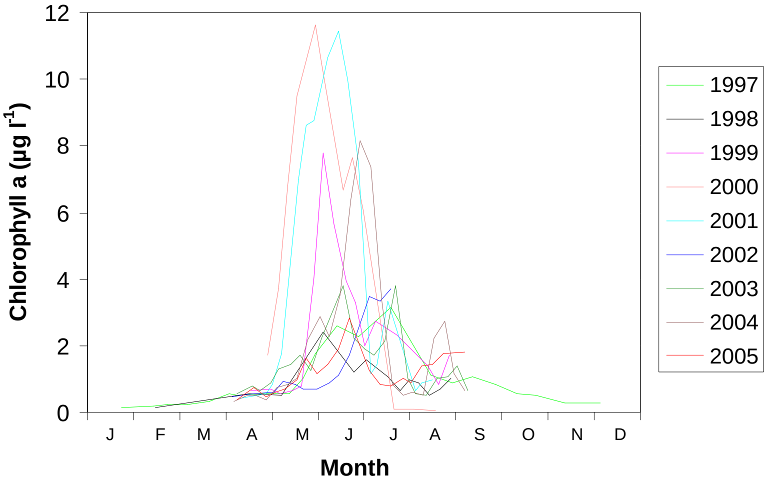

Figure 2.4.2. Chlorophyll a concentrations on the central shelf since 1997.

There is also a very high interannual variability primary production (Gaard 2003, Eliasen et al 2005). From 1990 to 2005 this new primary production (from spring to mid summer) has fluctuated by a factor ~5 (Figure 2.4.3). The new primary production index for 2005 is below the 1990-2005 average (Figure 2.4.3).

The mechanisms controlling the primary production on the shelf are not well understood. However, recent modelling studies indicate that variable exchange rates between on-shelf and off-shelf waters may be a main controlling factor for the timing and intensity of the spring bloom (Eliasen et al. 2005, Hansen *et al*. 2005).

The variability in primary production between years (Figure 2.4.3) highly affects production in higher trophic levels in the ecosystem. The primary production is identified as a main driver for biological productivity in the in the shelf ecosystem, including fish and seabirds (Gaard et al. 2002, 2006, Steingrund and Gaard 2005). Below is described observed affects on fish growth, recruitment, and production, behaviour and catchability.

Primary production variability thus can be used as the first indicator for productive status in the system 1-2 years ahead.

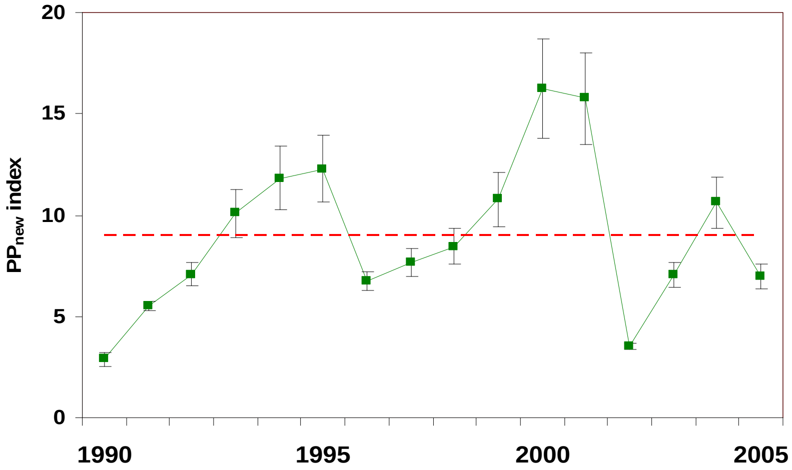

Figure 2.4.3. Index of new primary production from spring to mid-summer on the Faroe shelf since 1990. The horizontal line represents the average index during the 1990-2005 period.

2.4.1.3 Zooplankton

While the zooplankton community outside the shelf front is largely dominated by the copepod *Calanus finmarchicus*, the shelf zooplankton community is basically neritic (shelf related species). During spring and summer the zooplankton in the Shelf water is largely dominated by the copepods *Temora longicornis* and *Acartia longiremis*. *C. finmarchicus*, is advected from offshelf and occurs in the shelf water in highly variable abundance between years. Usually the abundance of *C. finmarchicus* is highest in spring and early summer. Meroplanktonic larvae (mainly barnacle larvae) may also be abundant, and decapod larvae and fish larvae and juveniles are common on the Shelf during spring and summer (Gaard 1999, 2003).

Reproduction rates of copepods depend largely on their feeding conditions and co-occurring fluctuations have been observed between phytoplankton timing and abundance, and copepod egg production rates, abundance and composition (Gaard 1999, Debes et al. 2005). This variability seems to affect feeding conditions for fish larvae in general on the shelf.

2.4.1.4 Fish community

A total of 225 fish species are recorded in Faroese waters. Most of these species are, however, rare and are not exploited. The number of commercially exploited species on the Faroe Plateau is about 25. An overview of typical depth distribution of the main species in offshore and shelf areas (deeper then 65 m bottom depth) is shown in Figure 2.4.4. Most of these species spawn locally, however, some species (e.g. redfish and Greenland halibut have their spawning grounds outside Faroese area and apparently are common stocks over large parts of the Northeast Atlantic.

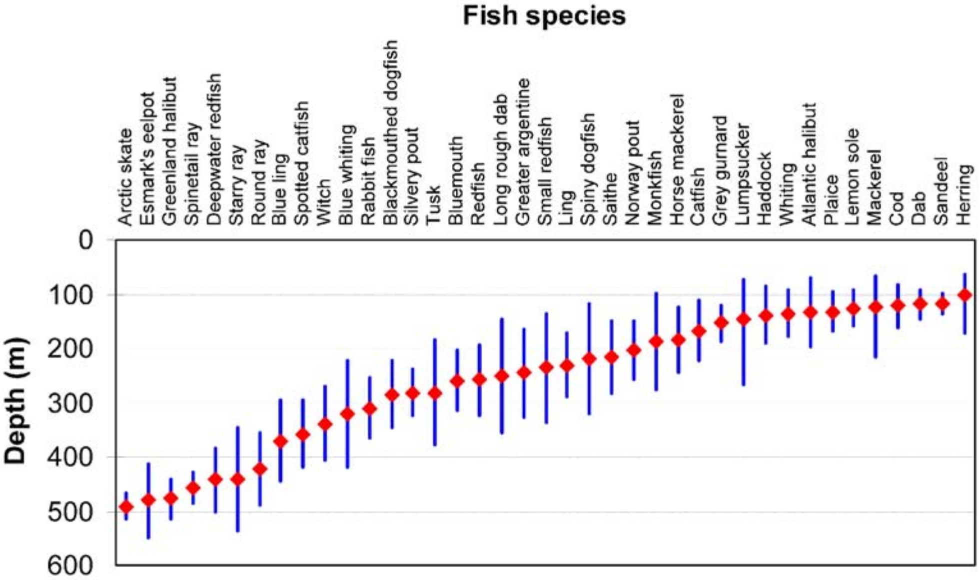

Figure 2.4.4. Typical depth distribution of fish in areas deeper than ~65 m on the Faroe shelf and in the ocean around the Faroes.

Of pelagic fish blue whiting is the most abundant. After spawning to the west of the British Isles in early spring, they start their feeding migration further north into the Norwegian Sea. They usually enter the Faroe eco-region in late April. They feed mainly on krill, amphipods, and other large zooplankton at depths between 300 and 500 meters and partly also on the copepod *Calanus finmarchicus* closer to the surface. In late summer and autumn mature individuals migrate southwards again towards the spawning area while juveniles stay in Faroese water and the Norwegian Sea. Mackerel make a similar migration, although is has a more eastern and shallower distribution. Their main food items are *C. finmarchicus* and krill. Norwegian spring spawning herring may migrate after spawning on the Norwegian shelf in March into the northernmost part of the Faroe eco-region to feed. Later the herring distribution is further north in the Norwegian Sea.

Cod and haddock and saithe are the most commercially important demersal stocks in Faroese waters. Their spawning takes place on the shelf in spring. The saithe spawns mainly in the north-eastern and northern part of the shelf slope in February-March, and the offspring is found close to the shores already in May. At an age of about 3 years they migrate into deep habitats, mainly on the upper slope.

Cod spawns in the northern and western part of the shelf, mainly in March. The spawning grounds of the haddock are more disperse than those of cod and saithe and spawning takes place mainly in April. Their offspring is dispersed by the strong currents throughout the shelf area where they feed, mainly on copepods and decapod larvae (Gaard and Steingrund, 2001; Gaard and Reinert, 2002). In July, at lengths of about 4 cm, the cod juveniles migrate into shallow areas close to shore, while the haddock make the transition to a predominant demersal habit on the plateau and the banks at depths of 90-200 m. At an age of 1-2 years cod starts migration to deeper areas on the shelf.

Two ecologically important fish species in the ecosystem are sandeel and Norway pout. After spawning in spring their offspring too is dispersed by the tidal currents throughout the shelf area where they feed on zooplankton. Both species are important food items for seabirds and demersal fish on the shelf and the upper slope, and are important links between zooplankton and higher trophic levels. Especially sandeels occur in variable abundances between years. They are not commercially exploited.

Detailed knowledge about variability in food consumption of demersal cod, haddock and saithe in Faroese waters is not conclusive. Saithe feeds on the shelf slope largely on fish (mainly blue whiting and Norway pout) with smaller amounts of krill added to their diet. Cod and haddock show higher diversity in prey items, and predate on benthic fauna as well as fish, with fish being a more prevalent prey item for cod than for haddock. Of the fish prey, sandeel appear to be a key species in the shallow areas. When abundant they are a preferred food item for cod on the shelf and hence, already as 0-group sandeels, affecting the feeding conditions for demersal cod on the shelf. Years with high cod production seem to be associated with a high abundance of sandeels. In deeper areas on the plateau other species (mainly Norway pout) are more important as prey item for cod. On the slope other species (mainly blue whiting) may be important.

Despite a marked increase in fishing effort on cod and haddock, the landings have not increased correspondingly. The long-term landings of the cod usually have fluctuated between 20,000 and 40,000 tonnes during the 20th century and of haddock between 12,000 and 25,000 tonnes since the 1950s. The catches of these two main fish stocks therefore have for a long time reached the limit for long-term production within the ecosystem. Variability between years in catches of these species reflects variability in production of the fish stocks.

During the early 1990s the catches of cod and haddock decreased to the lowest on record. The decrease coincided with a severe decrease in productivity in the ecosystem in general, covering all trophic levels, from primary production to fish and seabird feeding conditions, reproduction and growth rates. The ecosystem productivity increased markedly during the first half of 1990s, and the cod and haddock stocks recovered rapidly, due to increased recruitment success, individual growth rates, and due to low fishing mortality during that period (Gaard et al. 2002; Steingrund et al. 2003, ICES 2005, Steingrund and Gaard 2005).

Since monitoring of environmental parameters started in 1990 there has been observed a clear relationship, from primary production to the higher trophic levels, which seem to respond quickly to variability in primary production in the ecosystem.

2.4.1.5 Fish migration versus age and feeding conditions

After the pelagic phase juvenile cod and saithe migrate into shallow areas while the haddock juveniles are dispersing all over the shelf area. At an age of about 2 years cod gradually migrate into deeper habitats on the shelf. Saithe migrates into deeper waters on the upper shelf slope at an age of about 3 years (Figure 2.4.5).

For cod there is, however, observed high variability in distribution between years. During years with poor feeding conditions adult cod tend to migrate into shallow areas. This seems to affect cod recruitment negatively.

Tagging experiments have shown that migration between Faroe Plateau and neighbouring areas is negligible (Joensen et al. 2005).

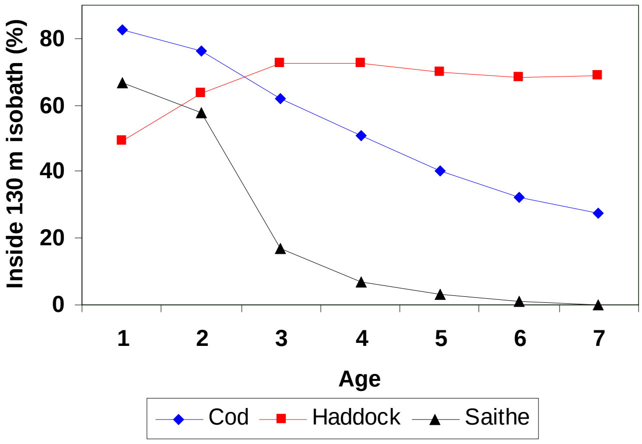

Figure 2.4.5. Proportion of cod, haddock and saithe caught inside the 130 m isobath during summer groundfish surveys 1996-2003. (From Steingrund and Gaard 2005).

2.4.1.6 Cod and haddock recruitment

Data series for cod since 1961 and since 1970 for haddock show no direct relationship between SSB and recruitment fluctuations on the Faroe plateau. On the other hand, long-term relations between cod and haddock recruitment and weight-at-age have demonstrated that periods with high weight-at-age occur simultaneously with good recruitment of 2-years old fish and *vice versa* (Figure 2.4.6) (Gaard *et al.*, 2002; 2006). This underlines strong simultaneous environmental affects on cod and haddock recruitment and growth rates.

Environmental conditions on the Faroe plateau are highly variable and their strong effects on cod and haddock recruitment overshadow spawning stock effects.

The cod and haddock stocks have proven that when environmental conditions are favourable, they are, even with very small SSB, able to recover quickly. It is, however, when the environmental conditions are poor, that the spawning stock influence on recruitment success most likely is highest. Therefore the importance of spawning stocks should not be underestimated – although it is no guarantee for recruitment success.

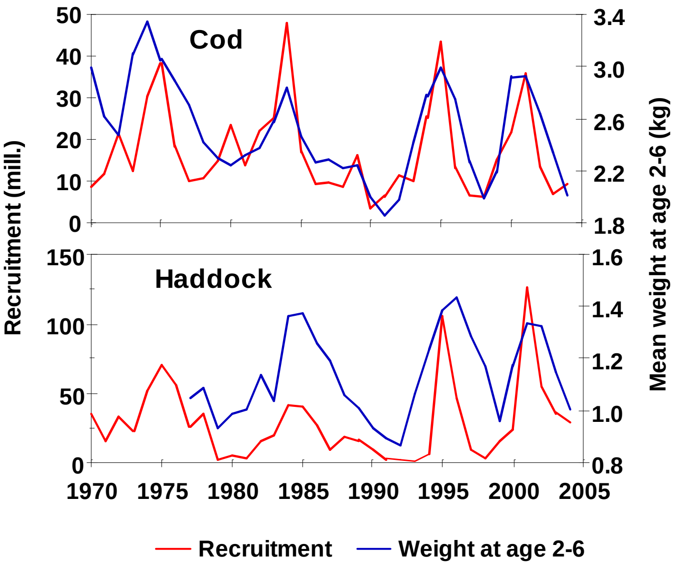

Figure 2.4.6. Relationship between recruitment of 2 years old cod and haddock and the mean weight of 2–6 years old cod during 1970–2004 and haddock during 1976–2004 on the Faroe shelf.

Since 1990, when monitoring of environmental parameters in the Faroe shelf ecosystem started, clear co-occurring fluctuations can be observed in primary production and recruitment of cod and haddock (Figure 2.4.7). However, the abundance of older cod in shallow areas also affects cod recruitment negatively. During periods with low food abundance (low primary production) adult cod (mainly those with low condition factor) tend to migrate into shallow areas, and this affects cod recruitment negatively. When comparing cod recruitment with a combined positive effect from primary production and a negative effect from abundance of adult cod in shallow areas, a very good correlation ($R^2 > 0.8$) is obtained (Steingrund unpubl. data). It should be kept in mind that the available time series is rather short (since 1998), however, the correlation is very strong and seems convincing.

The year-class strength of cod seems to be determined rather late in live: Recruitment estimates of 2 years old cod co-fluctuates positively with primary production the year before. These fluctuations indicate that year-class strength is mainly determined when the cod is 1 year old. (Steingrund and Gaard, 2005; Steingrund unpublished data).

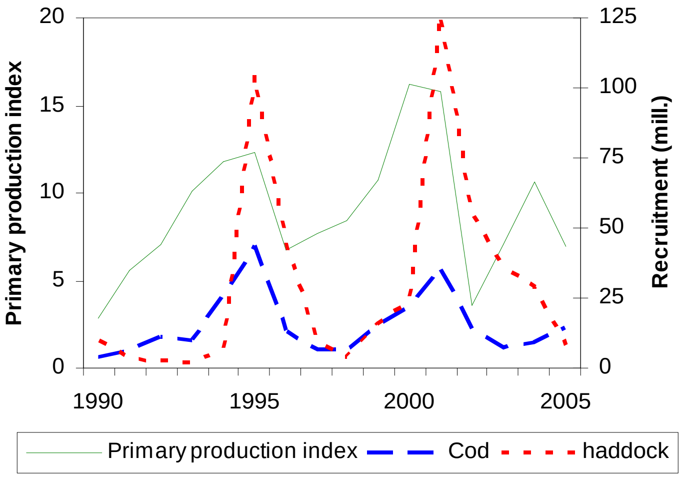

Figure 2.4.7. Primary production and recruitment of 2 years old cod and haddock during the 1990-2005 period.

2.4.1.7 Cod and haddock growth rates

Growth rates on cod and haddock on the Faroe plateau are highly variable. Since 1990 the mean growth rates of 2-7 years old cod have fluctuated between 0.2 and 1.4 kg individual^{-1} year^{-1} and the mean growth rates of 2-7 years haddock between 0.1 and 0.5 kg individual^{-1} year^{-1}. No correlation is between the growth rates and the *in situ* temperature, but good relationship is found between primary production and growth variability of both species (Figure 2.4.8). The growth rates are mainly affected by the highly variable food production. The causal mechanism seems to be a positive relationship between phytoplankton production, zooplankton production and production of food organisms for cod and haddock (e.g., benthic crustaceans, polychaets, Norway pout and especially sandeels).

Since primary production is rapidly transferred to cod and haddock, they obviously eat young prey items, at least during periods with high growth rates. Detailed analysis of interannual variability in food items for cod and haddock are not available at the present, but the available information indicates that sandeel is the main food item during productive years. In low-productive years they seem to predate more on benthic fauna. Fish furthermore seems to be a much more prevalent prey item for cod than for haddock. This may be a reason for why haddock growth variability often is lagging one year behind cod growth variability, especially during low productive periods (Figure 2.4.8).

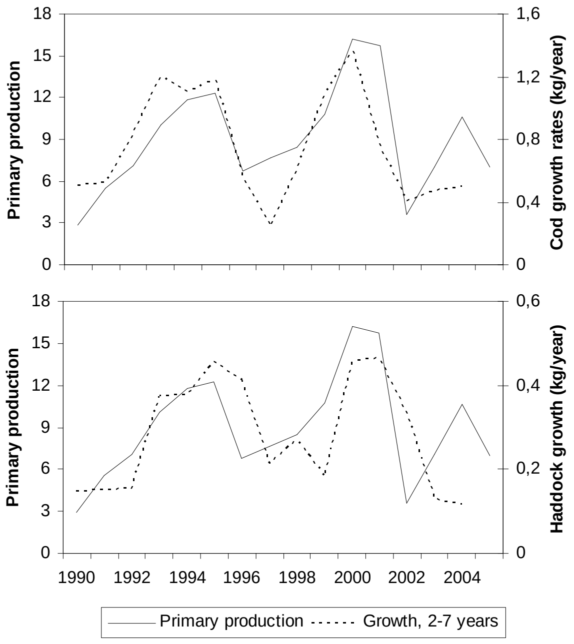

Figure 2.4.8. Index of new primary production and cod growth rates (upper panel) and haddock growth rates (lower panel) during the 1990-2005 period.

2.4.1.8 Fish production

Fish production in the ecosystem is clearly food limited. Mainly cod production (numbers x individual growth summed up for all age groups) fluctuates well with primary production (Figure 2.4.9). When comparing primary production with production of cod haddock and saithe combined, the correlation is even better.

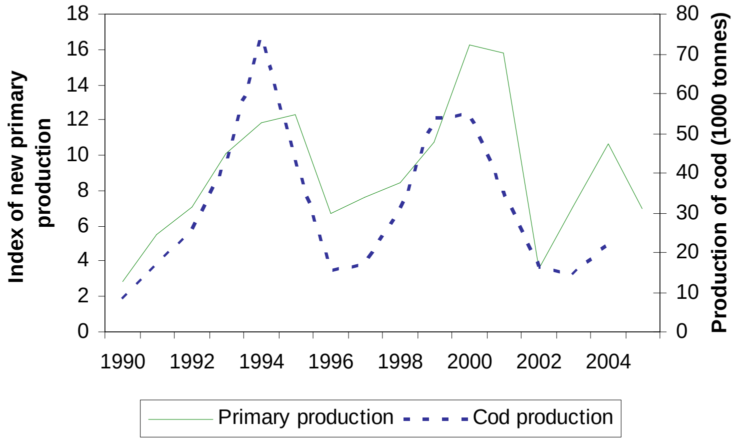

Figure 2.4.9. Index of new primary production on the Faroe shelf and corresponding production of Faroe Plateau cod older than 1.5 years.

Since young age groups are the most numerous (mainly in the productive years) the observed variability in cod production in Figure 9 largely is due to variable abundances of recruits (Figure 2.4.10). The figure furthermore illustrates, that in the 1960s and 1970s the proportion of production of older age classes was clearly higher than in recent times. The reason most likely is higher fishing mortalities in the later years.

As cod grow older, they tend to move into deeper areas (Figure 2.4.5), a part of them feeding on the slope outside the shelf front. This may, increase production capacity of the cod stocks. However, information is not available at the moment to quantify this potential effect.

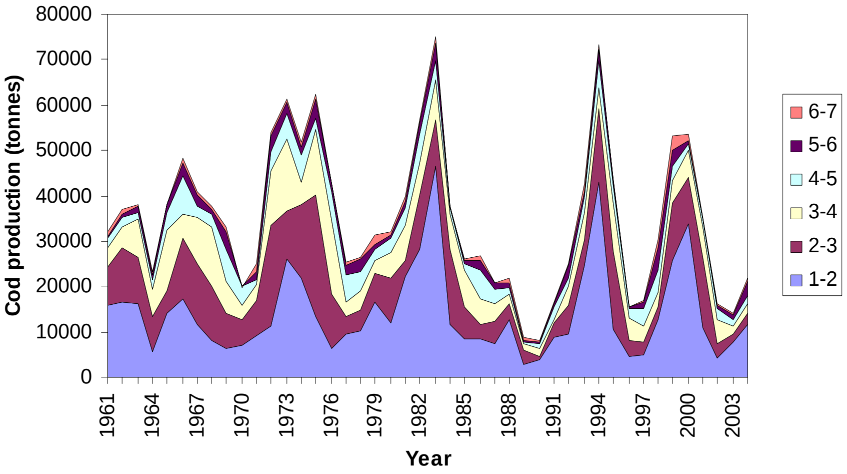

Figure 2.4.10. Production of Faroe Plateau cod split into age groups.

2.4.1.9 Benthos

Due to strong tidal currents, the seabed in shallow regions on the shelf (except sheltered fjords) consists mainly of sand on stones. In deeper areas is mort silt and organic material. The benthic fauna on the shelf is diverse with e.g. polychaetes, decapods, echinoderms, and bivalves as important groups. On the slope coral and sponge areas occur. The coral areas have been reduced due to trawling and therefore the authorities in 2004 have closed three areas for trawling. On the shelf there is local fishery (dredging) for scallops and in inshore areas there is trap fishery for Norway lobster (*Nephrops*).

2.4.2 Ecosystem Effects of the Fisheries

Trawling activity has caused a significantly reduce the distribution areas of corals (*Lophelia pertusa*) on the shelf and bank slopes. Therefore the Faroese authorities in 2004 have closed three coral areas for trawling.

Since fishery on the Faroe Plateau is effort regulated, discard of commercially fish most likely is small. The level of by-catch of non-commercial species and of non-commercial size in unknown and may be higher, especially during periods of high recruitment.

In addition to effort regulation (limited number of fishing days), spawning grounds are closed for fishing activity, and large areas on the shelf are permanently or periodically closed for trawling. Furthermore, trawling is regulated by mesh sized. The current management regime which limits effort and spatial access for certain gear is likely to be effective for demersal fish stocks (Zeller and Reinert 2004).

2.4.3 Concluding remarks

The Faroe Islands utilize an effort- and spatial-based system of fisheries management. Successful management of such a system is depending on information on influences from environmental variables on the fish stocks, individual behaviour and catchability.

Environmental effects in the Faroe shelf ecosystem are strong may be useful in prediction of cod and haddock recruitment and growth rates as well as in management regulations.

The highly variable environmental conditions on the Faroe plateau have very strong influences on cod and haddock recruitment. Recruitment of 2-years old cod correlates positively with primary production and negatively with abundance of adult cod in shallow areas the year before. In years with low food abundance cod tend to migrate into shallow areas, affecting cod recruitment negatively. A high correlation between recruitment of 2 years old cod and environmental conditions for cod (primary production combined with abundance of adult cod in shallow areas) one year before, indicating that recruitment mainly is determined as 1 years old cod.

Growth rates of cod and haddock are also highly affected by feeding conditions.

Relationship between environmental conditions for cod and haddock (food abundance) and longline catchability may also be useful information from a management perspective. In and effort management regime with a limited number of fishing days, expected catchability changes may need to be incorporated in the advice on fisheries. For cod there is observed a link between primary production and individual growth rates (Figure 2.4.8). The cod growth rates seem to be negatively correlated with the catchability of longlines, suggesting that cod prefer longline baits when natural food abundance is low. Since longliners usually take a large proportion of cod catch, the total fishing mortality fluctuates in the same was as the longline catchability and there is thus a negative relationship between cod growth and mortality.

For haddock there seems a similar mechanism as for cod. Although the catchability for longliners (which take the majority of the catch) as estimated for the longliners logbooks does not follow the expected pattern for the first time of the series (1986-1995), it may be a result of very small catches in that period when the stock biomass was low. The fact that a negative relationship is observed between growth rates and fishing mortality suggests that the same mechanism is valid for haddock as for cod.

It is, however, important to note that the relationship between productivity of the ecosystem and the catchability of longlines depends on age of the fish. The relationship is most clear for fish age 5. For cod age 3 and 4 the relationship is less clear, and for young haddock there apparently is no such relationship between productivity and catchability.

For saithe no clear relationship is observed between catchability for pair trawlers (which take the majority of the catches) and other variables such as primary production, growth and stock size.

The catchability analysis reported above suggests that natural factors may have a large influence on longline catchability for cod and haddock. Based on information on primary production in 2005, which is below average (Figure 2.4.3) there is a potential for increased longline catchability.

2.4.3.1 Considerations for assessments and advice

The primary production decreased from slightly above average in 2004 to below average in 2005. Although neither of the two years was dramatically different from average years, the decrease in 2005 is expected to affect longline catchability for cod and haddock, and also recruitment and growth rates of the two species.

The following environmental information should considered implemented in assessment and management advice of the Faroe plateau cod stock and the Faroe haddock stock:

- In effort regulation variable longline catchability for cod and haddock seems to be affected by variable feeding conditions. Variability in catchability is therefore important in management advice.

  Expected environmental effects on longline catchability for cod and haddock were included in the assessment and the advice for 2005. However, estimated variability in cod and haddock catchability, based on environmental information, and growth rates of cod and haddock, should be considered implemented even further quantitatively, in future assessment work.

- The co-fluctuation between plankton productivity and cod and haddock recruitment and growth rates (weight at age) since 1990 should be considered used for improved predictions for recruitment and weight for cod and haddock.

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2.5 Regional ecosystem E: Celtic seas

2.5.1 Bottom topography substrate and circulation

In the Celtic seas (ICES sub-areas VI and VII) the continental shelf is of variable width. The Celtic sea, south of Ireland is an extended shelf which most of the area is shallower than 100m. It is limited to the west by the slope of the Porcupine seabight and the Goban Spur. In this area the slope is rather gentle and sedimentary. To the west of Ireland the Porcupine bank forms a large extension of the shelf limited to the west by the Rockall Trough, the transition between the Porcupine bank and the trough is a steep and rocky slope along which reefs of deepwater corals occur. Further North, to West of Scotland the slope of the Rockall Trough is closer to the coast line, particularly off NW Ireland, and the Hebrides. West of the shelf break and the Rockall Trough is the Rockall Plateau with depths of less than 200m. The shelf area itself contains mixed substrates, generally with soft sediments (sand and mud) in the west and tending to more rocky, pinnacle areas to the east. The Irish Sea is shallow (less than 100m deep in most places) and largely sheltered from the winds and currents of the North Atlantic, although relatively high salinity indicates the influence of oceanic water from the south. In the Irish Sea, the inshore Coastal Current carries water from St. Georges’s Channel northwards through the North Channel, mixing with water from the outer Clyde.

At these latitudes (55° to 58°N) the continental slope is mainly sedimentary and a trawl fishery for mid slope fish such as roundnose grenadier, Blackscabbard fish, deep sea squalids, blue ling and Orange roughy have been operating since the late 80s. The eco-region also contains several important seamounts; Anton Dohrn, Hebrides and Rosemary Bank, which have soft sediments on top and rocky slopes.

The water circulation in this area is dominated by the poleward flowing slope current. This persists throughout the year north of Porcupine Bank, and is stronger in the summer. South of the bank the current is present in the winter months, but breaks down in the summer, when flow becomes complex. There is also a weaker current flowing north from Brittany and splitting east and west along the Irish coast. (source; OSPAR QSR 2000) Porcupine Bank and the Rockall plateau tend to be retention zones.

The main oceanographic front in the Atlantic region is the Irish Shelf Front that occurs to the south and west of Ireland (at c. 11°W) around the 150m isobath, and exists year-round. This front marks the boundary between water over the Irish shelf (often mixed vertically by the tide) and offshore North Atlantic water. The turbulence caused by the front may bring nutrients from deeper water to the surface where they promote the growth of phytoplankton, especially diatoms in spring, but also dinoflagellates where there is increased stratification. These may in-turn be fed on by swarms of zooplankton and associated with these, aggregations of fish (Reid et al. 2003).

Seasonal fronts occur at several other locations immediately west of Britain, including the Ushant Front in the English Channel, the Celtic Sea front at the southern entrance to the Irish Sea, and the Islay Front between Islay and the coast of Northern Ireland. The Islay Front persists through the winter due to stratification of water masses of different salinity. Similarly, where tides are moderate, uneven bottom topography can have a considerable mixing effect, for example in the seas around the Hebrides.

2.5.2 Physical and chemical oceanography

2.5.2.1 Temperature/salinity

The slope current introduces warm saline water from further south into the whole area. The ICES Annual Ocean Climate Status Summary (IAOCSS) does not deal with this ICES Advisory Region as a bloc, but data are available for the Rockall Trough area in detail. The report suggests that the Rockall trough has been warming steadily over recent years. Similar trends appear for salinity (see Figure 2.5.1 below).

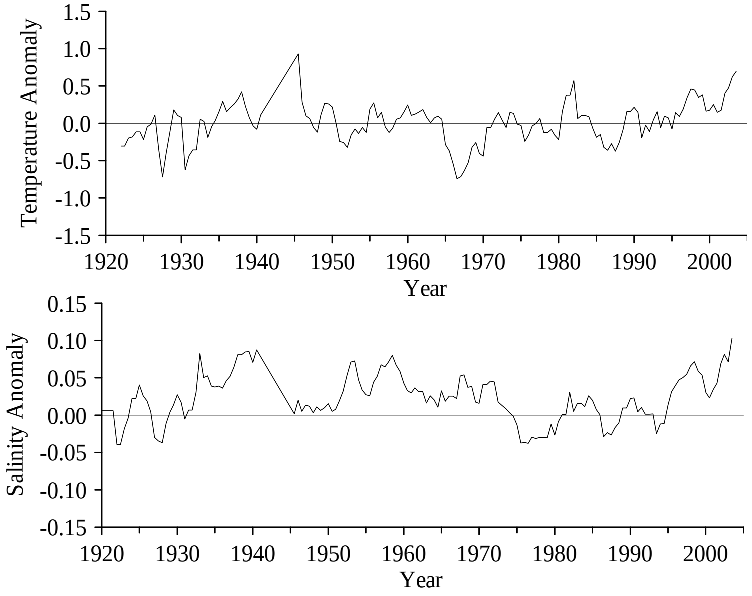

Figure 2.5.1. Rockall Trough temperature and salinity anomalies for the upper ocean (0–800 m) of the northern Rockall Trough. Average across section, seasonal cycle removed.

Hydrographic observations for the area of the Northern Shelf (ICES area VI) were considered by *WGNSDS* in 2005 (ICES 2005a). Of particular note is the highlighted variability in local temperature observed in western waters (Figs 2.5.2and 2.5.3).

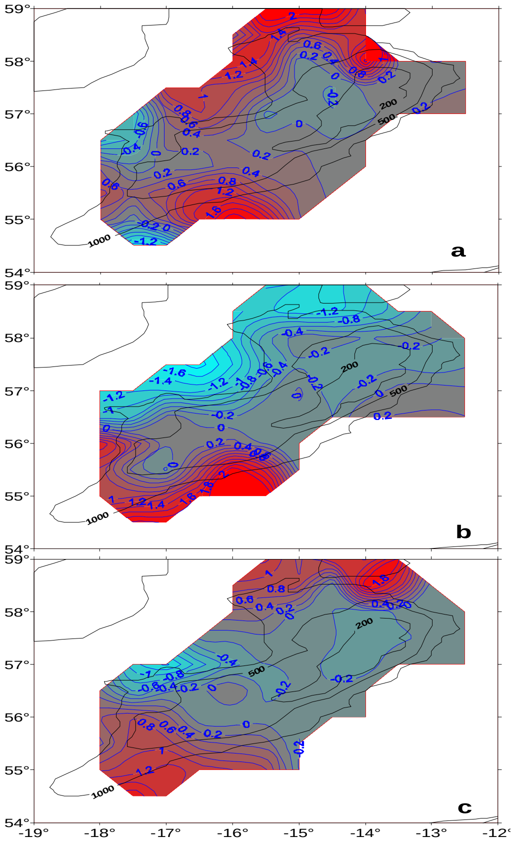

Figure 2.5.2 Difference of bottom temperature (°C) in the Rockall Bank area in spring 2005 from temperature in 2002 (a), 2003 (b) and 2004 (c).

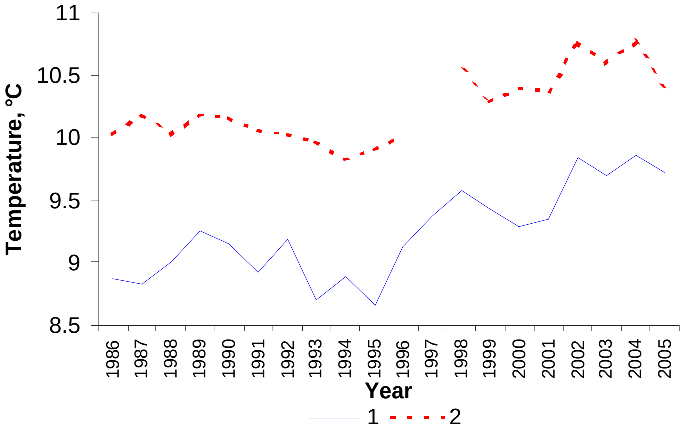

Figure 2.5.3. Yearly mean temperature in the areas west of the British Islands in 1986-2005: 1 - Rockall Bank area, 55-58°N 14-18°W (surface temperature in January-March), 2 - west of the Porcupine Bank, 52-54°N 14-16°W (temperature from 50-600 m in March-April).

No new temperature and salinity data were available for the Rockall area in 2005, although the positive temperature and salinity anomalies observed since the mid 1990s were expected to continue. Modified Atlantic waters in the Faroe-Shetland channel were warmer and saltier in 2003 than at any period in the last 50 years. Temperature and salinity decreased a little in 2004, but remained higher than the long-term average, suggesting that the general warming trend observed over the last 20 years was continuing. The North Atlantic Oscillation index

(NAO) was near median in the winter of 2004. Early indications for the winter in 2005 are that the index will also be only slightly below median (ICES, 2005).

Inshore waters off the west of Scotland have also continued to warm, consistent with open ocean conditions. At Millport, where monitoring has been conducted since 1953, gradual warming is apparent, and the more rapid warming that has taken place since the mid 1990s continued until the time of the last reported data in 2003 (FRS, 2005).

2.5.2.2 Input of Freshwater

The major river inputs are into the Bristol channel, Irish Sea and The Malin Sea north of Ireland. These are locally important in reducing salinity in these areas. Because of the complex fjordic nature of west coast of Scotland there is also a substantial freshwater input from the numerous sea-lochs, notably the Firth of Lorne sealoch system.

2.5.3 Broad-scale climate & Oceanographic features

See general text on this topic in separate section on the NE Atlantic (section 2.9).

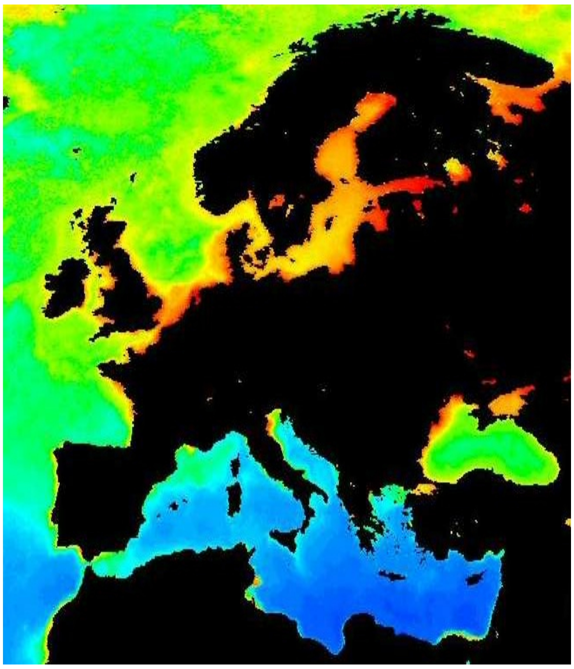

Figure 2.5.4. Spring chlorophyll (1998-2003).

2.5.4 Phytoplankton

For phytoplankton, the main feature is the strong primary productivity found along the shelf break – see figure 2.5.4. This is stimulated by the warmer, nutrient rich waters found here. Productivity is reasonably strong on the shelf but drops rapidly west of the shelf break. Based on CPR greenness records for this area the spring bloom occurs around April and collapses by October, although in recent years has continued into December. CPR data also suggest that there has been a steady increase in phytoplankton colour index across the whole area over at least the last 20 years. Details on the taxa involved have not been located but are assumed to be dominated by diatoms (at least in the spring bloom), but will also include dinoflaggelates.

2.5.5 Zooplankton

Like the adjacent North Sea waters, the overall zooplankton abundance in this area has declined in recent years. CPR areas C5, D5 and E5 all show substantial drops in *Calanus* abundance and these are now below the long term mean. *Calanus finmarchicus* is known to overwinter in the Faroe-Shetland channel and the abundance of these is known to have been reduced in recent years. This species distribution in deep waters further south is unknown. More detailed information should be available from the CPR programme but this is not available at present.

Zooplankton monitoring data are available from one station in waters about 50 m deep in the English Channel. These data exhibited a decreasing trend from 1988 to 1995 but a recovery thereafter. This recovery was mainly due to two autumn developing small species of copepod, *Euterpina* sp. and *Oncaea* sp. In 1999 there was a decline in the Zooplankton population, with the top ten species all below their typical average values (apart from *Temora* and *Corycaeus*, which exhibited very little variation). However, 2000, 2001 and 2002 experienced a recovery in Zooplankton population abundance comparable to that after 1995 (reported in ICES Zooplankton Monitoring Status Summary 2001/2002). Data for 2004 and 2005 are not yet available.

2.5.6 Benthos, larger invertebrates (cephalopods, crustaceans etc), biogenic habitat taxa

The major commercial invertebrate species is Nephrops. It is targeted by trawl fisheries on the shelf west of Scotland, the Rockall plateau and south and west of Ireland. Cuttlefish is also exploited in the Celtic Sea, and scallops in the Irish Sea and west of Scotland.

Major fisheries dredging for scallops and some smaller bivalves exist in the western Channel, Irish Sea and west of Scotland. Pot fisheries exploit the lobster *Homarus gamarus* and brown crab *Cancer pagurus* in the water around the Channel Islands, off France (French landing about 150 t/year), and the west of Scotland. Estimated landings of whelk (*Buccinum ondatum*) are as high as 12 000 t/year from at targeted pot fishery. Cuttlefish are also targeted by pot fishery but trawl catch are much higher and target juvenile in coastal water in some areas.

In addition to major aquaculture activity for oysters and mussels, some beds of oysters and buried bivalves such as cockles *Cardium edule* are exploited by professional and recreational fisheries.

The benthos of the Celtic seas (northern shelf, Irish Sea and Celtic Sea) is largely influenced by shelf sea dynamic processes that generate areas with high levels of seabed stress and erosion. Over 340 species of invertebrate and fish were captured in a survey of the epibenthos in ICES area VIIf-h (Ellis et al (2002), the most ubiquitous species being the hermit crab *Pagurus prideaux* and the spotted dragonet *Callionymus maculatus*, both of which are major prey items for commercial fish (Pinnegar et al.2003). Two epibenthic assemblages predominate in the Celtic Sea. The first is dominated by the anemone *Actinauge richardi* (41.8% of faunal biomass) and occurs along the shelf edge and slope in waters 132-350m deep. The second assemblage is more widely distributed on the continental shelf (depth range: 66-232m) and *P. prideaux* dominates along with other mobile invertebrates (shrimps and echinoderms), although there are some spatial differences in assemblage structure and relative abundance.

Biogenic reefs of horse mussels *Modiolus modiolus*, maerl and Serpulid worms occur in specific locations (Irish Sea, West coast of Scotland). The latter can support benthos of conservation interest such as sea fans and structurally complex bryozoans. Offshore areas on the shelf slope support reefs of deep water corals such as *Lophelia pertusa.*

2.5.7 Fish Community

This ICES Advisory Region includes two distinct types of ecosystem; shelf seas and deep water communities. In the northern part of the area, (Irish Sea, West of Ireland and western Scotland) there are important commercial fisheries for Nephrops, cod, haddock and whiting and a number of flatfish species. Hake and angler fish are also fished across the whole area. The Rockall plateau is subject to a haddock and small-scale Nephrops fishery. Commercial fisheries for, cod, plaice and sole are conducted in the Irish Sea. The whole area is also characterised as a spawning area for a number of key wide ranging, migratory species, notably mackerel, horse mackerel and blue whiting. These species are also commercially exploited within the area. Key pelagic species are herring, considered as consisting of a number of different stocks, as well as sardine, in the southern part of the area, and sprat, particularly in the Celtic Sea proper. The area also accommodates considerable stocks of argentines (two species) and large numbers of small mesopelagic myctophids along the shelf break.

The shelf slope (500-1800m) comprises a quite different species assemblage including roundnose grenadier, black scabbard fish, blue ling and orange roughy as well as deep sea squalids (sharks) and macrouridae. For the most part none of these species are subject to stock assessment, although some are likely to have been severely depleted by the deep water fisheries carried out in this area. A notable example would be orange roughy, which has probably been largely fished out. All these fish are characterised as being long lived, slow growing and having a low fecundity, making them very vulnerable to overfishing.

The Celtic sea groundfish community consists of over a hundred species and the most abundant 25 make up 99 percent of the total estimated biomass and around 93 percent of total estimated numbers (Trenkel and Rochet 2003). Population and community analyses have shown that fishing has impacted a number of commercial species, primarily because individuals of too small a size have been killed in the past (Trenkel and Rochet 2003). This can be considered as resulting partly from observed large discards (Rochet et al., 2002).

The size structure of the fish community has changed significantly over time, and that a decrease in the relative abundance of larger fish has been accompanied by an increase in smaller fish (4–25g) (Blanchard et al 2005; Trenkel et al 2004).. Temporal analyses of the effects of fishing and climate variation suggest that fishing generally has had a stronger effect on size-structure than changes in temperature. A marked decline in mean trophic level of the fish community over time has also been documented (Pinnegar et al 2003) and this resulted from a reduction in the abundance of large piscivorous fishes and an increase in smaller pelagic species which feed at a lower trophic level. Since 1990 the non-exploited species *Capros aper* has become particularly abundant in French and UK survey catches. This phenomenon has been reported as occurring elsewhere in the North Atlantic including the Bay of Biscay (Farina et al. 1997) and offshore seamounts (Fock et al. 2002).

2.5.7.1 Trophic web

For the Celtic Sea, two sources of fish stomach data have recently been collated and these are described in UK researchers collected stomachs for 66 species during routine annual groundfish surveys from 1986 to 1994. French researchers (du Buit and co-workers) sampled stomachs of seven species aboard commercial fishing vessels, throughout the years 1977 to 1992 (in all seasons).

Several studies for fish stomach contents and diets have concluded that the main predator species in the Celtic Sea (hake, megrim, monkfish, whiting, cod, saithe) are generalist feeders which exhibit size-dependent, temporal and spatial prey-switching behaviour (Pinnegar et al.2003, Trenkel et al. 2005). Consequently, utilisation of a conventional multispecies assessment model such as MSVPA in such a system would be unlikely to yield useful insights.

Overall, there was general agreement between higher prey densities in the environment and higher occurrences of particular prey species in predator stomachs, which lead to distinct spatial and temporal feeding patterns (Trenkel, et al. 2005). Blue whiting was found more often in predator stomachs over the shelf edge during the summer months while mackerel and *Triopterus* spp were relatively more prevalent in stomachs sampled on the continental shelf during the winter half year. The general impression is one of a highly interlinked food web, where several predators feed on the same prey resources, i.e. their trophic niche overlaps substantially. These results derive from the Celtic sea sensus stricto (the southern part of region E, limited to the North by Ireland, and between longitudes of 4°E and 12°W). Less is known concerning trophic interactions among fish species in the Irish Sea and northwest Scotland (although see du Buit 1989; 1991a,b). No major studies of forage fish have been conducted in the north of the eco-region. Sand eel, sprat and Norway pout are known to be present, however their role and importance in the ecosystem is unclear.

Fish taken from the shelf edge areas of the Celtic Seas tend overall to be less planktivorous and from a higher trophic level than those in the North and Baltic Seas (2005a). For instance, the secondary production required per unit of landed fish from the southern part of the Celtic Seas is twice that for North Sea fish. In this area zooplankton production accounts for only a small fraction of the secondary production demands of the fisheries. In the Celtic Seas benthos production can be seen as a ‘bottom-up’ driver for fisheries production, which seems to be independent of variability in plankton production. As this situation is very different to the situation in the North Sea (see NS section), climate change and fishing pressures can be expected to influence these regional fisheries in very different ways. Overall, there appear to be strong spatial patterns in the fish food web structure and function, which should be important considerations in the establishment of regional management plans for fisheries (see Heath 2005b).

Heath (2005b) argues that, because the blue-whiting fishery is conducted mainly off the continental shelf, there is no rationale for a foodweb connection between the bulk of the blue whiting catch and the other landed species from the Celtic Sea and west of Scotland. By contrast, Pinnegar et al. (2003) and Trenkel et al. (2005) have both highlighted the importance of this species as a prey for fish on the shelf-edge, notably for hake and megrim.

For cod in the Irish Sea, the decapod *Nephrops norvegicus* is known to be an important prey item (Armstrong, 1982), whereas whiting, Norway-pout and *Nephrops* are known to be important for monkfish (Crozier 1985). In north-west of Scotland there have been additional studies focusing on inshore demersal assemblages (e.g. Gibson & Ezzi, 1987). Feeding relationships among deep-water species on the Wyville Thomson ridge have also been examined (du Buit 1978).

2.5.8 Vulnerable species

The blackspot (red) seabream (*Pagellus bogaraveo*) used to be an important target species of English fisheries in the 1930s (Desbrosses, 1932), catches in the Celtic seas declined well before the collapse of the fishery in region G (see this chapter for a longer account on this species). The species can be considered as eradicated from the Celtic seas.

The red lobster (*Palinurus elephas*) was exploited by pot fisheries prior to the late 1990s, and current catches and the stock of this species can be considered as residual.

Skates are arguably the most vulnerable of exploited marine fishes because of their large size, slow growth rate, late maturity and low fecundity. Dulvy *et al.* (2000) discussed the disappearance of skate species (*Dipturus oxyrhinchus*, *Rostooraja alba* and *D. batis*) in the Irish Sea, and the widespread decline in the abundance of smaller species.

As mentioned above, several species of deep water fish are considered as being severely depleted and meriting protection.

2.5.9 Birds, Mammals & Large Elasmobranches

Basking shark (*Cetorhinus maximus*), are seen throughout the Celtic Sea, Irish Sea and Northern Shelf region, from April through to October. Basking shark is protected within British territorial waters. Blue shark (*Prionace glauca*) are found in the summer in the southern part of the area. They are subject to a variety of fisheries, both recreational and directed (longlines and gillnet) as well as bycatch in offshore tuna fisheries. Porbeagle (*Lamna* nasus) and tope (*Galeorhinus* galeus) are also targeted in both recreational and commercial fishing.

Six species of cetacean are regularly observed in this Advisory Region (Reid et al 2003). SCANS line transect surveys in 1994 estimated numbers of some of these occurring in the Celtic Sea.

Minke whale *Balaenoptera acutorostrata* is found throughout the region, particularly off western Scotland and Ireland. SCANS estimate was 1195 animals. Bottlenosed dolphin *Tursiops truncatus* occur in large numbers off western and southwest Ireland and in smaller numbers throughout the region. No SCANS estimate. Common dolphin *Delphinus delphis* are widely distributed in shelf waters throughout the region, especially in the Celtic Sea and adjacent waters. SCANS estimate was 75500 animals. White-beaked dolphin and White-sided dolphin (*Lagenorhynchus albirostris* and *L. acutus*) occur over much shelf area, but are less common in the southwest part of the area. Harbour porpoise *Phocoena phocoena* is the smallest but by far the most numerous of the cetaceans found in the shelf area, particularly south-west Ireland, the Irish Sea and west of Scotland. SCANS estimate was 36280 animals.

Grey seals (*Halichoerus grypus*) are common in many parts of the area, with population estimates ranging from approximately 50,000 to 110,000 animals (SCOS 2005), the majority in the Hebrides and in Orkney. Common seals (*Phoca vitulina*) are also widespread in the northern part of the area with around 15,000 animals estimated (SCOS 2005). Smaller numbers are seen in Ireland (c. 4,000) and very few further south.

In 2002, the ICES Working Group on Seabird Ecology reported seabird population estimates within all ICES areas. For ICES Area VIa west of Scotland a total of 1.2 million pairs of breeding seabirds were reported. Auks, predominantly the common guillemot (*Uria aalge*), razorbill (*Alca torda*) and the Atlantic puffin (*Fratercula arctica*) accounted for 51% of the total, while petrels (including fulmar, *Fulmarus glacialis*; storm petrel, *Hydrobates pelagicus*; and Manx shearwater, (*Puffinus puffinus*) accounted for 29%, Northern gannet accounted for 10%, and gulls (particularly kittiwake and herring gull) 9%(ICES 2002). In the Irish Sea, Bristol Channel and English Channel (ICES areas VIIa,d,e,f) gulls predominate (47%, 66%, 90%, 68% respectively), in particular black-headed, lesser black-backed and herring gulls as well as guillemots. Petrels (fulmar and storm-petrel) dominate in the west of Ireland and Celtic Sea region (area VIIb,g,j 48%, 60% and 79% respectively) but there also large breeding colonies of kittiwake, guillemot and gannet.

Climate change is likely to impact on seabird populations. The breeding success of some seabird populations in the Celtic Sea has already been linked to climatic fluctuations in the North Atlantic, such as the North Atlantic Oscillation (NAO). Projected consequences of global warming, such as sea level rises, increased storminess and rises in sea/air temperatures are likely to have a direct impact on seabird populations.

2.5.10 Fishery effects on benthos and fish communities

This ICES Advisory Region is characterized by the presence of a number of important benthic features which are considered important and vulnerable to fishing activity. These include cold water corals, and particularly the Darwin mounds, other biogenic reefs and natural reefs. Cold water corals structures have been identified in many areas including Porcupine Bank, Rockall, the slope areas west of Scotland & Ireland and on the seamounts. ICES has advised on the occurrence of cold-water corals in the North East Atlantic for the past two years. It has also advised that should managers wish to protect these habitats from the effects of fishing, the only effective way to do this is by closing them to all damaging fishing gear. In Subarea VI, one such area has been closed by fishery managers: the Darwin Mounds. This area lies to the south of the Wyville Thomson ridge (to the northeast in Figure 2.5.5). The Darwin Mounds have been impacted by towed bottom-fishing gear (ICES, 2002). These have been extensive use of bottom-set nets on shelf, slope and even deep-sea areas. Although documentation is hard to acquire, there is substantial concern about ecosystem effects due to ghost fishing by lost gear from these fisheries, and about unsustainable fishing practices.

Figure 2.5.5. Distribution of cold-water coral records within ICES Subarea VI (from ICES, 2005a).

Not all of the records of cold-water coral in Figure 2.5.5 are of reefs: some records are of individual fragments trawled or dredged up from the seabed. Accurate determination of the existence and location of reefs requires either remote sonar surveys or visual inspection, either using cameras or manned submersibles, coupled with accurate geo-referencing of the seafloor. In Subarea VI, reefs have been found in UK internal waters to the east of Mingualay in the Outer Hebrides of Scotland (ICES, 2004), on the Rockall Bank (Figure 2.5.6), particularly on the northwestern and southeastern parts of the Bank. On the southeast Rockall Bank, the coral reefs are associated with large carbonate mounds (the Logachev Mound province) and are particularly well developed. Tangle nets and trawl scar marks have been observed in these reefs (ICES, 2005a).

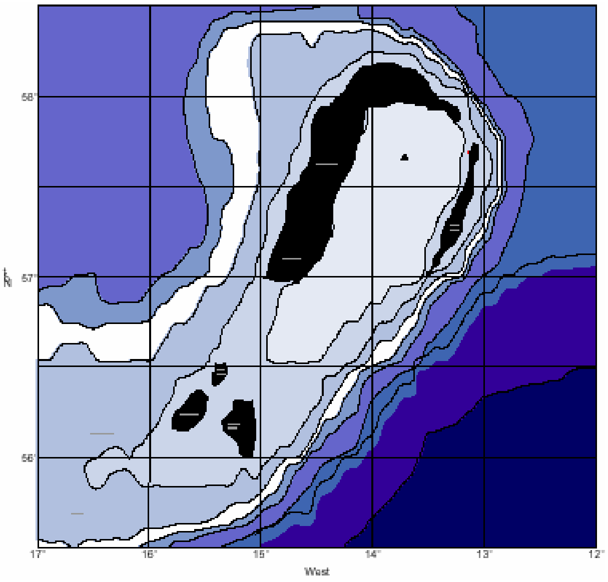

Figure 2.5.6. The distribution of coral reefs on Rockall Bank from fishermen's records (J. Hall-Spencer, pers comm.). The cross-hatched areas indicate the presence of *Lophelia* reefs (From ICES, 2003).

The impact of fishing activities on the shelf fish communities is unclear, although there are numbers of severely depleted stocks e.g. cod, whiting and plaice and hake. Trawling in the deep waters has almost certainly caused substantial changes in the community structures of the deeper waters west of the shelf break. Initial studies of catch rates from surveys west of Scotland in the 1980s compared to the last 5-10 years suggest substantial reductions in large, slow growing species and a switch to smaller faster growing fish.

Based on the above, the sustainability of deep water trawling should be reconsidered given the vulnerability of both the fish communities and the benthic habitats.

Cetacean bycatch in fisheries has been acknowledged to be a threat to the conservation of cetaceans in this eco-region (CEC 2002a, Ross & Isaacs 2004). As in other areas this mainly affects small cetaceans – i.e. dolphins, porpoises and the smaller toothed whales. Species caught in the region are primarily the harbour porpoise, common dolphin, striped dolphin, Atlantic white-sided dolphin, white-beaked dolphin, bottlenose dolphin and long-finned pilot whale (CEC 2002a). However, other larger cetaceans, such as the minke whale, can also be affected.

An extensive review of the bycatch of cetaceans in pelagic trawls was carried out for Greenpeace in 2004 (Ross & Isaacs 2004). This report considered published and anecdotal information. In the Celtic Seas the report identified a small number of fisheries where cetacean bycatch could be documented. These were;

- Bass fishing in the western channel
- Mackerel and horse mackerel trawling SW of Ireland
- Gill netting for hake in the Celtic Sea

In the last two cases, the number of animals caught was low, however, it is probably higher in the bass fishery and has attracted considerable public attention. The report identified that many countries had initiated cetacean bycatch monitoring programmes, and had generally found little or no evidence that serious bycatch had occurred.

2.5.11 Major environmental signals and implications

No obvious environmental signals were identified that should be considered in assessment or management in this area. The major trends in the ecosystem noted above are the steady warming of the area, particularly in the context of the slope current. The Rockall trough waters have been warming steadily for some years and are currently at an all time high. The general and continuing reduction of copepod abundance is also of major concern given the major role of these organisms in the food web.

Both these factors are likely to have an impact on the life histories of many species, but particularly on the migratory pelagic species; mackerel, horse mackerel and blue whiting. Both mackerel and horse mackerel migrations are closely associated with the slope current. Mackerel migration is known to be modulated by temperature (Reid et al 2001). Continued warming of the slope current is likely to affect the timing of this migration. The timing and location of spawning by all these species is also likely to be affected by warming. The impact on recruitment is difficult to assess, as mackerel generally recruits well, and the horse mackerel stock depends on very rare massive recruitments. No ecosystem link has been identified for either species.

The widespread and sudden increase in occurrence of non-commercial species such as *Capros aper,* particularly after 1990 (Pinnegar et al. 2003) might indicate some change in environmental conditions but mechanisms and consequences are poorly understood.

2.5.11.1 Data gaps

In general this eco-region has attracted less attention than areas such as the North Sea. It is probably not that data do not exist, but that they have not been correlated and integrated. For example, the ICES Annual Ocean Climate Status Summary does not address this area as a whole. The WG would recommend that ICES develops an inclusive approach so that all output data can be matched up easily. The CPR programme samples within the area, but detailed breakdown of these data has not been carried out. As noted above, the primary, and hence presumably secondary production change substantially from the shelf, to the shelf break to the open ocean. Therefore, data aggregated over all these systems is likely to be difficult to interpret. There is also no single assessment working group responsible for the fisheries in the area. These are covered by nine groups, including both northern and southern shelf demersal WGs, (see Table 4.5.1). This also makes the integration of data by eco-region more complex. There is currently no multi-species working group for this region, and hence there has been no coordinated effort towards exploring predator-prey relationships and inter-dependencies among commercial species.

2.5.12 References

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2.6 North Sea

2.6.1 Ecosystem Components

2.6.1.1 Sea bed topography and substrates

The topography of the North Sea can broadly be described as having a shallow (<50m) south-eastern part, which is sharply separated by the Doggerbank from a much deeper (50-100m) central part that runs north along the British coast. The central northern part of the shelf gradually slopes down to 200m before reaching the shelf edge. Another main feature is the Norwegian Trench running in the east along the Norwegian coast into the Skagerrak with depths up to 500m. Further to the east, the Norwegian trench abruptly ends, and the Kattegat is of similar depth as the main part of the North Sea.

The substrates are dominated by sands in the southern and coastal regions and fine muds in deeper and more central parts. Sands become generally coarser to the east and west, with patches of gravel and stones existing as well. In the shallow southern part, concentrations of boulders may be found locally, originating from transport by glaciers during the ice ages. This specific hard-bottom habitat has become scarcer, because boulders caught in beam trawls are often brought ashore. The area around, and to the west of the Orkney/Shetland archipelago is dominated by course sand and gravel. The deep areas of the Norwegian trench are covered with extensive layers of fine muds, while some of the slopes have rocky bottoms. Several underwater canyons extend further towards the coasts of Norway and Sweden.

A number of sand banks across the North Sea qualify for protection under the EU habitats directive, mainly along the UK coast, eastern Channel, the approaches to the Skagerrak and the Dogger bank. Extensive biogenic reefs of Lophelia have recently been mapped along the Norwegian coastline in the eastern Skagerrak, while Sabellaria reefs have been reported in the south, although their distribution and extent is not known. Gravels also qualify for protection, but comprehensive maps at a total North Sea scale are not readily available.

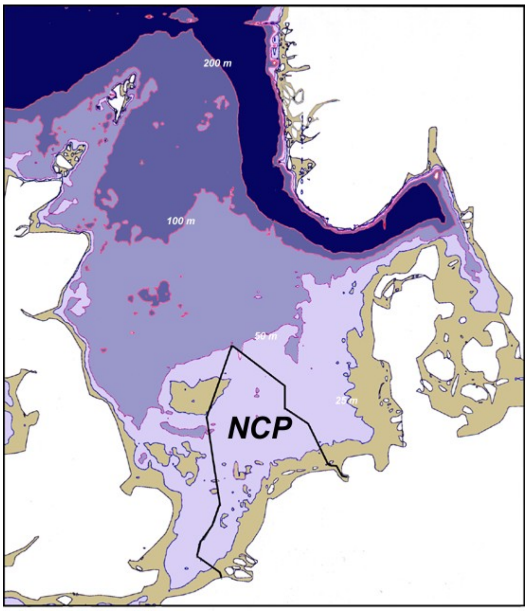
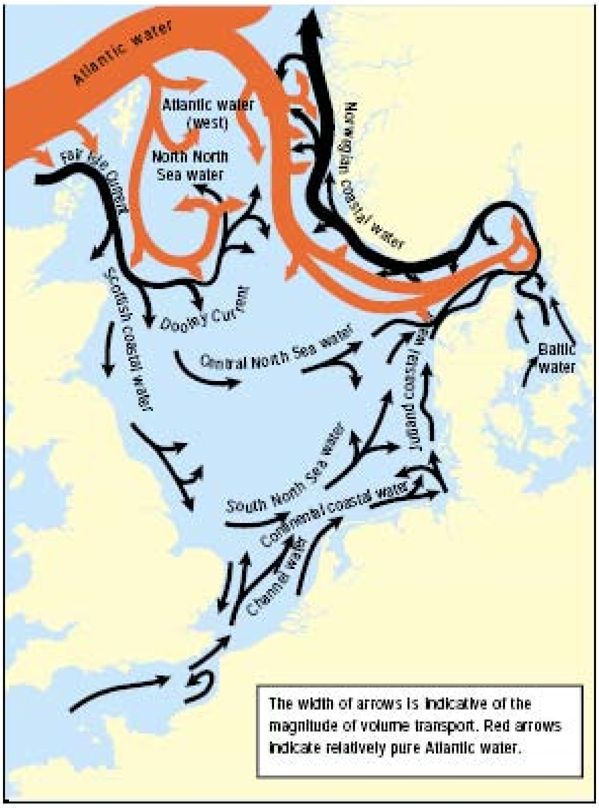


Figure 2.6.1 Bathymetry (left) of the North Sea (source – RIVO- alternative from ICES).

2.6.1.2 Circulation patterns

Circulation in the North Sea is classically presented as an anticlockwise gyre driven mainly by wind forcing. However, empirical observations as well as modelling results indicate that the pattern may be reversed temporally as a result of wind forcing, or split into two separate gyres in the north and south. Circulation may even cease for limited times (Kauker & von Storch 2000). Such changes and their timings may be important for specific life history stages of various species because they can, for instance, affect the transport of eggs and larvae to specific nursery areas or feeding conditions.

The main inflow is of relatively warm (at least during winter) and more saline North Atlantic water along the shelf break into the Norwegian Trench and also around the Shetland and Orkney Islands. Changes in zooplankton and fish distributions have been linked to the strength of these inflows. Atlantic water also enters into the southern North Sea, via the Channel (Hughes & Lavin, 2004). The Kattegat and eastern Skagerrak are strongly influenced by brackish surface water entering from the Baltic that follows the Swedish coast and turns west along southern Norway. However, the bottom water layer is of oceanic origin and runs below the brackish water layer in the opposite direction. Residence time of North Sea water is estimated to be in the order of one year. The general circulation pattern is shown in Figure 2.6.2.



The width of arrows is indicative of the magnitude of volume transport. Red arrows indicate relatively pure Atlantic water.

Figure 2.6.2. General circulation pattern in the North Sea. Copied from Regional QSR II (after Turrell et al., 1992)

There are a number of frontal systems (e.g. Fair Isle, Flamborough, Frisian front and Skagerrak), but they vary considerably in time and space depending on wind forcing, current strength and the physical properties of the different water masses. Tidal currents are strong in the southern North Sea, especially the coastal regions.

2.6.1.3 Physical and chemical oceanography

North Sea oceanographic conditions are mainly determined by the inflow of saline Atlantic water through the northern entrances and to a lesser degree through the Channel. These waters mix with river runoff in coastal regions and the lower-salinity Baltic outflow through the Kattegat. The temperature of surface waters is largely controlled by local solar heating and atmospheric heat exchange, while temperature in the deeper waters of the northern North Sea is influenced largely by the inflow of Atlantic water. Figure 2.6.3. shows average bottom temperatures in winter and summer for 1997-2002.

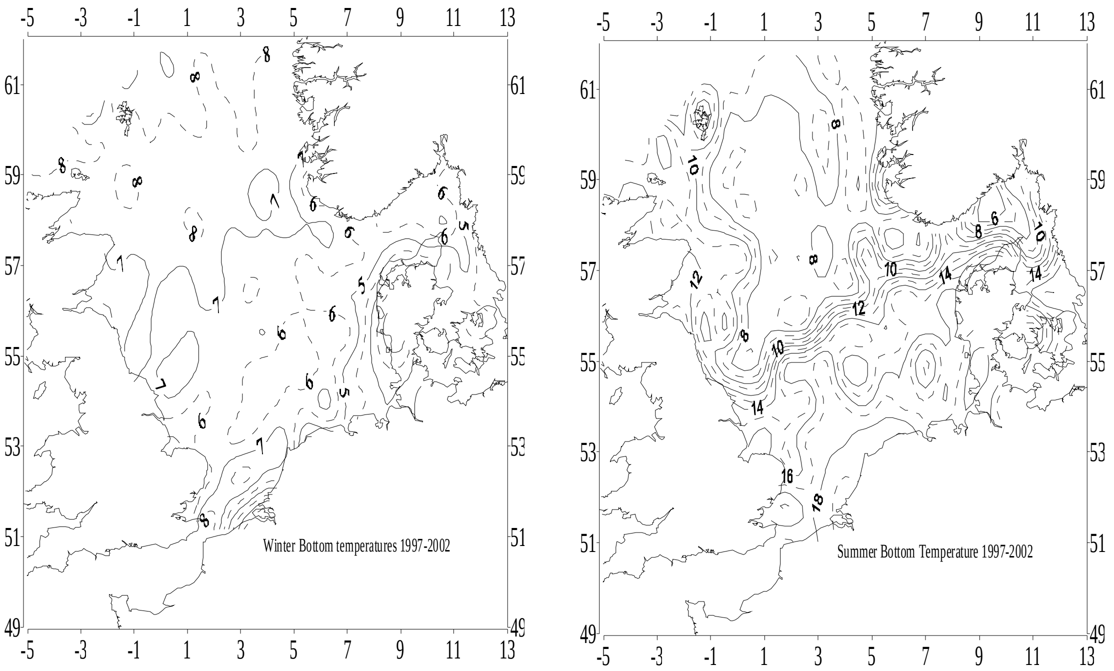


Figure 2.6.3. Average distribution of winter (left) and summer (right) bottom temperatures (courtesy ICES).

The salinity and the temperature variations generally reflect the influence of the North Atlantic Oscillation (NAO) on the movement of Atlantic water into the North Sea and the ocean-atmosphere heat exchange. Numerical model simulations show strong differences in the circulation depending on the state of the NAO. A balance of tidal mixing and local heating force the development of a seasonal stratification from April/May to September in most parts of the North Sea. This stratification is absent in the shallower waters of the southern North Sea throughout the summer. The extent and duration of this mixed area is probably an important environmental factor for fish in this area

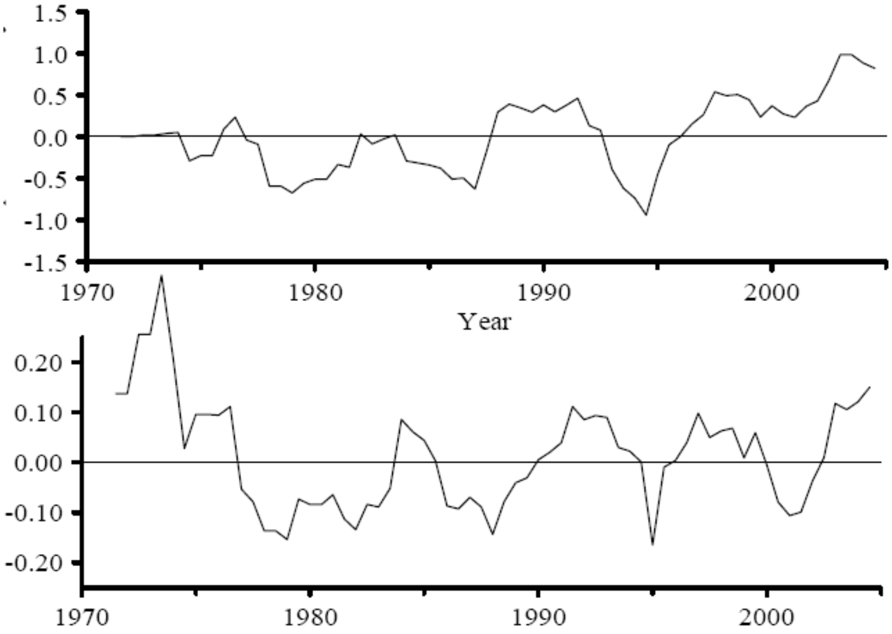


Figure 2.6.4 Temperature and salinity anomalies in the Fair Isle Current (FIC) entering the North Sea from the North Atlantic

Recently, the NAO index (Hurrell winter index) was weak after a strong negative in 2001. The ICES Annual Ocean Climate Status Summary (IAOCSS) for 2003/04 suggests that it may have been negative in the winter of 2004/05 as in the previous winter (Hughes & Lavin 2005).

The long-term temperature and salinity anomalies in the Atlantic waters flowing into the North Sea with the Faire Isle current provide a broadly similar cyclical behaviour up to the late 1990s (Figure 2.6.4). However, in more recent years the two signals appear to diverge, with relatively high temperatures persisting during years showing a marked decline in salinity (Hughes & Lavin 2005).

Both 2003 and 2004 were both unusually warm years, particularly in August and September. The inflowing Atlantic water was also warmer than the long term mean. The temperature anomalies can be overstated however. While in 2003 August was the warmest on record since 1968, the pattern was closer to average from December 2002 to May 2003. Surface salinity levels also rose in recent years but from a recent low value to close to the long term average. Initial indications from a coastal monitoring site in the north western North Sea suggest that summer temperatures in 2004 did not quite reach the extremes of 2003; however, Norwegian stations suggest similar or higher summer temperatures, at least in the Atlantic inflow. (www.marlab.ac.uk/FRS.web/Delivery/display_standalone.aspx?contentid=1166).

In 2005 SST in the North Sea was close to the long term mean for the first eight months of the year, but showed strong positive anomalies in September to December (source http://www.bsh.de/en/index.jsp). This increased temperature late in the year was also evident in deeper waters as well as in surface waters. In December 2005 the temperature on the Torungen-Hirtshals section in the Skagerrak was 2-4°C above normal in the top 50m, and across the entire section the temperature was above normal (Figure 2.6.5)

On a station on the section we find water of Atlantic origin at 150m depth (Figure 2.6.6.). Here the temperature was about 0.5°C above normal throughout the year and except for January the salinity was 0.2 above normal. This shows that he inflowing Atlantic Water to the North Sea was warmer and more saline than usual.

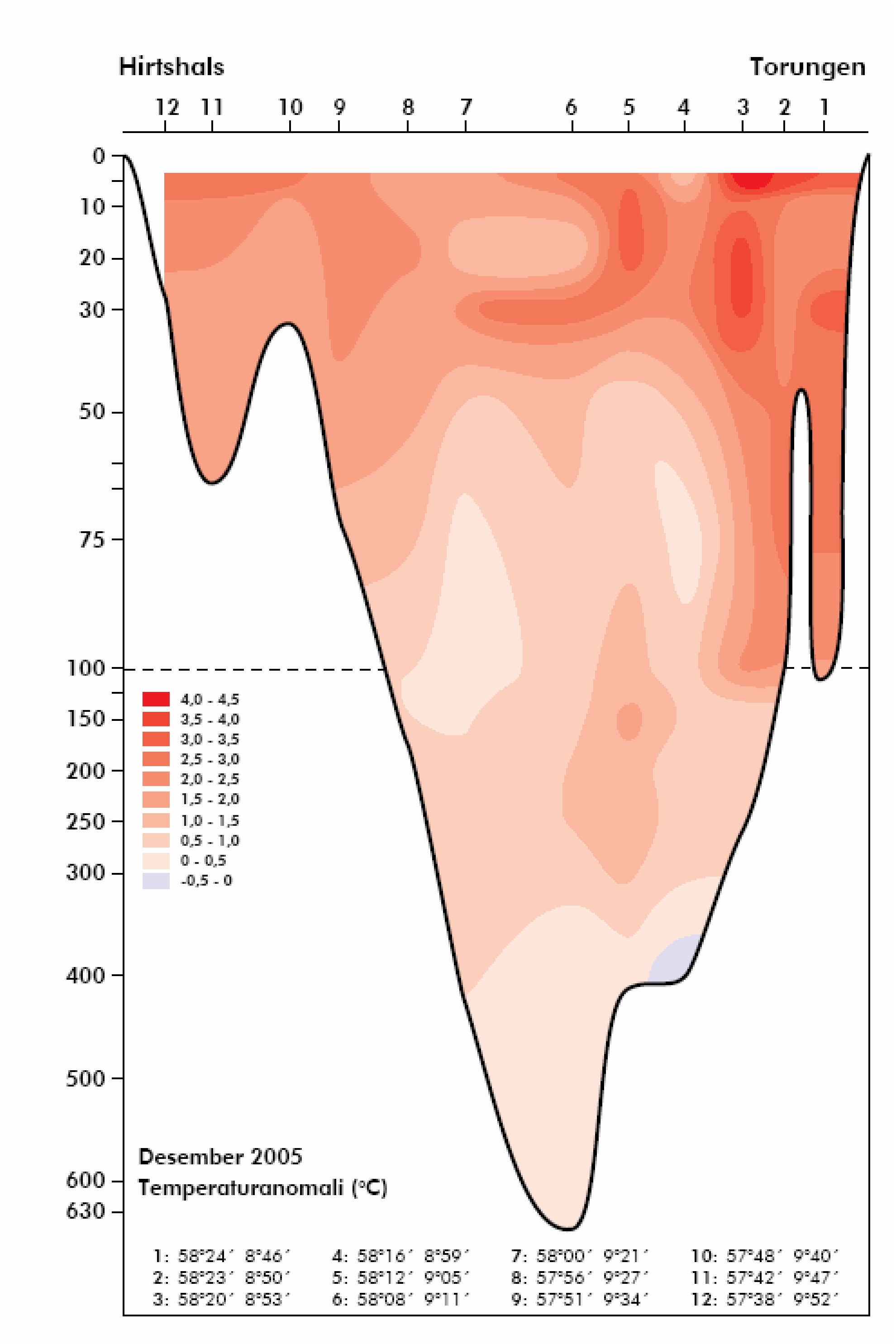


Figure 2.6.5. Temperature deviation (from the norm 1960-1987) along the Torungen-Hirtshals section in December 2005.

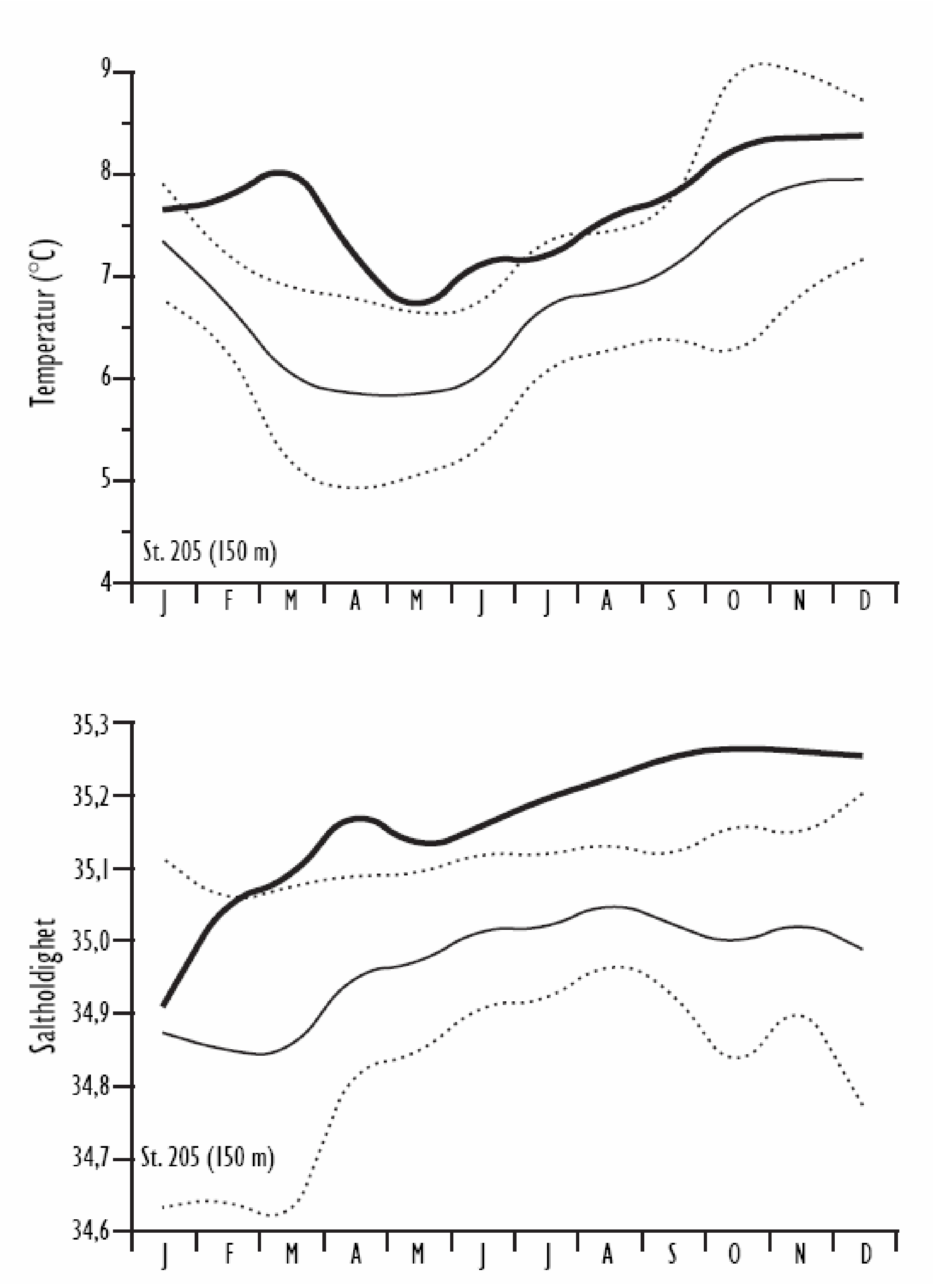


Figure 2.6.6. Temperature and salinity at 150 m depth based on monthly observations in 2005, 10 km off Torungen lighthouse near Arendal. Long term mean (thin line) and standard deviation (dotted lines) for the period 1961–1990.

Surface salinity also rose in the recent years but from a recent low value to close to the long term average. Near bottom salinity in the north western North Sea showed higher values in the summer of 2004 than in previous years (Figure 2.6.7)

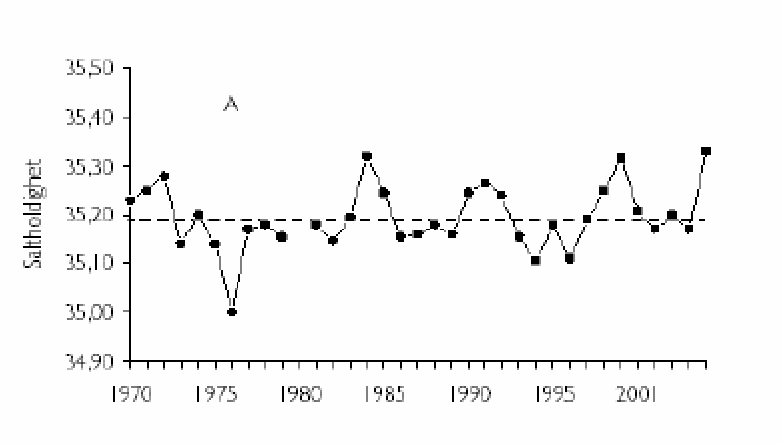


Figure 2.6.7. Salinity near bottom in the north-western part of the North Sea in the summers of 1970-2004.

Several southern species have increased in abundance, even to the extent that a directed fishery for striped red mullet and sea bass is developing.

There is considerable eutrophication in some areas of the North Sea, particularly in the Wadden Sea area, the southern part of the Kattegatt and coastal part of the Skagerrak, as well as shallow waters and estuaries along the UK and European mainland coast. Below the halocline, decomposition of organic matter has occasionally caused oxygen deficiency during late summer/autumn. This phenomenon is linked to enhanced primary productivity but may locally be a natural process, especially in enclosed inshore areas such as the Kattegatt, fjords and estuaries. However, oxygen deficiency is accelerated by large scale eutrophication (Karlsson et al. 2002).

See also the general text on major climatic and oceanographic features in a separate section on the NE Atlantic (Section 2.1).

2.6.1.4 Major climatic and oceanographic features

See general text on this topic in separate section on the NE Atlantic (Section 2.1).

2.6.1.5 Phytoplankton

Primary productivity is dominated by diatoms and dinoflagellates. Up to the 1970s primary production classically followed a spring/autumn bloom pattern. This is borne out by Continuous Plankton Recorder (CPR) “greenness” values. Since the 1970s this separation has become increasingly blurred and primary production has been continuous over much of the year and also over a longer period (Hughes & Lavin 2004). This longer and less bipolar productivity has led to a much greater primary production in all recent years, associated with a reduction in diatom production and an increase in dinoflagelates. Both trends appear to be continuing in the most recent years. Theoretically this should provide more food at the base of the food web (SAHFOS 2003). After the recent changes, the primary productivity in the North Sea can be considered as stronger and lasting longer than in adjacent Atlantic waters.

2.6.1.6 Zooplankton

Zooplankton production is dominated by copepods and euphausids, both important food items for many key commercial stocks. Changes in the zooplankton community have been linked to Atlantic inflow patterns across the twentieth century (Reid et al 2003). CPR and other data sources show that the abundance of copepods (particularly Calanus finmarchicus) has declined severely in the last 10 years. (Heath et al 1999 and www.marlab.ac.uk/ FRS.web/Uploads/

Documents/Zooplankton.pdf). This decline shows a strong link to the NAO through spring wind patterns and the volume of cold bottom water in the Faroe-Shetland Channel rather than to conditions in the North Sea per se. The relative proportions of C. finmarchicus to C. helgolandicus also have changed markedly, the former dominating up to the 1970s (representing around 70% of the zooplankton biomass) and the latter since 1995. C. helgolandicus prefers warmer waters and is generally a smaller and less profitable prey than C. finmarchicus. These trends appear to be continuing (Figure 2.6.8) and links have been made with cod and flatfish recruitment (Beaugrand et al 2003, Beaugrand 2004) see Figure 2.6.9. and herring growth and migration patterns (REF). The CPR data also show a reduction in euphausid availability. However no changes have been recorded in the total zooplankton biomass and in total copepod abundance (e.g. northern North Sea areas B1 and B2; SAHFOS 2004, Heath 2005). The overall picture is one of a changing community structure Figure 2.6.10.

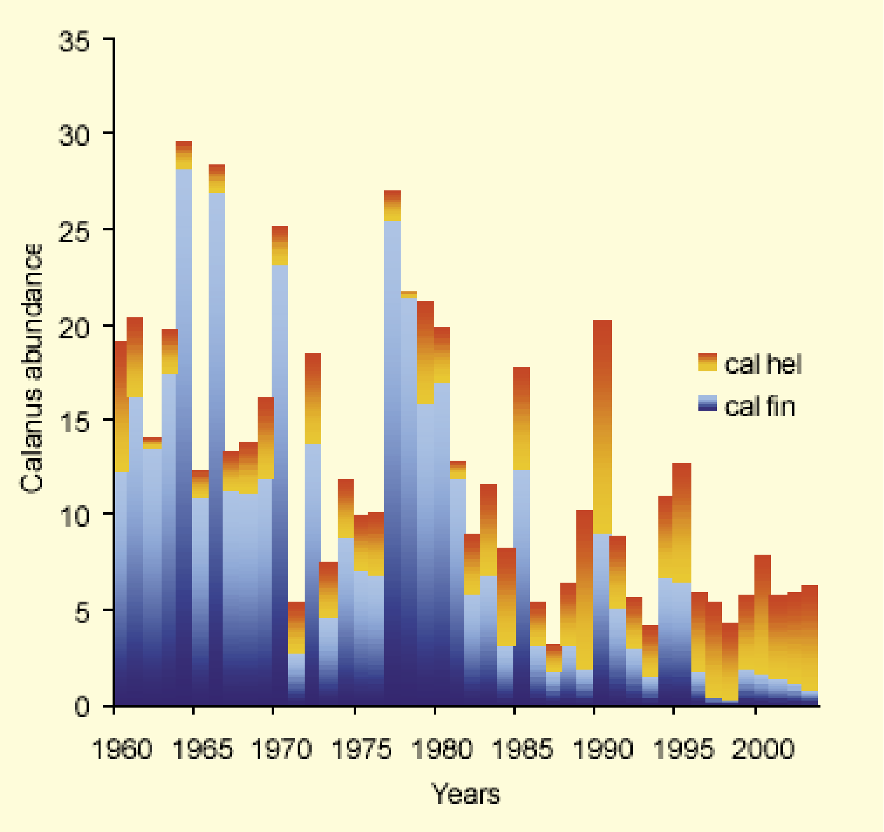


Figure 2.6.8. The abundance of Calanus populations in the North Sea from 1960 to 2003. The percentage ratio of Calanus finmarchicus (blue) and Calanus helgolandicus (red) are shown in relation to total Calanus abundance in each annual bar. From www.sahfos.org, Ecological Status 2004/5

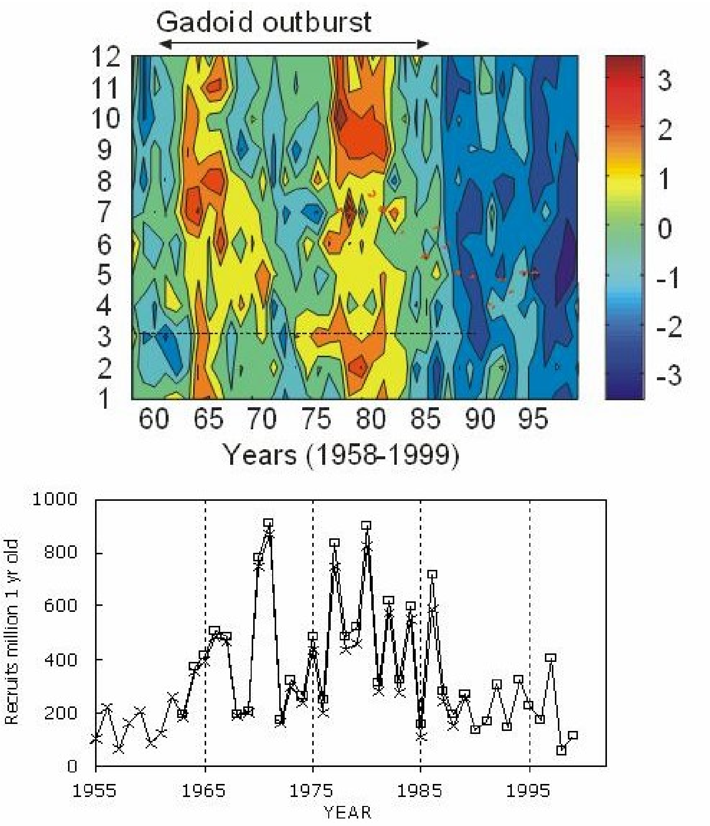


Figure 2.6.9. Top; long-term monthly changes (1958-1999) in the Beaugrand et al. (2003) plankton index. A negative anomaly in the index indicates a low value for Calanus finmarchicus, euphausiids, mean size of calanoid copepods with the exception of C. helgolandicus (opposite pattern) and Pseudocalanus spp. (no relationship). A positive anomaly indicates a high abundance of prey (and prey of suitable size). The lower plot shows cod recruitment (in decimal logarithm) in the North Sea. The period of the Gadoid Outburst is also indicated. Source; SAHFOS 2003 - modified, from Beaugrand et al. (2003).

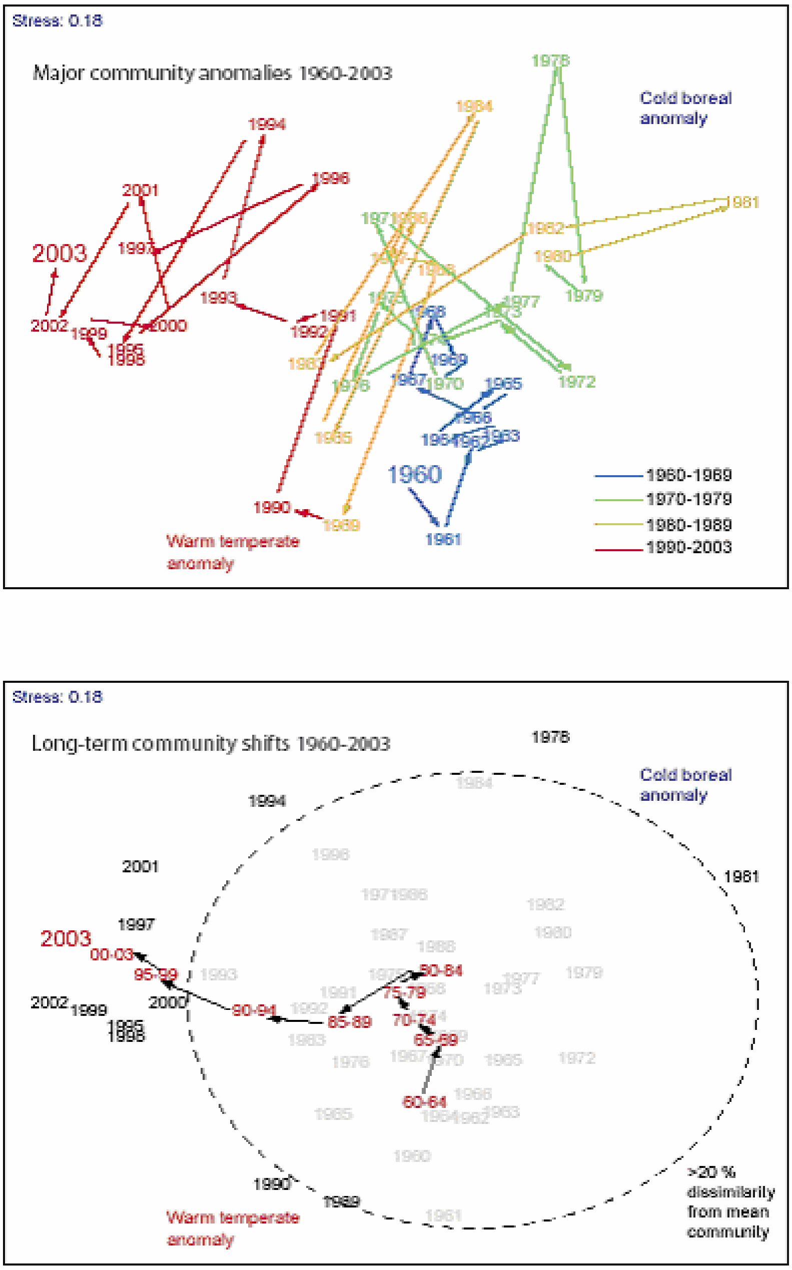


Figure 2.6.10 Multi-dimensional scaling plot of the annual zooplankton community structure in the central North Sea from 1960-2003 showing major structural shifts (top figure) and five-year community averages (bottom figure). Similarity matrix based on Bray-Curtis and log (x+1) transformations. From www.sahfos.org, Ecological Status 2004

2.6.1.7 Benthos and larger invertebrates

The 50m, 100m and 200m depth contours broadly define the boundaries between the main benthic communities in the North Sea, with local community structure further modified by sediment type (Künitzer et al., 1992; Callaway et al., 2001). Descriptions of the spatial distribution of infaunal and epifaunal invertebrates show that the diversity of infauna and epifauna is lower in the southern North Sea than in central and northern North Sea. However, large-scale spatial gradients in biomass are less pronounced. Bottom temperature, sediment type and trawling intensity have been identified as the main environmental variables affecting community structure. Epifaunal communities are dominated by free living species in the south and sessile species in the North.

Reliable information on trends in biomass of benthic species is largely lacking. Although there is a large body of evidence that towed bottom gears kill off large quantities of benthic animals and direct effects are undoubtedly large, the long-term impact is unknown.

Large-scale discarding of a variety of macrobenthos species occurs in the mixed demersal trawl fisheries, particularly in the beam-trawl fishery for sole and plaice and the otter-trawl fishery for Norway lobsters. These fisheries alter the biomass, production, size structure and diversity of benthic communities, with the intensity and patchiness determining the aggregate impacts (ICES 1999). In areas with periodical oxygen deficiency e.g. in the Kattegatt, the benthic fauna is affected by mortality or reduced growth (Diaz and Rosenberg 1995). This may in turn cause shortage of food for demersal fish.

Directed fisheries exist for Nephrops norvegicus, Pandalus borealis and brown shrimp Crangon crangon.

2.6.1.8 Fish community

2.6.1.8.1 Dominant species

Estimates of the total biomass of North Sea fish in the 1980s were in the order of 12 million tonnes, 2/3 of which comprised of the major eleven exploited species (Daan et al, 1990). Throughout the year, the pelagic component is dominated by herring. Mackerel and horse mackerel are mainly present in the summer half year when they enter the area from the south and from the northwest. Dominating gadoid species are cod, haddock, whiting and saithe, whereas the main flatfish species are dab, plaice, long rough dab, lemon sole and sole. The major forage fish species are sandeels, Norway pout and sprat, but juvenile herring and gadoids also represent an important part of the forage stock. However, large annual variations in species composition occur as a consequence of natural fluctuations in recruitment success of the individual species.

The late 1960s up to the early 1980s were characterised by a sudden and yet unexplained increase in the abundance of the large commercially important gadoid species, the ‘gadoid outburst’. During this period, cod, haddock, whiting and saithe, all produced a series of strong year classes. Since the late 1980s however, the stocks of these species have been decreasing and especially cod is at the lowest level observed over the last century. North Sea herring and mackerel were heavily overfished in the 1960s and 1970s and the stocks collapsed. The herring stock has recovered following a closure of the fishery in the late 1970s. The North Sea mackerel stock has remained low, but during the second half of the year they are believed to be mixed with large numbers of fish of NE Atlantic stock origin, are likely to be implicated in the fishery for these.

Over the last decade a number of so-called ‘southern’ species have increased which is probably a response to the raise in water temperatures (Beare et al, 2004). However, many ‘northern’ species have also increased, although less markedly (Daan pers comm).

2.6.1.8.2 Size spectrum

Absolute numbers of both small fish belonging to all species and of demersal species with a low maximum length have steadily and significantly increased over large parts of the area during the last 30 years, while the abundance of large fish has decreased (Daan et al., 2005). For comparison along the Swedish Skagerrak coast see Svedäng (2003). The best available explanation for this is provided by a reduction of the predation pressure on juvenile fish in general and on species that remain small specifically, as an indirect effect of overexploitation of the large predatory fish species.

2.6.1.8.3 Species Richness

Species richness in the North Sea is highest around the edges, and particularly in Scottish waters, in the Southern Bight and in the Kattegat, while it is lowest in the central North Sea (Figure 2.6.11). This may be explained by these areas are frequently invaded by species from adjacent areas that are atypical for the North Sea. Based on the IBTS surveys in February, species richness appears to have increased steadily over the last 30 years (Figure 2.6.12) and trends have been roughly comparable for northerly and southerly species.

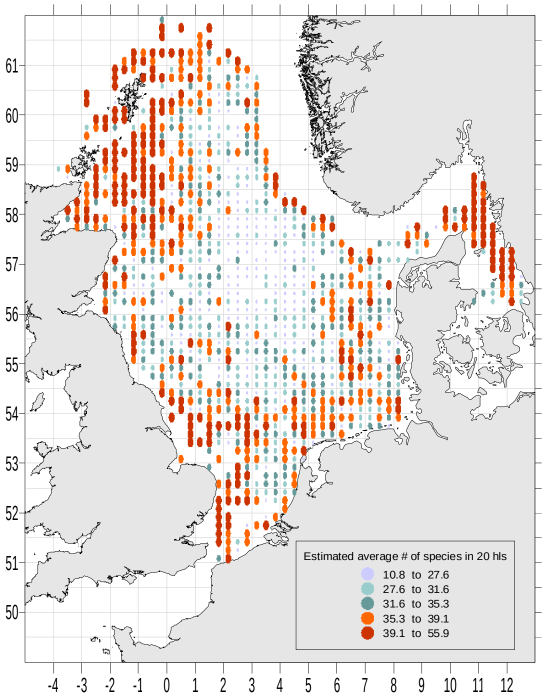


Figure 2.6.11 Spatial indices of species richness for all species

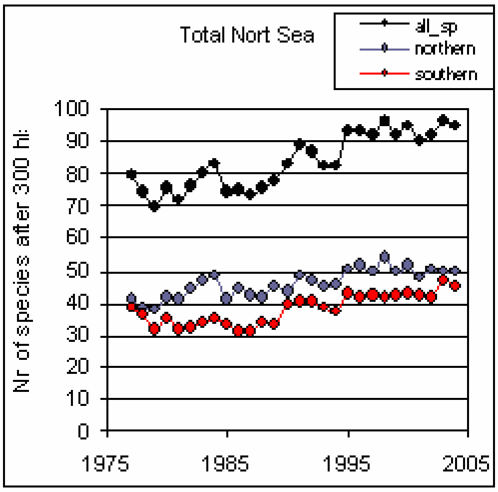


Figure 2.6.12 Species richness based on IBTS surveys

The principal effects of fishing on the size and species composition of the fish community have been that as mortality rose, the mean size of individuals in the community dropped, and species with larger body sizes formed a smaller proportion of community biomass (Gislason & Sinclair 2000). This is reflected in the slopes of size spectra becoming steeper (Rice & Gislason 1996), reductions in the abundance of large species with low intrinsic rates of increase, such as many elasmobranches, (Walker & Heessen 1996; Walker & Hislop 1998), and increases in abundance of many smaller species (Greenstreet & Hall 1996; Heessen & Daan 1996; Greenstreet et al. 1998; Daan et al., 2003, 2005).

2.6.1.8.4 Biomass/abundance of crucial species in the food chain

Landings of Norway pout in 2003 were the lowest of the past two decades. Spawning biomass of sandeel was at the lowest level observed in 2004 (reference). Sandeels are an essential component of the diet of most piscivorous fish species as well as birds and marine mammals and their low abundance is therefore expected to have severe implications for the whole North Sea ecosystem.

2.6.1.8.5 Status of vulnerable species

Certain highly migratory species that have been fairly common historically in the North Sea have disappeared completely (e.g. tuna) or have become very rare (e.g. halibut). Recently species like hake and pollack in the Skagerrak and Kattegat are decreasing. The stocks of most elasmobranchs are at low levels. The spurdog (*Squalus acanthias*) was the most common shark species but is now considered to be depleted to approximately 5% of its virgin biomass in the whole Northeast Atlantic (Hammond & Ellis 2005). Species as porbeagle and tope have become rare. Most ray species are at low levels and have disappeared from large parts of the North Sea (Walker & Heessen, 1996). Spatial management measures have been proposed, and in some cases implemented to protect the remaining stocks.

2.6.1.8.6 Fish population structure

There is generally a lack of information about the population structure of many important fish species such as cod in the North Sea, Skagerrak and Kattegat, both in a genetic sense and with regards to spatial distribution of spawning aggregations. For instance, due to the disappearance of local spawning subpopulations of cod in the last 20 years, the North Sea spawning stock has become increasingly more important, for the recruitment of cod in the Kattegat-Skagerrak area (Svedäng 2003; Cardinale & Svedäng 2004).

2.6.1.9 Birds

About 2.5 million pairs of seabirds breed around the coasts of the North Sea, belonging to some 28 species. While most species breed in dense colonies along the coast, they make a very different use of the marine ecosystem, During the breeding season, some species depend on local feeding conditions within tens of km around their colony, while others may cover several hundreds of km during their foraging trips. Outside the breeding season, some species stay quite close to their breeding grounds whereas others migrate across the North Sea or elsewhere, even as far as the Antarctic. Feeding habits also diverge. Auks and cormorants dive from the surface, gannets and terns use plunge diving, and gulls feed mostly from the surface. A few (esp. skuas) are kleptoparasites (Dunnet et al., 1990). Their food resources vary accordingly, ranging from epiplankton to small schooling fish and discards. Because of all these differences, seabirds do not represent a homogeneous group that responds to fisheries in some specific way. A few species profit directly from human consumption fisheries, either discards or offal e.g. fulmars and gulls.

The current seasonal distributions, status and trends of these species are well known and documented in ICES (2003). Most have shown a marked increasing trend over the last century. Historically, auks and cormorants have been hunted, but are now protected in some areas (e.g. southern North Sea and Kattegat). Gulls have been controlled in many areas. Fulmars may have benefited from expansion in fishing. Skuas may have profited directly from the increase in population size of seabirds in general. On a shorter time scale, 12 out of 28 species show an increasing trend during the last decade and 4 a decreasing trend, while 4 appear to be stable and for another 4 the situation is unknown. Local breeding success of some species has been low in some recent years. This been related to a local shortage of forage fish. Although the industrial sandeel fishery has been blamed by some for this failure, there is only limited evidence to support this. The current view is that natural (or maybe climate-change induced) variation in sandeel recruitment is largely responsible. Nevertheless, industrial fishing at these times does not improve the situation and various restrictions have been implemented.

ICES has recommended that trends in breeding success within individual colonies of kittiwakes might serve as an index of seabird community health within the framework of Ecological Quality Objectives (EcoQO) proposed by OSPAR.

2.6.1.10 Mammals

Many cetacean and pinniped species have been observed within the North Sea, but most of these must be considered vagrants and only a few constitute typical representatives of the North Sea ecosystem.

Harbour Phoca vitulina and grey Halichoerus grypus seals have gone through large population changes over the past century. Both species typically inhabit coastal habitats, because they need haul out sites for pupping and weaning. However, they make extensive foraging trips into the open sea. Because of extensive hunting, followed by reduced reproduction rates owing to effects of contamination, the populations of harbour seals along the continental coast reached an all-time low in the 1970s. Subsequently, these populations have increased steadily at an annual rate of 4%, with two major interruptions in 1988 and 2002, when the populations were hit by outbreaks of the phocine distemper virus. Grey seals occur predominantly along the British coast and have been increasing also. In recent years, new colonies have been founded along the continental coast as well. Seals interact with various fishing operations, because they may feed on fish caught in passive gear, but also because they may be caught in various gears. Finally, Scottish fishers claim that the increasing grey seal population rather than their own activities is responsible for the reduced availability of commercial fish species and therefore advocate culls.

Much less is known about the cetacean species inhabiting the North Sea. Population estimates derived from surveys made in 1994 are only available for harbour porpoise Phocoena phocoena (300 000), white-beaked dolphin Lagenorhynchus albirostris (7900), minke whale Balaenoptera acutorostrata (7300) and bottlenose dolphin Tursiops truncatus (120). New population figures will be available during 2006. Although trends are uncertain, harbour porpoise and bottlenose dolphin appear to have reduced ranges compared with the early 20th century. In terms of biomass, the minke whale is the most important marine mammal occurring and consumes small fish such as sandeel. Harbour porpoise is the second most important from a biomass perspective, and the North Sea may represent the most important habitat for this species on the planet.

The main concern about interactions with human activities is the by-catch in fishing operations and effects of contaminants. Specifically, the large by-catch of harbour porpoise in gill net fisheries has led to management measures.

2.6.2 Major environmental influences on ecosystem dynamics

No specific environmental signals were identified specifically to be considered in assessment or management in this area in 2006.

2.6.3 Fishery effects on benthos and fish communities

Large scale discarding is known to occur in the mixed demersal trawl fisheries in the North Sea. In the roundfish fishery (cod, haddock) discards will mainly consist of small sized specimens of the target species, in the flatfish (plaice, sole) and the Nephrops norvegicus fishery there is also discarding of a variety of macrobenthos species.

Bottom trawling modifies the biomass, production, size structure and diversity of benthic communities, with the intensity and patchiness of bottom trawling disturbance determining the aggregate impacts (ICES 1999). One recent estimate suggests that beam trawling in the southern and central North Sea beam trawl fleets reduces total benthic biomass by 39% and benthic production by 15% relative to the unfished state (Hiddink et al. in press), but similar estimates are not available for most other fleets. Historically trawling effort has not been homogeneous, with effort greatly concentrated in preferred fishing grounds. Cumulative trawling impacts would increase if trawling effort were spread more homogeneously or relocated, particularly to more vulnerable habitats, because the first impacts of trawling on a previously untrawled community are greater than subsequent effects (Duplisea et al., 2002). For example, the cod box closure of 2001 led to the beam trawl vessels fishing in previously unimpacted areas (Rijnsdorp et al 2001), and led to a greater reduction in the total productivity of benthic communities (Dinmore et al., 2003).

Closed areas and/or seasons generally result in effort redistribution, which may lead to increased fishery impacts on benthic communities and vulnerable habitats or species. Management advice should take this factor into account when evaluating proposed measures.

The principal effects of fishing on the size and species composition of the North Sea fish community has been that as fishing mortality rose, the mean size of individuals in the community fell, and species with larger body sizes formed a smaller proportion of community biomass (Gislason & Sinclair 2000). This is reflected in the steeper slopes of size spectra (Rice & Gislason 1996), reductions in the abundance of large species, such as many elasmobranches, with low intrinsic rates of increase (Walker & Heessen 1996; Walker & Hislop 1998), increases in abundance of many smaller species (Greenstreet & Hall 1996; Heessen & Daan 1996; Greenstreet et al. 1998; Daan et al., 2003, 2005). The changes in size composition of the community redistribute predation mortality among species and sizes of fish, and these changes should be taken into account in the natural mortality values used in assessments. Changes in size composition of species and communities due to overfishing also can affect population fecundity both directly (reduction of larger, more fecund spawners), and indirectly (earlier maturation at smaller sizes). These changes should be considered in setting reference points as well as provision of management advice to protect the productivity of the exploited resources.

Recent studies (Rochet et al., 2005), based on IBTS data from the southern north sea 1990-2000, developed a diagnostic based on indicators for 13 fish populations and the fish community. The study demonstrated deteriorating trends in the populations and a stable community status (i.e. not improving with reference to the start of the time-series in 1990). The overall conclusion was for a deteriorating situation.

The long-term effects of an eroded population structure must be considered. The differences between the various subpopulations may be behavioural or genetic, but go unobserved by both the fishermen and regulators who believe there is a gradual decline in one big stock while in fact they are witnessing the successive disappearance of a series of sub-populations. Fishing also has differential effects on species with contrasting life histories (Jennings et al. 1999), with many large and vulnerable species subject to unsustainable mortality rates when taken as bycatch in mixed fisheries. Management should take account of the status of these species, and ensure that fishing mortality on bycatch species does not exceed estimates of sustainable mortality for vulnerable species (e.g. Pope et al., 2000).

2.6.3.1 Increased effort and landings in the unregulated fishery for witch in the Skagerrak

As and when exploited species become depleted fisheries may move to other areas or species. Examination of Swedish landings of witch Glyptocephalus cynoglossus in the Skagerrak and the northern Kattegat indicate that this fishery has increased between 1997 to 2004. Several fisheries (Pandalus, Nephrops and mixed demersal trawling) land witch and the directed fishery (landings>30% witch) have increased. During the same period the spatial extent of the fishery has also increased and landings are now registered from five ICES rectangles in the Norwegian Trench. This species is long lived (~30 yrs), slow growing and matures late (5-6 years) so it is likely to be easily overfished. By-catches and discards in the directed witch-fishery include cod and vulnerable species of elasmobranchs e.g. skates and rays and piked dogfish. The development of this fishery in the Skagerrak is an illustration that the fishery impact on the ecosystem is sequential. Although the major moves may be towards more productive/short lived/lower trophic level species, some may also direct long-lived species traditionally not targeted e.g. because of low economic value. This illustrates the fact that ICES needs to be proactive.

2.6.4 Important topics for further research (Knowledge gaps)

Many of the issues which arise in the North Sea, and for which additional research is necessary for improved scientific advice, are also issues in the other ecological areas. However, because of the greater availability of data and information for the North Sea, and the focused scientific effort historically and currently through, for example REGNS (ICES 2005), it may be appropriate to highlight the research needs for this area. Progress in this area should be viewed with regard to implications for other areas, however, and opportunities for collaborative and integrative work should be sought.

- Community ecology: what are the ecological effects of a diminishing size spectrum and a dominance of prey species like herring. Can these changes be readily reversed through management.
- Temperature preferences i.e. what are the effects of climate change on reproduction, egg mortality, growth, and the implications for changes stock population dynamics and distributions
- What are the consequences of the loss of meta-population structure and erosion of spawning aggregations in depleted populations.
- There should be better estimations of population fecundity, i.e. better understanding of reproduction biology including better estimates of maturity ogives, variation in maturation rates, the linkage between maturation and growth, temperature, for a more realistic view of stock productivity

Using this information, it is important to investigate and test management strategies which would be sustainable in the fact of these dynamic ecological conditions; how to preserve the productivity of the seas and have some revenues from fishing at the same time

2.6.5 Conclusions

2.6.5.1 Short term

No major short term changes with implications for fisheries management were noted by WGRED. It should be noted that SST across much of the North Sea was close to the mean from January to August 2005, but showed strong positive anomalies thereafter. In contrast the inflowing Atlantic water was well above average temperature and salinity throughout the year.

2.6.5.2 Medium term

The observed low abundance of species that play an important role in the North Sea food web (Calanus, sandeels, and Norway pout) has persisted into 2005. It is still expected to have considerable impact on growth, maturation and possibly recruitment of a range of fish species and on the breeding success of seabirds.

Many North Sea fish stocks presently remain seriously depleted (e.g. cod and plaice). Recruitment of commercially important gadoids is at a low level and this has led to speculation that the ecosystem may be changing in an irreversible direction. However, there are preliminary indication s of improved recruitment in some parts of the North Sea for haddock and possibly very localised recruitment of cod. Thus far these should not be taken as indicating a major recovery in gadoid recruitment in the North Sea. Another phenomenon worth mentioning is the increase in a number of southern species e.g. anchovy (*Engraulis encrasicola*). In the case of red mullet *Mullus surmulletus* the increase is so significant that a new fishery is developing.

WGRED notes the initial analysis carried out by the REGNS group. In particular, the Principle Component Analysis on the full data set (see Figure 2.6.13 – taken from Figure 4 of the REGNS report (ICES 2005)). This plot clearly shows the late 1980s regime shift. It also shows a possible change in 2004/05, however, this was not emphasised by REGNS, and the analysis should probably be considered as preliminary.

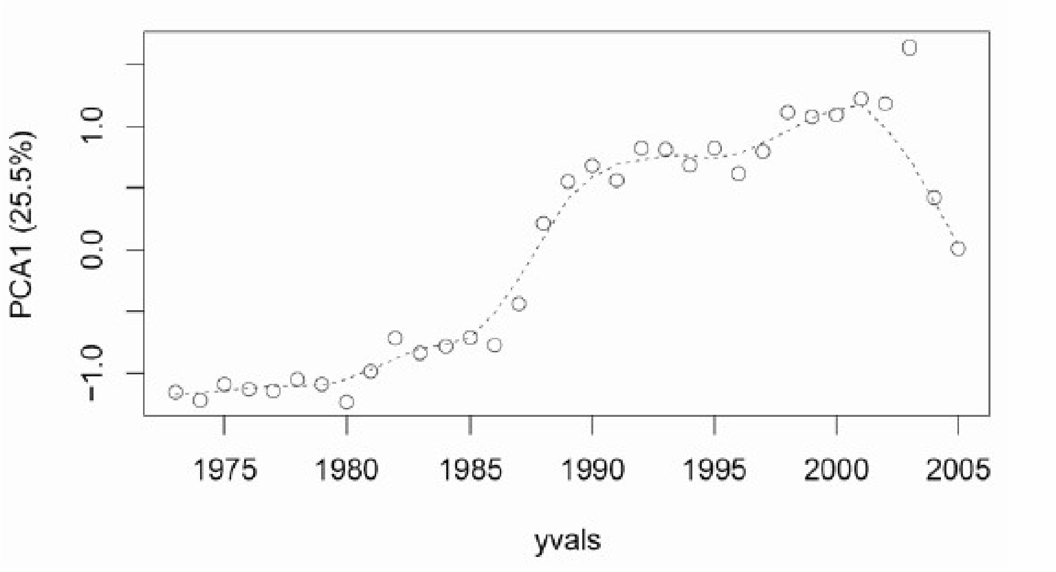


Figure 2.6.13. Time-series of the composite variables (PCA1) that summarises some of the changes ob-served in the North Sea (ICES 2005).

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2.7 The Baltic Sea

2.7.1 Ecosystem Components

2.7.1.1 Bottom topography, substrates and circulation

The Baltic Sea is one of the largest brackish areas in the world. It receives freshwater from a number of larger and smaller rivers while saltwater enters from the North Sea along the bottom of the narrow straits between Denmark and Sweden. This creates a salinity gradient from southwest to northeast and a water circulation characterised by the inflow of saline bottom water and a surface current of brackish water flowing out of the area.

The Baltic Sea is characterised by large areas (ca 30%) that are less than 25 m deep interspersed by a number of deeper basins with a maximum depth of 459 m. The Gulf of Bothnia and the Gulf of Riga are internal fjords, while the Baltic Proper and the Gulf of Finland feature several deep basins separated by sills. The western and northern parts of the Baltic have rocky bottoms and extended archipelagos, while the bottom in the central, southern and eastern parts consists mostly of sandy or muddy sediment.

2.7.1.2 Physical and Chemical Oceanography

The water column in the open Baltic is permanently stratified with a top layer of brackish water separated from a deeper layer of saline water. This separation limits the transport of oxygen from the surface and as a result the oxygen in the deeper layer can become depleted due to breakdown of organic matter.

A strong inflow of new saline and oxygen rich water from the North Sea can lead to a renewal of the oxygen depleted bottom water. Strong inflows can occur when a high air pressure over the Baltic is followed by a steep air pressure gradient across the transition area between the North Sea and the Baltic. Such situations typically occur in winter. Strong inflows were frequent prior to mid-1970’s, but have since become rarer and as a result salinity has decreased over the last 25 years. Major inflows occurred, however, in 1976, 1983, and 1993. In 2003 an inflow of medium size (200 km^3, ICES 2004) introduced salty, cold and welloxygenated water into all main basins of the Baltic Sea, including the Gotland Deep, Figure 2.7.1.

The Baltic receives nutrients and industrial waste from rivers, and airborne substances from the atmosphere. As a result the Baltic has become eutrophied during the 20th century. In general, nutrient concentrations in the Baltic Sea have not decreased since the mid-1990s, and remain persistently high (Helcom 2003). Low oxygen conditions in deep water affect the amounts of nutrients in the water. Phosphorus is easily released from sediments under anoxic conditions. Nitrogen cycles in deep water layers also change in anoxic conditions: mineralization eventually produces ammonium, and no oxidation occurs to form nitrates. Consequently, the process of denitrification, which needs oxygen from nitrates, will not occur. The resulting nutrient surplus in the deep water layers is a potential source of nutrients for the surface layers, where primary production may be further increased (Helcom 2003). This effect may counterbalance the decrease in nutrient input into some parts of the Baltic Sea. In addition a long-term decrease in silicate concentrations is apparent in most parts of the Baltic, and silicate has recently been limiting growth of diatoms in the Gulf of Riga in spring. Silicate limitation changes the structure of the phytoplankton community rather than limiting the total production (Helcom 2002, p. 181).

Furthermore, hypoxia in shallow coastal waters seriously affects biodiversity, and seems to be an increasing problem – especially in the archipelagos of the northern Baltic Sea. These irregular events are caused by local topography, hydrography and drifting algal mats. (Helcom 2002, p. 166).

Contaminants

The Baltic Sea is severely contaminated, and contamination status is regularly assessed through Helcom (e.g., Helcom 2002, 2003), where details are available. Whereas DDT pollution has decreased substantially, the decline of PCB and Dioxin concentrations has levelled off, suggesting that some input of these compounds continue (Helcom 2002). Contaminant levels in northern Baltic herring and salmon are so high that consumption is being regulated (Helcom 2002, 2004).

Broad scale climate and oceanographic features and drivers

The oceanographic conditions in the Baltic are very much driven by meteorological forcing influencing inflow from the North Sea. Significant correlations have been demonstrated between the NAO and total freshwater runoff, westerly winds and salinity (Häninnen *et al.* 2000), ice conditions (Koslowski & Loewe 1994) as well as local circulation and upwelling (Lehmann *et al.* 2002). Climate variability has been shown to affect the dynamics of many of the components of the Baltic ecosystem.

2.7.1.3 Phytoplankton

The species composition of the phytoplankton depends on local nutrients and salinity and changes gradually from the southwest to the northeast. Primary production exhibits large seasonal and interannual variability (Helcom 2002, p. 182). Normally, an intense spring bloom starts in March in the western Baltic, but only in May-June in the Gulf of Bothnia. In the southern and western parts the spring bloom is dominated by diatoms, whereas it is dominated by dinoflagellates in the central and northern parts. Over the period from 1979 to 1999 downward trends were found for diatoms in spring and summer, whereas dinoflagellates generally increased in the Baltic proper, but decreased in the Kattegat. Chlorophyll a, a proxy indicator for total phytoplankton biomass, also increased in the Baltic proper (Wasmund and Uhlig 2003).

Summer blooms of nitrogen-fixing cyanobacteria ("blue-green algae") are normal in the central Baltic, Bothnian Sea, Gulf of Finland and Gulf of Riga. Such blooms have occurred in the Baltic Sea for at least 7,000 years, but their frequency and intensity seem to have increased since the 1960s. Mass occurrences of blue-green algae are often made up of several species. Since 1992 the relative abundance of the most common species has shown a clear trend in the Arkona Basin (southern Baltic) and in the northern Baltic Sea: the toxin-producing species Nodularia spumigena has become more abundant compared to the non-toxic Aphanizomenon flos-aquae. Red tides (dinoflagellate blooms) are regularly observed, including blooms of the toxic Gymnodinium mikimotoi (Helcom 2002, 2003).

2.7.1.4 Zooplankton

The zooplankton of the Baltic Sea is dominated by calanoid copepod and cladocerans. The species composition is influenced by the salinity gradient. Generally marine species (e.g. Pseudocalanus sp.) prevail in the southern more saline part, while brackish species (e.g. Eurytemora affinis and Bosmina longispina maritima) dominate in the northern areas. Changes in the species composition of the zooplankton have been linked to changes in salinity and temperature. For the shallower northern areas of the Baltic Sea a decline of large neritic copepods and a increase of species with freshwater origin, i.e. cladocerans has been related to a reduction of salinity caused by increased river runoff (Viitasalo et al. 1995, Vuorinen et al. 1998, Ojaveer et al. 1998). In the Central Baltic deep basins the abundance and biomass of Pseudocalanus sp. has declined since the 1980s, whereas the abundance of *Temora longicornis* and *Acartia spp*. increased (Figure 2.7.2). The decrease in *Pseudocalanus sp*. is correlated to the decrease in deep water salinity resulting from the reduced frequency of inflow events (Möllmann et al. 2000, 2003 a). Recent investigations indicate that the combination of low salinity and oxygen conditions in the halocline of the deep basins, might have a detrimental effect on the viability of *Pseudocalanus sp.* eggs and nauplii (Schmidt et al. 2003, Renz and Hirche 2005). The increase in *Acartia spp.* and *T. longicornis* during the 1990s is correlated with temperature (Möllmann et al. 2000, 2003 a), a result of the persistently strong positive state of the NAO (Alheit et al. 2005, Möllmann et al. 2005). Recent investigations indicate that temperature-dependent resting egg activation is the responsible process behind the temperature-Acartia spp. relationship (Alheit et al. 2005). Information on long-term trends of macrozooplankton (e.g. mysids) and gelatinous zooplankton is generally insufficient.

2.7.1.5 Benthos

The composition of the benthos depends both on the sediment type and salinity, with suspension feeding mussels being important on hard substrate while deposit feeders and burrowing forms dominate on soft bottoms. The species richness of the zoobenthos is generally poor and declines from the southwest towards the north due to the drop in salinity. However, species poor areas and low benthos biomasses are also found in the deep basins in the central Baltic due to the low oxygen content of the bottom water. After major inflows a colonisation of these areas can, however, be seen.

In the south-western part of the Baltic the bivalve *Macoma balthica* characterises the community found on shallow soft bottoms while a community characterised by the bivalves *Abra alba* and *Arctica islandica* are found in the deeper parts. East of the Dars sill various polychaetes become important in the deeper parts. In the central areas the major parts of the hard bottoms are inhabited by communities of *Fucus vesiculosus* and *Mytilus edulis,* while the fauna of the main part of the soft bottoms has been classified as a *Macoma* community (Voipio, 1981). In the Bothnian Bay and the central part of the Bothnian Sea the isopod *Saduria entomon* and the amphipod *Pontoporeia spp*. dominate the zoobenthos (Laine 2003). In shallow areas seaweed and seagrass form important habitats (including nursery grounds) for many animals. The distribution of seaweed and seagrass has changed over time, in some cases in response to eutrophication (Helcom 2003, p. 114).

2.7.1.6 Fish

The distribution of the roughly 100 fish species inhabiting the Baltic is largely governed by salinity. Marine species (some 70 species) dominate in the Baltic Proper, while freshwater species (some 30-40 species) occur in coastal areas and in the innermost parts (Nellen and Thiel 1996, cited in Helcom 2002). Cod, sea and sprat comprise the large majority of the fish community in both biomass and numbers. Commercially important marine species are sprat, herring, cod, various flatfish, and salmon. Sea trout and eel, once abundant, are of very low population sizes. Sturgeons, once common in the Baltic Sea and its large rivers are now extinct from the area. Recruitment failures of coastal fish, e.g. perch (*Perca fluviatilis*) and pike (*Esox lucius*) in Sweden have been observed along the Swedish Baltic coast (Nilsson *et al.* 2004, Sandström and Karås 2002). Further studies show that several species have failed in the outer archipelagos and that these failures correlate with low densities of zooplankton.

Cod is the main predator on herring and sprat, and there is also some cannibalism on small cod (Köster *et al.* 2003a). Herring and sprat prey on cod eggs, and sprat are cannibalistic on their eggs, although there is seasonal and inter-annual variation in these effects (Köster and Möllmann 2000a). The trophic interactions between cod, herring and sprat may periodically exert a strong influence on the state of the fish stocks in the Baltic. To accommodate predator-prey effects in the assessment (e.g., predation by cod on herring and sprat) multispecies models are used to estimate the natural mortality of herring and sprat. Due to the coastal spawning of herring, it is also subject to interactions with freshwater species in the coastal zone. For example, pikeperch predation on young herring can decrease local herring production considerably (Hansson *et al.*, 1997). Immature cod are also commonly found in shallower areas (Baranova 1995), but the relative importance of its interactions with coastal dwelling species remains unclear.

Climate driven changes in the salinity, temperature and oxygen content of the water affect the recruitment and growth of cod, herring and sprat. The reduction in salinity and oxygen and the increase in temperature caused by the high NAO index in the 1990s resulted in a reduction of the growth rate of herring, and sprat growth declined during the 1980s and 1990s, probably due to changes in the zooplankton composition and abundance (Rönkkonen *et al.* 2004, Möllmann *et al*. 2005) and as a result of increases in food competition (Casini et al. 2006), while the recruitment of herring in the Gulf of Riga and sprat in the entire Baltic increased during the 1990s (MacKenzie and Köster 2004).

In the past the eastern cod stock spawned in the Bornholm, Gdansk, and Gotland Deeps (Figure 2.7.3), but in the later years the salinity and oxygen conditions have only allowed successful spawning, egg fertilisation and egg development in the Bornholm Deep (MacKenzie et al 2000). Cod eggs can only develop successfully if the oxygen concentration is larger than 2ml*l^{-1} and the salinity is higher than 11 psu, and the volume of water where this is fulfilled, the so-called "reproductive volume", has generally been very low or zero since the mid-1980s in the Gotland and Gdansk Deeps (Figure 2.7.4) (MacKenzie *et al.* 2000). Furthermore, recruitment to the cod stock declined as the spawning stock was reduced by heavy fishing, the decline in the biomass of *Pseudocalanus sp*. reduced the available of food for the cod larvae, and the increase in the sprat biomass meant increased the predation of cod eggs by sprat.

Hydrographic-climatic variability (i.e., low frequency of inflows from the North Sea, warm temperatures) and heavy fishing during the past 10-15 years have thus led to a shift in the fish community from cod to clupeids (herring, sprat) by first weakening cod recruitment (Jarre-

Teichmann *et al.* 2000) and subsequently generating favourable recruitment conditions for sprat (Köster and Möllmann, 2000, Köster *et al.*, 2003; MacKenzie and Köster, 2004).

2.7.1.7 Birds and mammals

The marine mammals in the Baltic consist of grey (*Halichoerus grypus*), ringed (*Phoca hispida*), and harbour seals (*Phoca vitulina*), and a small population of harbour porpoise (*Phocoena phocoena*). Seals and harbour porpoise were much more abundant in the early 1900s than they are today (Elmgren 1989; Harding and Härkönen 1999) where their fish consumption may have been an important regulating factor for the abundance of fish (MacKenzie *et al.*, 2002). Baltic seal populations – harbour seals, grey seals and ringed seals – are generally increasing. Little is known about recent changes in the abundance of the harbour porpoise (Helcom 2001).

The seabirds in the Baltic Sea comprise pelagic species like divers, gulls and auks, as well as benthic feeding species like dabbling ducks, sea ducks, mergansers and coots (ICES 2003). The Baltic Sea is more important for wintering (c.10 million) than for breeding (c.0.5 million) seabirds and sea ducks. The common eider exploits marine waters throughout the annual cycle, but ranges from being highly migratory (e.g., in Finland) to being more sedentary (e.g., in Denmark).

Population trends for seabirds breeding within the different countries of the Baltic Sea show an overall decrease for nine of the 19 breeding seabird species. Black-headed gulls are assessed as decreasing throughout the Baltic Sea, whereas the eight other species are considered decreasing in parts of the Baltic Sea. The status of other species, which predominantly breed in the archipelago areas, like common eider, arctic skua, Caspian tern and black guillemot, is uncertain, and populations of these species may be decreasing in parts of the archipelago areas (ICES 2003).

2.7.2 The major effects of fishing on the ecosystem

In the Central Baltic cod and sprat spawn in the same deep basins and have partly overlapping spawning seasons. However, their reproductive success is largely out of phase. Hydrographic-climatic variability (i.e., low frequency of inflows from the North Sea, warm temperatures) and heavy fishing during the past three decades have led to a shift in the fish community from cod to clupeids (herring, sprat) by first weakening cod recruitment (Jarre-Teichmann *et al.* 2000) and subsequently generating favourable recruitment conditions for sprat thereby resulting increasing clupeid predation on early life stages of cod (Köster and Möllmann, 2000, Köster *et al.*, 2003; MacKenzie and Köster, 2004). The shift from a cod to a sprat-dominated system may thus be explained by differences in the reproductive requirements of both species in a changing marine environment. Additionally, the dominance shift was supported by the continued high fishing pressure on cod (Jarre-Teichmann 1995).

Coastal commercial and recreational fisheries have also influenced ecosystem structures (Hansson *et al.*, 1997). This impact is generally more local than that of the offshore fishery, however, since most of the coastal fish species are relatively stationary.

2.7.2.1 Bycatch of fish

The total by-catch of fish in the Baltic fisheries is presently unknown. The EU has supported several very recent studies of by-catch, the results of which have been compiled by ICES (2000c). These studies primarily concern the major fisheries for cod, herring and sprat and these have low by-catches. The less important smaller fisheries can have a high proportion of by-catch (Helcom 2002).

The occurrence of lost net have been surveyed in areas where gillnet fishing are practiced and lost nets are frequent (www.fiskeriverket.se/miljofragor/pdf/okt-rapp_webb.pdf). Lost gillnets in the Baltic cod fishery are most likely of concern for cod fishing mortality since 30-50% of the landings originate from the net fishery. Experiments show that during the first 3 months, the relative catching efficiency of “lost” nets decrease by around 80%, thereafter stabilising around 5–6% of the initial level (Tschernij and Larsson 2003).

2.7.2.2 Bycatch of seabirds and mammals

Fishing nets, in particular set nets, have caused considerable mortality for long-tailed ducks (*Clangula hyemalis*), velvet scoters (*Melanitta fusca*), eiders (*Somateria mollissima*) and black scoters (*Melanitta nigra*). There are also reports of guillemot and razorbill (*Alca torda*) mortality in the driftnet fishery for salmon (Helcom 2003).

Reports suggest that fisheries by-catches amount to 0.5–0.8% of the porpoise population in the south-western part of the Baltic Marine Area each year, as well as 1.2% of the porpoise population in the Kiel and Mecklenburg Bays and inner Danish waters (Kock and Behnke 1996). Estimates of the harbour porpoise population are uncertain, however, and the number of porpoises by-caught in fisheries is probably underestimated. The loss of porpoises to fishery in the Baltic Marine Area may be too high to sustain the population (ICES, 1997).

Seals have been recorded caught in fyke nets, set nets and salmon driftnets, but although the recorded data almost certainly underestimate the total number of by-caught seals, the added mortality does not appear to restrain the seal populations from increasing (Helander and Härkönen, 1997).

2.7.2.3 Other effects of fishing on seabirds and mammals

Fishing activities will also affect the seabird community through the discarding of unwanted catch and fish offal. Studies indicate, for example, that over 50% of the offal discarded in the Baltic Marine Area will be consumed by seabirds (ICES, 2000c).

2.7.3 Other effects of human use of the ecosystem

Human society uses the Baltic for many purposes including shipping, tourism, and mariculture. Overviews are given in Helcom (2002, 2003) and Frid *et al.* (2003). Shipping may pose threats due to transport and release of hazardous substances (e.g., oil) and non-indigenous organisms. The former would likely have only relatively short-term effects (e.g., direct mortality of individuals in a restricted time and area), whereas the latter are more likely to have longer-term and more widespread effects (e.g., influences on energy flows or species interactions in food webs.

2.7.4 Conclusions

2.7.4.1 Short term

The WG was unable to identify strong environmental signals likely to have implications for short term management advice.

2.7.4.2 Medium-term

Depletion of cod in the Baltic has contributed to a shift in the trophic structure from a cod dominated system to a clupeoid dominated system. This has been accompanied by shift in zooplankton and phytoplankton, which may be related to a reduced inflow of saline water, higher average temperatures and to increased precipitation due to a consistently high NAO in the 1990s. There is no evidence to suggest that the current situation will reverse, given the low level of cod biomass and lack of major inflow events.

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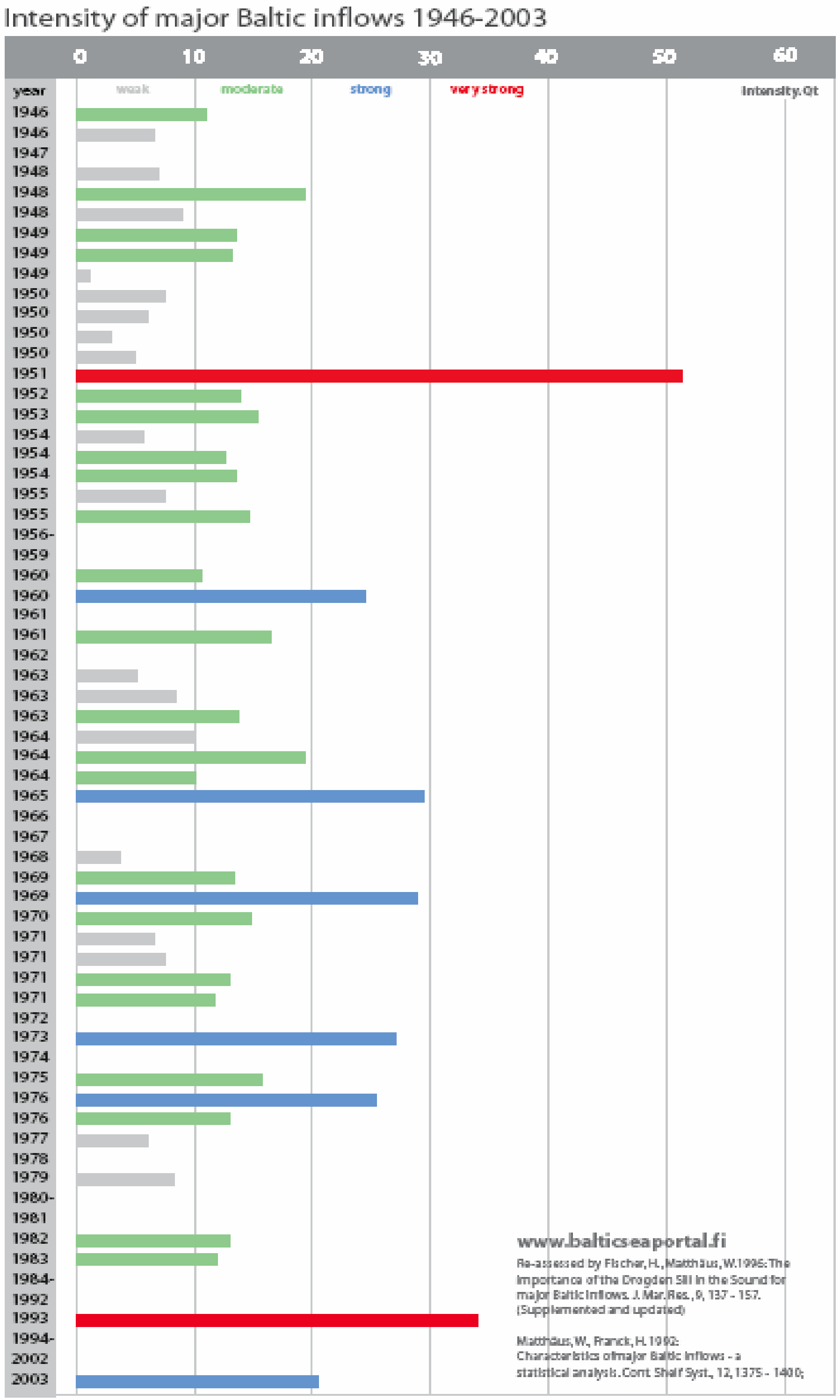

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Figure 2.7.1 Intensity of inflows to the Baltic, 1946-2003.

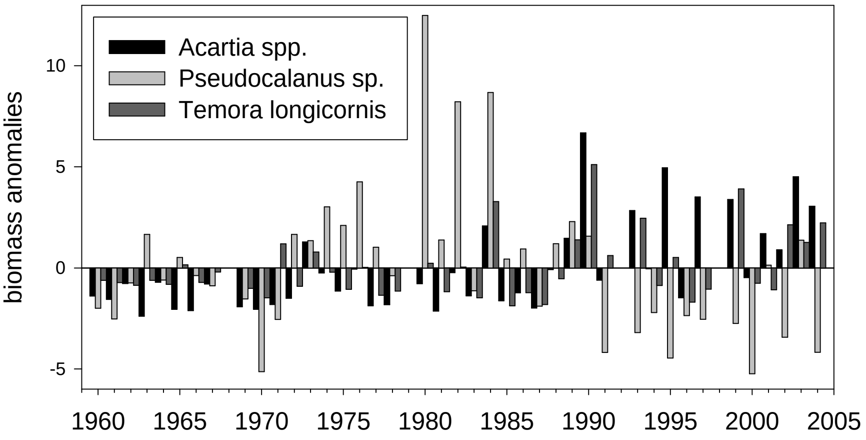


Figure 2.7.2 Time-series on spring biomass (mg*m-3) anomalies for the dominant mesozooplankton species in the Eastern Baltic, i.e. the calanoid copepods Acartia spp., Pseudocalanus sp. and Temora longicornis; data are from the Latvian Fish Resource Agency LatFRA in Riga.

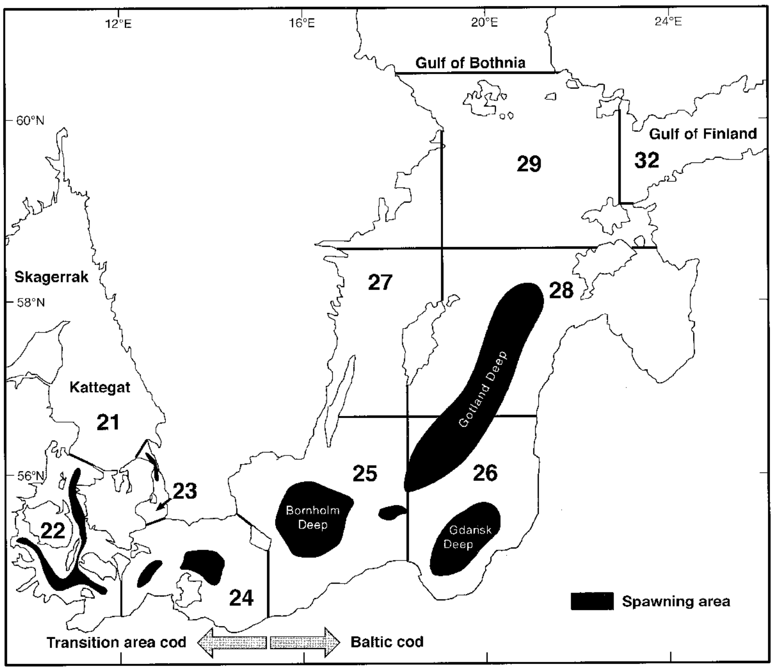
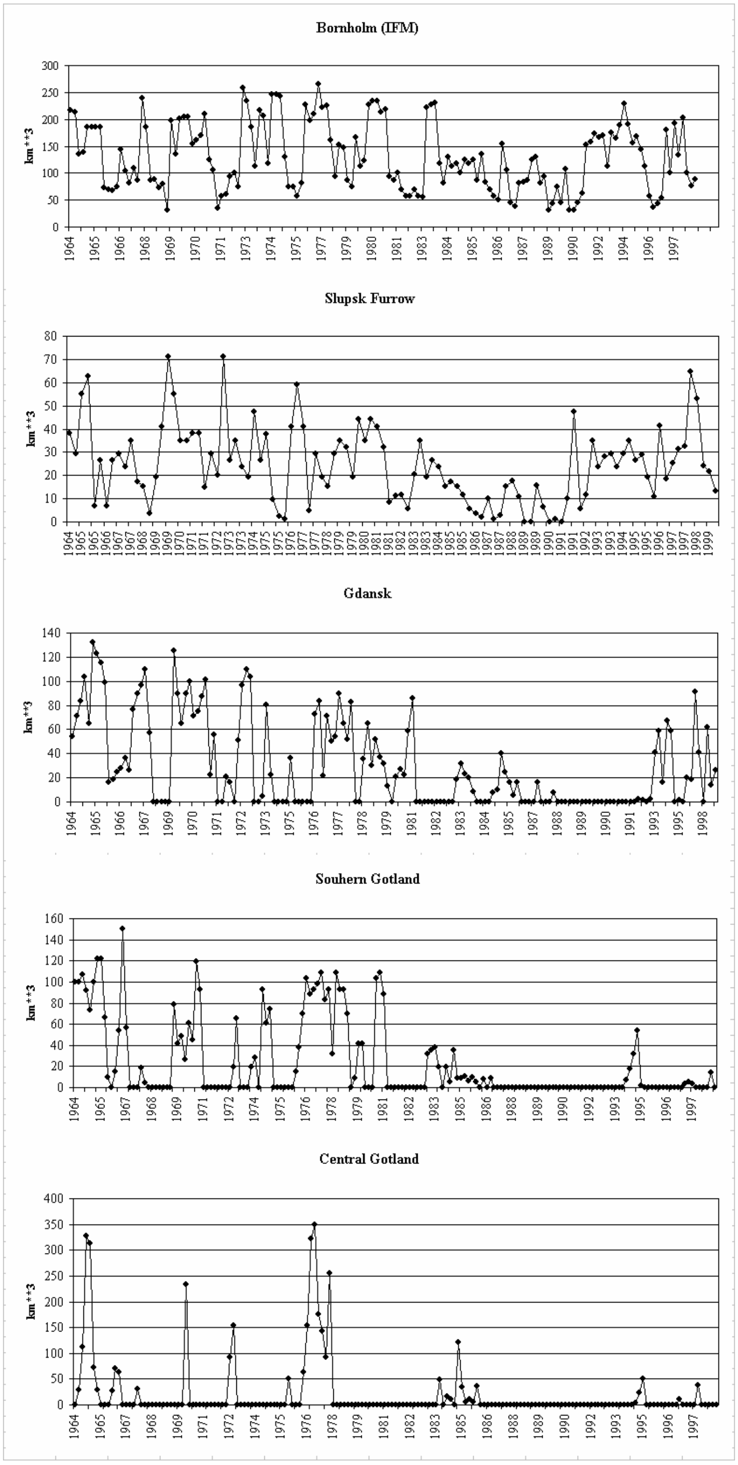


Figure 2.7.3 Historical spawning areas for cod in the Baltic Sea. From Bagge, O., Thurow, F., Steffensen, E., Bay, J. 1994. The Baltic Cod. Dana Vol. 10:1-28, modified by Aro, E. 2000. The spatial and temporal distribution patterns of cod (Gadus morhua callarias) in the Baltic Sea and their dependence on environmental variability – implications for fishery management. Academic dissertation. University of Helsinki and Finnish Game and Fisheries Research Institute, Helsinki 2000, ISBN-951-776-271-2, 75 pp.



Bornholm (IFM)

Slupsk Furrow

Gdansk

Souhern Gotland

Central Gotland

Figure 2.7.4 Time-series of reproductive volume for each spawning site. From MacKenzie, B. R., Hinrichsen, H.-H., Plikshs, M., Wieland, K., Zezera, A. 2000. Quantifying environmental heterogeneity: estimating the size of habitat for successful cod Gadus morhua egg development in the Baltic Sea. Marine Ecology Progress Series 193: 143-156. With updates by Maris Plikshs (Pers. Comm.).

2.8 Bay of Biscay and Iberian Seas

2.8.1 Ecosystem Components

2.8.1.1 General description

The advisory region extends from west of Brittany (48°N) to the Gibraltar Straight (36°N). To the North, the Bay of Biscay is limited by the Brittany coast. A large shelf extends west of France. The southern part of the Bay of Biscay, along the Northern Spanish coast is known as the Cantabrian Sea and is characterised by a narrow shelf. Further south a narrow shelf continues west off Portugal (Figure 2.8.1). Lastly, to the south, the Gulf of Cadiz has a wider shelf strongly influenced by the Mediterranean Sea. Within these zones the topographic diversity and the wide range of substrates result in many different types of coastal habitat (OSPAR, 2000).

2.8.1.2 Bottom topography, substrates, and circulation

2.8.1.2.1 Bottom topography and substrates

The continental shelf in the northern Bay of Biscay is about 140 km wide, it become narrower to the south (about 50 km off southern France). From coast to offshore, the depth increases almost regularly down to 200 m, the shelf is mainly flat. One major sedimentary area off South West Brittany is known as Grande Vasière (large muddy area). On the southern border of the Bay of Biscay, the continental shelf of the Cantabrian sea is as narrow as 12 km. Off western Iberia the only relatively wide shelf section is between the river Miño/Minho and the Nazaré Canyon, whereas the continental shelf in the Gulf of Cadiz is of the order of 50 km wide, particularly to the east (OSPAR, 2000). The shelf-break occurs at depths of around 200 m to the north of the advisory region, and at 130-150 m in the Gulf of Cadiz. The slope is mainly steep and made of rough bottom, with canyons and cliffs, with the only exceptions of a few small terraces mainly to the north and the deep (500m-800m) Landes Plateau in the southern Bay of Biscay.

The sediment cover of the continental margin mainly consists of thick turbidity sheet-fan deposits. These alternate with deposits reflecting periods with less energetic sedimentation. Contouritic deposits occur in the Cantabrian Sea and in the Gulf of Cadiz. The continental shelf and upper slope sediments originate mostly from the continent. The inner shelf (depth <100 m) has mainly rocky or sandy substrate, whereas the outer shelf has predominantly muddy substrate. This muddy substrate is associated with deep canyons on the shelf-break, while in the Galician shelf appear also related to the large estuarine systems of the "*rias*" (López-Jamar *et al.*, 1992).

2.8.1.2.2 Circulation

Most of the water masses are of North Atlantic origin, including those that have been transformed after mixing with the Mediterranean water. The region is affected by both the subpolar and subtropical gyres depending on latitude, but the general circulation in the area mainly follows the subtropical anticyclonic gyre in a relatively weak manner (1-2 $cm.s^{-1}$). Figure 2.8.1 indicates the principal water masses and currents as explained by Mason et al. (2005).

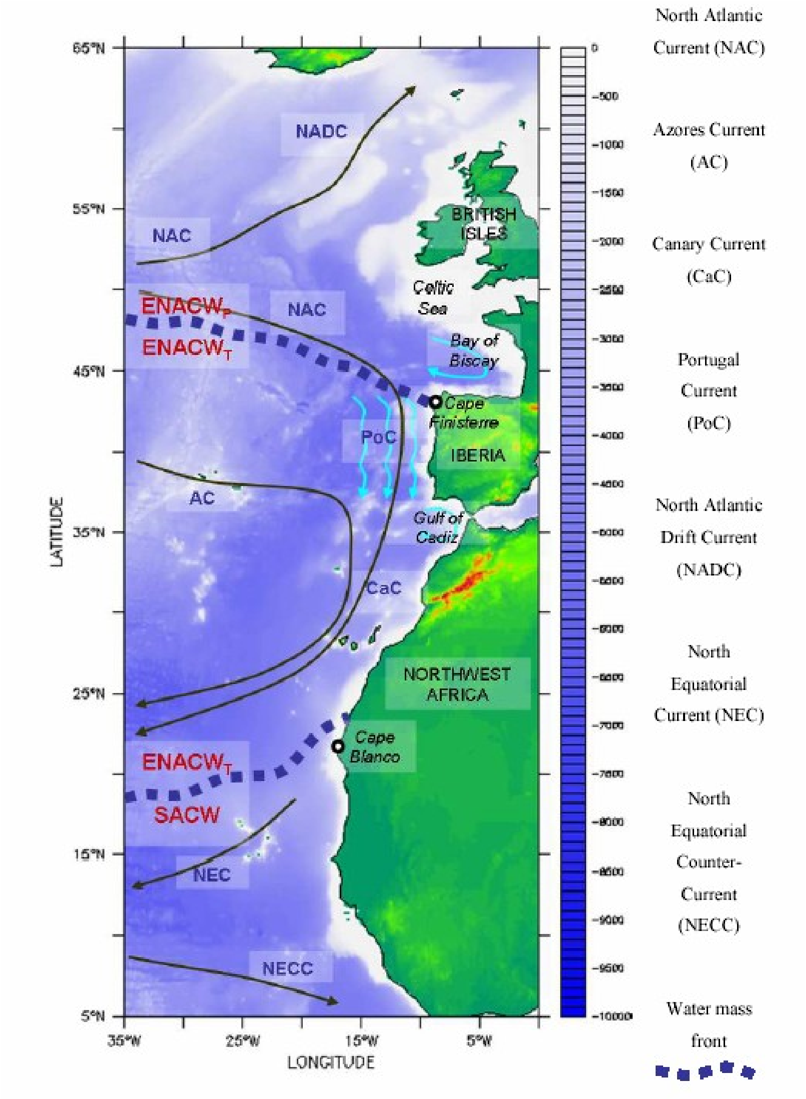


Figure 2.8.1. The main water masses in the Advisory region G are North Atlantic Central Water of sub-polar (ENACWp) and sub-tropical (ENACWt) origins and South Atlantic Central Water (SACW). The main large-scale surface currents are the North Atlantic Current (NAC), the Azores Current (AC), the Canary Current (CaC) and the Portugal Current (PoC). Also shown are the North Atlantic Drift Current (NADC), the North Equatorial Current (NEC) and the North Equatorial Counter Current (NECC). The general circulation of the Bay of Biscay and the Gulf of Cadiz are indicated. Source from Mason et al (2005).

Off France, at the slope of the Bay of Biscay, the mean residual current flows towards the north, although at slope depth (below ca 500 m) it goes down the slope (Pingree & Le Cann, 1990). In the Cantabrian Sea the surface currents generally flow eastwards during winter and spring and change westwards in the summer following the wind forcing (Lavin et al 2006). These changes in the currents direction produce seasonal coastal upwellings. The circulation of the west coast of the Iberian Peninsula is characterized by a complex current system subject to strong seasonality and mesoscale variability, showing reversing patterns between summer and winter in the upper layers of the slope and outer shelf (e.g., Barton, 1998; Peliz *et al.*, 2005, Ruiz Villareal et al, in press). During spring and summer northerly winds along the coast are dominant causing coastal upwelling and producing a southward flowing at the surface and a northward undercurrent at the slope (Fiúza *et al.*, 1982; Haynes and Barton, 1990; Peliz et al., 2005, Mason et al. 2005).

In the autumn and winter, the surface circulation is predominantly northward, partially driven by meridional alongshore density gradients (Peliz *et al.*, 2003a,b), and transporting higher salinity and warmer (subtropical) waters over the slope and shelf break (Frouin *et al.,* 1990; Haynes and Barton, 1990; Pingree and Le Cann, 1990) - the Iberian Poleward Current (Peliz *et al.,* 2003b). These waters are nutrient poor and contribute to fronts which determine the distribution of plankton, fish eggs and larvae (Fernández *et al.,* 1993; González-Quirós *et al.,* 2003). Strong subtropical water intrusions in the Cantabrian Sea may be a feature strongly influenced by wind events (Villamor et al., 2005). Another important features of the upper layer is the Western Iberia Buoyant Plume (WIBP) (Peliz *et al.,* 2002), which is a low salinity surface water body fed by winter-intensified runoff from several rivers from the northwest coast of Portugal and the Galician Rias. The WIBP could play an important role in the survival of fish larvae (Santos *et al.,* 2004).

The intermediate layers are mainly occupied by a poleward flow of Mediterranean Water (MW), which tends to contour the southwestern slope of the Iberia (Ambar and Howe, 1979), generating mesoscale features called Meddies (e.g., Serra and Ambar, 2002), which can transport salty and warm MW over great distance. The exchange of water masses through the Gibraltar Straits is driven by the deep highly saline ($S>37$) and warm Mediterranean Outflow Water (MOW) that flows into the Gulf of Cadiz and the less saline, cool water mass of the Atlantic Intermediate Water (AIW) at the surface.

2.8.1.3 Physical and chemical Oceanography (temperature, salinity, nutrients)

Most important features enhancing primary production are coastal upwelling, coastal run-off and river plumes, seasonal currents and internal waves and tidal fronts.

Upwelling events are a common feature in Portugal, Galicia and western Cantabrian Sea, especially in summer (Fraga, 1981, Fiuza *et al.,* 1982, Blanton *et al.,* 1984). The occurrence of upwelling pulses during summer is important since the upwelling process injects nutrients in the surface layer that fuel primary production. Under conditions of moderate upwelling, the innermost coastal 25 km are about 10 times more productive than offshore waters and the upwelling centres about 20 times more. However upwelling events in the northern Iberian Shelf are generally restricted to a narrow band near the coast in the western Cantabrian Sea (Botas *et al.,* 1990; OSPAR, 2000). In northeast Bay of Biscay, mainly in summer, weak upwelling events occur off South Brittany and the Landes coastline (Figure 2.8.2).

The wind-speed during the 1990s, was greater by 1 $m.s^{-1}$ than over the previous decades. Since the 1940s annual mean speed has tended to decrease in the south of the Bay of Biscay while it has increased in the north. However, these trends are small in comparison with the degree of inter-annual variability at each station (Planque *et al.,* 2003). Regarding off northwest Iberian a notable shift in the winds has occurred during the last two decades, resulting in a reduction in the spring-summer upwelling (Cabanas *et al.,* 2003).

Water temperature is highest to the south, where it is influenced by the MW. For example, the yearly mean temperature at 100m depth is 11.2 °C to the North of the advisory region, 48°N, and 15.6 to the South, 36°N (Levitus, 2001).

Mean surface water temperatures increased 1.4ºC in the southeast Bay of Biscay for the period 1972-1993 (0.6ºC per decade), and. 1.03°C over the last Century (Koutsikopoulos et al., 1998 ; Planque *et al.* 2003). Heat stored in central waters below the mixed layer underwent an important increase in the last decade. ENACW (Eastern North Atlantic Current Water) increased at rates of 0.032ºC yr^{-1} and Mediterranean water about 0.020ºC yr^{-1}, linked to a density compensating salinity increase. These warming rates are from two to six times greater than those accepted for the North Atlantic in the course of the 20th century. The overall result is a net warming of 0.24 ºC for this water column in the period 1992-2003 (Gonzalez-Pola and Lavin, 2003; Gonzalez-Pola et al., 2005).

On the continental shelf, bottom salinity is close to 35. At slope depth, high salinities are found due to the MW (values around 37.0 in the Gulf of Cadiz and above 35.5 in the Bay of Biscay). Low salinity lens from rivers is an important feature in the inner Bay of Biscay (Lavín et al, 2006). On yearly average, the French region received 27000 m^3 s^{-1} of run-off from the major rivers. The major indicators show that flows for 2002 and 2003 are slightly below the long-term average from 1952-2003 and the last 10 years average and preliminary data indicate that in 2004 is close to the long term average (Figure 2.8.3). In the northern Spanish coast, rivers flowing into the Cantabrian Sea are of short length and with smaller importance compared with those of the French coast, as Garonne or Loire. In the north west Spanish coast the rias constitute an important sediment and fresh water source.

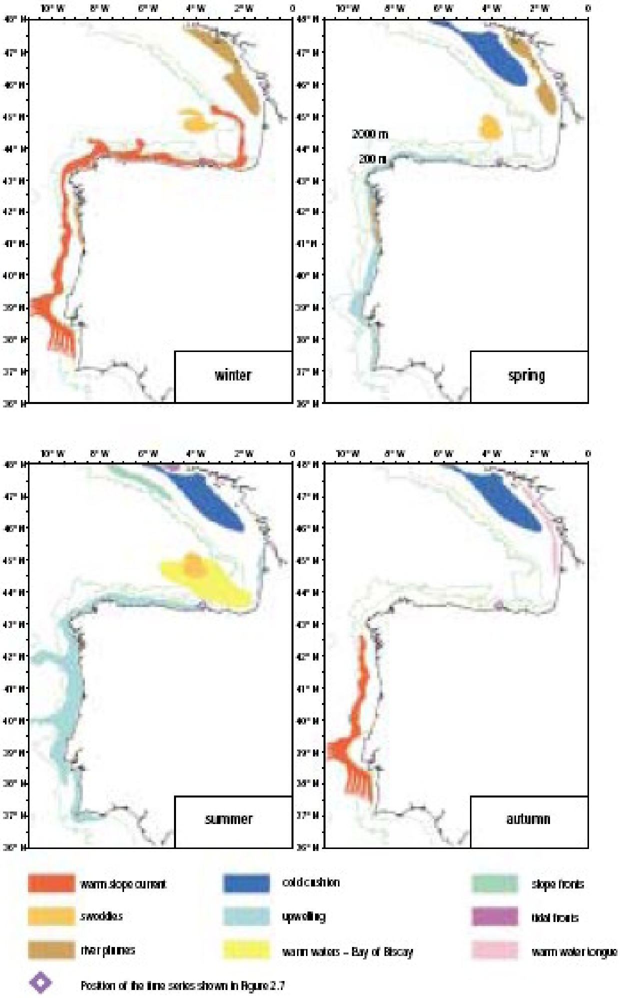


Figure 2.8.2. Seasonal variation in the main hydrographic features. Source: Koutsikopoulos and Le Cann (1996).

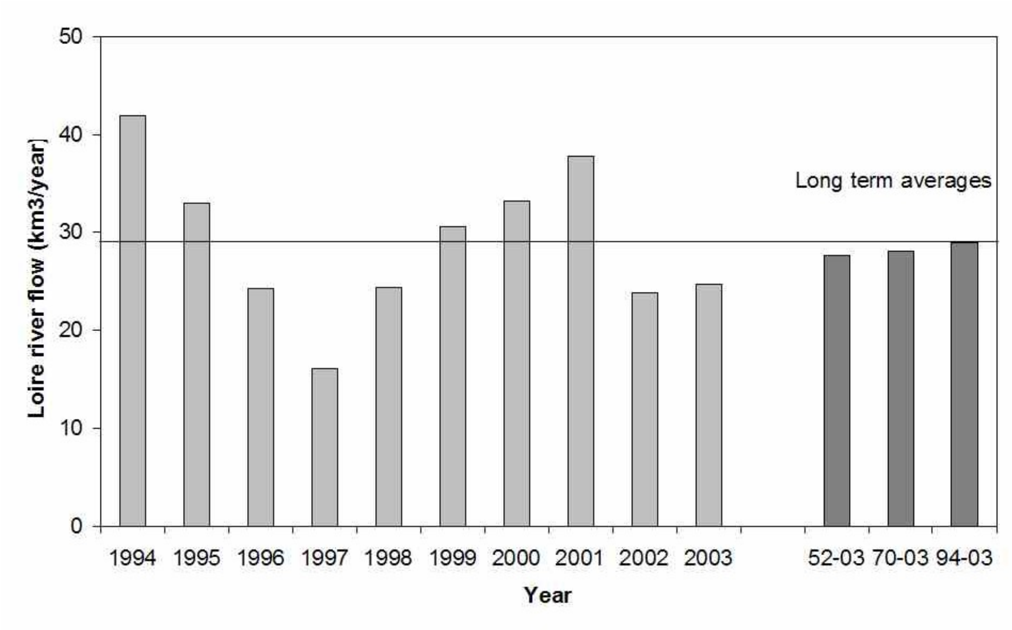


Figure 2.8.3. Time series of the river Loire outflow. Data from the French data bank on hydrology and hydrometry, available at http://hydro.rnde.tm.fr/

2.8.1.3.1 Broad- scale climate & Oceanographic features & and drivers:

Large positive values of the NAO index are associated with higher dominance of the middle-latitude easterly wind flow during winter that can lead to increased winter upwelling episodes. Dickson *et al.* (1988) related the decline in zooplankton and phytoplankton in the North Atlantic and in the catch of sardines off Portugal with the increase in northerly winds during the 1970s. These increased winter upwelling episodes related with large positive NAO indices were also observed during the 1990s (Borges, *et.al*. 2003). Over recent years the Hurrell NAO index was close to long-term (100 years) average.

2.8.1.4 Phytoplankton

The onset of the spring bloom occurs sometimes as soon as February in western Iberia and the south of the advisory region (Nogueira *et al.*, 1997; Moita, 2001, Manzano et al., 2004) and, with remarkable regularity in March, in the Bay of Biscay. By March-early April the spring bloom covers the entire region. From May onwards, chlorophyll drops sharply, and the lowest values are observed in summer. The autumn bloom is variable in timing and intensity, and restricted to coastal areas, for example, high chlorophyll concentrations are found in the Rías Baixas, at the time of seasonal transition from upwelling to downwelling (Nogueira *et al.*, 1997; Figueiras *et al.*, 2002). During winter months and in the coastal areas inwards the 100 m isobath chlorophyll estimates persist relatively high.

Diatoms dominate the phytoplankton community during most of the year and specially during upwelling events, while microflagellates and small naked dinoflagellates dominate during winter. Small dinoflagellates dominate in warmer, stratified waters, offshore (Valdés *et al.*, 1991 ; Fernandez and Bode, 1994 ; Varela, 1996 ; Casas *et al.*, 1997).

2.8.1.5 Zooplankton

Zooplankton blooms follow the pulse of phytoplanktonic production. In coastal zones, mesozooplankton abundance presents a seasonal variation with absolute values rarely over 3000 ind/m^3 in spring. In winter values are 250 ind/m^3. The oceanic area off Iberia is oligotrophic and zooplankton biomass varies little throughout the year with a peak in April.

Regarding the whole Bay of Biscay, since 1992, temporal and spatial biomass distribution of mesozooplankton (200-2000 µm) show the same patterns described for phytoplankton with biomass (values of ~70 mgDW m^{-3}) closely after the phytoplankton spring bloom. After the spring bloom, zooplankton decreases showing a patchy distribution with some hot spots in coincidence with upwelling regions and freshwater plumes.

In summer, due to the upwelling, the regional zooplankton biomass production is highest off Galicia where it is often over 30 mg DW m^{-3} (60 mg DW m^{-3} peak are frequent) (Bode *et al.*, 1998). Along the Cantabrian Sea the biomass decreases towards the east (Figure 2.8.4) (Llope et al., 2003).

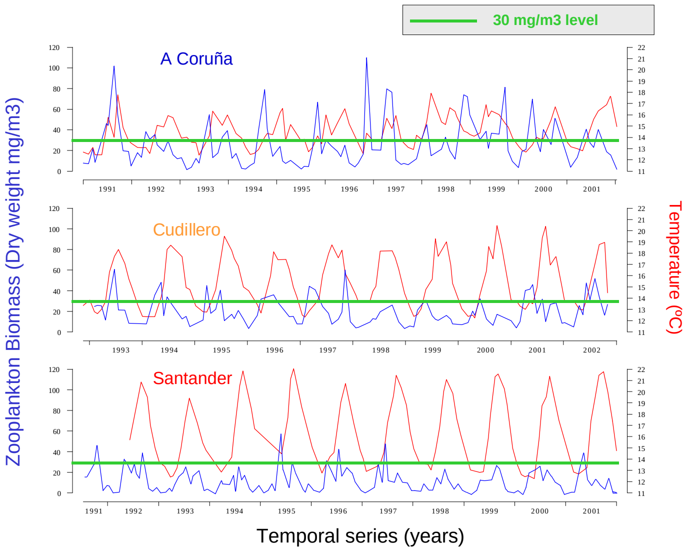


Figure 2.8.4 Variations in zooplankton biomass and temperature in the Cantabrian Sea. (Llope et al ; 2003, modified by Valdés).

Zooplankton in the Iberian coastal and shelf waters is very rich in terms of taxonomic groups and species. Copepods account for 60-85% of total zooplankton abundance off the north coast of Spain, and are present all the year round, whereas other holoplankton and meroplankton groups have a marked seasonal distribution.

2.8.1.6 Benthos

In the Cantabrian Sea, an most probably in the whole region, the depth is the main factor of the distribution of both epibenthic an endobenthic communities, a second factor is the sediment characteristics (grain size and organic contents). The mean fish species richness shows a progressive decrease with depth (Sánchez, 1993) while the inverse phenomena appears in invertebrates (Olaso, 1990), which prefer deeper water and muddy substrates due to their predominantly detritivorous feeding habits. Mediterranean species occur in the south of the advisory region, their occurence decrease eastwards in the Cantabrian Sea at least for shallow species. The dominant mobile invertebrates on the soft grounds on the shelf are detritivorous–crustaceans and molluscs, while the same type of grounds in deeper areas are dominated by filter feeders such as sponges and cnidarians. These later are abundant on rocky bottoms together with echinoderms (Serrano et al. in. press). Bioherm such as maerl beds in shallow waters and *Lophelia* reefs on the slope occur in some areas.

The main exploited invertebrates in the advisory region are: red shrimp (*Aristeus antennatus*) rose shrimp (*Parapeneus longirostris*), Nephrops and Cephalopods (*Octopus vulgaris*, *Sepia officinalis*, *Loligo* spp., and others). Smaller fisheries exist for rocklobster (*Palinurus elephas*) and red crab (*Chaceon affinis*). Nephrops occurs in almost all the advisory region it is exploited from coastal water (eg south of Brittany) to the upper slope as in the Gulf of Cadiz. Various bivalves species are exploited on the coastal shelf and in the intertidal area (eg Scallops *Pecten maximus* but also clam *Ruditapes decussatu*s, cockle *Cerastoderma edule*, telline *Donax truncates*). Some species were introduced for aquaculture purposes and some settled as wild populations (eg *Ruditapes phillipinarum*) now exploited. The introduced slipper limpet (*Crepidula fornicata*) is locally abundant. It may be a competitor of exploited filter feeders and has a negative effect on the substrat availability to juvenile sole in their nurseries (Le Pape et al., 2003c). This advisory region is locally suitable for shellfish aquaculture, e.g. more than 200.000 tons per year of mussels from raft aquaculture are produced off Galicia.

2.8.1.7 Fish community

2.8.1.7.1 Species composition and diversity

Fish diversity is quite high in relation to the co-occurrence of sub-tropical, temperate and boreal species which relative abundances follow latitudinal gradients.

The main pelagic species are sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*), mackerel (*Scomber scombrus*), horse mackerel (*Trachurus trachurus*) and blue whiting (*Micromesistius poutassou*). To the south west of the Iberian Peninsula, other mackerels and horse mackerels such as the chub mackerel (*Scomber japonicus*), the Mediterranean horse mackerel (*Trachurus mediterraneus*) and the blue jack mackerel (*T. picturatus*) are also common. Seasonally, albacore (*Thunnus alalunga*) occur along the shelf break. To the south, northern bluefin tuna (*Thunnus thynnus*) is caught in the Gulf of Cadiz during its migratory way (in or out) to the Mediterranean.

Throughout the advisory region, the demersal fish community is organised according to depth, bottom and latitude and is stable over time despite species abundance variations and trends (Souissi *et al.,* 2001, Poulard *et al.,* 2003 Gomes, *et.al*., 2001; Sousa, *et al,* 2005). In general, the same species composition and population structures occur on the French and the Cantabrian shelves (ICES, 2005). However, some differences were found in the shelf off the Gironde estuary, which seems to be the southern limit of cold water species, such as the herring (*Clupea harengus*), haddock (*P. virens*), Norway pout (*T. esmarkii*), dab (*L. limanda*), sprat (*S. sprattus*) and whiting (*M. merlangus*).

More than 200 species occur in the northeast Bay of Biscay (Bertrand *et al.,* 2004). Only 5 species make up more than 50% of the total biomass and abundance of demersal fish (Blanchard, 2001). Species richness is highest in coastal shallow waters, down to 50 m (Blanchard, 2001). Strong environmental gradients occur in the Cantabrian Sea and affect the fish distribution. Due to the narrow and steep shelf, depth is the most influential factor determining the assemblages observed in this area. The physical and faunal variability are larger in both the coastal and shelf break strata. Regarding trends in species richness and diversity both have remained quite stable during the 1990s (Sánchez & Serrano, 2003).

Off Portugal horse mackerel (*Trachurus trachurus*) is more important in autumn assemblages whereas the boarfish (*Capros aper*) dominates in summer. On the upper slope the fish community is dominated by blue whiting (*Micromesistius poutassou*). The importance of Sparids in the fish community increases to the south (Gomes et al., 2001).The shallow fish community of the Gulf of Cadiz has some affinities with subtropical and tropical fish communities, due to the occurrence of species such as *Umbrina canariensis*, *Pomadasys* *incisus, Spicara flexuosa*, *Diplodus bellottii*, *Pagelus bellottii bellottii*, *Halobratrachus didactylus, Caranx rhonchus, Pomatomus saltatrix*, *Dentex* spp. and *Epinephelus* spp**.** (Fernández-Delgado, 1987). Some of these species also occur in part of the Mediterranean Sea. Deeper, the scabbardfish *Lepidopus caudatus* is abundant.

The main Elasmobranch species in the region are the rays, *Raja clavata, R. montagui,* and *R. miraletus* and the catsharks, *Scyliorhinus canicula* and *Galeus melastomus* at the coast and on the inner and outer shelf respectively (Sánchez et al., 2005a; Rodríguez-Cabello *et al.* 2005). Several deepwater sharks and chimaeroids are also found (Sánchez and Serrano, 2003; Lorance *et al.* 2000). Widely migratory sharks occur in this region such as blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrnchus*), porbeagle (*Lamna nasus*), tope (*Galeorhinus galeus*) and spurdog (*Squalus acanthias*). Some are taken in mixed demersal and pelagic (especially for tuna and swordfish) fisheries.

The main commercial demersal species caught by the trawl are hake, megrims (*Lepidorhombus boscii* and *L. whiffiagonis*), monkfishes and sole. Most of these species are distributed all through the advisory region, although not evenly.

2.8.1.7.2 Trophic web

In the northern Iberian shelf ecosystem, most of the biomass and production are contained within the pelagic domain. Phytoplankton grazing is low, consequently, detritivorous species are important. Suspension and deposit feeders constitute a high percentage of the biomass to the detriment of pelagic plankton (Sanchez and Olaso, 2004). Abundant suprabenthic zooplankton is available to pelagic and small demersal fish species (mackerel, horse mackerel, blue whiting, *Gadiculus argenteus*, *Capros aper*). Decapod crustaceans play an important role as preys of benthic fish species as megrims, gurnards, skates and *Trisopterus* spp. (Rodríguez-Marín, 2002)

Blue whiting is one of the main preys of many demersal piscivorous fishes (Velasco and Olaso, 1998a,b; Preciado *et al*., In Press). Sardine, anchovy, mackerel and horse mackerel have all been found in the diet of fish species (e.g. hake, tuna, John Dory, etc. with sardine and anchovy being taken also by mackerel and horse mackerel). There is a degree of cannibalism by adults on juveniles and/or eggs when food is scarce (e.g. Silva, 1999; Cabral & Murta, 2002).

The cetaceans may play an important role in the regional trophic web both as zooplankton consumers as well as competitors with the commercial fisheries. Sardine and anchovy are the main preys of common dolphins (*Delphinus delphis*) (Silva, 1999; Santos *et al.,* 2004, Meynier, 2004).

There are evidences of an important utilization of discards by demersal fishes in Galicia and the Cantabrian Sea (Olaso *et al.* 1998; 2002).

2.8.1.8 Mammals and birds

2.8.1.8.1 Mammals

Seven species of mysticeti, twenty-three species of odontocet and seven species of pinnipeds have been reported in the eco-region. The main habitat and status of these species is summarised in Table 2.8.1. Detailed information on distribution and migratory patterns is restricted to the most common species.

Table 2.8.1 Main marine mammals species

SPECIES	FREQUENCY AND TRENDS	HABITAT, OR TEMPORAL OCCURRENCE
Grey seal (*Halichoerus grypus*)	Permanent in Brittany, southernmost breeding colony, 7% increase	Dispersion of youngs from British breeding colonies
Harbour seal (*Phoca vitulina*)	Permanent along French Channel coasts, southernmost breeding groups, increasing rapidly	
Habour porpoise (*Phocoena phocoena*)	Probably decreasing	All region
Fin Whale (*Balaenoptera Physalus*)	Fairly common	Oceanic waters only
Sperm whale (*Physeter macrocephalus*)	Fairly common	Summer aggregation feeding on cephalopods over continental slope
Cuvier's beaked whale (*Ziphius cavirostris*)	Small permanent numbers	Slope and canyons
Killer whale (*Orcinus orca*)	Rare	All region
Common dolphin (*Delphinus delphis*)	Most common (>50% of strandings)	Continental shelf, slope and oceanic waters
Bottlenose dolphin (*Tursiops truncatus*)	Common	All region (mainly coastal)
Striped dolphin (*Stenella coerulaeoalba*)	Most common	Oceanic waters
Long-finned pilot whale (*Globicephala melas*)	Common	Mostly slope waters, visits into coastal waters in the summer

2.8.1.8.2 Birds

The Iberian Peninsula gives rise to large seabird populations due to its strategic geographical position regarding their migratory pattern. Seabirds are grouped in terms of pelagic species (e.g. yelkouan shearwater (*Puffinus puffinus*), Leach's petrel (*Oceanodroma leucorhoa*), northern gannet (*Morus bassanus*) and razorbill (*Alca torda*), coastal species (e.g. shag (*Phalacrocorax aristotelis*), terns (*Sterna* spp.) and common scoter (*Melanitta nigra*) and gulls. The seabird community is dominated by the yellow-legged gull (*Larus cachinnans*) which makes up 70 % of the total number of seabirds. Its feeding habits (fish discards and rubbish dumps) together with the protection of their colonies explains their strong demographic growth in recent decades. Other nesting seabirds of importance are the very similar lesser black-backed gull (*L. fuscus*), the shag, European storm-petrel (*Hydrobates pelagicus*), black legged kittiwake (*Rissa tridactyla*) and guillemot (*Uria aalge*) (OSPAR, 2000).

2.8.1.8.3 Turtles

Two marine turtles species the loggerhead (*Caretta caretta* and the leatherback *Dermochelys coriacea*) occur year round in the south of the advisory region. Seasonal variations in abundance in the Gulf of Cádiz are related to a migration pattern through the Gibraltar Straits (Camiñas and Valeiras, 2001). As a consequence of the long migrations undertaken by the oceanic marine turtles using the Gulf Stream some occasional occurrences of *C. Caretta*, *D. coriacea*, *Chelonia mydas*, *Eretmochelys imbricate* and *Lepidochelys kempii* are also reported throughout the advisory region.

2.8.2 The major effects of the ecosystem on fisheries

Upwelling intensity, and to lesser extent other factors such as water stability, retention areas produced by local or general current fields and other mesoscale features like river plumes and eddies affect biological processes, recruitment, mortality and food availability to the small pelagic fish community (Bode *et al.* 2001; Allain *et al.* 2001). Indices of the strength of upwelling have been used to improve environmental-stock-recruitment relationships in some pelagic species (Carrera and Porteiro 2003, Villamor *et al*., 2004). Subtropical water intrusions in the Cantabrian Sea and/or early spring extreme wind forcing events are of great importance for the pelagic ecosystem understanding and may be linked to important failures in the recruitment of mackerel (Villamor *et al.* 2004). Also in relation with the strength of the upwellings and the Navidad current optimal environmental windows have been defined for some demersal species such as hake and megrims (Sánchez and Gil, 2000; Sánchez *et al.*, 2003a, b).

At the coast, sole recruitment was shown to be related to river output, higher fluvial discharge in winter-spring increasing the estuarine nurseries size (Le Pape et al. 2003a,b).

Borges *et al.*, (2003) showed that a NAO positive phase, increased the winter upwelling events and constrained the productivity to a low recruitment period of sardine, whereas a NAO negative phase favoured the occurrence of high recruitment years. There is circumstantial evidence of a relation between low NAO values and high recruitment levels /CPUE in the Spanish swordfish fishery (Mejuto, 1998). Also, the strength of upwelling and its indexes have been used to improve environmental-stock-recruitment relationships in some pelagic species (Carrera and Porteiro 2003, Villamor *et al.,* 2004).

Temperature increase has been related with changes on the distribution of several species (Quéro *et al.* 1998) that are progressively increasing their northernmost distribution limits. Some species may be favoured by warming (Blanchard and Vandermeirsch, 2005) and recently, species from North Africa were reported in the Algarve (Brander *et al.* 2003).

2.8.3 The major effects of fishing on the ecosystem

Fishing is a major disturbance factor of the continental shelf communities of the region. Trawling may have some impact on the sediment compound. The sediment compound of a large area of sedimentary bottom know as "Grande Vasiere" and trawled for *Nephrops*, to the south west of Brittany, appeared to have changed over the last 30 years. The proportion of mud decreased, and the change may be due to sediment remobilization by storms and trawling (Bourillet et al., 2004). Such an habitat change may have adverse effect on sedimentary facies and burying animal such as *Nephrops*. Nevertheless, the participation of natural (storms) and anthropic (fishing) drivers of this change is still uncertain. In the same area, diversity studies of benthic megafauna showed that large invertebrates were less abundant in the most exploited stations. In the heavily exploited stations, the dominant species were opportunistic carnivorous species of minor or no commercial interest and there was no fragile invertebrates (Blanchard *et al.,* 2004).

Recent studies (Rochet et al., 2005), based on bottom-trawl survey data (yearly EVHOE cruise) from the Bay of Biscay 1987-2002, developed a diagnostic based on indicators for 51 fish populations and the fish community. At the start of the time series (1987) the shelf fish community was considered impacted by fishing. Over the study period, the situation of the fish populations and community did not improve and the overall diagnostic was for a steady (not improving) situation.

In the Cantabrian Sea, the fisheries have a major effect on the structure and dynamics of the ecosystem. In recent decades, the mean trophic level of the demersal and benthic fisheries declined. This is reflected in a gradual transition of landings from long-lived, high trophic level piscivorous groundfish (hake, anglerfish, megrim) towards lower trophic level planktivorous fish (blue whiting, horse mackerel). The mean trophic level was estimated to have declined from 4.10 in 1983 to 3.95 in 1993, then to have varied without clear trend (Sánchez and Olaso, 2004).

On the long term some large bottoms chondrichthyans (*Echinorhinus brucus, Squatina squatina, Raja batis, Raja brachyura, Dasyatis pastanica Myliobatis aquila, Galeorhinus galeus, Mustelus asterias, Raja clavata*) declined severely (Quéro and Cendrero, 1996) in the Bay of Biscay. Further south, although the fishing mortality of catshark (*S. canicula*) seems excessive it also profits from discards. The recovery of elasmobranchs in the Cantabrian Sea in recent years can be attributed to reduced fishing mortality associated with a reduction of the trawl fishing effort (Sánchez et al., 2005a). The sturgeon (*Acipenser sturio*) is a critically endangered species due to fishing and alteration of freshwaters habitats. The blackspot(=red) seabream (*Pagellus bogaraveo*) is depleted in the Bay of Biscay.

The common spiny lobster, *Palinurus elephas*, (catches dropped from about 1000 t/year in the first half on 20th century to about 100 t now) and the deeper pink spiny lobster (*Palinurus mauritanicus)* were depleted as a result of overexploitation from bottom net fisheries.

In relation to discards in the Bay of Biscay, bottom trawl reach the biggest rate of discards, due to the mixed species fishery. Among fishes, the main species discarded in number are the small fish snipe-fish (*Macrorramphosus scolopax*) silver pout (*Gadiculus argenteus*) and the medium sized blue whiting (*Micromesistius poutassou*). All these species are dead when discarded (Pérez et. al, 1996).

Fisheries have a considerable influence at different levels on the distribution of seabirds at sea due to the supply of discards that are used as food for scavenging species.

2.8.4 Other effects of human use of the ecosystem

2.8.4.1 Impact of the “Prestige” oil spill

Concerning other anthropogenic impacts on the ecosystem it is important to mention the “Prestige” oil spill off Galicia in November 2002. This event affected most of the northern Spanish coast and especially the northern part of Galicia.

From November 2002 to August 2003, 23000 birds (6000 alive and 17000 dead) were collected on French, Spanish and Portuguese coasts. More than 90 species were identified. The most affected species was the guillemot (51 %), followed by the razorbill and the Atlantic puffin (*Fratercula arctica*). Other species found in significant numbers were the black-legged kittiwake, the little auk (*Alle alle*) and the great northern diver (*Gavia immer*). According to their relative abundance, the yellow-legged gull and the common scoter were the less impacted species. In general, more than 60 % of the oily birds were females (http://www.seo.org/2002/prestige).

Three years after the Prestige oil spill, there has not been a clear effect of the event on the demersal and pelagic domains of the Iberian shelf. Although, based upon abundance indices and bottom trawl surveys, an initial abundance decrease of some primarily benthic species (e.g. four-spot megrim, Norway lobster and other benthic decapod crustaceans) was observed in 2003, it was followed by an increase in 2004 (Sánchez et al. In press; Serrano et al. In press [b], Trujillo et al, 2005)

2.8.4.2 Incidental catch of cetaceans

Some incidental catches of mammals were recorded in pelagic trawl fisheries (Morizur *et al.*, 1999). Catches in bottom trammel net for sole also occur to an unknown level. Over 1998-2003, 200 to 700 strandings per year were recorded, the common dolphin (*Delphinus delphis*) makes up 60% of strandings (Van Canneyt *et al.*, 2004), 30 to 60 % of all stranded animals have prints of fishing gears.

2.8.5 References

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2.9 Oceanic and deep sea area

2.9.1 Bottom topography, substrates, and circulation

Most of the surface of the advisory region K is abyssal plain with average depth >ca 4 000 m. To the east the continental slope of Europe is mainly rocky and hard from south to the Latitude of Ireland, further north important sediment cover occurs to the west of the British Isles. West of the Rockall Trough there is a large bank area which the two major shallowest parts are known as Rockall Bank to the west of Scotland and Hatton bank. The North of the advisory region coincides with the Wyville Thomson and Iceland-Faroe Ridges. In the west, the major topography feature is the mid-Atlantic Ridge (MAR) starting from Iceland where it is known as Reykjanes Ridge, down to the Azores. At the ridge new oceanic floor is formed and western and eastern parts of the North Atlantic basin spread at a speed of 2-6 cm/year. Numerous seamounts of variable height occur all along the ridge and isolated seamounts are known over the whole basin. The ridge and the associated complexes of seamounts form an extremely rugged topography, the European slope is comparatively gentle. The western part of the advisory region extends beyond the MAR over north east Atlantic deep basin. Along the reef, the Charlie Gibbs Fracture Zone (CGFZ) is a major transversal feature at about 52°N. At the CGFZ the axis of the southern part of ridge shifts of about 6° east from that of the northern part. This feature has major interaction with the hydrology, and flow of deep-water between the western and eastern deep-sea basins of the North Atlantic occur through these deep channels and affects to whole circulation (see http://www.mar-eco.no).

The general circulation in the epipelagic zone (0-200m) is well understood as a warm current flowing from the Southwest Atlantic towards the European coast with several branching. Cold current flow south form the Labrador sea and Irminger sea (Figure 2.9.1).

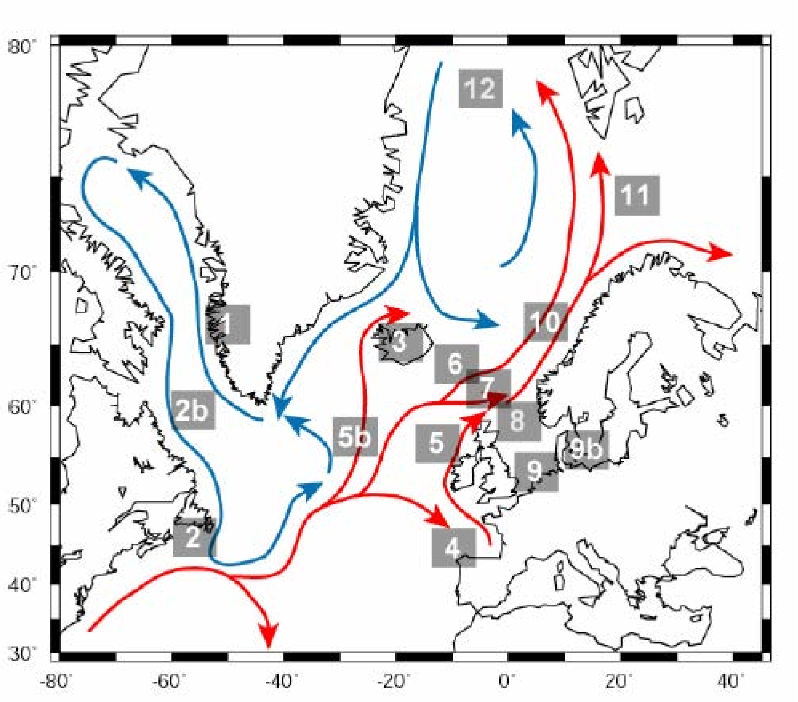

Figure 2.9.1. Schematic of the general circulation of the North Atlantic in relation to the numbered areas presented in the Annual ICES Ocean Climate Status Summary 2004/2005 (ICES, 2005a). The blue arrows indicate the cooler waters of the sub-polar gyre. The red arrows show the movement of the warmer waters in the sub-tropical gyre.

2.9.2 Physical and Chemical Oceanography (temperature, salinity, nutrients)

Below ca 700 m the seasonality in temperature is almost negligible, and spatial variations within the advisory region are small. Average temperatures are 7 to 8°C by 1000 m and lower than 4°C below 2000 m (Figure 2.9.2).

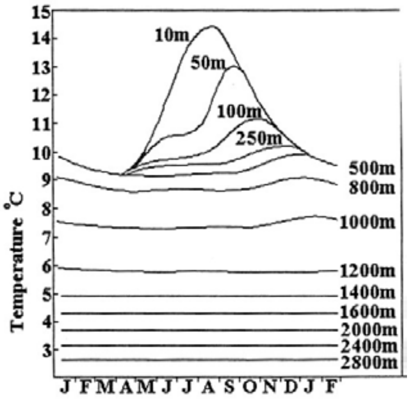

Figure 2.9.2. Seasonal variations of the sea temperature by depth in the Rockall Trough, west of Scotland (Gordon et al., 1995).

Nutrients are permanently present in the deep water as a result of mineralisation processes. However, due to darkness, there is not photosynthesis in the deepsea where primary production only occurs at hydrothermal vents and cold seeps from chemo-autotrophic bacteria and archaeas either as free cells or symbiotics of larger organisms. This primary production is fuelled by the oxidation of reductive fluids flowing out of the seabed. Although this deep primary production supports exceptionally dense, diverse and original communities including reigns of animals unknown in any other ecosystem such as the vestimentifer worms it is not believed to produce a significant part of the total primary production at the advisory region's scale.

Phytoplancton and other particles for the residuals of the primary production in the epipelagic zone sinking into deeper waters is known as planktonic snow. This process together with falls of carcass of large animals and particulate organic matter flowing down slopes from shelves and continental bring organic matter to the deep environment (Figure 2.9.3.).

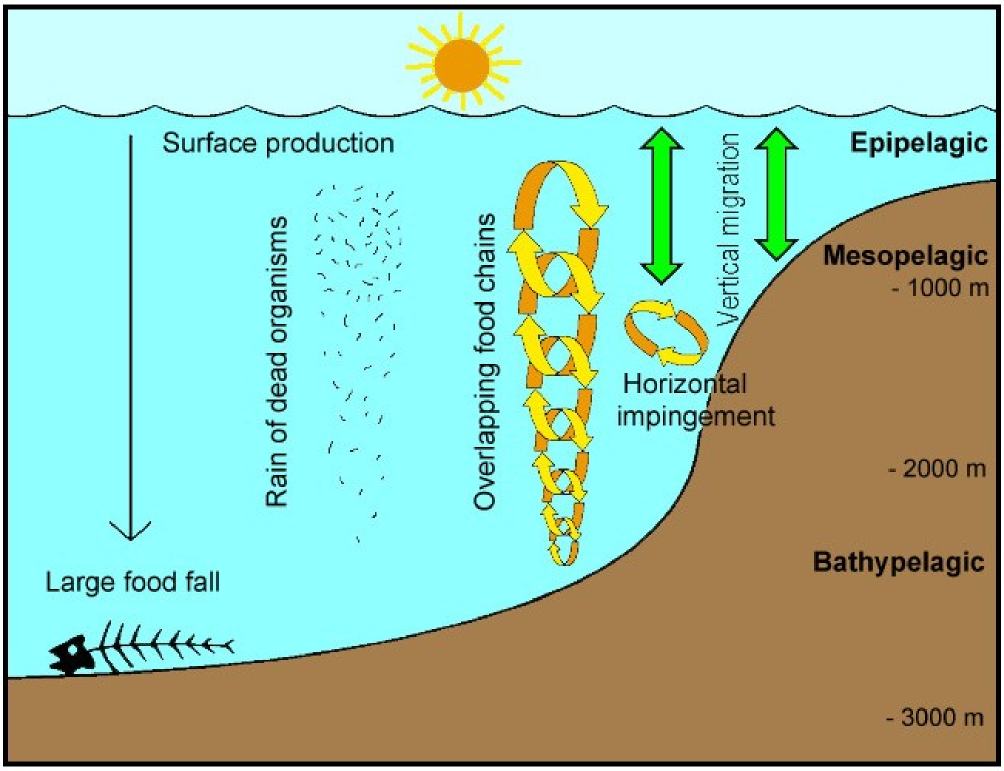

Figure 2.9.3: Trophic transport in the deepwater ocean (courtesy from Dr. J. Gordon, Scottish Association for Marine Science, see also Gordon, 1979).

Except in hydrothermal and cold seeps areas, primary production in the ocean is limited to the so-called euphotic zone near the surface where there is enough ambient light to allow photosynthesis. This zone goes down between 150 m and 200 m at the most. The organic matter available for deep-sea heterotrophic organisms results from the flow of matter from the surface towards the seafloor, however, only 1%-3% of this primary organic production reaches the depths of the abyssal plain in some form or other (Gage and Tyler, 1991). The use and gradual depletion of this organic matter is reflected in the logarithmic decline in the concentration of plankton as depth increases (Angel and Baker in Merret and Haedrich, 1997). However, this pattern does not explain the distribution of fish biomass along the slope, which does not in fact decline regularly as depth increases. For example, to the west of Scotland, biomass reaches its maximum level at around 1,200 m (Gordon and Bergstad, 1992; Gordon and Duncan, 1985), while primary production at the surface directly above the continental slope is insufficient to maintain the biomass level (Koslow, 1997). This means that other processes bring a flow of energy to the fish living along the slope, so that the slope is believed to benefit from oceanic input (Figure 2.9.3). Such processes are also involved in the distribution and density of deepsea corals (Genin et al., 1986). Slope fishes feed on meso- and bathy-pelagic fauna daily brought to the slope by tidal currents (Gordon, 1979 ;Koslow, 1997).

2.9.3 Broad-scale climate & Oceanographic features & drivers like NAO, major currents

The NAO is known to control or modify three of the main parameters which drive the circulation in the ocean area covered by this climate summary (i.e. wind speed, air/sea heat exchange and evaporation/-precipitation). The NAO is presented here is terms of the Hurrell index, which is more closely correlated with conditions over the eastern North Atlantic. Following a long period of increase from an extreme and persistent negative phase in the 1960s to a most extreme and persistent positive phase during the late 1980s and early 1990s, the Hurrell NAO index underwent a large and rapid decrease during the winter preceding 1996. Since 1996 the Hurrell NAO index has been fairly weak but mainly positive, except for the winter preceding 2001 (Figure 2.9.4). (ICES, 2005a).

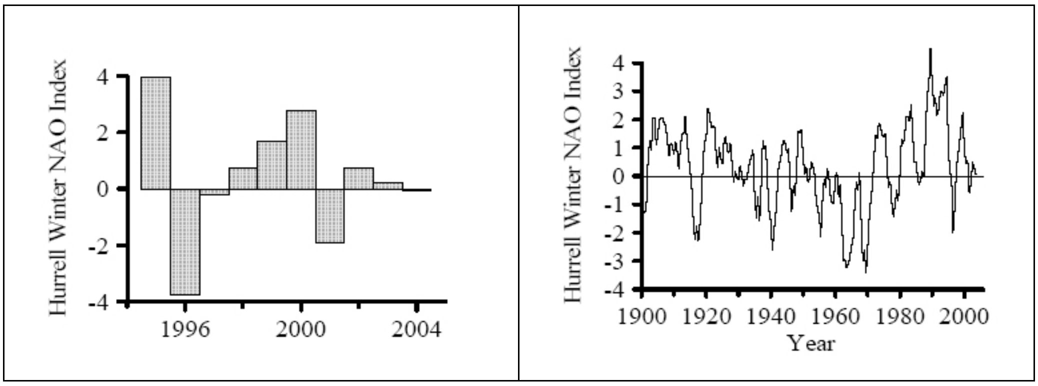

Figure 2.9.4. The winter NAO Hurell index (see text) in terms of the present decade (left) and the last 100 years (right–a two-year running mean has been applied), (from ICES, 2005a). The effect of the NAO on deep layers is poorly known.

2.9.4 Benthos, larger invertebrates (cephalopods, crustaceans etc), biogenic habitat taxa

There is little commercial exploitation of large invertebrates in the ICES part of the advisory region. Deep-water trawling is known to catch some cephalopods, the landings might most often be reported as miscellaneous cephalopods and are limited. The crab *Chaceon affinis* occurs at slope depths over the advisory region, it is a by-catch of deep-water trawling and netting and a target of a pots and nets fisheries.

Biogenic habitat occur along the slope, the main biogenic organism is the sclera*ctinian Lophelia pertusa* a colonial coral, which locally forms large bioherms, along the slope and on seamounts . No exhaustive description of the distribution of *Lophelia pertusa* exist, it is still unclear if modern multibeam echosounding can provide full mapping of *Lophelia pertusa* reefs. However, synthesis of available data show that such reefs may be found in all parts of the advisory region (Figure 2.9.5) (Freiwald, 1998; Rogers, 1999). Like the general distribution, the information on the size of reefs remains partial, to the south and west of Ireland several reefs of 150 to 200 m height and about 1 km wide are known.

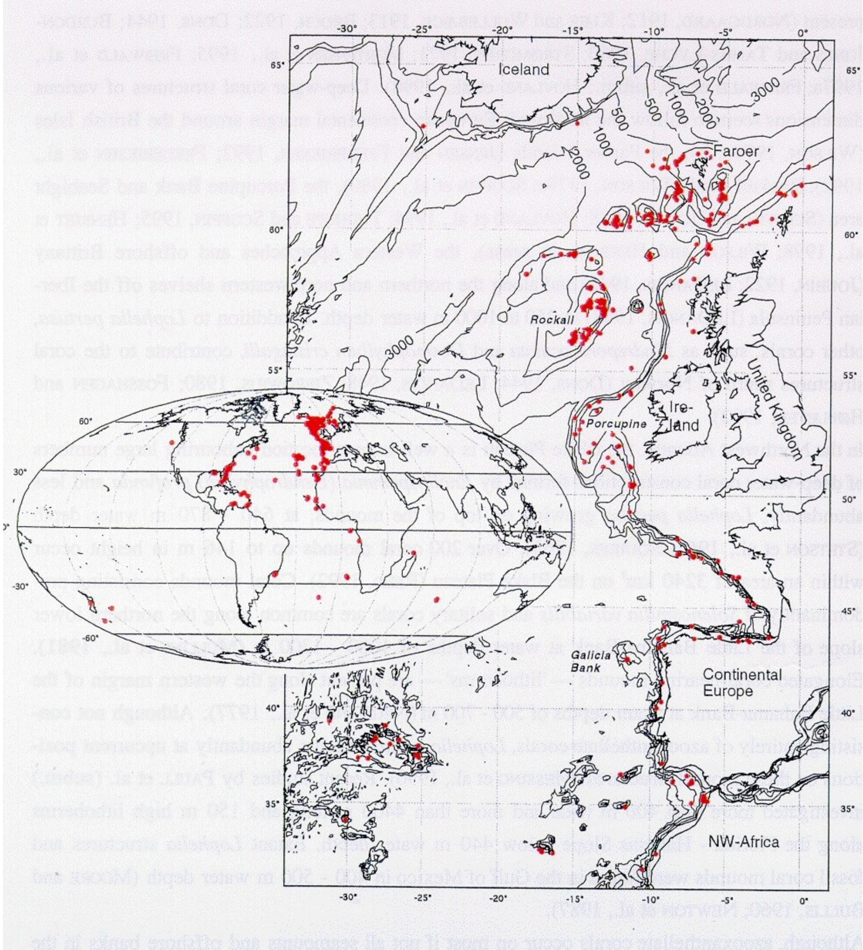

Figure 2.9.5. Distribution of deepwater coral reefs in the North East Atlantic and in the world ocean and (from Freiwald, 1998).

A dense and diverse megafauna is associated to *Lophelia* reefs. This includes fixed (anthipatarians, gorgonians, sponges…) and mobile invertebrates (echinoderms, crustaceans…). The species richness of macrofauna associated to coral reefs is up to three time higher than on surrounding sedimentary seabed (Mortensen et al., 1995). Several species of deepwater fish occur on corals, some are more abundant is corals but the possible functional links between fish and coral are still to be confirmed but are likely for some species (Husebo et al., 2002)

2.9.5 Fish Community: Dominant species composition, Size composition, biomass/abundance of species with crucial role in the food chain, status of species which are particularly vulnerable or protected (especially if not included in the single-stock annexes).

Large epi-pelagic fish (tunas and others eg swordfishes, sharks) are not dealt upon in this section.

In the advisory region the two major small epi-pelagic species are blue whiting and greater argentine. Both occur mainly over the slope and at the shelf edge, mainly blue whiting is a major prey fish for some deepwater (eg Black scabbard fish) and shelf (eg hake) predators.

The meso-pelagic zone (200-1000 m) comprise a high diversity of small species presenting striking morphological characters and adaptations such as large mouth and teeth, light organs, specialized eyes. The most abundant families are Myctophidae and Gonostomatidae (with

Cyclothone, the most common vertebrate genus on earth), these may form up to 50 % of the catch when sampling this fauna. The most diverse (number of genus and species) families are Myctophidae and Stomiidae (F. Uiblein, IMR, pers. comm.). Many if not all meso-pelagic fish migrate daily to feed on pelagic prey in upper water layers during the night and return to the deeper darker waters during daytime when they would be more vulnerable to epi-pelagic predators, in this way they participate to the process of overlapping food chain (Figure 2.9.3).

Similar fauna is found in the bathy-pelagic zone (1000-3000m), is it understood as less abundant. Bathylagidae forms the most common family, other common families are Platytroctidae and Searsidae (F. Uiblein, IMR, pers. Comm.).

The demersal deepsea fish community accounts several larger species. Species composition primarily depends on depth and most deepwater species have large areas of distribution, in particular some species from slope environment are found in both hemispheres and Atlantic, Pacific, Indian oceans (eg orange roughy, Alphonsinos., several deepsea squalids sharks and smaller non commercial species such as *Halagyreus johnsonii*). Several large demersal species typically living between ca 400 to 2000 m, are found is environment as different as the continental slope, the MAR and isolated seamounts.

In the advisory region, the dominant commercial species at 200-2000m are species such as ling, blue ling, tusk, roundnose genadier, orange roughy, black scabbard fish (dealt upon by WGDEEP) and deep-water sharks and chimaeriforms (WGFE). Amongst sharks, *Centroscymnus coelolepis* and *Centrophorus squamosus*, the two main commercial species (1 to 1.5 m long) are seriously depleted. The status of a number of smaller or less common species (*Centroscymnus crepidater*, *Deania calcea*, *Dalatias licha*, *Scymnodon ringens*, *Etmopterus* spp. *Galeus* spp. *Apristurus* spp.) is less clear. Chimaeriforms occur at least down to 3000 m but are more abundant on the upper slope, 400-800m (Lorance et al., 2000). All deep-water shark species are assumed highly vulnerable and of these that are commercial seem currently overexploited. The status of chimaeriform populations is unknown. Most of these species are discarded but there is some directed fishing for *Chimaera monstrosa* on the upper slope.

Most deepwater demersal fish are typically longlived and poorly productive so that they can only sustain low exploitation rates. For example the maximum exploitation rate of orange roughy is estimated between 1 and 2% of the unexploited biomass (Koslow et al., 2000). The sensitivity of species to over exploitation depends upon their production, their catchability and their commercial interest. As a result orange roughy, which is poorly productive and has a high catchability as it forms dense aggregation (Koslow et al. 2000 ; McClatchie et al., 2000, Lorance et al., 2002) was depleted in the early 90s in some ICES areas, in particular off west Scotland and Ireland (Lorance and Dupouy, 2001; ICES, 2004). The distribution and abundance of the remaining biomass in unknown. The blue ling, exploited on the upper slope, was depleted longer ago.

Many demersal slope species are not commercial because they do not reach sufficient size while the alepocephalid are large but are poorly palatable because of the high proportion of water in their flesh. By 1000-1500 m *Alepocephalus bairdii* is the dominant species in biomass to the west of the British Isles (Gordon, 1986 ; Gordon and bergstad, 1992) so that it makes the bulk of fisheries discards (Allain et al., 2003).

2.9.6 Birds & Mammals

The only possible location for bird breeding in the advisory region is the Azores where, the main breeding species are the Cory's shearwater, *Calonectris diomedea* (189000 breeding couples), common tern, *Sterna hirundo* (4000), yellow-legged gull, *Larus cachinnans* (3000), little shearwater, *Puffinus assimilis* (1200), Madeiran storm-petrel, *Oceanodroma castro* (1000), roseate tern, *Sterna dougalii* (700) and Manx shearwater, *Puffinus puffinus* (180).

Common marine mammals species in the advisory region are *Delphinus dephis*, *Stenella coeruleoalba*, *Globicephala melas*, *Grampus griseus*, *Balaenoptera physalus*, *Physeter macrocephalus*. Population numbers are not available for all species and have wide confidence intervals. Amongst species for which estimates exist, the most abundant might be *G. melas*, *B. physalus* and *L. acutus* (ICES, 2005b).

Uncommon occasional or rare species occurring are *Stenella frontalis, Stenella longirostris, Lagenorhynchus acutus, Lagenorhynchus albirostris, Lagenodelphis hosei Globicephala macrorhynchus, Pseudorca crassidens, Orcinus orca, Peponocephala electra, Kogia breviceps, Kogia simus, Ziphius cavirostris, Hyperoodon ampullatus, Mesoplodon densirostris, Mesoplodon europaeus, Mesoplodon grayi, Mesoplodon bidens, Mesoplodon mirus, Eubalaena glacialis, Megaptera novaeangliae, Balaenoptera acutorostrata, Balaenoptera borealis, Balaenoptera musculus.*

2.9.7 The major environmental impacts on the ecosystem dynamics

The deepsea environmental is considered to be less variable that the surface systems. Moreover, due to the long life span of exploited species, variations in annual recruitment have a minor effect on the standing biomass so that in these deep systems the variability of the environment is not considered to have short term effects. How the deepseas will be impacted in the long term by the global warming is not known.

2.9.8 The major fishery effects on the ecosystem

Modern fishing fleets are capable of causing a very significant reduction in demersal deepsea fish biomass in just a few years, this as resulted in the collapse of several fisheries (Koslow et al., 2000). Along the MAR, fishery for roundnose grenadier depleted the stock in the 70s (Merrett and Haedrich, 1997). However, Polish fleets have been exploiting the same species over recent year on the MAR, it is not know if the fishing areas in the 70s and the 90-00s were the same.

It is likely that large predators populations on oceanic bathymetric features are particularly sensitive to overfishing, due to low productivity and in some cases high catchability. On the southern part of the MAR and adjacent seamounts, populations of alphonsinos were depleted too in the 70s. More recently, longline fisheries seem to have depleted seamounts populations of “giant” redfish of seamounts of the northern MAR (Hareide and Garnes, 2001).

These depletions of dominant species induce major changes to demersal deepsea fish communities that loose their larger predators and the corresponding ecological functions. In addition to catching target species, deepwater fisheries by-catch unwanted species that are either too small or unpalatable. Discarding rates are often high (in the order of 50%) and the bulk of the discards is made of smoothheads (Alepocephalidae) because of their high abundance (Allain et al., 2003).

Deep-water trawling impacts deepsea benthic communities. Over recent years attention was particularly drawn to the impact of trawling on *Lophelia* reefs. Measures to reduce the impact and protect some areas were taken. Fishery impact to such communities are ancient (Joubin, 1922) and extent shallower than what we currently term "deepwater", the original extend and role of these reefs in the fish production is unknown. At least under some conditions (long soaking time, operation of hundredths km of nets, deployments over coral reefs) deep-water set nets was also shown to have severe impact mainly on the fish community by generating ghost fishing and targeting more vulnerable species such as sharks. High discards of monkfish may also occur (Hareide et al., 2005). As a result deepwater netting is banned in ICES divisions VIa,b, VIIb,c,j,k and part of sub-area XII in 2006, based on the annual TAC regulation (COUNCIL REGULATION (EC) No 51/2006) and is subject to further introduction of management measure.

2.9.9 Concluding remarks

Over the last 15 to 20 years, the deep-water ecosystem was significantly impacted by fishing as and when fishery extended deeper partly as a result of overexploitation of shelf stocks. Deepwater stock are typically low productive and their sustainable levels of exploitation are much smaller than those of shelf stocks.

Towed fishing gears have severe impacts on benthic communities; this is a major problem on structurally complex habitat including biogenic reefs. On the same kind of reefs netting is also considered undesirable as it can generate (i) habitat disturbance because of lots nets and dumping of used nets and (ii) ghost fishing. Therefore deepwater trawling should be restricted to primarily sedimentary bottoms and where possible fisheries should shift to longlining and closely managed netting (out of coral areas) as was successfully done in some southern hemisphere fisheries (fishery for Patagonian toothfish, *Disostichus eleginoides*, in the South Georgia and South Shetland Islands).

Although this is probably improving thanks to the Data Collection Regulation (Council Regulation (EC) No 1543/2000 of 29 June 2000) and on-board observers programs (Council Regulation (EC) N° 2347/2002 of 16 December 2002) there are serious gaps in the knowledge of exploited stocks structure and biomass. Better reporting of catches and effort data is necessary especially in International waters (NEAFC regulatory area). VMS (Vessel Monitoring System) data should be made available to National Research Institutions.

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3 Short Term Considerations

3.1 Introduction

In the process of preparing the ecosystem overviews, the Working Group identified two specific environmental factors which were suspected of being in anomalous conditions in the recent past (roughly, but not precisely the past one or two years), relative to the long-term more usual conditions. In each case the anomalous state of the environmental feature was thought to pose a higher than usual risk that applying routine assessment practices might lead to assumptions about stock status or dynamics that were incorrect. For these two anomalous environmental factors, the Working Group recommended some practical steps to take in the 2006 assessment and advisory process, which would allow the additional risk posed by the environmental conditions to be addressed. These were discussed with AMAWGC, to allow the Assessment Working Group chairs to consider how to implement the recommended steps. A third environmental consideration was identified that should be addressed explicitly the fisheries advice that ICES will provide in 2006, although it does not require special treatment in the assessment computations.

In the rest of this section, for each of the ecosystems, we describe the environmental feature(s), stocks possibly affected, and potential steps in the assessment and advisory process to address the risks.

3.2 Iceland – East Greenland

3.2.1 Environmental Consideration:

Waters have been exceptionally warm in the West and North of Iceland since 2003. In 2003/04 and 2004/05 this resulted in a displacement of capelin to the north of Iceland, and greatly reduced the overlap between feeding cod and capelin. In 2003 Cod were able to partially compensate by increasing their feeding on shrimp. However in since 2004 both capelin and shrimp appear to have altered their distribution and have even less availability to feeding cod.

3.2.2 Opportunity to Address in Assessment Process:

Pessimistic assumptions about weight at age of cod are appropriate in the projection phase of the assessment this year. It is noted that the assessment model does an estimate of weight at age and does not assume recent average, but it is unclear if the algorithm compensates adequately for the low food availability. It would be possible to test the algorithm’s retrospective performance by predicting the 2004 and 2005 weights (which are now available) from the data available in the previous assessment. Results of this test are a guide to whether the model compensates adequately for these highly anomalous feeding conditions.

3.3 Barent Sea

3.3.1 Environmental Considerations

High temperatures are expected in most of the Barents Sea in 2006. At the end of 2005 the temperature in the southern Barents Sea was still 1 degree above normal; also the temperature in the Norwegian coastal current was around 2 degrees warmer than normal along the whole Norwegian coast. The temperature in the inner branch of the North-Atlantic current along the Norwegian coast in the Norwegian Sea went towards normal temperatures during the end of 2005. Together, this indicates high temperatures in most of the Barents Sea in the beginning of

2006, but the temperature is expected to decrease towards normal in the second half of 2006 as colder water enters the Barents Sea.

The 2004 Joint Norwegian/Russian Ecosystem Survey in the Barents Sea showed that there was 1.4 million tonnes of blue whiting in the western part of the Barents Sea in August - October of that year. During the 2005 survey 1.1 million tonnes of blue whiting was found in the western part of the Barents Sea and north along the western coast of Spitsbergen. Although a quantitative estimation of this species has not normally been done during this survey, it is clear that this is greatly more blue whiting that has been previously recorded in the area. There is insufficient knowledge to predict the specific impacts of such a change in the fish community, but the blue whiting may now be an important competitor for the other plankton-feeding species in the area, and it may play a role as prey for larger species as well.

It has been documented that the predation pressure inflicted by large abundances of juvenile herring in Barents Sea cause a major reduction in capelin eggs and larvae, and the subsequent lack of capelin leads to reduced growth on predatory sizes of cod. During the 2005 Joint Norwegian/Russian Ecosystem Survey the abundance of juvenile herring was still high, but slightly lower than in 2004. The capelin abundance is still very low.

3.3.2 Opportunity to Address in Assessment Process

Assessment models for cod and capelin in the Barents Sea already have some predator-prey relationships in them. Due to the continued high abundance of young herring and low abundance of capelin the results of the models need to be examined very carefully.

There is no easy way to include the potential ecological impact of the large amount of blue whiting into the assessment models. However, the large amounts of blue whiting may reduce the growth of capelin and herring and increase the uncertainty about the food supply for cod in the short term. A particularly precautionary harvesting approach for cod would be appropriate, until the uncertainty about the impacts of the blue whiting can be reduced.

3.4 North Sea

3.4.1 Environmental Considerations

Food supply for piscivorous predators: - Landings of Norway pout in 2003 were the lowest of the past two decades. Spawning biomass of sandeel was at the lowest level observed in 2004 (reference). Sandeels are an essential component of the diet of most piscivorous fish species as well as birds and marine mammals and their low abundance is therefore expected to have severe implications for the whole North Sea ecosystem.

Also it should be noted that SST across much of the North Sea was close to the mean from January to August 2005, but showed strong positive anomalies thereafter. In contrast the inflowing Atlantic water was well above average temperature and salinity throughout the year.

3.4.2 Opportunity to address in the assessment process:

Because of the broad diets of North Sea fish predators, it is uncertain if the low abundance of both sand eel and Norway pout, and patchy abundance of sprat will be reflected as lower than usual weights at age. However the most recent possible information should be considered when making projections for cod, haddock, whiting, and saithe in the North Sea.

3.4.3 Considerations for the Medium term:

The observed low abundance of species that play an important role in the North Sea food web (Calanus, sandeels, and Norway pout) has persisted into 2005. It is still expected to have considerable impact on growth, maturation and possibly recruitment of a range of fish species and on the breeding success of seabirds.

Many North Sea fish stocks presently remain seriously depleted (e.g. cod and plaice). Recruitment of commercially important gadoids is at a low level and this has led to speculation that the ecosystem may be changing in an irreversible direction. However, there are preliminary indications of improved recruitment in some parts of the North Sea for haddock and possibly very localised recruitment of cod. Thus far these should not be taken as indicating a major recovery in gadoid recruitment in the North Sea. Another phenomenon worth mentioning is the increase in a number of southern species e.g. anchovy (*Engraulis encrasicola*). In the case of red mullet *Mullus surmulletus* the increase is so significant that a new fishery is developing.

WGRED notes the initial analysis carried out by the REGNS group. In particular, the Principle Component Analysis on the full data set (see figure 3.4.1 – taken from Figure 4 of the REGNS report (ICES 2005)). This plot clearly shows the late 1980s regime shift. It also shows a possible change in 2004/05, however, this was not emphasised by REGNS, and the analysis should probably be considered as preliminary.

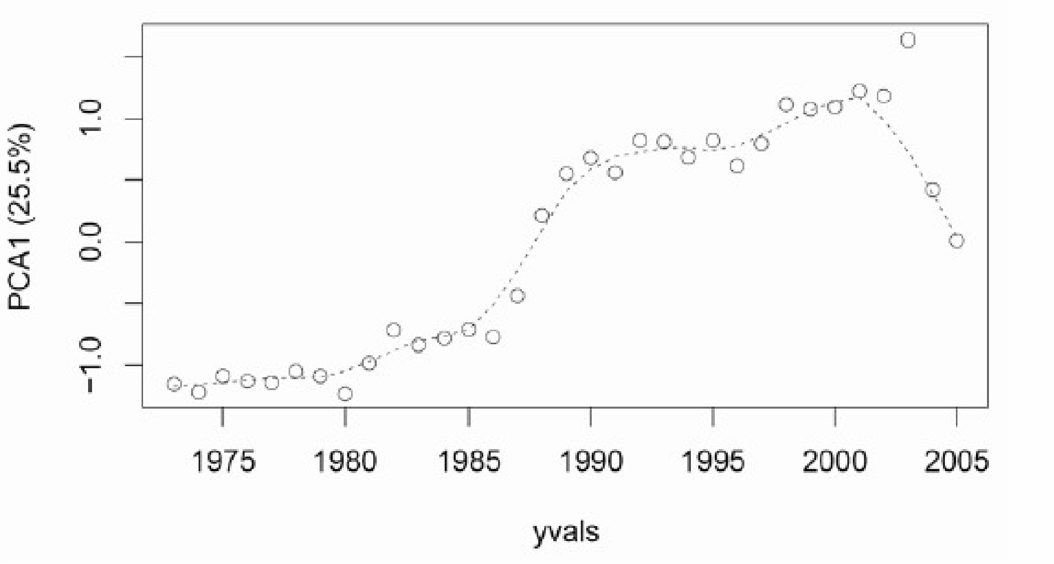

Figure 3.4.1. Time-series of the composite variables (PCA1) that summarises some of the changes ob-served in the North Sea (ICES 2005).

3.5 Iberian Seas – Bay of Biscay

3.5.1 Environmental issue

The NAO has changed from a period of being strongly positive to values slightly below average. This change has the potential to spark speculation that a regime shift has occurred in the southern upwelling zone and stocks like hake and horse mackerel may be more productive. There are concerns that such messages may be picked up with enthusiasm by groups with an interest in increased of harvesting of such stocks, particularly because after a period of low productivity, there are indications of improved recruitment in the recent few years for southern hake and possibly southern horse mackerel. WGRED considers that such speculation is premature, and there is not yet evidence that a regime shift has occurred, or that improved productivity of these stocks will persist.

3.5.2 Potential ICES Response

ACFM should consider the biomass expected from the improved year-classes as an important contributor to the rebuilding required by the southern hake stock. A special comment might be warranted that there is no convincing evidence yet that a regime shift has occurred, or that improved productivity of this stock will persist into the future.

In the next few years emphasis should be place on rapid review of information from oceanographic and biological monitoring from the area.

4 Advancing the use of environmental information in ICES fisheries (and other) advice

4.1 General comment

WGRED feels that ICES needs to increase the attention that it gives to environmental information in its fisheries assessments and advice that is the case at present. Three examples illustrate why the environment matters to the fisheries advice that ICES provides

4.1.1 Long term climate changes and Global warming

In a recent press statement the World Meteorological Organisation (**http://www.wmo.ch/web/wcp/wcdmp/Press743_E.doc**) stated that:

"The global mean surface temperature in 2005 is currently estimated to be +0.48^{o} C above the 1961-1990 annual average (14^{o}C), according to the records maintained by Members of the World Meteorological Organization (WMO). 2005 is currently the second warmest year on record and 2005 is likely to be among the warmest 4 years in the temperature record since 1861. The last 10 years (1996-2005), with the exception of 1996, are the warmest years on record."

There is little doubt that global warming almost inevitably will have major effects on the structure and function of marine ecosystems and the yield from the fisheries they support. Since the 1950s records from the North Sea has shown a gradual change in temperature (Cook & Heath 2005) and it is predicted that this increase will continue with average annual surface temperature rising more than 1 C within the next 40 years (Kell et al 2005). Perry et al (2005) showed that the distributions of both exploited and non-exploited North Sea fishes have changed, with nearly two-thirds of species shifting in mean latitude or depth or both over 25 years. For species with northerly or southerly range margins in the North Sea, half have shown boundary shifts with warming, and all but one shifted northward. Species with shifting distributions were found to have smaller body sizes than non-shifting species and the authors concluded that further temperature rises are likely to have profound impacts on commercial fisheries through continued shifts in distribution and alterations in community interactions. Analysis of the February IBTS data also provided evidence for major changes in species distributions, but in this case the results were more complicated to interpret as the changes involved increases in both southerly and northerly species (Daan pers comm). While climate change is likely to have caused the increase in abundance of southerly species, it is not directly obvious why the northerly species would have increased as well. It may well be that the two main anthropogenic factors – exploitation and climate change – interact in a complicated manner, exploitation leading to increased recruitment of both northerly and southerly species, but climate change favouring the southerly species especially.

With changes in climate and temperature the utility of past monitoring efforts will no doubt decline as it will be increasingly doubtful whether stock recruitment relationships, natural mortalities and growth can be extrapolated into the future. The distribution and life-history of exploited fish stocks is likely to change leading to changes in overall species composition and productivity. Peaks of larval occurrence may no longer overlap with peaks of food abundance provided by secondary and primary producers or with favourable oceanographic conditions for larval retention and transport to nursery areas. Stock recruitment relationships may therefore change, with knock-on effects on trophic interactions, species composition, biodiversity and yield.

It is plausible that climatic change will make the use of parameter estimates to derive BRP's and longer term management advice from historical time-series increasingly questionable. Cook and Heath (2005) used a modified Ricker S/R-relationship with temperature adjustments to account for temperature in equilibrium SSB and Yield predictions for six North Sea species. The results showed significant changes in Fmsy and MSY and the authors concluded that current precautionary biomass reference points may not be achieved with the fishing mortality thresholds established during past climate conditions. Kell et al (2005) evaluated the robustness of short-term recovery and long term management strategies for North Sea cod under different climate scenarios. In the short term climate had little effect on cod stock recovery, in the longer term the results depended on the way temperature was included in the models. Both authors concluded that the methods they used for including temperature effects in their models were unlikely to capture the full range of uncertainty about the biological response.

Information useful for predicting the effects of environmental change can be gathered from analysis of stock specific time series or from meta-analysis of available data. Meta-analysis thus suggests that populations at the border of the species distribution area will tend to be influenced more by a given environmental change than populations in the middle of the area and can be used to provide priors for the maximum slope of S/R relationships and guidance on how reductions in the size of suitable nursery areas will affect recruitment (Myers 2001). Recruitment data often show significant cross species correlations that may constrain the outcome of predictions of changes in species interactions. Similarly quite a lot is known about the relationship between environmental parameters and growth, how changes in predator abundance will influence natural mortalities (e.g. cod vs shrimp (Worm and Myers 2002)), and how changes in growth and mortality will affect maturity.

Methods are also available to include uncertainty about climate change in predictions. Bayesian statistics offer flexibility for incorporating environmental data in traditional assessment models. Decision theory (Rothschild et al 2005), Bayesian influence diagrams (Kuikka et a.l 1999) and a wealth of other methods can aid in making the most out of the available data. Furthermore guidance is available on the design of reference points and management strategies that are robust to environmental and trophic change (Kell et al. 2005, Collie & Gislason 2001).

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4.2.1 Regime shifts and its implications to fisheries management

Regime shifts are a special kind of change in major parts of the ecosystem, and have important implications for assessment and management strategies. There are opportunities at present to make progress on accommodating regime information in assessments and advice in both the medium term and long term.

In the 2004 Annual Conference ICES convened a Theme Session on Regime Shifts in the North Atlantic Ocean to see whether there are consistent and coherent patterns as observed in the North Atlantic. http://www.ices.dk/iceswork/asc/2004/Theme%20Session.pdf

Several papers in the Theme Session presented evidence that the North Atlantic Oscillation (NAO) index, and regional correlates of it, plays a major role in the ocean climate in the North Atlantic. A coherent regime shift in both the North Sea and the Baltic Sea seems to correspond to a change in the NAO in 1988-89 (deYoung, *et al* 2004). Other papers in the Theme Session demonstrated that regional comparisons help to define when a regime shift occurred and to identify the underlying mechanisms.

With good knowledge of processes, physical environment or climatic forcing fish productivity regimes should be relatively easy to include in key population dynamics models and parameter estimates, and this would contribute to fisheries management advice (Ricker, 1958; Beverton &Holt, 1957; Shepherd 1982). Also climatically driven alternate low and high productivity regimes can be incorporated in fisheries management harvest control rules. For example, in the North Pacific methods are being developed to incorporate low frequency variability in fish production (regime-shifts) into harvest advice (PICES 2005).

Progress in the medium term can be made by the use of these developing tools and insights on regime patterns to adapt assessment parameters and management advice to given productivity regimes. This can improve harvest advice, by ensuring that the exploitation rate being applied is appropriate for the regime-specific productivity of the stock. Continuing to ignore regime-like changes in stock productivity means that exploitation rates estimated from observations taken over several regime changes will not be optimal for any specific set of environmental conditions, and have a moderate likelihood of being excessive for any regime with lower than average productivity for a stock.

Periods of regime change pose particular challenges to the provision of fisheries management advice. Accumulating evidence suggests that ecosystems may not simply flip back and forth between only two possible regimes (PICES 2005). Hence, even when evidence for a potential regime change is detected in the oceanographic information, during the transition period of the regime shift uncertainty may be higher than at other times. Specifically, it may be difficult to predict how productive each stock will be in the regime that will persist when the transition is over, and during the transition, productivities of individual stocks may be changing so rapidly that it is difficult to specify correct parameter settings for some assessment parameters, particularly in the short and medium-term projection steps. (This happened, for example, with Canadian cod stocks in the period form 1988-1991 [CSAS 1999]). The transitions between more persistent regimes is a time when intensive monitoring and review of biological parameters is particularly important to assessments. However, the uncertainty in the assessment and advice is still likely to be especially high during these periods of transition. This higher than usual uncertainty during regime transitions should be reflected in the projections of stock development, and accommodated in medium term management approaches.

Because of the increased uncertainty, the consequences of different exploitation rates are also more uncertain during these regime transition periods, and advice and management should be particularly risk averse (Walters and Martell 2005). In many cases a reduction in catches will be needed until the productivity of stocks in the new regime can be established. This need for extra caution in times of high uncertainty is explicit in all formulations of the Precautionary Approach in international legal instruments on marine environmental protection (Rice 2005).

ICES assessment and advisory practices and culture to not readily accommodate being less risk prone when uncertainty is high, nor have clients demonstrated a receptivity to such more cautious advice at times of particularly high scientific uncertainty Cultural change proceeds slowly, so dialogue on this point is needed urgently within ICES and between ICES and clients of its advice.

In the long term the most important progress involves moving from analyzing time series to establishing the functional relationships between the response and forcing variables. As this process-based understanding matures these relationships can be incorporated directly into simulation frameworks that are used to evaluate the performance of fishing control rules.

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4.3.1 Recovery strategies and ecological niche theory

When exploited fish populations decline to a small percent of their historical biomasses, the depleted populations cannot be considered to continue to play the same role in the ecosystem that the original population played. There are two different general processes which could result in major declines in an exploited population. Each has important but different implications for ecologically realistic recovery plans.

One possible cause of a major decline in an exploited fish populations is an overall change in the ecosystem productivity and/or carrying capacity for the entire linked food web of predators and prey (Hallowed et al. 2001, Conner et al. 2002). Such changes may be considered regime shifts, particularly if triggered by abrupt changes in important oceanographic drivers of the stock dynamics (PICES 2005). Several aspects of regime shifts are discussed in section 4.1.4. However, the relevance of niche theory here is that the ecological niche for the depleted population may actually have been reduced greatly in size. For recovery to be possible at all, at least the prey components of the food web have to increase substantially. Experiments to facilitate recovery through artificial enhancement of the food supply have had some successes in freshwater ecosystems (Hyatt et al 2004) but successful examples are rare in open marine systems (Bjornsson 2001). Culls of predators have sometimes been proposed to facilitate recovery of a prey, again attempting to manipulate a trophodynamic link to achieve an intended result. However, careful studies of such recovery efforts show that major culls of predators often have ecological consequences, but the species which benefit are almost never predictable in advance (Polis and Strong 1996, Yodzis) and often are not the depleted commercial species of particular interest (Punt and Butterworth 1995, Anonymous 1995). Overall when major reductions in ecological niche size was a major contributor to the decline of a commercial stock, recovery plans for the populations must take full account of the reduced niche size, but engineering recovery of the full niche space is unlikely to be feasible. Patience is necessary.

The other possible cause of a major decline in an exploited fish population is excessive fishing mortality. In this case the prey base and predator spectrum of can be largely intact. In classical niche theory such a situation might be called a “vacant niche” (Schoener 1989), although more contemporary ecological theory rarely considers such a notion to be valid (e.g. Hubbell 2001). However, the very reason that the concept of vacant niches is not considered valid has important implications for recovery planning. Other predators may expand their consumption of the prey previously exploited by the overfished population. Sometimes these other predators may be from other stocks of the same species, particularly of highly migratory species, (as *might* be the case for North Sea mackerel and Northwestern mackerel or Gurnard and cod in the North Sea. Other times they may be other species (Persson and Hansson 1998), but the consequence is the same. The recovery plan may assume that with reduced fishing mortality the population can increase in abundance, and the increase population can resume use of its previous prey, whereas the prey are now fully utilized by other predators.

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4.5 Present Status and Issues

Given the implications of the environment for assessment practices and provision of advice, as illustrated above, WGRED was concerned about the apparently little uptake of its proposal from February 2005 by the assessment and advisory committees in their 2005 work and products. To determine if the problem was real or just one of perception, WG members reviewed the environmental content of a number of assessment working group reports. The findings are tabulated below:

Table 4.5.1 Did assessment working-groups include environmental or ecosystem information in their 2005 report?

Working Group	Reference to Information from WGRED	Environmental data series used in assessment and advice?	Reference to WGPRISM, SGGROMAT
WGBFAS (Baltic Fisheries Assessment)	No (although one of TORs)	Yes (Ecosystem aspects covered for many of the species. Temperature and zooplankton abundance included in RCT3 for Gulf of Riga Herring and ice-cover partly included for Baltic sprat)	No
WGMHSA (Assessment of Mackerel, Horse Mackerel, Sardine and Anchovy)	No (although one of ToRs)	Yes (particularly with regard to anchovy)	No

HAWG (Herring Assessment Working Group for the Area South of 62° N)	Yes (provided detailed response to WGRED text)	YES (provided detailed response to WGRED text and some consideration of trends in recruitment)	No
WGNEPH (*Nephrops* stocks)	(Dissolved from 2005)	(Dissolved from 2005)	(Dissolved from 2005)
WGDEEP (biology & assessment of deep-sea fisheries resources)	No	No (but environmental and ecosystem considerations discussed extensively in 2004)	No
WGNPBW (northern-pelagic, blue whiting fisheries)	No (although one of ToRs)	Yes (provide an extensive 'ecosystem overview' including hydrography, plankton & trophic'. Assessments not changed using ecos. Data, but work on zooplankton, temp. and NSS herring presented)	No
WGNEW (assessment of new MoU species)	(Not yet met)	(Not yet met)	(Not yet met)
WGHMM (hake, megrim & monkfish)	Yes (extensive use of WGRED text)	Yes ('ecosystem aspects' considered for each species, including recruitment and feeding etc. – however assessments not changed using ecos. data)	No
WGSSDS (southern shelf demersal stocks)	No (although one of ToRs)	No (stated that WGRED did not suggest any specific actions – no discussion of ecosystem issues)	No
WGNSDS (northern shelf demersal stocks)	Yes (WGRED cited extensively and additional data provided)	Yes (discussion of 'environmental drivers' but not used in assessments)	No
WGNSSK (Demersal Stocks in the North Sea and Skagerrak)	Yes (use of WGRED text in the overview section)	Yes ('ecosystem aspects' considered for each species – however assessments not changed using ecos. data)	No
WGEF (elasmobranch fishes)	No	Short discussion of 'ecosystem implications' (mostly trophic)	No
AFWG (Arctic Fisheries)	Yes (WGRED text extended and requests answered)	Yes (cannibalism in cod assessment, predation by cod in haddock assessment and predation by cod in capelin assessment and short term predictions. There are plans to incorporate more ecosystem effects in predictions of some of the stocks)	No

North-western WG	Recommendation Addressed	Indirectly for cod. Discussed but not used for haddock & redfish. Predation accounted for in capelin management Discussed for Greenland cod	No
NWWG		Faroe Plateau cod and haddock. Catchability	

From this review of content it is clear that the concern is real. At the same time, the reservations of the Working Group chairs were heard clearly. It is far from clear how to use many types of environmental information, even if it is relevant to accounting for stock fluctuations. Where there are explicit ways to use environmental information, there may be reservations that the use of the information could still be speculative, making the advice at least vulnerable to criticism, and possibly to greater rather than lesser error.

WGRED recognises that incorporating environmental factors either quantitatively or qualitatively into assessment and advice carries a risk to both ICES credibility and to the effectiveness of management based on the advice. . In many studies environmental links to factors such as growth, maturity natural mortality and recruitment are not completely reliable, even when relationships may be statistically significant. This results in a reluctance to take the risk of taking up these relationships in advice. It is the view of WGRED that there is also a risk in NOT including these relationships in advice, particularly where demonstrated effects are substantial. We would also point out that landings data and surveys cannot always be considered as completely reliable. There is thus an urgent need to develop tools and mechanisms to incorporate environmental influences in advice and in the definition of management strategies/HCR that are robust to the uncertainties in this type of data.

WGRED joins a number of past ICES Expert Groups such as WGPRISM and SGGROMAT in finding the situation frustrating – science progress is being made on elucidating, sometimes quantifying, and sometimes even gaining process-based understanding of how the biotic and abiotic environment interact with fish stock dynamics. Uptake of that increasing knowledge in the assessment and advisory process is simply very slow and sometimes non-existent. WGRED concluded that it can play a key role in facilitating the transition of knowledge to application within ICES, and should serve as a clearing house / communication agent to feed ecosystem information into the fisheries assessment and advisory process. However, it has to approach that task is very practical and explicit ways. Without being perceived as being intrusively proscriptive, it must nonetheless be concrete and directive in filling that role. Towards that end, it discussed specific tasks that it could undertake intersessionally, to be in a position for its 2007 meeting where it could review concrete results of environmental-fisheries population interactions, and make equally concrete proposals for action by assessment groups and advisory committees. WGRED concluded:

1. The near total lack of uptake of environmental information in the computation aspects of population reconstructions / analysis is undesirable. However, there is nothing we can think of that would have a better chance of affecting the population analyses than the work of WGPRISM and SGGROMAT, and neither of those expert groups produced a detectable impact on practice.
2. There is opportunity to bring environmental considerations quantitatively into the advisory step (and, when assessment working groups are conducting their computations in the FLR framework, to the assessment step as well) through targeted action on the SGMAS guideline that harvest control rules and management strategies should be tested for robustness to environmental variation / uncertainty states of nature. WGRED will pick

a very small number of case studies (see next section) where members will work intersessionally with experts from ICES Expert Groups such as SGMAS, SGBFFI, and SGRECVAP, and/or working on EU-funded projects such as EFIMAS, INEXFISH, UNCOVER, and BECAUSE. The goal will be to have some concrete tests of the robustness of control rules to environmental forcers for a few selected stocks ready for consideration at the 2007 WGRED meeting. Those results would be the basis for concrete dialogue and possibly specific recommendations for practice to assessment working groups.

3. The transition to conducting assessments and providing advice with environmentally tested harvest control rules / management strategies will take time. During the transition phase, WGRED accepts that there will be little quantitative incorporation of environmental information in assessment computations. However, WGRED feels there is substantial scope for use of environmental information qualitatively in ICES advisory products. In the work done at its 2007 meeting that would correspond to addressing ToR d) of the current year, WGRED will continue to identify specific environmental considerations that are especially important in the current time. However, it will focus on proposals for using the information in the advisory interpretation of the working group computations, rather than on proposals for use of the information in the computation parts of the assessments.

4. It would be appropriate for ICES to formulate a strategy for including ecosystem considerations into the assessments. It should be kept in mind that ecosystem considerations must include both the physical part of the ecosystem and the biological part.

Such a plan would address points such as:

a) Assessment WGs should be required to include in their reports a brief description of the present state of the ecosystem, including recent changes and perceived trends. This could be based on the ecosystem descriptions from WGRED. If WGREDs descriptions are found lacking, they should give feedback to WGRED.

b) The WGs should also be required to give a qualitative evaluation of whether those changes and trends are taken (sufficiently) into account in the assessments - and if not, to evaluate how the changes and trends can be expected to influence the assessments. In this evaluation they should particularly consider possible effects of the changes and trends on natural mortality and individual growth and recruitment, and how they may increase or decrease uncertainty in the estimates. Possible ways to carry out sensitivity analyses should be explored.

c) The assessment WGs should also be encouraged to try out software which can include ecosystem trends in the assessments in a quantitative way. If necessary, they must then request input about specific ecosystem variables from WGRED or appropriate WGs.

d) Qualitative evaluations must have a prominent place in the output from the advisory groups, alongside numerical advice.

e) The clients are shaping ICES advice through their requests and perceived needs. Presently the most strongly requested advice is numerical advice about quotas, where every tonne counts. ICES should try to motivate clients for more long-range planning, seeking an optimal use of the biological resources. It would then be more natural for clients to consider qualitative advice as well as numerical.

4.6 Preparations for 2007 meeting

In its role as the clearing house and communication link between the accumulating science and knowledge of how stock dynamics are affected by the physical and biotic environment and the activities of specific assessment and advisory components of ICES, WGRED proposes to focus each meeting on a well defined set of tasks to facilitate transition from “research to operations” in this important area. It proposes that in 2007 one focus would be a consideration of several case histories on how to test management strategies and harvest control rules for their robustness to environmental uncertainty. A few cases we expect to consider are listed below, but others will be sought intersessionally as well.

a) Harvest control rule for a planktivorous commercially exploited fish.

WGRED proposes that WGRED, SGRECVAP & SGMAS collaborate to adapt the existing simulation framework developed by SGMAS to incorporate plausible environmental variability and to propose and evaluate harvest control rules that are robust to environmental variability. We propose a case study based on the hypotheses for recent recruitment failure in North Sea herring developed by SGRECVAP.

WGRED (ICES 2005) highlighted the recent serial recruitment failure in three planktivorous fish species in the North Sea in recent years. Following this, a study group (SGRECVAP – report in prep.) was set up to examine potential causes for this failure and make recommendations on future work. Of the three species, herring is currently the most important commercially, and is also important as a forage species. It is currently a healthy stock (above B_{pa} and below F_{pa}), although continuation of recruitment failure is likely to change this. Furthermore the failure was localised in time to the survival of larvae through the winter. SGRECVAP identified two significant environmental correlates to recruitment of North Sea planktivorous fish in general. These were the availability of prey either for the larvae themselves or for the adults, presumably prior to spawning, and water temperature. Increased temperature was positively and significantly linked to herring recruitment. At the same time, it is broadly recognised that the North Sea is experiencing ongoing changes in both temperature and zooplankton productivity and community structure

The simulation framework developed under SGMAS to evaluate management plans (SGMAS 2005 – report in prep) may be able to provide a tool to evaluate the impact of environmental changes on stocks and the robustness of harvest control rules. The SGMAS approach allows the production of an operational model for the given stock that encompasses a fishery model and a biological model. The biological model can include biological factors that may be modulated by environmental variability; e.g. growth rates and development/recruitment.

b) Barents Sea capelin – an example where species interactions are taken into account in management advice

Next year we will present how ecosystem aspects are taken into consideration in the assessment and advice of the capelin stock and how the uncertainties are handled in the harvest control rule.

Both in the assessment and the prediction of the capelin stock, the predation by cod is included. There is only one annual survey that covers this stock, and this survey is carried out before the capelin migrates through an area with young cod that feed on capelin. The survey index is taken as an absolute stock level and a model, especially developed for this stock, predicts the level of spawning stock biomass taking the predation into account. Thus the size and the predicted size of the cod stock is input to the capelin model. The predation is also based on analysis of annual data with stomach contents. There is no Bpa for this stock as the harvest control rule is based on the probability of falling below Blim and the uncertainties may vary from year to year.

There are plans to implement the implications of strong herring yearclasses on the recruitment of capelin that may be implemented before next WGRED meeting. In that case, this will also be presented.

c) Harvest rules for Canadian cod stocks experiencing changes in productivity. Canadian cod stocks underwent major decreases in productivity in the 1990s, which combined with overfishing, lead to major declines in several stocks. Current harvesting rates of these stocks with the reduced productivity is thought to be impeding recovery, even thought the rates were thought to be sustainable for the stocks under previous conditions (Shelton et al 2005). Canada is currently exploring harvest control rules which would accommodate these changes in productivity, as well as rules that would be robust to future changes in productivity. Results of these ongoing investigations will be brought to WGRED for review, and could contribute to developing practical guidance on developing and testing harvest control rules that are robust to environmentally driven changes in stock productivity.

d) The Joint Russian-Norwegian Fishery Commission (JRNFC) and “control rule” for ecosystem based advice

In 2004 the JRNFC requested an evaluation of the maximum sustainable yield from the Barents Sea, taking into account species interactions and the influence from the environment. The request was directed to the science community of PINRO, Russia, and IMR, Norway. JRNFC decided that the work should start with cod and gradually incorporate other species and that the scientist should provide a work plan.

A work plan up till 2014 was made and includes the development of multi-species model(s). The work plan shows how to move gradually from single species modelling to a multi-species simulation model by including one by one relation/interaction. There is also a list on what species to incorporate. The work is reviewed annually at joint meetings.

The JRNFC has also been active in proposing harvest control rules for Northeast Arctic cod and Northeast Arctic haddock. The cod rule has been accepted by ICES while the haddock rule will be evaluated by ICES this year.

We also propose that the work of the ICES Cod and Climate Change initiative also be reviewed, with the objective of specify exactly what links ICES needs to make between specific practices of specific assessment working groups and advisory committees and findings of that initiative.

We also propose to consider reviews which update scientific progress since SGGROMAT and WGPRISM concluded their work. The intent is to consolidate the rationales for *why* a continuation of practices that do not take adequate account of environmental forcing on stock dynamics and sustainable management risks undermining the soundness and credibility of ICES fisheries advice.

Taken together this proposed workplan is thought to commence a role for WGRED as the operational link between the science progress within ICES and more broadly, and the practices of its assessment groups and advisory committees.

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Annex 2: Agenda

Day 1 – Morning – Develop workplan for the week

Day 1 – Afternoon – Meet jointly with AMAWGC

Day 2 – Work on ToRs

Day 3 – Work on ToRs

Day 3 – Mid-afternoon – Meet jointly with AMAWGC

Day 4 Morning – Work on ToRs

Day 4 Afternoon – Review Text

Day 5 Morning – Meet Jointly with AMAWGC

Day 5 – Finalize text for report.

Annex 3: WGRED terms of reference 2006

The **Working Group for Regional Ecosystem Description [WGRED**] (Chair: Jake Rice, Canada) will meet back-to-back with AMAWGC at ICES Headquarters from xxx to yyy 2007 and in the margin of the ASC 2007 to:

a) Consider feedback from ICES Expert Groups and Advisory Groups, and clients of ICES advice, regarding the report template for the ecosystem description in the advisory reports, and adapt the template as appropriate

b) For each Eco-region to be used in the 2007 ICES advice, review drafts of Ecosystem Overviews that have been prepared by teams of national experts, as appointed by the Chair, for clarity, accuracy, consistency, and usefulness in the ICES Advisory Reports, and revise as necessary;

c) Identify and document any major environmental or anthropogenic events in each of the Eco-regions that should be taken into special account in ICES assessments and advice in 2007, and to the extent possible recommend ways in which this information could be used by Expert Groups and Advisory Committees

d) Review the work undertaken intersessionally to test the robustness of harvest control strategies to environmental forcing, for selected case histories proposed in Section 4.6, or alternatives as available, and to the extent possible recommend improvements to practice in use of harvest control rules in ICES assessments and advice.

e) Review the progress made by the Cod and Climate Change initiative of ICES, in the context of current practice of assessment working groups, with the objective of identifying opportunities to alter assessment practices to operationalize the results of that initiative. To the extent justified by the results, recommend improvements to practice in assessment working groups.

Supporting Information

PRIORITY:	.
SCIENTIFIC JUSTIFICATION AND RELATION TO ACTION PLAN:	Action Plan No: 1.
RESOURCE REQUIREMENTS:	.
PARTICIPANTS:	The Group is normally attended by some 15–25 members .
SECRETARIAT FACILITIES:	None.
FINANCIAL:	No financial implications.
LINKAGES TO ADVISORY COMMITTEES:	There overviews prepared by WGRED are used directly by all three advisory committees. The work done on including environmental considerations in assessments and advice is directly relevant to ACFM and ACE.
LINKAGES TO OTHER COMMITTEES OR GROUPS:	There is a very close working relationship with all the groups of the Fisheries Technology Committee. It is also very relevant to the Working Group on Ecosystem Effects of Fisheries.
LINKAGES TO OTHER ORGANIZATIONS:	The work of this group is closely aligned to major research projects funded by the EU and work conducted by other ICES expert groups
SECRETARIAT MARGINAL COST SHARE:	ICES:100%.

Annex 4: Recommendations

RECOMMENDATION	ACTION
1.There are no specific recommendations however in Section 3 SUGGESTIONS are made to three Assessment Working Groups for practices in the 2006 assessments, to consider environmental information	Assessment Working Groups for the Northwest, for Barents Sea, and North Sea, should take account of the proposed actions in Section 3.2, 3.3, and 3.4, respectively..
2.In additon a new role for WGRED within ICES is PROPOSED in Sections 4.5 and 4.6	ConC should consider the proposed role for WGRED as early as posisble in 2006. If they agree, an early signal is required to allow intersessional work to commence.
3.	
4.	
5.	
6.	