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19 -23 FEBRUARY 2007

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Contents

1 Opening of the meeting

The meeting was opened at 10:00 on Monday, February 19, but the Chairman, Dr. Jake Rice, of Canada. The Secretariat briefed the Working Group on new procedures within ICES, including the use of Sharepoint as the major site for document preparation and management. The group listed with its usual enthusiasm to yet more changes in how the Secretariat expected them to do their business.

2 Adoption of the agenda

The agenda, reflecting the Terms of Reference assigned to the working group, were adopted, It was noted that joint meetings were planned with AMAWC on Tuesday afternoon and with PGWKRFA on Wednesday afternoon. The schedule focused on work on the overviews on the first days, and treatment of the other terms of reference later in the week

3 Overviews

3.1 Introduction to section

Term of reference a) was to:

a) For each Eco-region to be used in the 2007 ICES advice, review drafts of Ecosystem Overviews that have been prepared by teams of experts from fisheries and environmental laboratories in each Eco-region, coordinated by a designated WGRED member from each Eco-region, for clarity, accuracy, consistency, and usefulness in the ICES Advisory Reports, and revise as necessary;

The Working Group deliberated on feedback from other parts of the ICES community, and the nature of information that was available, relative to the ecoregions used in the report. It was decided that the Iceland – Greenland ecoregion should be divided into two separate Overviews, one for Iceland (3.3) and one for Greenland (3.2). This was justified by the lack of homogeneity in abiotic or biotic properties between the two regions, such that a single overview for the two regions was actually separate paragraphs for each subregion on each theme, and there was really no integrated overview. The Working Group did check the original ICES rationale for the larger zone, and found no strong argument for having the two very different areas combined in the first instance. The Greenland Overview is not fully developed in this meeting. However communication with researchers in Greenland led to an agreement that before the 2008 meeting of WRED, they wull work to augment incomplete sections of the Greenland Overview, to extent that information exists. The Working Group did discuss the possibility of subdividing other ecoregions, and concluded that the rationale for the other regions was sound.

In response to a specific request from ACFM, the Working Group also prepared a new Overview for the pelagic and highly migratory stocks in the ICES area (3.11). It as acknowledged that this Overview will overlap spatially with several of the Regional Overviews. However, the existence of a separate chapter of the ICES advice on these stocks creates a need for an Overview addressing the area on a scale not readily extracted from the existing Regional Overviews.

No countries around the Baltic Sea sent participants to the working Group meeting. The Working Group updated some time series data in cases where 2006 values could be located. Otherwise, however, THE OVERVIEW HAS NOT BEEN UPDATED AND WILL NEED ATTENTION FROM ICES.

3.2 Greenland

3.2.1 Ecosystem Components

3.2.1.1 Bottom topography, substrates, and circulation

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 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 organisms from Iceland into Greenland waters.

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

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 and 2006 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. This appears to have reversed in 2006, with satellite monitoring data indicating that water temperatures may be starting to increase again (NASA 2007). 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. Between April 2005 and April 2006 ice melted from the Greenland ice sheet at more than two and a half times times the rate in 2003 and 2004 (University of Colorado 2007).

The west Greenland marine ecosystem is considered to lie between about 60 N, the latitude of Cape Farewell, and about 70 N, the latitude of Disko Island. The near shore bottom topography is characterised by a continental shelf 60-200 km broad. The physical oceanographic conditions in West Greenland waters are controlled by the large scale circulation in the North Atlantic: a branch of the warm North Atlantic current circles anti-clockwise in the Irminger Sea off southern East Greenland to join the cold East Greenland Current and around Cape Farewell to form the north-setting West Greenland Current. Under the influence of this relatively warm current, the West Greenland marine ecosystem is Sub-Arctic. Sea ice in winter usually extends no further south than about 66 N. The transport of heat salt and nutrients, as well as plankton, fish eggs and larvae, to Greenland waters by these dominant North Atlantic current systems and their fluctuations as a consequence of climate change are together with the runoff of freshwater from land – the major governing processes for the Greenland marine ecosystem (Hunt and Drinkwater 2005).

For west Greenland there exists a continuous series of temperature and salinity observations spanning more than 50 years, but interdisciplinary research is needed to understand the physical, chemical and ecological processes that will be affected by climatic change and potentially cause changes in the marine ecosystem.

Investigations in other regions have documented the hydrographic fronts are important to plankton community structure and dynamics. Plankton production at fronts is transferred to higher trophic levels including commercially important fish stocks. Observations of fish catch and distribution of seabirds and marine mammals support the thesis that such sites are of key importance in understanding, as well as exploiting, the production from the West Greenland ecosystem. The coupling between frontal dynamics on the other hand, along the banks at West Greenland has not previously been investigated, but in particular, knowledge about frontal dynamics and upwelling of nutrients from the deeper parts of the surface layer is needed if the pelagic production is to be understood (Hunt and Drinkwater 2005).

The deep Greenland Sea 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.

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

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.

The microbial food web in the Arctic has received relatively little attention. However, in high latitude ecosystems the function of these small grazers in coupling the primary production to the fish stocks has to be considered. Recent investigations in Disco Bay and Young Sound and on the Banks off West Greenland have documented that bacterioplankton and unicellular zooplankton play prominent role (Rysgaard et al. 1999, Levinsen and Nielsen 2002). Judget on the relative biomass distribution, a large part of the primary production may be channelled through these micro-organisms.

3.2.1.4 Zooplankton

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*).

The pelagic ecosytem off West Greenland is poorly known, and baseline studies are therefore necessary before processes such as climate change can be addressed or scenarios modelled. Historically, most research in Arctic pelagic ecology has considered only the larger components of the food web, e.g. the diatoms and calanoid copepods. Research during the last century has documented the annual cycle and population dynamics of *Calanus* copepods and stressed the key role of these organisms in high latitude ecosystems. This part of the food web is the direct link to fish stocks. Several key seabird species also rely on *Calanus*.

From a carbon sediment point of view the composition of the grazer community is also essential. Zooplankton influences carbon dynamics in several ways: by vertical migration, through grazing activity, and accelerators of sedimentation of organic matter through production of fecal material. An efficient transfer of organic matter produced in the water column to the sea floor through a close pelagic-benthic coupling, together with a low metabolism of benthic fauna, are among the reasons why high benthic biomass can be maintained in Arctic regions. Despite permanently low temperatures, near-shore Arctic benthic communities mineralize organic matter as efficiently and as rapidly as communities in lower latitudes. Although it represents the link between pelagic production and benthic animal production, virtually no measurements of vertical export exist from West Greenland waters. Furthermore, knowledge of distributional patterns and remineralization potential of the benthos along the West coast is absent. No studies have dealt with growth and production of individual species, and such studies are necessary in ordet to elucidate the ecological role of macrobenthos in the Arctic food chain (Hunt and Drinkwater 2005).

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

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.

3.2.1.6 Fish Community

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 spawn in many west Greenland Fjords and off the banks of south and east Greenland. In some years considerable numbers of larvae drift from Iceland to Greenland and when mature these fish returns to Iceland to spawn. 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). The Greenland cod stock collapsed in the 1970s because of worsening climate 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 cod year-classes mature they will return to Icelandic waters.

Exploitation of, and research on, offshore fish in West Greenland has been dominated by demersal species. The Atlantic cod fishery is episodic. For example in the 1960s, catches were up to 400 K tonnes/year, but in 1990 they were close to zero. The most significant fishery since the 1970s has been that for northern shrimp, with catches up to 100 K tonnes/year from a biomass estimated by trawl survey to be near to 1000 K tonnes. Indications are that the stock has increased continuously during the decade ca. 1994-2004. Surveys in the area indicate that the composition of demersal fish species inhabiting the shelf and continental slope has changed fundamentally since the early 1980s. At the same time, there has been a dramatic change in biomass and size structure of ecologically important species. Today, northern shrimp and Greenland halibut are the only important offshore species fished in the area. In the past, the sand eel was a significant prey for other fishes, seabirds, seals and whales. Today there are indications that the sand eel is no longer as abundant, and its importance is uncertain. Unless the mechanism underlying these past radical changes in the offshore demersal system can be better understood, the response of the ecosystem to a changing environment will remain unpredictable (Hunt and Drinkwater 2005).

The pelagic fish community off West Greenland is poorly investigated. Arctic cod and capelin are probably the principal fish species, and with squids the most important pelagic macrofauna. However, juvenile redfish, distributed both demersally and pelagically on the slopes of the banks, compose a huge resource in the West Greenland marine ecosystem, and probably come from stocks in waters east of Greenland. An important task is to determine the structure and function of higher-level components of the pelagic system, and the implications of fishery exploitaion on the internal stabilty of this sub-system.

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

Seabirds constitute a conspicuous component of West Greenland ecosystem in winter. At least 3.4 million birds are estimated to winter in the area, not counting unknown numbers, probably also in the millions, of little auks (*Alle alle*). The winter seabird community is dominated by pursuit-diving Alcidae – Brünnich´s guillemot, black guillemot, little auk – and bottom feeding eiders: king eiders on the banks and common eiders along the coasts. In summer, the offshore seabird density is lower and mainly consists of wide-ranging surface-feeding fulmars and gulls (kittiwake, glaucous gull and Iceland gull) (Hunt and Drinkwater 2005).

Seabirds harvests in West Greenland have been high, in particular Brünnich´s guillemot (>200.000/yr) and eiders (>80.000/yr), and declines in breeding populations both in Greenland and elsewhere in the Arctic have been ascribed to hunting in West Greenland. It is currently a major management problem to develop locally accepted and sustainable management regimes for seabirds in the West Greenland ecosystem, both in terms of harvest levels and in terms of ensuring that production is not reduced by disturbance in breeding and critical foraging areas.

The West Greenland marine mammal faun reflects both Atlantic and Arctic influences. North Atlantic whale species occur in West Greenland: minke, fin, sei and humpback whales mostly feed on small schooling fish or on large invertebrates. Atlantic odontocetes include such cool-water species as the harbour porpoise, the Atlantic white-sided dolphin, the white-beaked dolphin, the killer whale, the long-finned pilot whale and the northern bottlenose whale. Among Arctic species, the bowhead occurs in West Greenland in winter but in low numbers, belugas and narwhals are also present in the more northerly parts of the West Greenland system in winter, associated with the sea ice (Hunt and Drinkwater 2005).

The north-west Atlantic stocks of harp and hooded seals are migratory, and pelagic in summer, and are then numerous in West Greenland. Stock size for harp seal is of the order of 6 million, but it is not know what proportion come to Greenland waters. Ringed and bearded seals are restricted to areas with winter sea ice. Harbour seals and walruses are found in small numbers in West Greenland. Both these species have been reduced in numbers by hunting and other disturbances (Hunt and Drinkwater 2005).

3.2.2 Environmental Forcing on Ecosystem Dynamics

This section will be developed in future years.

3.2.3 References:

Hunt, G.L. Jr.and K.F. Drinkwater (Eds.). 2005. Background on the Climatology, Physical Oceanography and Ecosystems of the Sub-Arctic Seas. Appendix to the ESSAS Science Plan. GLOBEC Report No. 20, viii, 96 pp.

Levinsen, H. and T.G. Nielsen. 2002. The trophic role of marine pelagic ciliates and heterotrophic dinoflagellates in arctic and temperate coastal ecosystems: a cross latitude comparison. Limnology and Oceanography 47, 427-436

NASA 2007. Science Highlights – Hydrospheric and Biospheric Sciences Laboratory. http://neptune.gsfc.nasa.gov/science/pre/200602/

Rysgaard, S., T.G. Nielsen, and B. Hansen. 1999. Seasonal variation in nutrients, pelagic primary production and grazing in a high-arctic marine ecosystem, Young Sound, Northeast Greenland. Marine Ecology Progress Series 179, 13-25.

University of Colorado 2007. Greenland ice sheet still losing mass. Press release. http://www.sciencedaily.com/releases/2006/09/060920193210.htm

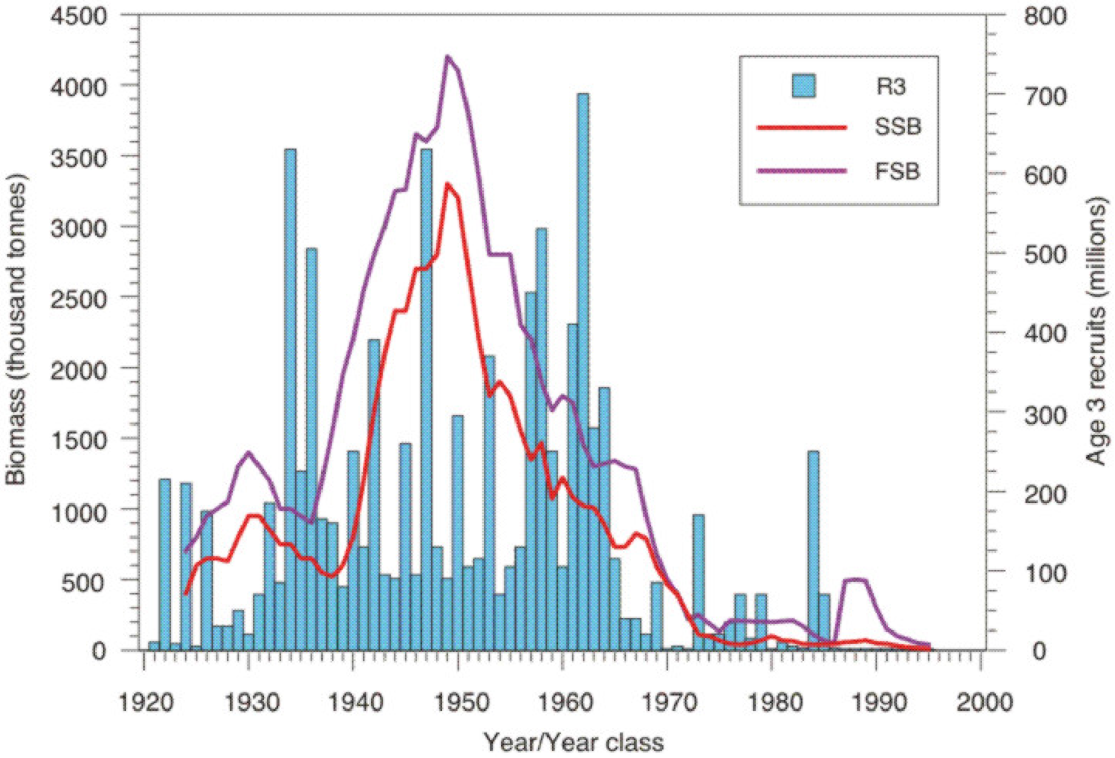

Figure 2.1. Recruitment at age 3, spawning biomass and fishable biomass of cod off West Greenland.

3.3 Iceland

3.3.1 Ecosystem Components

3.3.1.1 Bottom topography, substrates, and circulation

Iceland is located at the junction of the Mid-Atlantic Ridge and the Greenland-Scotland Ridge just south of the Arctic Circle. The bottom topography of this region is generally irregular, with hard rocky bottom prevailing in most areas. The shelf around Iceland is cut by many sub-sea canyons. It is narrowest off the south coast where in places it extends out only a few km. From there, the continental slope falls away to over 1000 m. Off the west, north and east coasts, however, the shelf is relatively broad and extends often over 150 km from the coast

To the south of Iceland the Iceland Basin is separated in the west from the Irminger Sea by the Reykjanes Ridge and in the east from the Norwegian Sea by the Iceland-Faroe Ridge. North of Iceland the Kolbeinsey Ridge stretches to the Jan Mayen Fracture Zone, between Jan Mayen and Greenland, which marks the northern limit of the Iceland Sea and separates it from the Greenland Sea. South from Jan Mayen, the Iceland-Jan Mayen Ridge extends to the Iceland-Faroe Ridge and separates the Iceland Sea from the Norwegian Sea (Astthorsson *et al.* 2007).

The Polar Front lies between Greenland and Iceland and separates the cold and relatively low saline south-flowing East Greenland Current from the Irminger Current, the westernmost branch of the warmer and more saline North Atlantic Current (Figure 3.1). South and east of Iceland the North Atlantic Current flows towards the Norwegian Sea. The Irminger Current flows northwards over and along the Reykjanes Ridge and into the Denmark Strait where it devides. One branch continues northeastward and eastward to the waters north of Iceland and the other branch flows south-westward parallel to the East Greenland Current. In the Iceland Sea north of Iceland a branch out of the cold East Greenland Current flows over the

Kolbeinsey Ridge and continues to the southeast along the northeastern shelf brake as the East Icelandic Current. This current is part of a cyclonic gyre in the Iceland Sea.

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

Icelandic waters are relatively warm due to Atlantic influence and are generally ice free. Infrequently for short periods in late winter and spring drift ice may come close inshore and even become landlocked off the northwest and north coasts. Waters to the south and west of Iceland are usually within the range of 6-10 °C whereas on the N-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 much less variable in the Atlantic water south and west of Iceland than in the waters to the north and east of the country where considerable inter-annual variations of hydrography have been observed. On longer timescales changes in the strength and position of major currents and water masses show some linkages to NAO regime shifts (Figure 3.2) (Malmberg *et al.* 1999). However, the atmospheric forces driving the observed seasonal and interannual variations in the ocean climate north of Iceland are also to a considerable extent of local origin. This is probably because the NAO index is mainly related to the westerly winds blowing across the Atlantic at mid-latitudes to the south of Iceland (Astthorsson *et al.* 2007).

3.3.1.3 Broad-scale climate & Oceanographic features & drivers

As pointed out above the NAO has an 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.

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

The Iceland Shelf is a 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-April rather than the more usual mid-May. “Cold” years, with less influence of North Atlantic Current waters to the north of Iceland tend to have lower primary productivity in comparison to years when the influence of the Atlantic water has been as extensive and predominant as during last decade.

Over the Icelandic shelf diatoms of the genera *Thalassiosira* spp. and *Chaetoceros* spp. typically dominate the phytoplankton spring bloom. During some years the prymnesiophyte *Phaeocystis pouchetti* may be abundant in the waters to the north of Iceland in spring. Dinoflagellates of the genera *Ceratium* spp. and *Protoperidinium* spp. increase in abundance after the spring bloom, while diatoms continue to be relatively abundant. In the autumn there is usually a second bloom of diatoms and dinoflagellates (Astthorsson *et al.* 2007).

3.3.1.5 Zooplankton

In terms of numbers of individuals, copepods dominate the mesozooplankton of Icelandic waters with *Calanus finmarchicus* being the most abundant species, often comprising between 60-80% of net-caught zooplankton in the uppermost 50 m (Astthorsson and Vilhjalmsson 2002, Astthorsson et al. 2007). Other copepod species occurring regularly over the shelf around Iceland are *Pseudocalanus* spp., *Acartia longiremis* and *Oithona* spp., while some species are more confined to the Atlantic water (e.g. *Temora longicornis*, *Centropages hamatus*) or to the Polar water (e.g. *Metridia longa*, *Calanus hyperboreus*, *Calanus glacialis*). The euphausiid *Thysanoessa raschi* is common in fjord areas while *Thysanoessa inermis* is the dominant euphausiid over the shelves. In addition, the euphausiids *Meganyctiphanes norvegica* and *Thysanoessa longicaudata*, are mainly found near the shelf edge in oceanic water to the south and west of Iceland (Einarsson 1945).

Since the early 1960s monitoring of zooplankton biomass in the upper 50 m in Icelandic waters has been carried out on standard transects during May-June (Astthorsson et al. 2007). *Calanus finmarchicus* is the dominant species of the plankton community, and therefore the biomass mainly reflects the biomass of this species. The spring zooplankton biomass generally ranges from ca. 1-10 g dry weight m^{-2}, with an average of 2-4 g dry weight m^{-2}. Higher biomass is usually observed in shelf waters off the south and west coasts, in the oceanic waters to the north and northeast of Iceland where Arctic influence is greatest and large Arctic species dominate and in offshore waters of the Irminger and Norwegian Seas.

Zooplankton biomass time series in the waters to the north of Iceland show maxima occurring approximately every 7-10 years. Also striking is the collapse in zooplankton biomass during the cold period in the North Atlantic and to the north of Iceland in the 1960s, and it was not until the warm period in the 1990s that biomass levels recovered (Astthorsson and Gislason 1995).

Zooplankton biomass variability to the north of Iceland is positively related to temperature which again reflects the inflow of Atlantic water into the area. On average, zooplankton biomass in “warm” years is about 2 times higher than in “cold” years (Astthorsson and Gislason 1998). Greater inflow of Atlantic water will lead to increased primary production which results in good feeding conditions for zooplankton. The warm temperatures will promote increased growth and faster development times of zooplankton, and the stronger inflow of Atlantic water may advect more zooplankton from the south and west (Astthorsson *et al.* 2007).

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). In 2005 and 2006 zooplankton biomass north of Iceland was again above long term average while to the south it was around average (Anon. 2006).

3.3.1.6 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. Species diversity of the hyperbenthic family Eusiridae have been shown to be lower in the deeper parts of the The Nordic Seas, i.e. the Norwegian, Greenland and Iceland Sea 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 (Weisshappel and Svavarsson 1998). 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 peracarid crustaceans 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).

Survey measurements indicate that shrimp biomass in Icelandic waters, both in inshore and offshore waters, has been declining in recent years. 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.

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 (Guijarro et al. 2007).

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 north and south Iceland and around the Reykjanes Ridge (Guijarro et al. 2007).

3.3.1.7 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, haddock, saithe, redfish, Greenland halibut and various other flatfish, wolffish, tusk *(Brosme brosme),* ling *(Molva molva)*, herring, capelin and blue whiting. 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 capelin 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 since 1970 to a historical high level in the last decade. 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 are collected in extensive bottom trawl surveys conducted in early spring and autumn, but information on their catches in fisheries, is not available.

3.3.1.8 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 1/4 of abundance and biomass in the area, respectively. The most abundant species are Atlantic puffin (*Fratercula arctica*), northern fulmar (*Fulmarus glacialis*), common (*Uria aalge*) and Brunnich’s guillemot (*Uria lomvia*), black-legget kittiwake (*Rissa tridactyla*) and common eider (*Somateria mollisima*). 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.

3.3.2 Environmental Forcing on Ecosystem Dynamics

The environmental conditions, particularly to the north of Iceland, have a major effect on the biology and distribution of many key species. Around the mid 1990s a rise in both temperature and salinity was observed in the Atlantic water to the south of Iceland. The positive trend has continued ever since and west of Iceland it amounts to an increase of temperature of about 1° C and a salinity of 0.1.

Off central N-Iceland a similar trend is observed, but more irregular since this is an area of variable mixing of warm and cold water masses. Nevertheless, the trend is clear and is indeed larger than in the Atlantic water off W-Iceland (the same has been observed off SE-Iceland as well). The increase of temperature and salinity north of Iceland in the last 10 years is on average about 1.5 ˚C and 1.5 salinity units.

During 2005 and 2006 temperature and salinity in the upper part of the water column to the south of Iceland were above long term average as has been the case since 1997. In the waters to the north of the country temperature and salinity were near the long term average. Bottom temperature over the shelf has been above average since 2002 and in winter 2003 it was higher than during decades previously. In February 2006 bottom temperature was near or above average all around Iceland (Anon. 2006).

In recent years capelin have both shifted their larval drift and nursing areas far to the west to the colder waters off E-Greenland. The arrival of adults on the overwintering grounds on the outer shelf off N-Iceland has also been delayed and migration routes to spawning grounds off S- and W-Iceland have been located farther off N- and E-Iceland and not reached as far west along the south coast as in most earlier years. This has resulted in a low availability of capelin for feeding by the Icelandic cod stock and thus a poorer condition of cod since 2003. There is evidence that change in the distribution of capelin and thus less overlap in the distribution with cod may be leading to a marked detrimental impact on cod growth (Anon. 2006).

Several southern gadoids such as haddock, saithe, and whiting (*Merlangius merlangus*) and the monkfish (*Lophius piscatorius*) are amongst the species that have shown the largest distribution extensions and increases in abundance in recent years. Recruitment investigations on haddock have further demonstrated that, except for that of 2001, all year classes between 1998 and 2003 have been strong. In fact, the 2003 year class is estimated to be the strongest in 45 years. This increased recruitment and more northward and northeastward distribution of haddock may be related to the positive temperature anomaly of recent years (Anon, 2006). Recent shifts in the distribution of the Icelandic summer spawning herring around Iceland have also been associated with the warming and the same probably applies to the increase of blue whiting in Icelandic waters (Astthorsson *et al*. 2007).

Icelandic cod has not taken advantage, or not been able to take advantage, of the milder marine climate of Icelandic waters. However, during the last warm epoch, which began around 1920 and lasted until 1965, the Icelandic cod flourished. By the early 1980s the cod had been fished down to a very low level as compared to previous decades and has remained relatively low since. During the last 20 years the Icelandic cod stock has not produced a large year class, the average number of age 3 recruits being about 150 million fish per annum, as compared to 205-210 million recruits in almost any period prior to that, even the cold years of 1965-1971. Immigrants from Greenland are not included in this comparison. It is not possible to pinpoint exactly what has caused this change, but a very small and young spawning stock is the most obvious common denominator for this protracted period of impaired recruitment to the Icelandic cod stock. Regulations, particularly the implementation of the catch rule in 1993 have resulted in lower fishing mortalities in the last ten years compared with the ten years prior and has, despite low recruitment resulted in almost doubling of the spawning stock biomass since 1993. This improvement in the SSB biomass has, however, not resulted in significant increase in production in recent years, despite increased inflow of warmer Atlantic water.

Astthorsson and Palsson (2006) reported on 22 southern fish species that during past 10 years were recorded for the first time within the Icelandic 200 mile EEZ have. Some of these species have been found on common fishing grounds and close to land and are therefore considered to reflect actual changes that are taking place in the fish fauna around Iceland. Nine of the first time records (flounder (*Platichthys flesus*), blue shark (*Prionace glauca*), violet cuskeel (*Brotulotaenia crassa*), blackdevil anglerfish (*Melanocetus johnsonii*), pink sabertooth (*Evermannella balbo*), palebelly searsid (*Barbantus curvifrons*), *Lycodes terraenovae*, *Poromitra megalops*, and *Chaunax suttkusi*) are from more than one location or from different years. Several rare species that used to be recorded only occasionally (or that had not been recorded for a long time) have in recent years been recorded almost annually (twaite shad (*Alosa fallax*), mackerel (*Scomber scombrus*), sea lamprey (*Petromyzon marinus*) and garpike (*Belone belone*)). Further several rare southern species have during recent years clearly been extending their distribution to more northern locations (snake pipe fish (*Entelurus aequoreus),* greater fork-beard (*Phycis blennoides*), blue antimora (*Antimora rostarata*)). The changes in fish distribution are believed to be relatated to the positive hydrographic anomaly (temperature and salinity) both the Atlantic water to the south and in the Sub-Arctic waters to the north of Iceland since the middle of the 1990s.

3.3.3 Fishery effects on benthos and fish communities

Many of the demersal fisheries use mobile gears and fish on hard bottoms. This may potentially cause 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 has a build in incentive for the fleet to direct effort to more valuable fish (high-grading). When juveniles are high proportion of the fishable biomass of the target stock or the TAC/biomass proportion is relatively high this may lead to increased discard of the target species. According to extensive discarding measurements that have been carried out in the Icelandic fisheries since 2001 (Pálsson 2003, 2004) dicards as a proportion landings in weight has been in the range of 0.6-7.1% for the main exploited demersal species (cod, haddock, saithe, redfish, plaice). Reliable information on non-target species taken as by-catch in these fisheries are not available.

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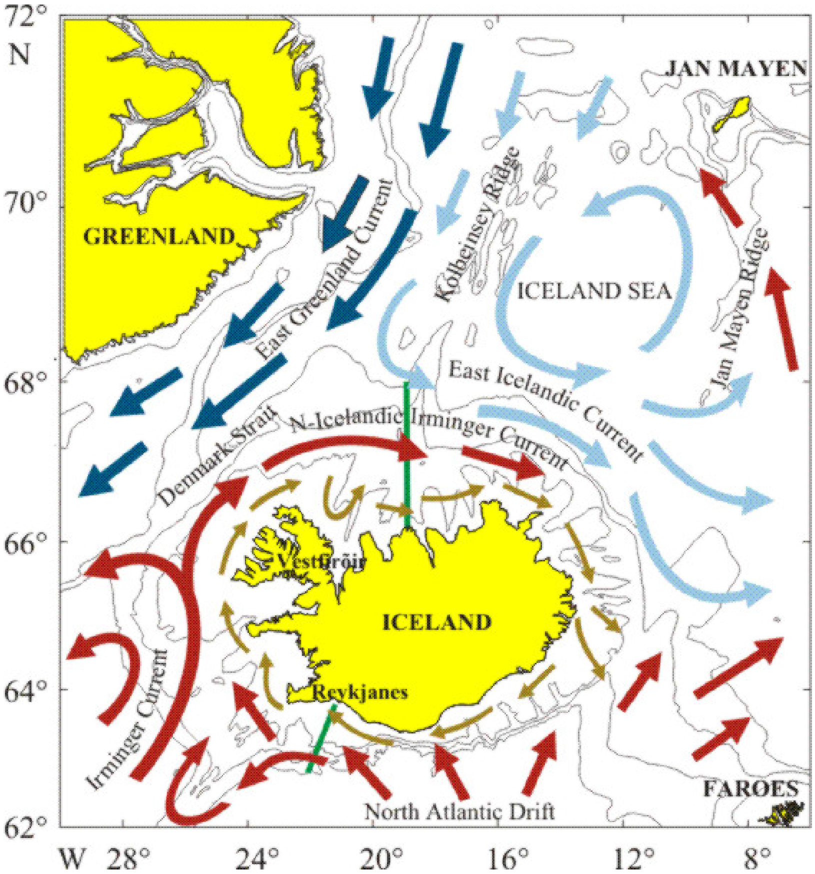

Figure 3.1. The system of ocean currents around Iceland and in the Iceland Sea

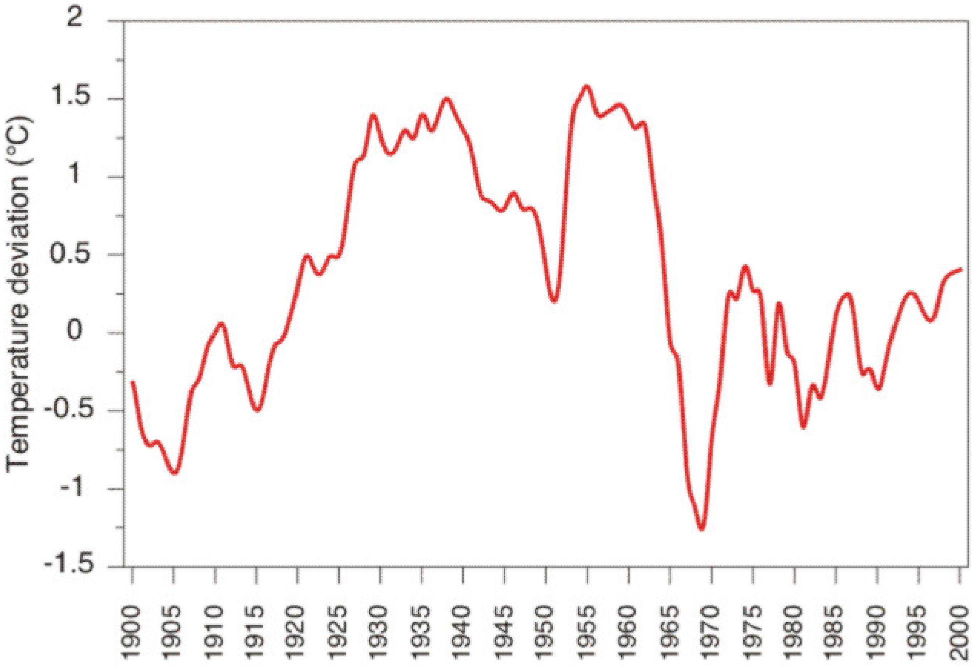

Figure 3.2. Temperature deviations north of Iceland 1900-2000, five year running averages.

3.4 The Barents Sea

3.4.1 Ecosystem Components

3.4.1.1 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, Novaya Zemlya in east and the coast of Norway and Russia in the south (Figure 3.1.1). 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 between 50-200 m.

3.4.1.2 General oceanography

The general circulation pattern in the Barents Sea is strongly influenced by topography. Warm Atlantic waters from the Norwegian Atlantic Current defined by salinity higher than 35 flow in through the western entrance. This current divides into two branches, one southern branch, which follows the coast eastwards against Novaya 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 characterized by strong gradients in both temperature and salinity. In the western Barents Sea the position of the front is relatively stable, although it seems to be pushed northwards during warm climatic periods., In the eastern part the position of the 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 northern Barents Sea, while in the summer the whole Sea may be ice-free. In general, the Barents Sea is characterized 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 and showed a pronounced warming toward present. During the last 10 years the mean temperature has increased with more than 1^{o}C, the annual mean volume flux of Atlantic Water inflow has nearly doubled and the warm water has spread eastwards. 2006 was the warmest year ever recorded (Figure 3.1.2).

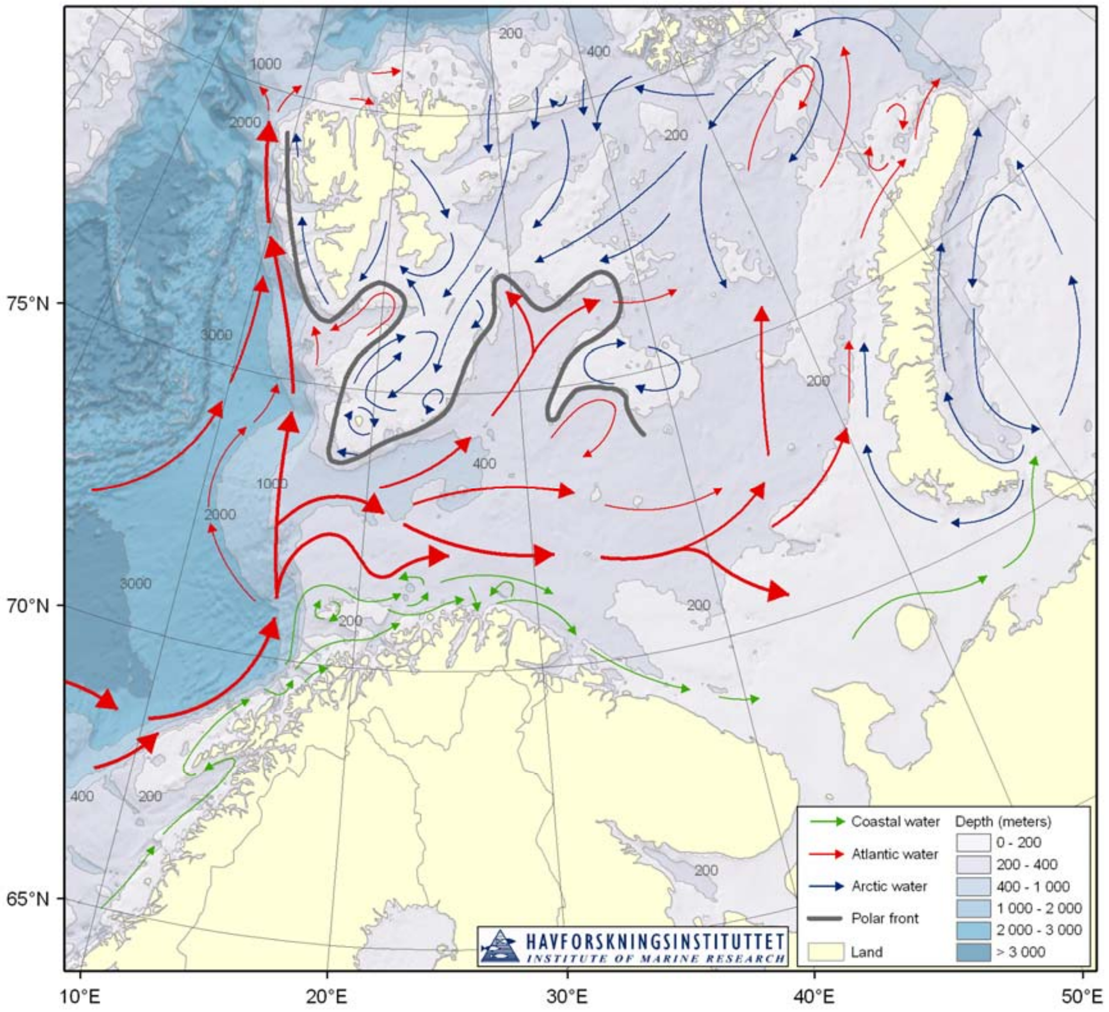

Figure 3.1.1 Bottom contours and current systems in the Barents Sea.

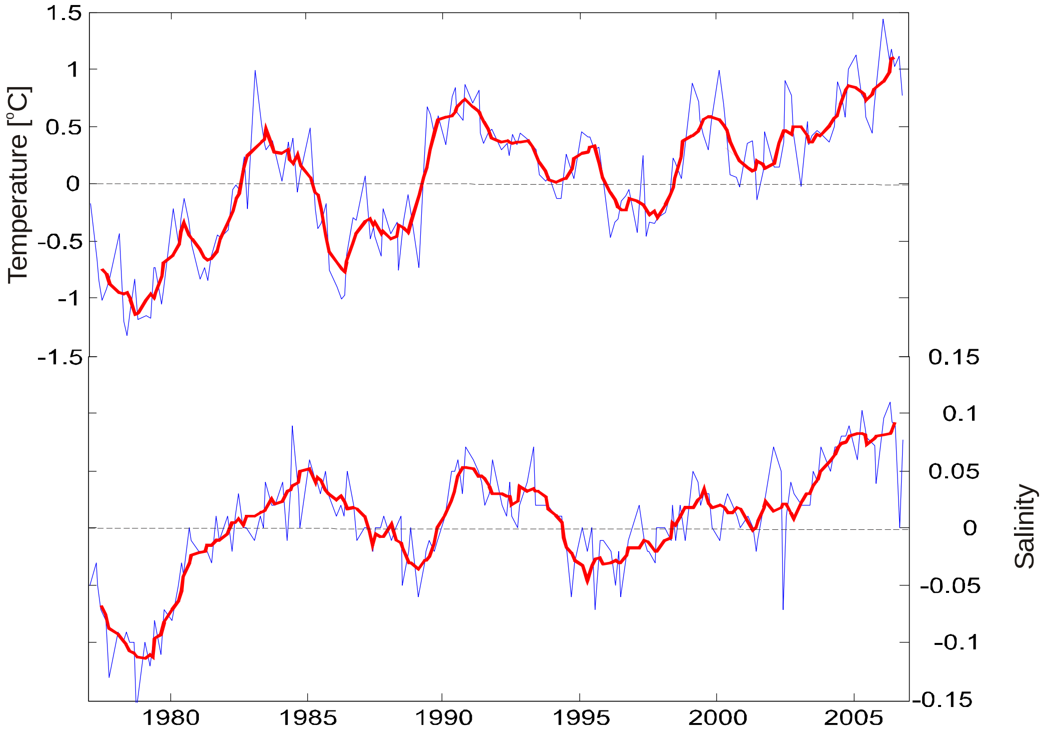

Figure 3.1.2 Temperature (upper graph) and salinity (lower graph) anomalies in the Fugløya – Bjørnøya transect during the period 1977 - 2006.

3.4.1.3 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.

3.4.1.4 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.

3.4.1.5 Benthic habitats

Benthic organisms (benthos) in the Barents Sea 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*. Reefs are known to be 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.

3.4.1.6 Fish communities

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 (*Micromesistius 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.

3.4.1.7 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.

3.4.1.8 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).

3.4.1.9 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 qualitative and quantitative understanding of the production system being harvested through fishing, and the effects of fishing on the ecosystem.

3.4.2 Human impacts on the ecosystem

3.4.2.1 Fisheries effects on benthos and fish communities

Barents Sea

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 and haddock the last years indicate that this is a considerable problem; around 20% in addition to official catches in the period 2001-2005 (ICES, 2006).

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3.5 The Norwegian Sea

3.5.1 Ecosystem Components

3.5.1.1 General geography

The Norwegian Sea is traditionally defined as the ocean bounded by a line drawn from the Norwegian Coast at about 62°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. The offshore boundaries follow in large part the mid Atlantic subsurface ridges.

The Norwegian Sea has an area of 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.

3.5.1.2 General oceanography

The circulation in the Norwegian Sea (Figure 3.1.3) 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.

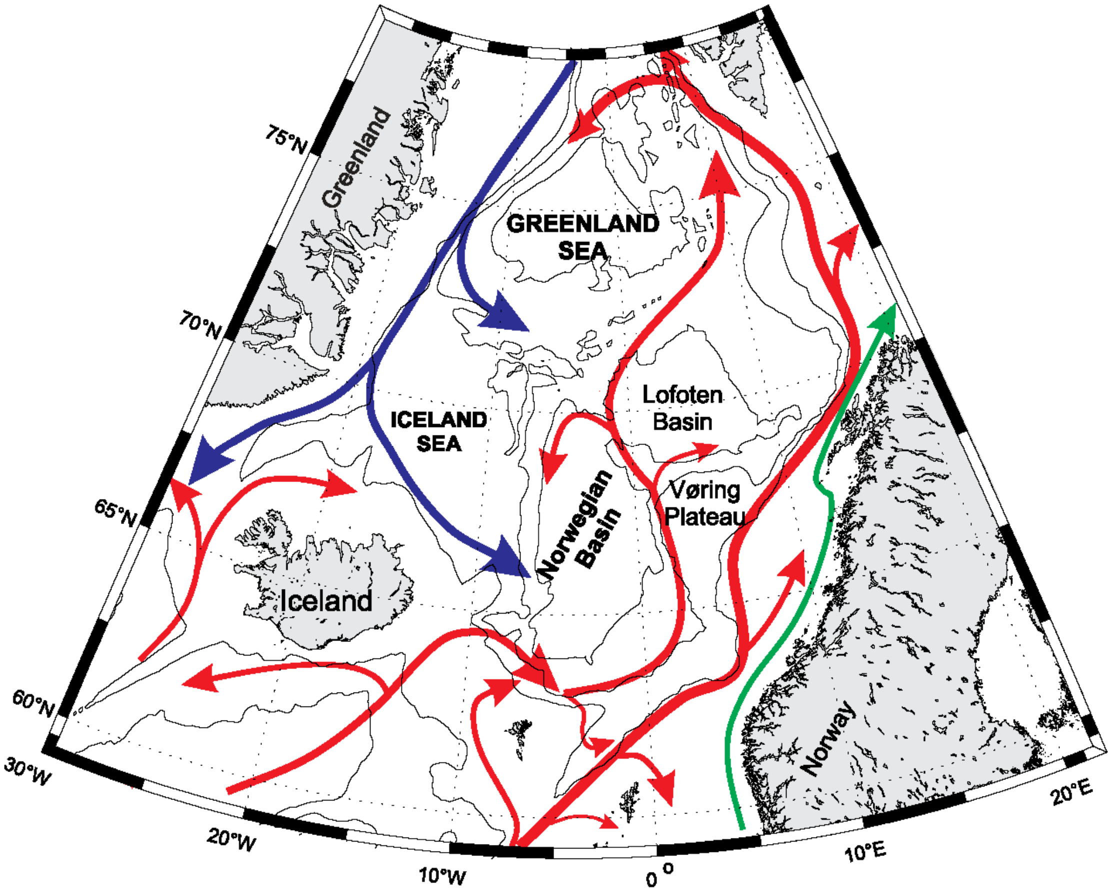

Figure 3.5.1 Norwegian Sea main circulation pattern. Red lines indicate warm currents, blue lines indicate cold currents and green lines show low salinity coastal water.

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. Generally, a high NAO index with strong westerly winds will result in an increased influence of Arctic waters in the western Norwegian Sea arriving from 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).

3.5.1.3 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} $year^{-1}$.

3.5.1.4 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.

3.5.1.5 Benthic habitats

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.

3.5.1.6 Fish communities

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.

3.5.1.7 Seabirds

It is estimated that about 6.1 million seabirds (1.8 million pairs) breed along the Norwegian coast of the Norwegian Sea. In addition about 270 000 pairs breed on Jan Mayen (Barrett et al. 2001). In addition a large number of northern fulmars are spread over most of the Norwegian Sea throughout the year, and a similarly large number of little auks breeding i the Barents Sea winter along the Norwegian coast. Altogether, it is estimated that the total consumption by all marine birds in the Norwegian Sea is nearly 680 000 tonnes. The most typical species are listed below, based on Barrett et al. 2001.

Among the species breeding along the Norwegian coast, the most common is the Atlantic puffin (Fratercula arctica) with about 1 225 000 breeding pairs. Blacklegged kittiwake (Rissa tridactyla) and common eider (Somateria mollissima) are the next most common species with 170 000 and 130 000 breeding pairs, respectively (Barrett et al. 2001).

The most common birds breeding on Jan Mayen are northern fulmars (Fulmarus glacialis), little auks (Alle alle), and Brünnich's guillemots (Uria lomvia).

3.5.1.8 Marine mammals

There are two seal stocks of particular importance in the Norwegian Sea: Harp and hooded seals. Both species are whelping on the pack ice off the east coast of Greenland (the Greenland Sea or West Ice stocks) in mid to late March (Haug et al. 2006; Salberg et al. 2007). During spring, harp seals exhibit a set sequence of activities – birthing (whelping) (in March-April), followed by 12 days of intensive lactation, then mating, after which the females wean their pups. Moulting of adults and immature animals takes place north of each whelping location after a further lapse of approximately 4 weeks. When the moult is over, the seals disperse in small herds to feed along the east coast of Greenland, from the Denmark Strait or farther south, northwards towards Spitsbergen and they also move far into the Barents Sea (Haug et al. 2004; Folkow et al. 2004). The movements of harp seals towards the breeding areas begins in November-December. Between breeding and moult, hooded seals perform feeding excursions to the continental shelf edges off the Faroe Islands and Northern Ireland, and to areas in the Norwegian Sea. During moult (June/July) the West Ice hooded seals haul out on pack ice north of the breeding area, i.e., northwest of the island of Jan Mayen (Folkow et al. 1996). Satellite tracking data have revealed that hooded seals from the West Ice stock appear to occupy ice-covered waters off the east coast of Greenland much of the summer. But, they make long excursions to distant waters (temperate as well as Arctic) such as the waters off the Faroe Islands, the Irminger Sea, north/northeast of Iceland, areas in the Norwegian Sea, and along the continental shelf edge from Norway to Svalbard, presumably to feed, before returning to the ice edge again (Folkow et al. 1996). Both species show opportunistic feeding patterns in that different prey are consumed in different areas and at different times of the year. Harp seals feeds primarily on zooplankton (krill and amphipods) and pelagic fish sopecies such as polar cod and capelin, whereas hooded seals feed on squid, polar cod and benthic fish species such as redfish and Greenland halibut (Haug et al. 2004, 2007). The Greenland Sea stocks of harp and hooded seals have been commercially exploited and managed jointly by Norway and Russia during the past two centuries. The most recent estimates of abundance suggest that there are approximately 600,000 harp seals and 70,000 hooded seals in the Greenland Sea (ICES 2006, 2007).

Due to topographical and hydrographic characteristics beneficial for production the Norwegian Sea has abundant stocks of whales feeding on plankton, pelagic fishes and Cephalopods. Large whales are visiting the area in summer while representatives of the smaller toothed whales are supposed to stay there all year around.

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.

Fin whale, Balaenoptera physalus, represents together with the sperm whale, Physeter macrocephalus, the largest cetacean biomass in the Norwegian Sea. In the summer months fin whales are especially abundant along the continental slope from Bear Island northwards to Spitsbergen, supposedly feeding on euphausiids. They are also known to feed on herring and capelin which become more important in spring and fall. There are around 5.000 fin whales in the Norwegian Sea. Of the other baleen whales, humpback whale, Megaptera novaeangliae, is quite common with its 1.000 individuals. They are also supposed to feed primarily on euphausiids in summer and switching to capelin during fall. Sei whales, Balaenoptera borealis, are usually associated with warmer water masses and are normally found in small numbers only within the Norwegian Sea. Blue whales, Balaenoptera musculus, are regular visitors in low numbers and seem to feed exclusively on euphausiids.

Sperm whales are abundant over the deep waters off the continental slopes south of Bear Island, where they feed on squids and mesopelagic fish. A high density area is found west of Andøya, associated with the bleik canyon. The sperm whales in the Norwegian Sea, numbering about 6.000 individuals, are solitary males.

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. Whitebeaked (Lagenorhynchus albirostris) and whitesided (L. acutus) dolphins are common especially in association with the continental slopes. Longfinned pilot whales, Globicephala melas, occur in large groups and are regular visitors to the Norwegian Sea. The northern bottlenose whale, Hyperoodon ampullatus, is an odontocid approximately the size of a minke whale, and occurring over the deep waters in modest numbers. This species is thought to have feeding preferences similar to the sperm whale.

3.5.1.9 Knowledge gaps

3.5.2 Major significant ecological events and trends

Generally warming climate during the last 28 years with about 0.8ºC increase since 1978 in the Atlantic Water on the Svinøy section. The years 2002-2006 are all warm years and 2006 was the warmest ever in the time series. The salinity has also increased during the last years, and since 2002 - 2003 it has been record high in both the the Svinøy and Gimsøy sections.

In May 2006 there was an increased influence of Arctic water from the East Icelandic Current, and the upper layer of the western Norwegian Sea was was then about 0.25 - 0.75°C colder in May 2006 compared to May 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.

Changes in herring feeding migration occurred during the summers 2004-2006 when increasing amounts of herring started to feed in the southwestern Norwegian Sea. At the same time only small numbers of herring were wintering in the fjords of northern Norway, and the winters 2005/2006 and 2006/2007 the main wintering area has been off the shelf north of Vesterålen to 72ºN.

3.5.3 Fisheries effects on benthos and fish communities

Destruction of deepwater coral reefs has been documented in the eastern shelf areas and has resulted in area closures for bottom trawling. Effects on other 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.

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3.6 Faroe Plateau Ecosystem

3.6.1 Ecosystem Components

3.6.1.1 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 3.6.1, upper left panel). This water is typically around 8°C with salinities around 35.25. Deeper than 500-600 m (Figure 3.6.1, 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 3.6.1, 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.

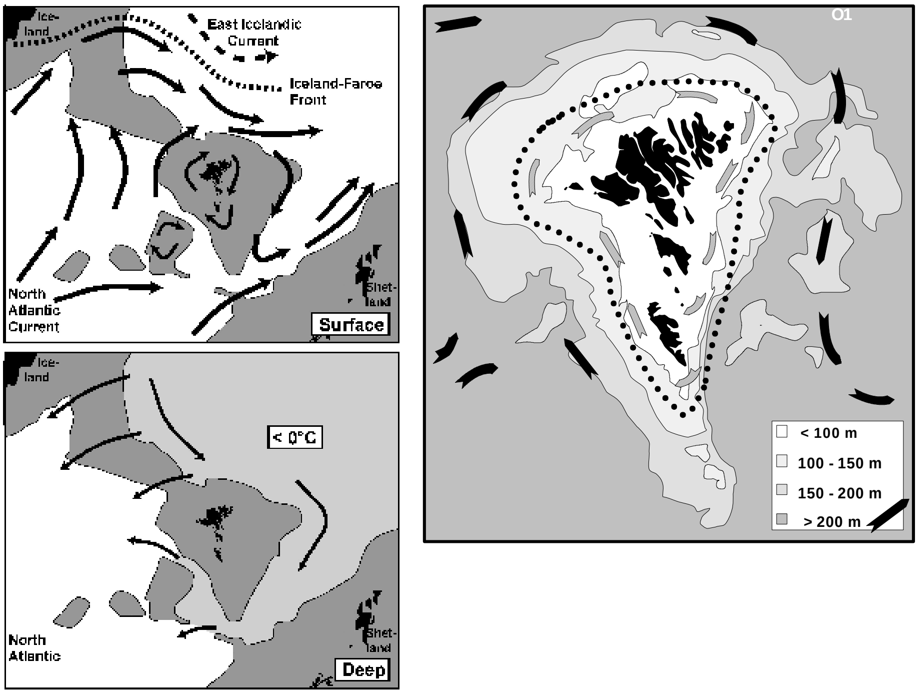

Figure 3.6.1. Bottom topography, circulation and water masses at the surface (top left panel), at depth greater than about 500 m (bottom left panel) in the area around the Faroes and on the Faroe shelf (right panel). Dashed lines indicate fronts.

3.6.1.2 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 environmental 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 3.6.2). This variability affects production of food for fish larvae in spring (Gaard 2003, Debes et al. 2005, Debes and Eliasen 2006), which mainly consists of copepod eggs and nauplii and small copepodites (Gaard and Steingrund 2001).

The phytoplankton on the Faroe shelf consists mainly of diatoms during spring and summer. However, during periods with low nutrient concentrations smaller flagellates may be relatively more abundant (Gaard et al. 1998; Debes et al. 2007a).

In 2006 the biomass was high in spring but decreased already in early June.

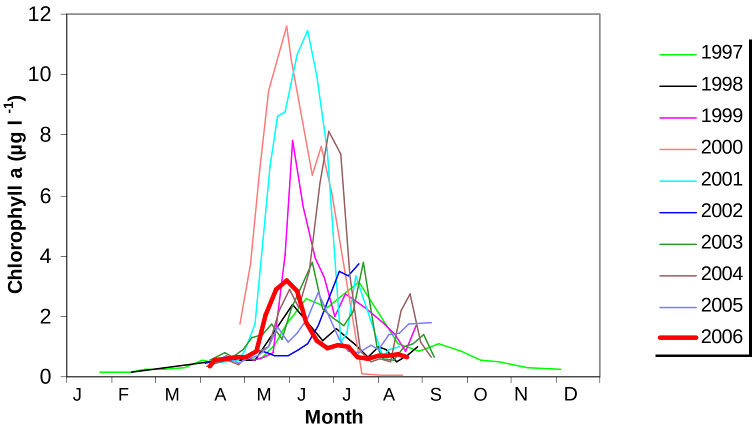

Figure 3.6.2. Chlorophyll *a* concentrations on the central shelf since 1997.

The mean annual primary production on the shelf is around 160 gC m^2 of which about 50-60% is estimated to be new production (Steingrund and Gaard 2005, Debes et al. 2007a). There is a very high interannual variability primary production (Gaard 2003, Eliasen et al. 2005). From 1990 to 2006 this new primary production (from spring to mid summer) has fluctuated by a factor ~5 (Figure 3.6.3). The new primary production index for 2006 was slightly below the 1990-2006 average (Figure 3.6.3).

The main reasons for the high interannual variability in timing and intensity of primary production on the shelf seem to be hydrographical. Modelling (Eliasen et al. 2005, Hansen et al. 2005) and field studies (Debes and Lund-Hansen 2007, Debes et al. 2007a,b) indicate that variable exchange rates between on-shelf and off-shelf waters, causing loss of phytoplankton form the shelf, may be a main controlling factor for the timing and intensity of the spring bloom.

The variability in primary production between years (Figure 3.6.3) highly affects production in higher trophic levels in the ecosystem. The primary production is identified as the 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 are 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.

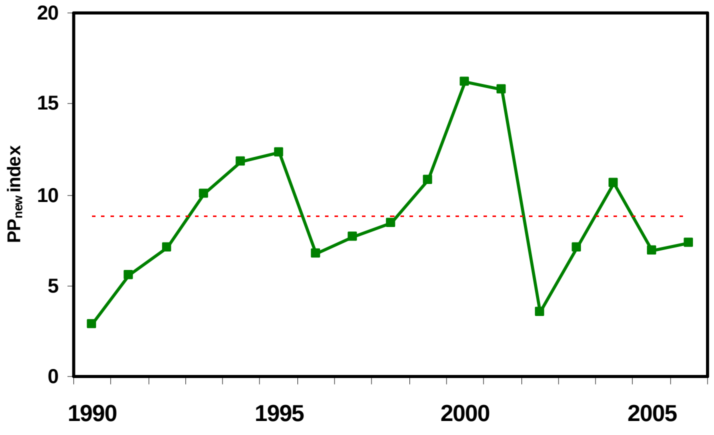

Figure 3.6.3. Index of new primary production from spring to mid-summer on the Faroe shelf since 1990. The horizontal line represents the average index during the 1990-2006 period.

3.6.1.3 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, Debes and Eliasen 2006).

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, Debes et al. 2007c). This variability affects feeding conditions for fish larvae in general on the shelf (Gaard and Steingrund 2001, Gaard and Reinert 2002).

3.6.1.4 Fish community

A total of about 240 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 3.6.4. 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.

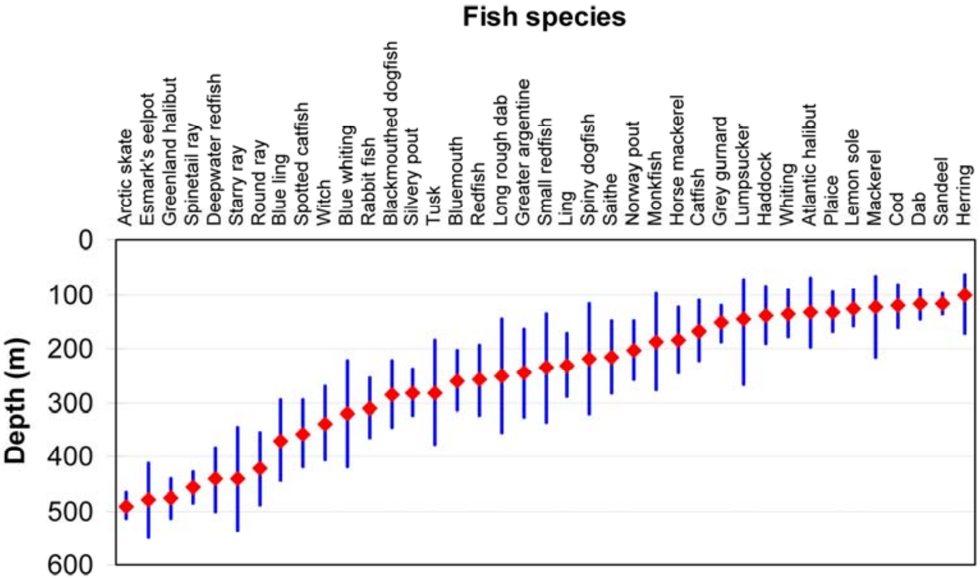

Figure 3.6.4. Typical depth distribution of fish in areas deeper than ~65 m on the Faroe shelf and in the ocean around the Faroes.

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. Neither of these two species is 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 2006, 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.

3.6.1.5 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 3.6.5).

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).

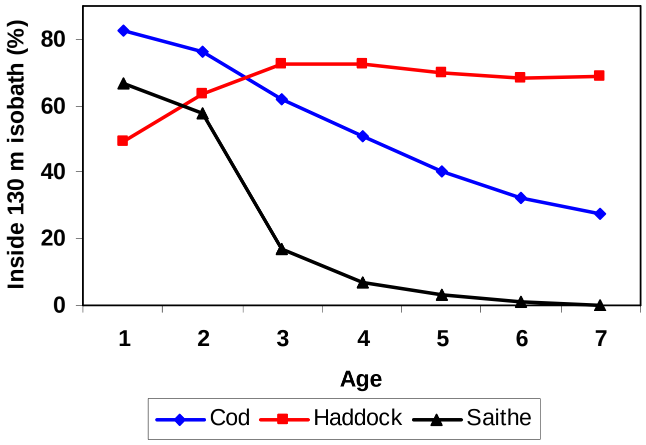

Figure 3.6.5. Proportion of cod, haddock and saithe caught inside the 130 m isobath during summer groundfish surveys 1996-2003. (From Steingrund and Gaard 2005).

3.6.1.6 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 3.6.6) (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 clearly 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.

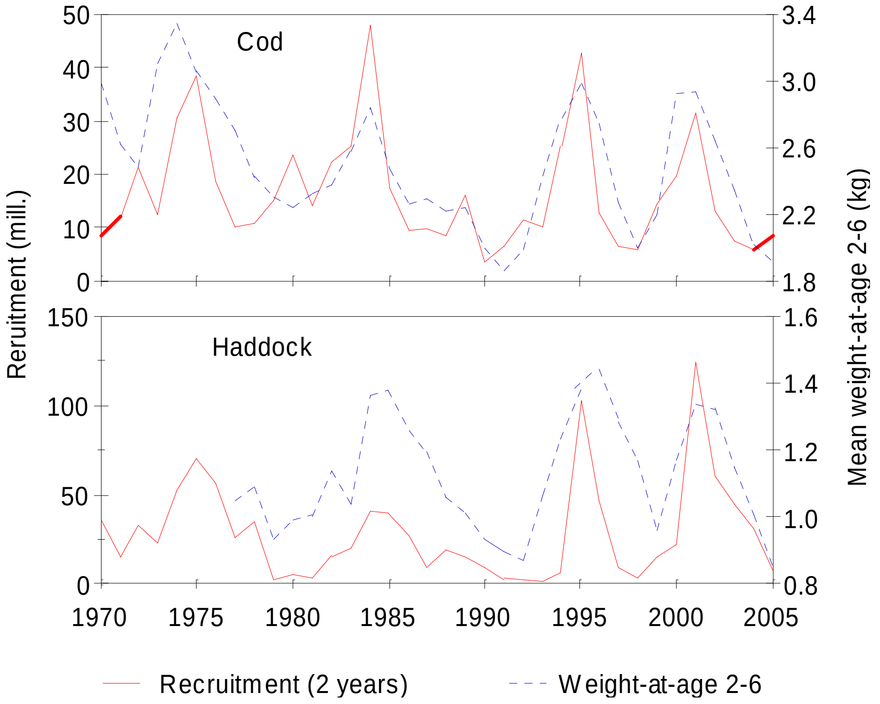

Figure 3.6.6. Relationship between recruitment of 2 years old cod and haddock and the mean weight of 2–6 years old cod during 1970–2005 and haddock during 1977–2005 on the Faroe shelf.

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. 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).

The year-class strength of Faroe Plateau 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).

The very good relationship between primary production combined with abundance of adult cod in shallow areas and cod recruitment allows prediction of cod stock recruitment earlier than traditional stock assessment methods.

3.6.1.7 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 2-8 years old cod have fluctuated between 0.3 and 1.6 kg individual^{-1} year^{-1} and the mean growth rates of 2-8 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 3.6.7). 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, and especially sandeels and Norway pout).

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 a 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 3.6.7).

Information on primary production can, thus, be used to predict cod and haddock growth rates on the Faroe shelf.

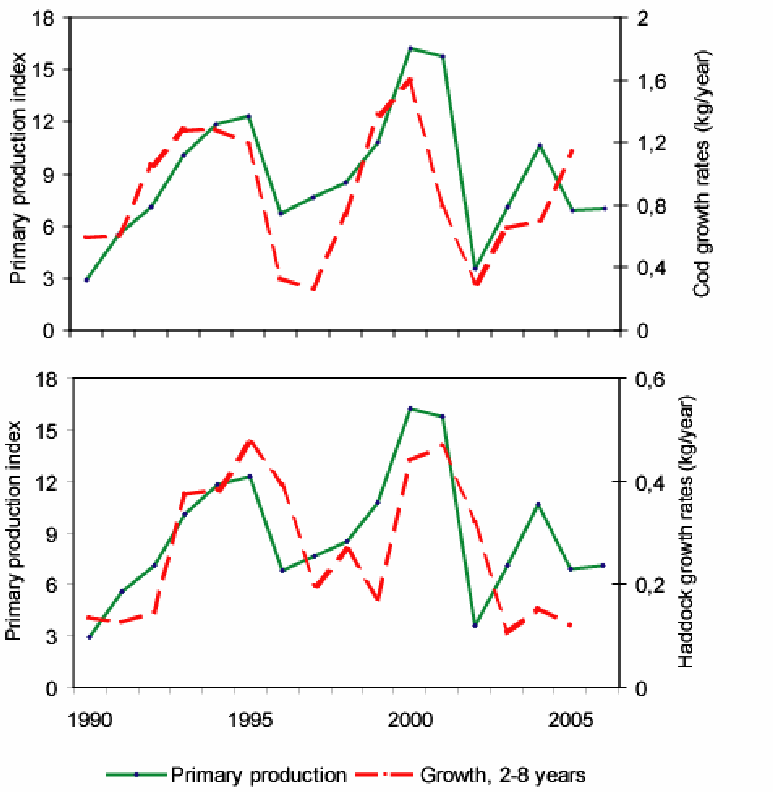

Figure 3.6.7. Index of new primary production and growth rates since the year before, for cod (upper panel) and haddock (lower panel) since 1990.

3.6.1.8 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 3.6.8). When comparing primary production with production of cod haddock and saithe combined, the correlation is even better.

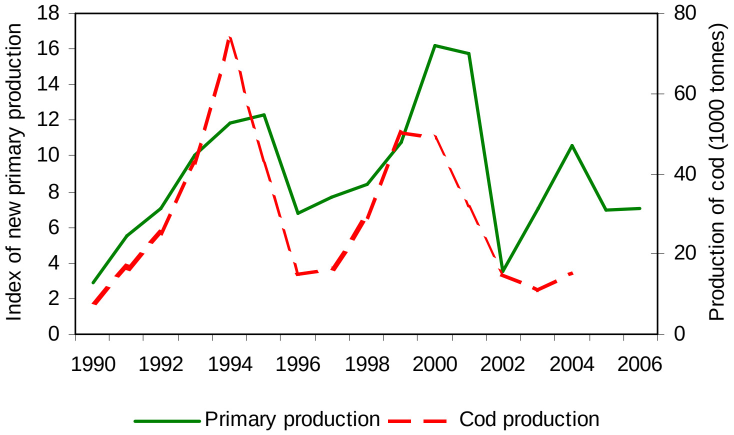

Figure 3.6.8. Index of new primary production on the Faroe shelf and corresponding production of Faroe Plateau cod older than 1.5 years, one year ahead.

Since young age groups are the most numerous (mainly in the productive years) the observed variability in cod production in Figure 3.6.8 largely is due to variable abundances of recruits (Figure 3.6.9). The recruitment variability is, thus, affected by variable recruitment and fishing effort. 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 3.6.5), 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.

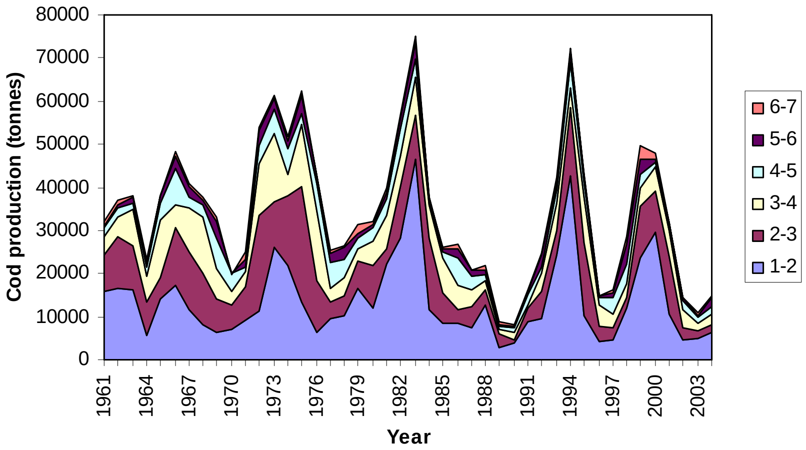

Figure 3.6.9. Production of Faroe Plateau cod, split into age groups.

3.6.1.9 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*).

3.6.2 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).

3.6.3 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 is observed 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 3.6.7). 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. In 2006 the primary production was slightly below average.

3.6.3.1 Considerations for assessments and advice

The primary production in 2006 was slightly below the 1990-2007 average and was close to the 2005 level and no major changes are therefore expected in cod and haddock feeding conditions from 2005 to 2006. 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 2006. 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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3.7 Regional ecosystem E: Celtic seas

3.7.1 Bottom topography substrate and circulation

The ‘Celtic Seas’ comprise the shelf area west of Scotland (ICES Subarea VIa), the Irish Sea (VIIa), west of Ireland (VIIb), as well as the Celtic Sea proper (VIIf-k) and western Channel (VIIe). Throughout this ecoregion the continental shelf is of variable width. The Celtic Sea south of Ireland is an extended shelf within 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. 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 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. The English Channel is a shallow (40-100m) part of the continental shelf. Its hydrology is marked by a west to east general circulation disrupted by strong tidal current.

To the west of the region there are several important seamounts, notably the Rosemary Bank, the Anton Dohrn sea mount and the Hebrides, which have soft sediments on top and rocky slopes.

Water circulation on the shelf is strongly influenced by the poleward flowing ‘slope current’. This persists throughout the year north of Porcupine Bank, but is stronger in the summer.

South of the bank, the current breaks down in the summer, when flow patterns becomes complex. Over the Porcupine Bank and the Rockall plateau, domes of cold water are associated with retentive circulation. On the shelf there is also a weaker current flowing north from Brittany across the mouth of the channel (source; OSPAR QSR 2000; Young et al. 2004). Thermal stratification and tidal mixing generates the Irish coastal current which runs westwards in the Celtic Sea and northwards along the west coast of Ireland (Fernand, et al. 2006). In the Irish Sea, an inshore coastal current carries water from the Celtic Sea and St. Georges's Channel northwards through the North Channel, mixing with water from the outer Clyde.

The main oceanographic front in the NE Atlantic region is the Irish Shelf Front that occurs to the south and west of Ireland (at c. 11°W), and exists all year-round. This front marks the boundary between waters of the shelf (often mixed vertically by the tide) and offshore North Atlantic waters. The turbulence caused by the front introduces nutrients from deeper water to the surface where they promote the growth of phytoplankton, especially diatoms in spring, but also dinoflagellates especially where there is pronounced stratification. These are in-turn be fed on by cohorts of zooplankton and associated with these, aggregations of fish (Reid et al. 2001).

On the shelf, tidal mixing and thermo/saline fronts occur at several locations immediately to the 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 throughout 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.

3.7.2 Physical and chemical oceanography

Temperature/salinity

The ICES Annual Ocean Climate Status Summary (IAOCSS) provides longterm timeseries for temperature amd salinity anomalies from the Rockall Trough situated west of Britain and Ireland dating back to 1975. Shorter data series are given for the western Irish shelf since 1999 (ICES 2006).

The Rockall Trough is an important pathway by which warmer North Atlantic surface waters reach the Norwegian Sea, where they are converted into cold dense overflow water as part of the thermohaline circulation in the North Atlantic. The IAOCSS report suggests that the surface waters in the Rockall Trough have been steadily warming over recent years. In 2005, the decade-long trend toward warmer and saltier upper ocean water continued. Temperatures were the highest ever recorded, although salinity showed a very small decrease from 2004 and 2003 (Figure 2.5.1). Upper ocean temperatures were 0.6°C and salinity 0.06, above the long-term mean (ICES 2006).

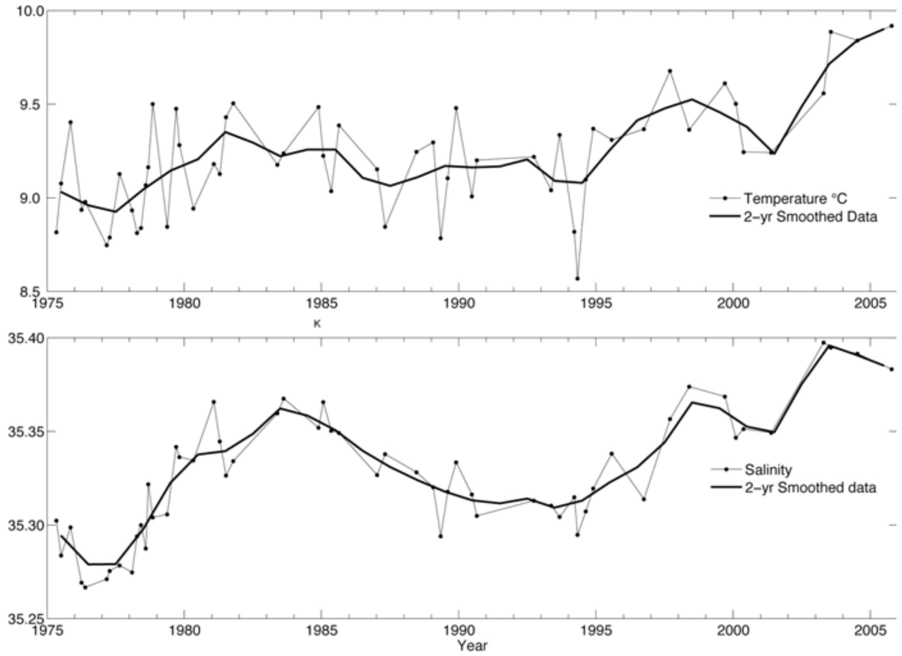

Figure 3.7.1 Rockall Trough temperature and salinity anomalies for the upper ocean (0–800 m) of the northern Rockall Trough. Average across section, seasonal cycle removed.

Summer CTD measurements made along a section at 53° North on the western Irish shelf since 1999 show warmer conditions in 2003 and 2004, broadly consistent with other regions of the NW European shelf while cooler conditions were observed in 2001 and 2002. Salinity also exhibits strong inter-annual variability along this section depending on the timing and magnitude of discharges both locally from Irish rivers and from rivers to the south of the section in the UK and France.

Sea surface temperatures measured in coastal stations northwest of Ireland since the 1960s show a trend of sustained positive temperature anomalies from 1990 (Nolan and Lyons, 2006).

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). Similarly, inshore temperature data from Wylfa Power Station and Amlwch in North Wales showed a pattern of warming from 1967 onwards as did temperatures at Port Erin in the Isle of Man (Joyce 2006, www.cefas.co.uk/data/seatempandsal/).

Several temperature time-series, including fortnightly records from a fixed station off the SW coast of the Isle of Man (the Cypris station), a more recent shorter series from a mooring in the western Irish Sea (Gowen, AFBI, Belfast), and two series of combined satellite and ship-recorded data compiled by the Climate Diagnostics Center, National Oceanographic and Atmospheric Administration of the US Department of Commerce (Figure 3.7.2) indicate a general warming trend in the Irish Sea since 1960, with particularly high temperatures in 1998 (ICS 2006b).

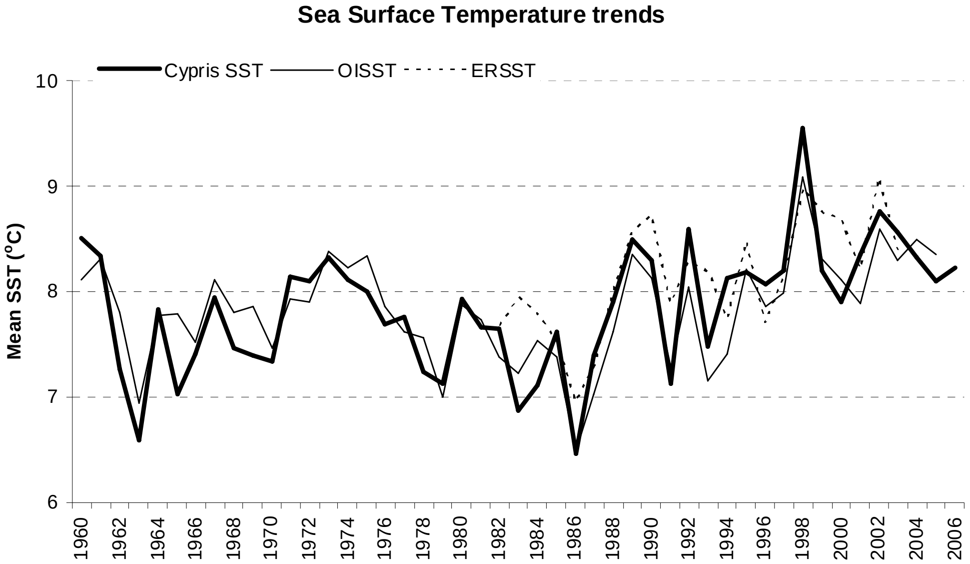

Figure 3.7.2. Sea surface temperature in the Irish Sea from 1960 to 2006 (ICES 2006b).

High-intensity, near 'real-time' temperature (and in some cases salinity) data are available from monitoring buoys in the Irish Sea (Liverpool Bay, Aberporth,, M2), the Bristol Channel/Celtic Sea (M5, Pembroke, Scarweather) and west of Ireland (M1, M3, M4, M6, K2, K4), operated by the Marine Institute (Ireland), CEFAS (UK) and the UK Met. Office (see www.cefas.co.uk/WaveNet/default.htm). Scottish monitoring stations exist at Loch Maddy (North Uist), Mallaig and Loch Ewe (www.frs-scotland.gov.uk).

The North Atlantic Oscillation index (NAO) is a measure of the difference in normalized sea level pressure between Iceland and the subtropical eastern North Atlantic. When the winter NAO index is positive, this coincides with colder and drier conditions over the western North Atlantic and warmer, wetter conditions in the eastern North Atlantic. During a negative NAO, a weakening of the Icelandic low and Azores high decreases the pressure gradient across the North Atlantic and tends to reverse the effect. The winter NAO experienced a strong negative phase in the 1960s, becoming more positive in the 1980s and early 1990s. It remained mainly negative from 1996 to 2004, but became positive in 2005 (6.7 mbar).

Input of Freshwater

Several rivers discharge freshwater into the ecoregion and influence the circulation patterns, these are notably the River Loire, the Severn and the Irish rivers Lee and Blackwater in the Celtic Sea (Figure.3.7.3). To the west of Ireland, fresh water discharges from Irish rivers (e.g. Shannon and Corrib) and those further afield (e.g. Loire, Severn) interact with Eastern North Atlantic Water. River inputs into the Irish Sea and The Malin Sea north of Ireland 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 (Nolan and Lyons, 2006).

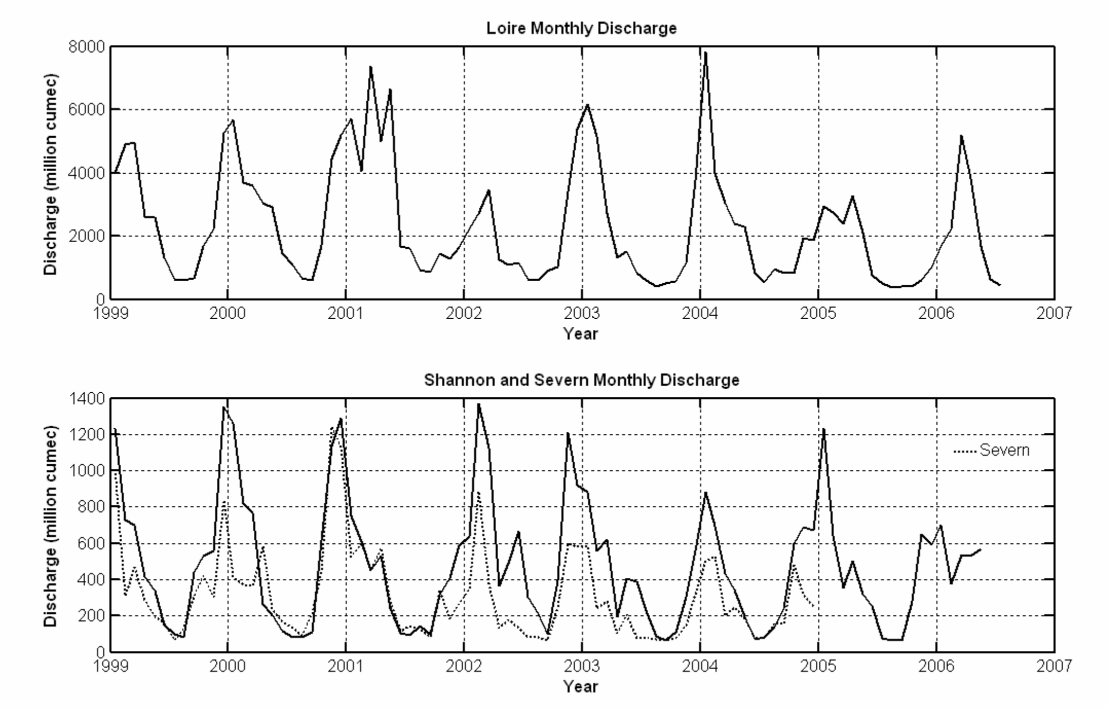

Figure 3.7.3 Discharges from rivers affecting the western Irish Shelf, river Loire (upper panel) and rivers Shannon and Severn (lower panel). Note different scales on Y axes.

3.7.3 Broad-scale climate & Oceanographic features

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

3.7.4 Phytoplankton

For most of the Celtic Seas ecoregion 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. Phytoplankton productivity and taxonomic composition in the Celtic Sea has been shown to depend on water column structure. Diatoms dominate well mixed areas with high nutrient content and display high rates of productivity, while dinoflagellates and microflagellates are found in stratified waters exhibiting lower rates of productivity (Raine, et al. 2002). Certain oceanographic conditions can lead to the formation of toxic algal blooms around Irish Coasts with highest occurrence of them noted along the southwest of Ireland. Large harmful algal blooms recorded in 2005were associated with the dinoflagellate *Karenia mikimotoi* and caused mortalities to benthic and pelagic marine organisms at a scale that has not previously been observed (Silke et al 2006)

3.7.5 Zooplankton

As is true of the adjacent North Sea, the overall abundance of zooplankton in this region 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 ("L4") in the English Channel. This station is influenced by seasonally stratified waters and is maintained by Plymouth Marine Laboratory (ICES 2005). Whether or not changes in the zooplankton community evident at this site are representative of changes and trends in the wider "Celtic Seas" remains uncertain, further analyses of CPR data or additional information from static sampling stations (e.g. Nash & Geffen 2004) are urgently needed to clarify the situation.

The ten most abundant zooplankton taxa at "L4" have been ranked according to their annual mean proportion of the total zooplankton (Table 3.7.1). In 2005, major changes in the zooplankton composition were reported. Not only has the rank order of the top ten species changed, but new groups, Echinoderm larvae, Noctiluca scintillans, Siphonophores, and C. helgolandicus appear in the dominant species for the first time, contributing 4.6% to 3% of the total zooplankton abundance respectively. In addition, Ps. elongatus, which was the most abundant species during the period 1988–2004 when it contributed nearly 12% of the total zooplankton abundance, represented only 2.3% of the zooplankton community in 2005. Ps. elongatus abundance in 2005 is the lowest abundance observed over the whole time-series (53 ind m−3). Peaks of high zooplankton abundance and chlorophyll a concentration are regularly observed in spring and late summer/beginning of autumn, the latter resulting from intense summer dinoflagellate blooms in some years. Zooplankton at L4 shows two decreasing trends from 1988 to 1995 and from 2001 to 2005. This is mainly the result of relatively low abundances of the spring species Paracalanus, Pseudocalanus, and A. clausi. Small copepods like Oncaea, Oithona, and Corycaeus contribute greatly to the total zooplankton population.

Table 3.7.1 Percentages and averages of the top taxa at Plymouth "L4" station during the sampling period 1988–2005 time-series and in 2005.

RANK	TAXA	% TOTAL ZOOPLANKTON 1988-2004	% TOTAL ZOOPLANKTON 2005	YEARLY AVERAGE 1998-2004 (N/M^3)	2005 AVERAGE (N/M^3)
1	*Pseudocalanus*	11.74	2.32	380	54
2	*Oithona*	11.30	6.23	366	144
3	*Oncaea*	11.11	7.69	360	178
4	*Paracalanus*	9.53	4.23	309	98
5	*Temora*	9.19	8.52	298	198
6	Cirripeda nauplii	8.69	7.93	281	184
7	*Acartia clausi*	6.18	2.74	200	64
8	*Evane*	5.85	2.25	190	52
9	*Appendicularia*	2.59	1.22	84	28
10	*Corycaeus*	2.25	5.72	73	133
Total		78.43	48.90	2540.62	1133.30
N/m^3				3239.60	2320.40

3.7.6 Benthos, larger invertebrates (cephalopods, crustaceans etc), biogenic habitats

The major commercial invertebrate species in the Celtic Seas ecoregion is Norway-lobster (*Nephrops norvegicus*). It is targeted by trawl fisheries on the continental shelf west of Scotland, on the Rockall plateau, and both south and west of Ireland. Cuttlefish (*Sepia officinalis*) is also exploited in the Celtic Sea. Major fisheries dredging for scallops and some smaller bivalves exist in the western Channel, Irish Sea and west of Scotland. Pot fisheries exploit lobster *Homarus gamarus* and brown crab *Cancer pagurus* in the waters around the Channel Islands (French landing about 150 t/year), and the west of Scotland. In addition to major aquaculture activity for oysters and mussels, some beds of wild oysters and buried bivalves such as cockles *Cardium edule* are exploited by professional and recreational fisheries (for example in Morecombe Bay).

The most abundant cephalopods species in the Celtic Sea and west of Ireland are *Loligo forbesi* and *Illex coindetii* which are mainly found close to the shelf break, while *Alloteuthis subulata* is a common species found close to shore in water depth of less than 75 m (Lordan, 2001).

Ellis et al. (2000) provided a review of benthic community structure in the Irish Sea and described six distinct assemblages. Plaice and dab dominated on fine substrates in inshore waters, whereas sea urchins and sun-stars dominated on the coarser substrates further offshore. Thickback sole *Microchirus variegates* and hermit crabs were typical of the transitional zone, while Norway-lobster and Witch (*Glyptocephalus cynoglossus*) dominated on the muddy sediments in the central Irish Sea. Beds of *Alcyonium digitatum* (Dead man's finger) occurred on coarse substrates throughout the study area, whereas common spider crabs were only dominant in the Bristol Channel (*Maja* assemblage). The common starfish (*Asterias rubens*) was an important component of all assemblages and the distribution of these assemblages was primarily correlated with depth, temperature and substrate type. Kaiser et al. (2004) added a distinct sandbank type habitat off the Welsh coast, typified by low species diversity and shared indicator species such as the weever fish *Echiichthys vipera*, the shrimp *Philocheras trispinosus* and the hermit crab *Pagurus bernhardus*.

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.

Rees et al (1999) provided a comparison of benthic biodiversity in the North Sea, English Channel, Celtic and Irish Seas. Similar infaunal assemblages were encountered on both the eastern and western UK coasts in comparable environmental conditions. Grab stations in the easternmost part of the English Channel, southern North Sea, and within the Bristol Channel, supported a very sparse infauna communities associated with sandy sediments. Highest diversities were generally encountered off the NE and SW English coast. Densities were also relatively high in coastal waters off Morecambe Bay, NW England.

Heath (2005) used the abundance of benthic invertebrate larvae in CPR (continuous-plankton-recorder) data, to establish trends in benthic production for the 'Celtic Seas' ecoregion. Based on these data the author reported an increasing long-term trend in benthic production (by 0.8 g C m^2y) between 1973 and 1999.

Biogenic reefs of horse mussels *Modiolus modiolus*, maerl and Serpulid worms occur in specific locations (Irish Sea, West coast of Scotland). The latter 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.*

3.7.7 Fish Community

In the northern part of this ecoregion, (Irish Sea, West of Ireland and western Scotland) there are important commercial fisheries for cod, haddock and whiting and a number of flatfish species. Hake *Merluccius merlucius* and angler fish *Lophius* spp.are also fished across the whole area. The Rockall plateau is subject to an important haddock *Melanogrammus aeglefinus* and small-scale *Nephrops* fishery. Commercial fisheries for, cod *Gadus morhua* , plaice *Pleuronectes platessa* and sole *Solea solea* are conducted in the Irish Sea. The whole area is characterised as a spawning area for a number of key wide-ranging, migratory species, notably mackerel *Scomber scombrus*, horse mackerel *Trachurus trachurus* and blue whiting *Micromesistius potassou*. These species are also commercially exploited within the area. Key pelagic species on the continental shelf are herring *Clupea harengus*, considered as consisting of a number of different stocks, as well as sardine *Sardina pilchardus* in the southern part of the area, and sprat *Sprattus sprattus*, particularly in the Celtic Sea. The area accommodates considerable stocks of argentines (two species) and also large numbers of small mesopelagic myctophids along the shelf break.

The shelf slope (500-1800m) comprises a distinct species assemblage including roundnose grenadier *Coryphaenoides rupestris*, black scabbard fish *Aphanopus carbo*, blue ling *Molva macrophthalma* and orange roughy *Hoplostethus atlanticus* as well as deep sea squalids (sharks) and macrouridae (see section 3.12). Stock assessment have been most often unreliable for these species so far. However, strong evidence exist that some have been severely depleted by the deep water fisheries carried out in this area. All these fish are characterised as being long lived, slow growing and having a low fecundity, making them very vulnerable to overfishing.

More than 170 species of marine fish have been recorded from within the Irish Sea, (Ellis et al. 2002). Trawl surveys in this region (Parker-Humphreys 2004) have revealed that dab *Limanda limanda*, plaice, solenette *Buglossidium luteum* and common dragonet *Callionymus lyra* are the most abundant species, along with large numbers of poor-cod, whiting and sole. Dab, solenette and scaldfish (*Arnoglossus laterna*), all non-commercial species, are thought to have increased in recent years, whereas hake, dragonets and pogge *Agonus cataphractus* have become less abundant. Red gurnards *Aspitrigla cuculus* are also thought to have increased in recent years.

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 caught and discarded in the past (Trenkel and Rochet 2003, Rochet et al., 2002).The size structure of the fish community has changed significantly over time, and 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 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 been documented (Pinnegar et al 2003) and this has resulted from a reduction in the abundance of large piscivorous fishes such as cod and hake, 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).

Limited information is available for the west coasts of Scotland and Ireland, however Scottish groundfish surveys between 1997 and 2000 revealed declines in most commercial fish stocks, including haddock, whiting, norway pout, herring and hake. Similarly, Irish groundfish surveys revealed a downward trend in the biomass and abundance of cod, whiting and hake between 1993 and 2000, in particular in the latter part of the time-series. Megrim were somewhat more abundant in recent years particularly along the coasts of southern Ireland and the Celtic Sea shelf edge (Mahé 2001).

3.7.8 Trophic web

For the Celtic and Irish Sea, two sources of fish stomach data have recently been collated and these are described by Pinnegar et al. (2003).UK researchers collected stomachs for 66 species during 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).

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, higher prey densities in the environment coincide with higher occurrences of particular prey species in predator stomachs (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. Little is known concerning trophic interactions among fish species west of Ireland and northwest Scotland (although see du Buit 1989; 1991a,b). No major studies of forage fish have been conducted in the eco-region. Sand eel Ammodytes spp., sprat and norway pout Trisopterus esmarki are known to be present, but their role and importance in the ecosystem remains unclear.

For cod in the Irish Sea, the decapod *Nephrops* norvegicus is known to be an important prey item (Armstrong, 1982). Consequently, Bennett & Lawler (1994) attempted to model cod-Nephrops a simple multispecies model. Whiting, Norway-pout and Nephrops are known to be important for monkfish in the Irish Sea (Crozier 1985). In north-west of Scotland there have been additional studies focusing on inshore demersal assemblages (e.g. Gibson & Ezzi,1987).

According to Heath (2005) 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 (Heath 2005). The secondary production required per unit of landed fish from the southern part of the Celtic Seas is suggested to be twice that for North Sea fish. In the Celtic Seas benthos production has been suggested to be 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 might 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 (Heath 2005).

Heath (2005) 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. However, 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.

3.7.9 Vulnerable species

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. In 2006 the Working Group on Fish Ecology (WGFE) evaluated the status of rarer elasmobanchs throughout the 'Celtic Seas' ecoregion. The Celtic Sea was highlighted as a particularly important area for common skate (*D. batis*), electric ray (*Torpedo nobiliana*), and shagreen ray (*Leucoraja fullonica*) whereas the English Channel is an important area for undulate ray (*Raja undulata*) and stingray (*Dasyatis pastinaca*) (ICES 2006c).

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

The red lobster (*Palinurus elephas*) was exploited by pot fisheries prior to the late 1970s, and current catches of this species can be considered as residual.

As mentioned above, several species of deep water fish are considered as being severely depleted and meriting protection (see section 3.12).

3.7.10 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 but the stock seems to be severely depleted. 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). Minke whale *Balaenoptera acutorostrata* is found throughout the region, particularly off western Scotland and Ireland. SCAN surveys and observer programmes on ships of oppurtunities have recorded that bottlenosed dolphin *Tursiops truncatus* occur in large numbers off western and southwest Ireland and in smaller numbers throughout the region. Common dolphin *Delphinus delphis* are widely distributed in shelf waters, but especially in the Celtic Sea and adjacent areas, White-beaked dolphin and White-sided dolphin (*Lagenorhynchus albirostris* and *L. acutus*) occur over much shelf area, but are less common in the southwest. Harbour porpoise *Phocoena phocoena* is the smallest but by far the most numerous of the cetaceans found in the Celtic Seas ecoregion, particularly south-west Ireland, and west of Scotland (Hammond et al. 2002, Wall et al.2004). Santos et al. (2004) has suggested that whiting and sandeels are the most important prey for porpoises around the coasts of Scotland, comprising around 80% of the diet.

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 of individuals are found in the Hebrides and in Orkney although some 5000-7000 are thought to exist in the Irish and Celtic Seas (Kiely et al. 2000). Studies of grey seal diet in the western Irish Sea reveal that the predominant prey species (Norway pout, bib, poor cod, whiting, plaice) are not the principle target species for commercial fisheries in this region (Kiely et al. 2000). However, a recent study (Hammond & Harris 2006) of seal diets off western Scotland revealed that grey seals may be an important predator for cod, herring and sandeels in this area. Common seals (*Phoca vitulina*) are also widespread in the northern part of the ecoregion 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 significantly 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 also likely to have a direct impact on seabird populations.

3.7.11 Fishery effects on benthos and fish communities

The impact of fishing activities on shelf fish communities is unclear, although there are numbers of severely depleted stocks e.g. cod, whiting and plaice and hake. Furthermore, the level of discarding in some fisheries can be significant. Analysis of discarding levels of the demersal fleet around Ireland has shown that a significant proportion of the catch is discarded (Borges, 2005). Discarding levels differ between the different fleets but have shown to be up to two thirds of the total catch. In this study Whiting, haddock, megrim and dogfish are the main species discarded by otter trawler, while the Scottish" seiners discard mostly whiting, haddock and grey gurnard and beam trawls mostly dab and plaice. The majority of these discard species consist of immature fish and discarding appears to be increasing in recent years.

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

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.

3.7.12 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. Surface waters of the Rockall trough have been steadily warming for some years and are currently at an all time high. The general and continuing reduction of copepod abundance and recent changes in zooplankton composition throughout the region are also causes of major concern given the key role that these organisms play in the food web.

In 2006 the Working Group on the Assessment of Northern Shelf Demersal Stocks (WGNSDS) considered the influence of sea temperatures on cod recruitment (ICES 2006b) in the Irish Sea. The time series of Irish Sea cod recruitment exhibited a decline in the 1990s, coincident with an increase in sea surface temperatures (SST). Analysis revealed a clear tendency for strong recruitment residuals to coincide with prominent negative SST residuals, and for weak recruitment to coincide with strong positive SST residuals. Further biological studies are needed to establish the causal mechanisms for any association between cod recruitment residuals and SST, before such an association could be considered to have any predictive power in the future. If causal mechanisms were established, the consequence would be an expectation of a continued high probability of very weak year classes occurring whilst SSB remains low and SST continues to vary around the elevated values observed since the 1990s. This does not preclude the possibility of strong recruitment occurring in any year, but the probability is likely to be much lower than was the case in the 1960s 1980s when SST was lower and SSB (and consequently egg production) was relatively high.

Increasing temperature and changes in zooplankton communities are likely to have an impact on the life histories of many species. The timing and location of spawning by all species is also likely to be affected by warming, as has been observed in the North Sea (Greve *et al.,* 2001).Southward et al (1988) demonstrated that the abundance of herring *Clupea harengus* and pilchard *Sardina pilchardus* occurring off the south-west of England, closely corresponded with fluctuations in water temperature. Sardine were generally more abundant and extended further to the east when climate was warmer whilst herring were generally more abundant in cooler times. This pattern has apparently been occurring for at least 400 years, and major changes were noted in the late 1960s as waters cooled and spawning of sardine was inhibited. In recent years herring populations have declined throughout the Celtic Seas ecoregion but is unclear whether sardine have increased in abundance.

The recent warming trend in the north-east Atlantic has coincided with a northward shift in the distribution of some fish species from southerly waters (Quero *et al.,* 1998; Beare *et al.,* 2004). Seabass *Dicentrarchus labrax* and red mullet *Mullus surmuletus* populations around British coasts have been growing in recent years. Similarly sightings of blue-fin tuna *Thunnus thynnus*, triggerfish *Balistes capriscus*, thresher *Alopias vulpinus* and blue sharks *Prionace glauca*, sting-rays, turtles and seahorses *Hippocampus* spp. in are all becoming more commonplace (Stebbing *et al.,* 2002).

Analysis of fish taxa in the western English Channel over a 26-year period indicated that 9 species responded strongly to increasing sea temperatures (Genner *et al.,* 2004). A parallel analysis of 33 species in the Bristol Channel over 22 years showed similar macroscopic trends, with one species declining in abundance with warming (the sea snail *Liparis liparis*), and 9 increasing (Genner *et al.,* 2004). The widespread and sudden increase in occurrence of non-commercial species such as *Capros aper,* in the Celtic Sea particularly after 1990 (Pinnegar et al. 2003) might indicate some change in oceanic conditions, as is true of increased sightings of ocean sunfish *Mola mola* (Houghton et al. 2006) but mechanisms and consequences are poorly understood.

As is true elsewhere in the NE Atlantic, the Celtic Seas ecoregion has recently experienced an unprecedented increase in the numbers of snake pipefish, *Entelurus aequoreus* (Harris et al. in press; Kloppmann & Ulleweit, in press). Kirby et al (2006) speculate that the increased abundance of larval and juvenile E. aequoreus in CPR plankton samples as far west as the Mid-Atlantic Ridge may coincide with a rise in winter, spring and summer sea temperatures (January–September), when the eggs of E. aqueoreus, which are brooded by the male, are developing and the larvae are growing in plankton.

3.7.13 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 a more integrative 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. There is also no single assessment working group responsible for the fisheries in the region. These are covered by nine different groups, including both northern and southern shelf demersal WGs. This 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.

3.7.14 References

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3.8 North Sea

3.8.1 Ecosystem Components

3.8.1.1 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 (Figure 3.8.1).

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.

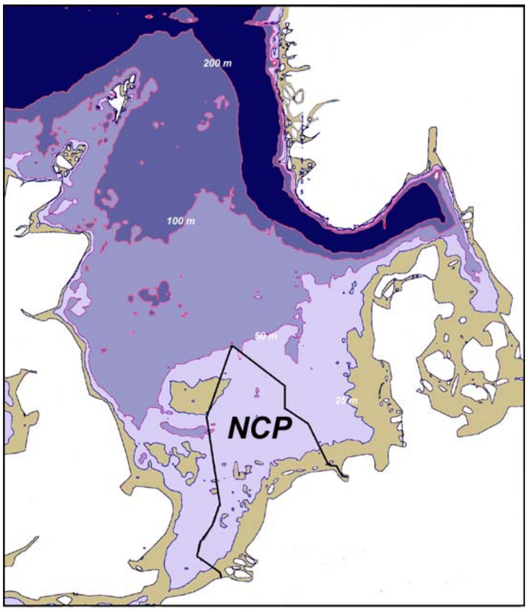
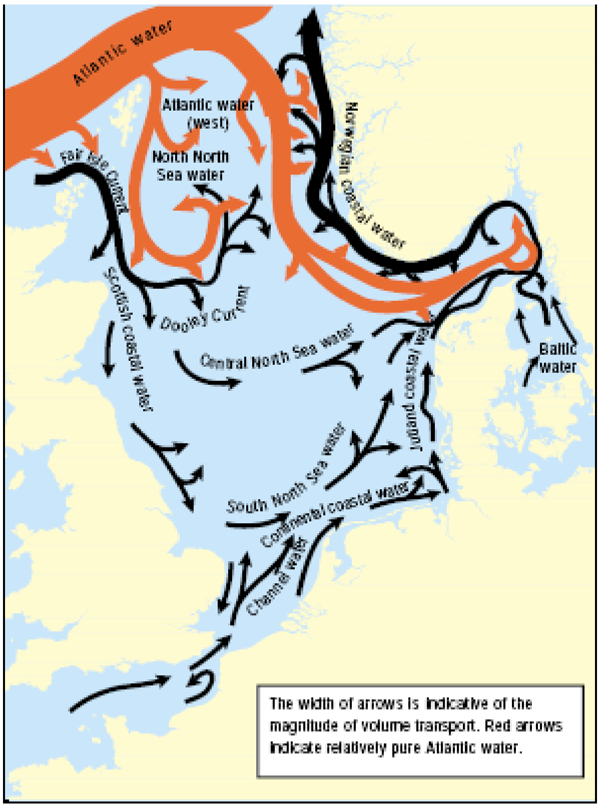


Figure 3.8.1 **Bathymetry of the North Sea (source – RIVO- alternative from ICES).**

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 3.8.2.



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

Figure 3.8.2 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.

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 3.8.3. shows average bottom temperatures in winter and summer for 1997-2002.

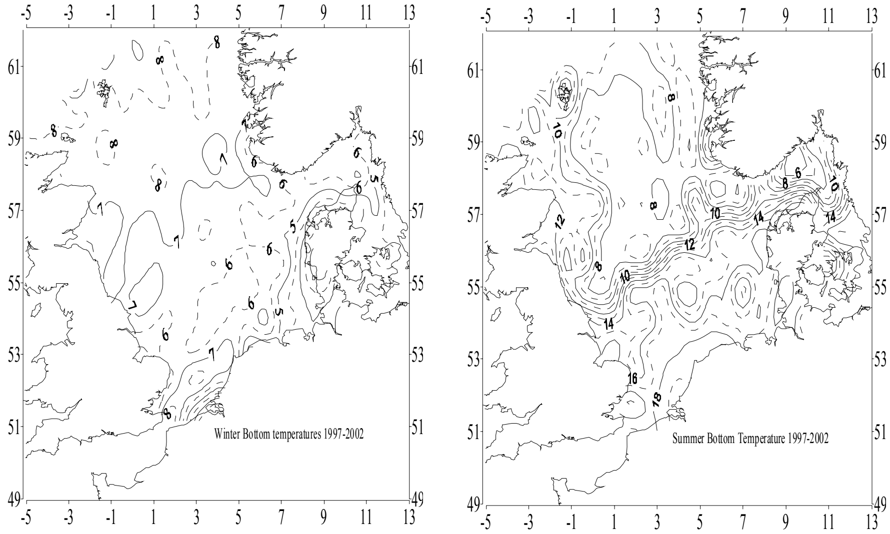


Figure 3.8.3 Average distribution of winter (left) and summer (right) bottom temperatures .

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 (eg Sharples et al 2006). 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

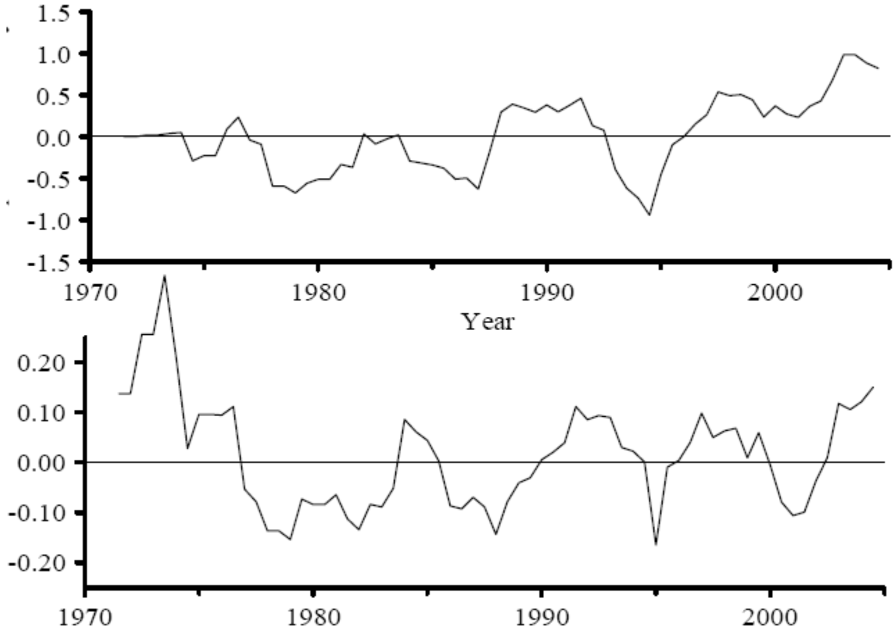


Figure 3.8.4 **Temperature and salinity anomalies in the Fair Isle Current (FIC) entering the North Sea from the North Atlantic**

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 3.8.4). 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 unusually warm years, particularly in August and September. 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. This resulted in very high temperatures at the beginning of 2006, about two degrees warmer than normal. A relatively cold winter caused a rapid cooling towards the normal. At the end of 2006 and the beginning of 2007, after a very warm summer and mild autumn weather, the temperatures in the North Sea were extremely high, from about 2 to near 4 degrees above the normal with the highest deviations in the south along the continental coast and east in the Skagerrak (Figure 3.8.5) and all along the Norwegian coast. Daily measurements at 75 m depth in in Skagerrak the temperature show the high temperatures early in 2006 and the cooling taking place. And then the temperatures in the 4th quarter is more than 2 degrees above normal (Figure 3.8.6). The cooling and heating is delayed by about 3months compared to the surface.

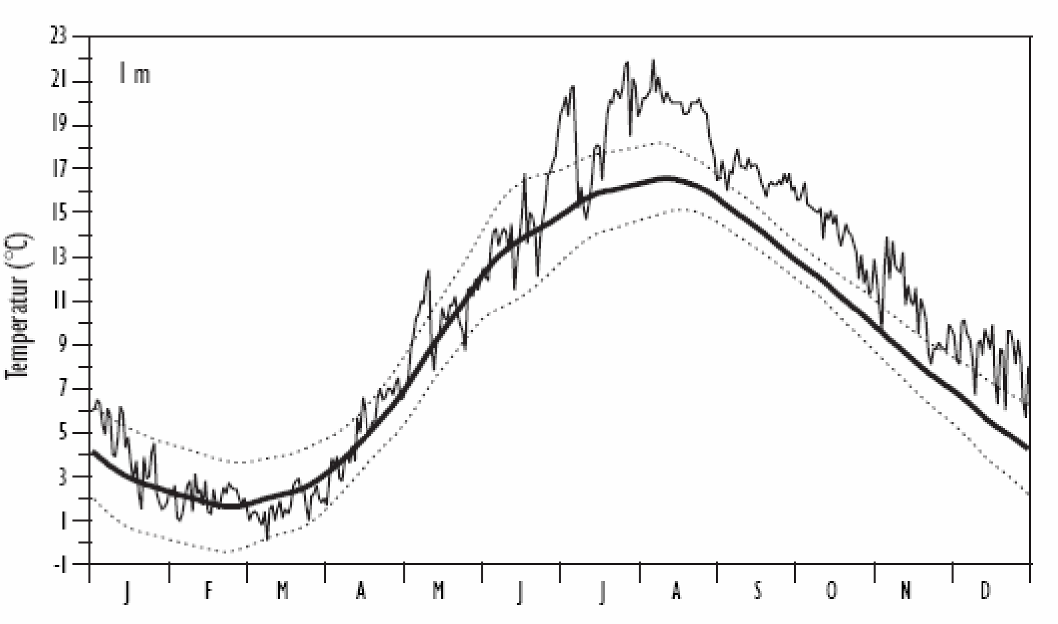


Figure 3.8.5. Daily temperature at 1 m depth in 2006 in Flødevigen Bay, Arendal. The thick line shows the smoothed mean temperature and the thin lines show the standard deviation, both for the period 1961–90.

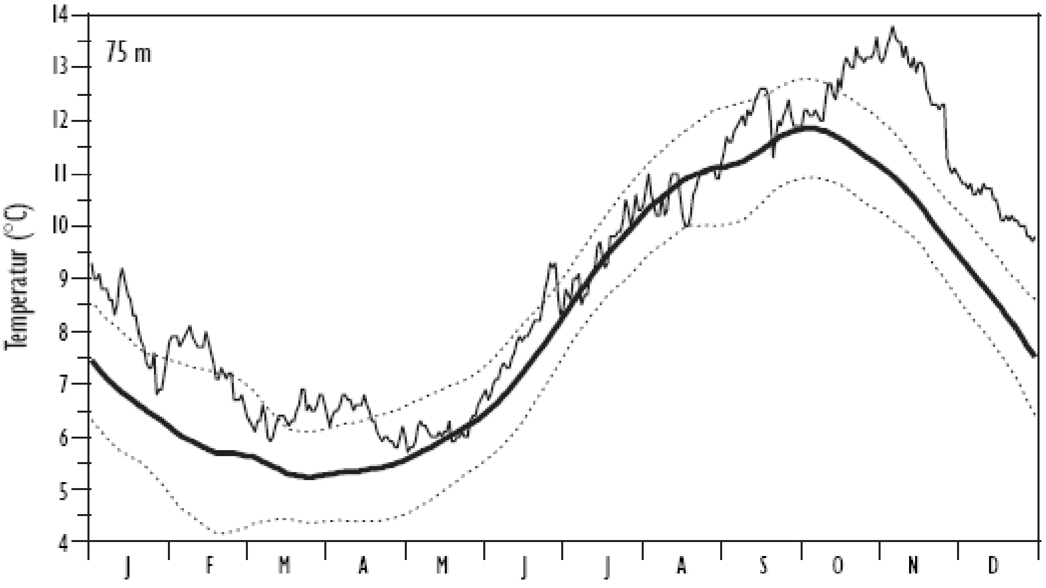


Figure 3.8.6 Daily temperature at 75 m depth in 2006 in Flødevigen Bay, Arendal. The thick line shows the smoothed mean temperature and the thin lines show the standard deviation, both for the period 1975–90.

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 have been above average the last three years, but last year it has dropped since the record high value observed in 2005. (Figure 3.8.7)

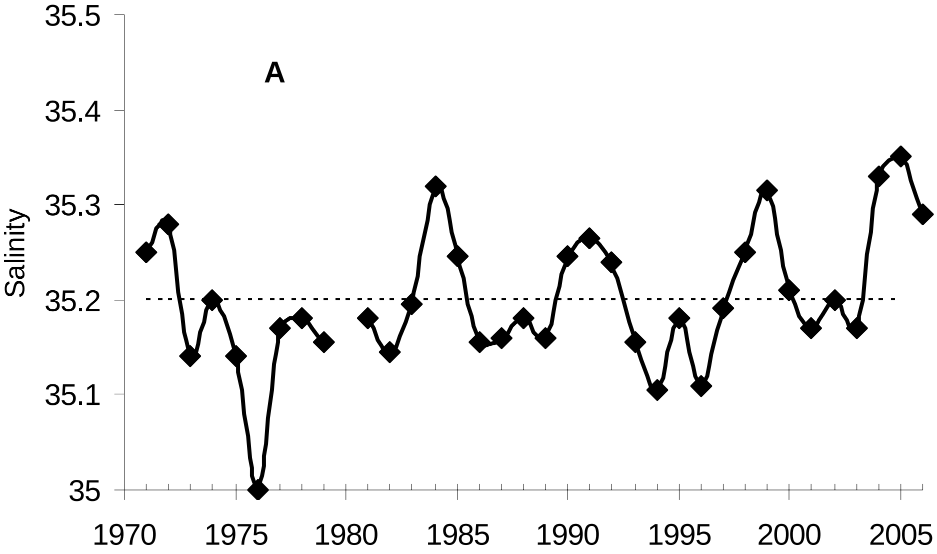


Figure 3.8.7 Salinity near bottom in the north-western part of the North Sea in the summers of 1970-2006.

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).

The circulation patterns in the North Sea largely determine its spatial physical and chemical status. A recent multivariate analysis of 13 abiotic variables using Principal Components Analysis for the period 1973 to 2004 (REGNS, 2006) reveals clear spatial gradients in its abiotic chraracteristics (Figure 3.8.8). This pattern of variation is also consistent with a study of North Sea hydrodynamics undertaken by an ICES Study Group (ICES, 1983) and which was used as the basis for sub-dividing the North Sea in the 1993 North Sea Quality Status Report (NSTF, 1993) as shown in Figure 3.8.9. Further analysis is required to investigate specifically how the physical and chemical status in each sub-region has changed over time as significant temporal trends for a number of abiotic and biotic parameters are apparent over this period. Nevertheless, it is important to appreciate the relative importance of the spatial gradients in the North Sea as determined by changes in bathymetry, sediment type and ocean currents which form the basis of the sub-divisions shown in Figure 3.8.9.

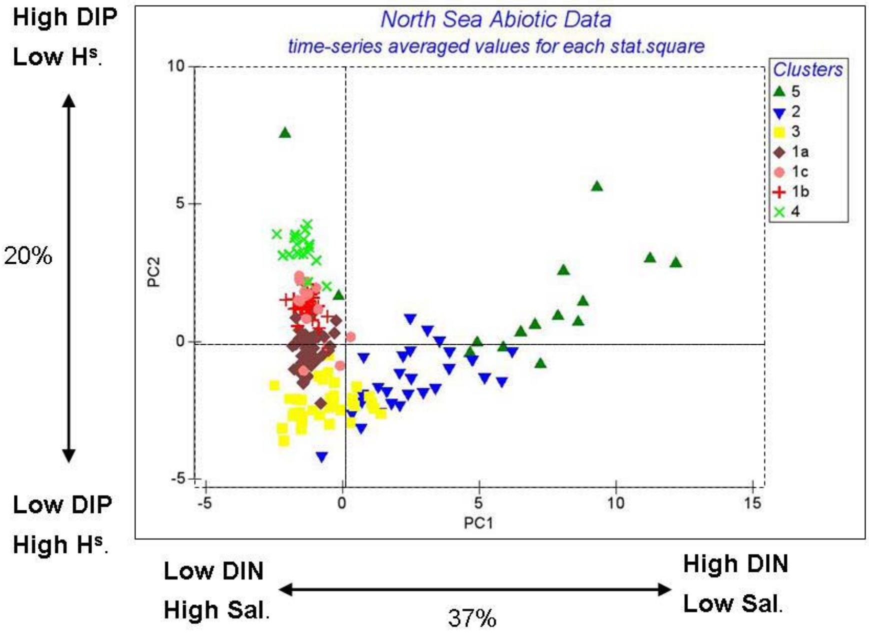


Figure 3.8.8. Spatial gradients in the North Sea physical/chemical characteristics based upon 13 variables averaged between 1973 and 2004 (REGNS, 2006 & Kenny *et al*, 2006). The variables explaining most of the variation are; Dissolved Inorganic Phosphate (DIP),Dissolved Inorganic Nitrogen (DIN), nearbed wave stress (H_s) and salinity (Sal). Each symbol represents the abiotic status of a single ICES statistical rectangle in the North Sea (about 200 statistical rectangles have been used in the present analysis to describe the North Sea) and these have been coloured according to their respective clusters based upon hierarchical cluster analysis at a significance level of >p=0.05, (REGNS, 2006).

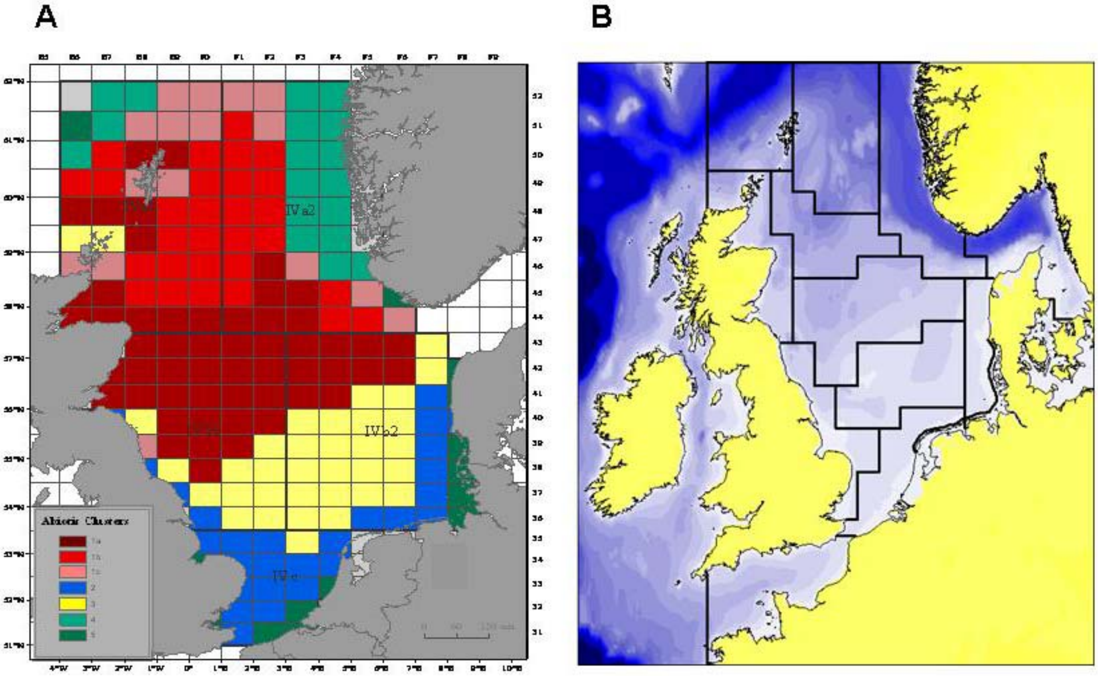


Figure 3.8.9. A) Spatial representation of physical/chemical status of ICES statistical rectangles based upon the analysis presented in Figure 3.8.8, B) Sub-divisions of the North Sea based upon a study of hydrodynamic properties undertaken by ICES (ICES, 1983).

A separate time-series analysis of the North Sea abiotic data between 1973 and 2004 reveal three notable clusters of years, namely; 1979-1984, 1985-1995 and 1996-2004, and these are highlighted in the PCA ordination shown in Figure 3.8.10. The variables which best explain the trends are; salinity, temperature, dissolved inorganic nitrogen and phosphate.

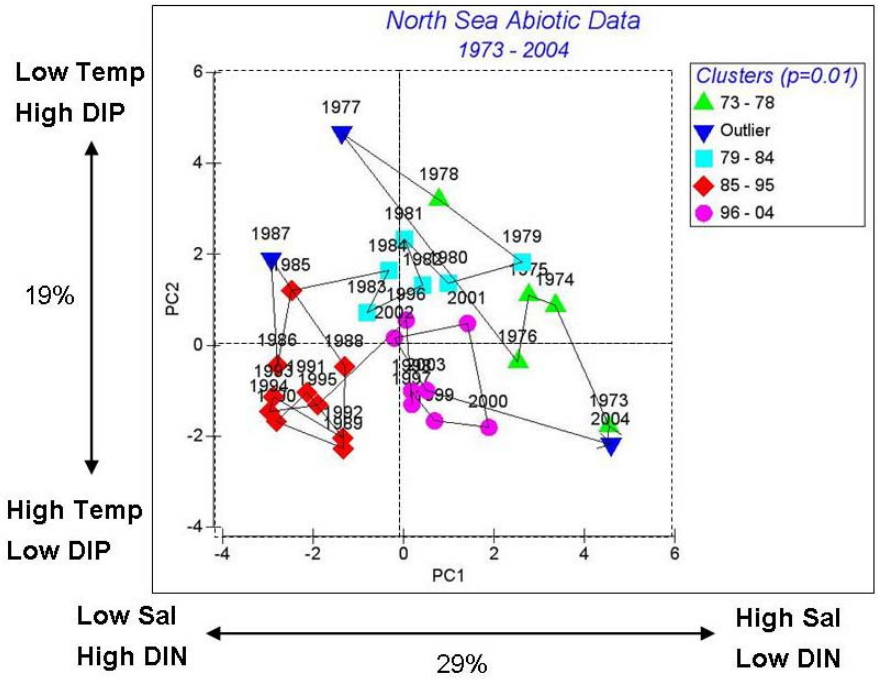


Figure 3.8.10. Changes in the abiotic state of the North Sea between 1973 and 2004, highlighting the importance of salinity, temperature and dissolved inorganic nutrients in explaining the trends over this period. Each symbol represents the average abiotic state in a specific year with groups of years coloured according to their corresponding cluster after hierarchical cluster analysis at a significance level of >p=0.05.

3.8.1.2 Major climatic and oceanographic features

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

3.8.1.3 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.

3.8.1.4 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 3.8.11) and links have been made with cod and flatfish recruitment (Beaugrand et al 2003, Beaugrand 2004) see Figure 3.8.12. 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 3.8.13.

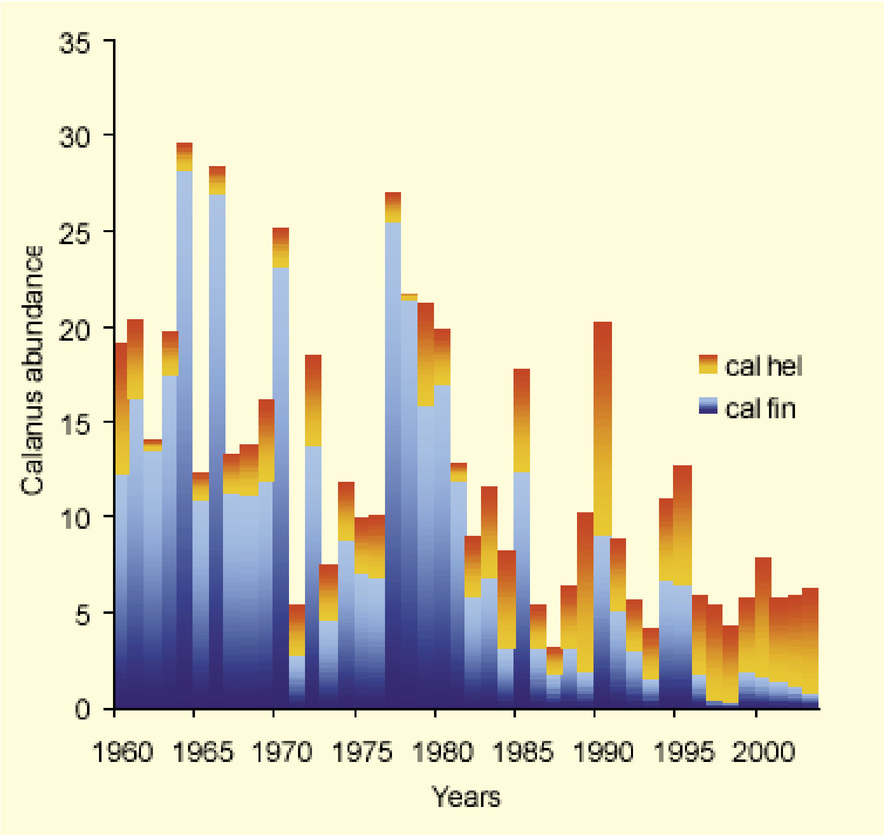


Figure 3.8.11. The abundance of *Calanus* populations in the North Sea from 1960 to 2003. The percentage ratio of *Calanus finmarchicus* (blue) and *Calanus helgolandicus* (red) are shown in relation to total Calanus abundance in each annual bar. From www.sahfos.org, Ecological Status 2004/5

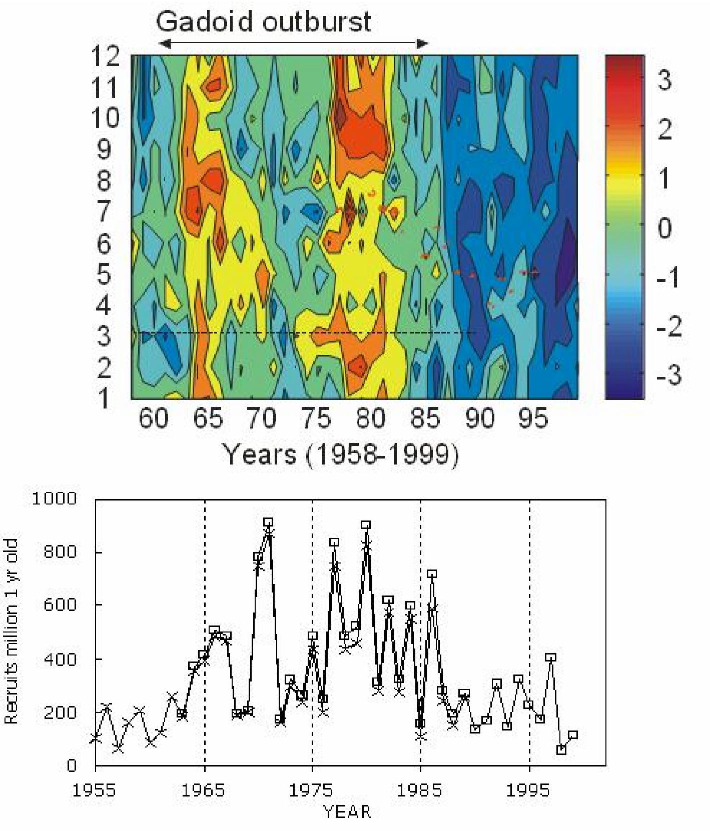


Figure 3.8.12 Top; long-term monthly changes (1958-1999) in the Beaugrand et al. (2003) plankton index. A negative anomaly in the index indicates a low value for *Calanus finmarchicus*, euphausiids, mean size of calanoid copepods with the exception of *C. helgolandicus* (opposite pattern) and *Pseudocalanus* 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).

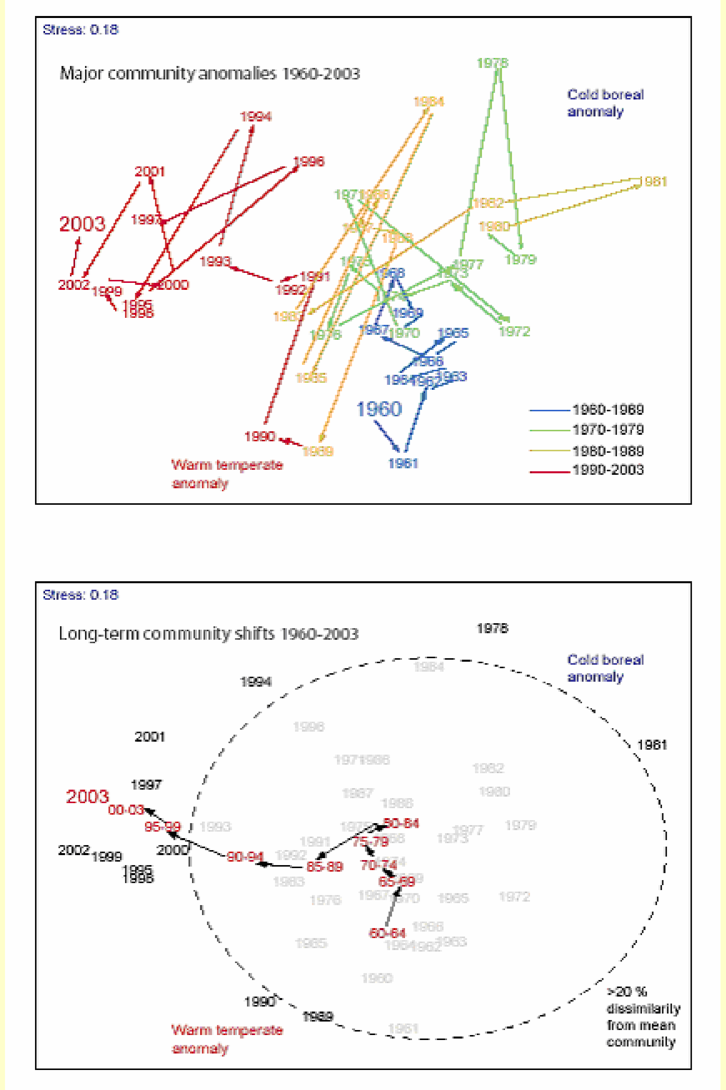


Figure 3.8.13 Multi-dimensional scaling plot of the annual zooplankton community structure in the central North Sea from 1960-2003 showing major structural shifts (top figure) and five-year community averages (bottom figure). Similarity matrix based on Bray-Curtis and log (x+1) transformations. From www.sahfos.org, Ecological Status 2004

3.8.1.5 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 (Collie et al 2000; Kaiser et al 2006, 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*.

3.8.1.6 Fish community

Dominant species

Estimates of the total biomass of North Sea fish in the 1980s were in the order of 12 million tonnes, approximately 67% of which consisted of the major eleven exploited species (Daan et al, 1990). Throughout the year, the pelagic component is dominated by herring *Clupea harengus*. Mackerel *Scomber scombrus* and horse mackerel *Trachurus trachurus* are mainly present in the summer when they enter the area from the south and from the northwest. Dominating gadoid species are cod *Gadus morhua*, haddock *Melanogrammus aeglefinus*, whiting *Merlangius merlangus* and saithe *Pollachius virens,* whereas the main flatfish species are common dab *Limanda limanda*, plaice *Pleuronectes platessa*, long rough dab *Hippoglossoides platessoides*, lemon sole *Microstomus kitt* and sole *Solea vulgaris*. The major forage fish species are sandeels *Ammodytes marinus*, Norway pout *Trisopterus esmarki* and sprat *Sprattus sprattus*, 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 increase in the abundance of large, commercially important gadoid species: the ‘gadoid outburst’. During this period, cod, haddock, whiting and saithe, all produced a series of strong year classes. These gadoid stocks of have been decreasing since then and cod especially 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. During the second half of the year North Sea mackerel mix with the Northeast Atlantic mackerel stock and are thus affected by the fishery for mackerel.

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

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 and 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 the reduction of the predation pressure on juvenile fish and on species that remain small. This is as an indirect effect of overexploitation of the large predatory fish species.

Species Richness

Species richness in the North Sea is highest around the edges (particularly in Scottish waters, in the Southern Bight and in the Kattegat) and lowest in the central North Sea (Figure 3.8.14).

The edge areas are frequently invaded by species from adjacent areas that are a-typical for the North Sea. Based on the IBTS surveys in February, species richness appears to have increased steadily over the last 30 years (Figure 3.8.15) and trends have been roughly comparable for northerly and southerly species. Other studies have reported negative trends in species richness, particularly in heavily fished areas in the northern North Sea (Greenstreet & Rogers 2006). Apparent species richness signals may be dependent on the survey gear used and the time of year and area that data were collected.

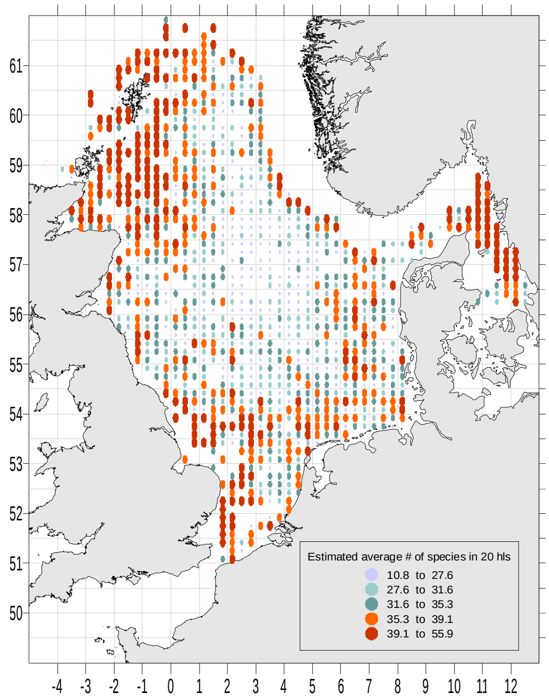


Figure 3.8.14 **Spatial indices of species richness for all species**

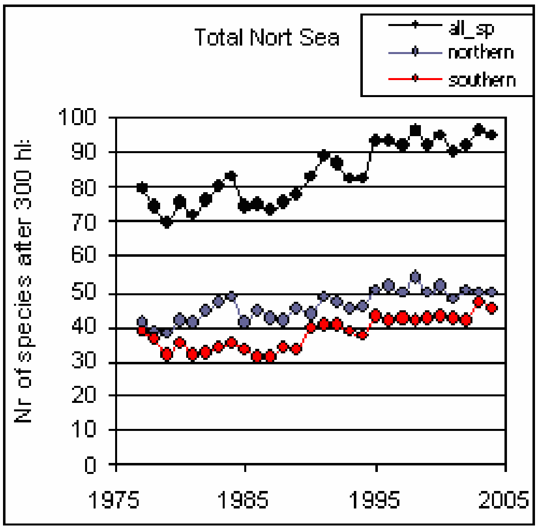


Figure 3.8.15 **Species richness based on IBTS surveys.**

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; Jennings et al 1999). 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. 1999; Daan et al., 2003, 2005).

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 (Daan et al 1989; Hislop et al 1997; Greenstreet et al 1997) as well as birds (Tasker & Furness 1996; Wanless et al 1998) and marine mammals (Hammond & Grellier 2006; Santos et al 2004) and their low abundance is therefore expected to have severe implications for the whole North Sea ecosystem.

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 *Hippoglossus hippoglossus*). Recently species like hake *Merluccius merluccius* and pollack *Pollachius pollachius* 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.

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).

3.8.1.7 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 plankton to small schooling fish and discards. Because of all these differences, seabirds do not represent a single homogeneous group that responds to fisheries in some uniform way. A few species profit directly from human consumption fisheries, either discards or offal e.g. fulmars and gulls.

Current seasonal distributions, status and trends of these species are well known and documented in ICES (2003). Many 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). Gull numbers 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 black-legged kittiwakes *Rissa tridactyla* might serve as an index of the quality of local feeding conditions within the framework of Ecological Quality Objectives (EcoQO) proposed by OSPAR (ICES 2003).

3.8.1.8 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 resident 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 (grey seals in particular). 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. The numbers of harbour seals at Orkney, Shetland and the Scottish North Sea coast have continued to decline since the phocine distemper virus (PDV) outbreak in 2002. This is in contrast to the situation following the 1988 outbreak, and in contrast to the harbour seals in other UK areas and in the southeastern North Sea. The reasons for the decline are not clear at present. 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. Estimates of annual consumption by grey seals increased substantially between 1985 and 2002 in line with the almost threefold increase in the grey seal population size. Estimated annual prey consumption was 49,000 t in 1985 and 161,000 t in 2002. In 2002 grey seals in the North Sea consumed mainly sandeel (69,000 t), cod (8,300 t), haddock (6,500 t) and plaice (5,200 t), but also commercial species such as whiting, saithe, ling and herring were taken. Of non-commercially exploited fish, there were large increases since 1985 in the estimated consumption of sea-scorpions (6,600 t) and dragonets (1,900 t). 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 they advocate culling of seals.

Although several cetacean species visit the North Sea, the dominating species are minke whales, harbour porpoises and whitebeaked dolphins.. Population estimates derived from surveys made in 1994 are available for harbour porpoise *Phocoena phocoena* (about 340 000), white-beaked dolphin *Lagenorhynchus albirostris* (7900) and minke whale *Balaenoptera acutorostrata* (7300). Preliminary abundance estimates from a survey conducted in 2005 indicate status quo for all these species. Harbour porpoises, however, have shifted their focal distribution from the northern part of the North Sea to the southern part. Minke whales and whitebeaked dolphins have overlapping distributions and are mainly found in the northern part of the North Sea. 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. A small resident population (approximately 130 individuals) of bottlenose dolphins *Tursiops truncatus* is located off the east coast of Scotland.

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.

3.8.1.9 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 2006), 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 gives, 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 face of these dynamic ecological conditions; how to preserve the productivity of the seas and have some revenues from fishing at the same time

3.8.2 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. 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.

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 low or depleted (e.g. plaice and cod). Recruitment of some 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. There is an increase in a number of southern species e.g. anchovy (*Engraulis encrasicola*) and red mullet (*Mullus surmulletus)*. In the latter case there is a new fishery developing.

There are notable similarities between trends in the abiotic, plankton, fish landings and seabird community data between 1973 and 2004 (Figure 3.8.16). However, whilst the environmental conditions in recent years show an increase in similarity to the conditions in state observed between 1973 and 1984, the plankton, fish landings and seabird community data are increasingly dissimilar to their 1973 to 1984 condition. This supports the assertion of a change in ecosystem regime for the North Sea over this period which is is not showing any signs of reversing. The specific causes of this require further investigation.

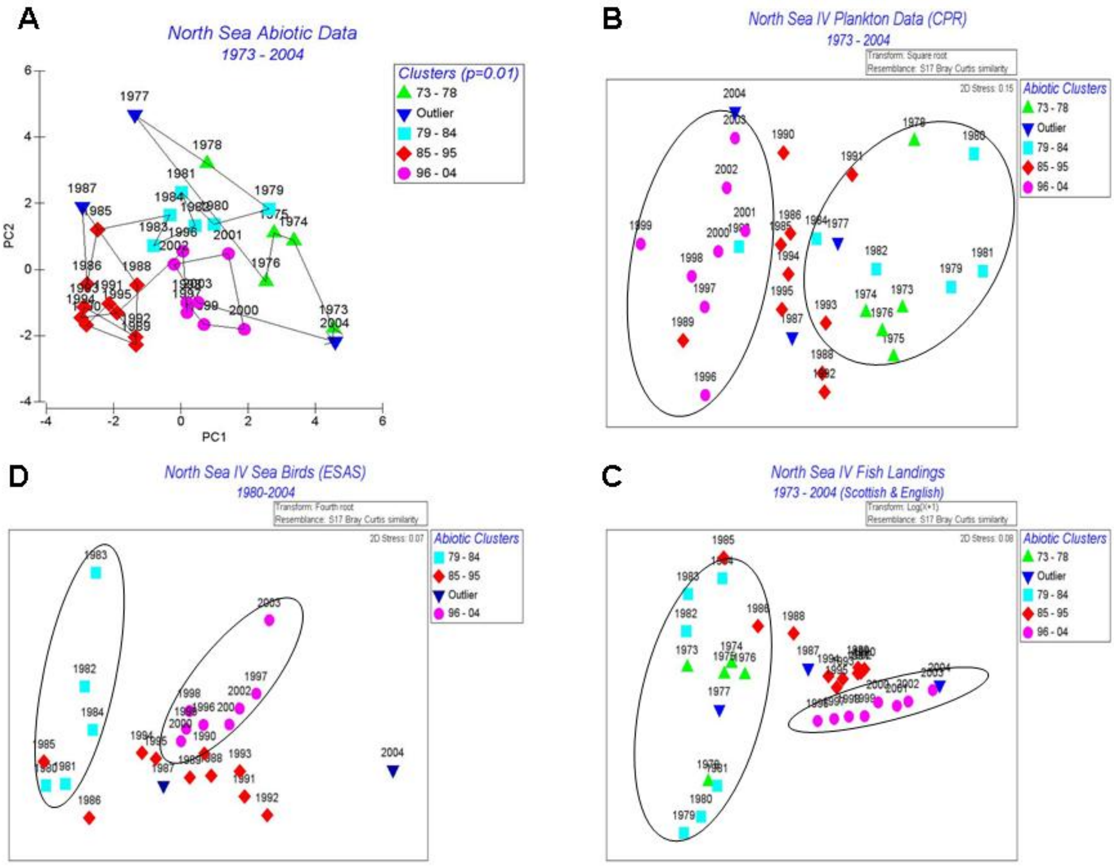


Figure 3.8.16. Comparative ordinations of North Sea abiotic and biotic data between 1973 and 2004 (see Kenny *et al*, 2006); A) abiotic state changes (see Figure 3.8.10 for an explanation), B) plankton community trends based upon plankton species from the CPR survey (note the similarity to figure 3.8.13), C) trends in Scottish & English fish landings data, D) seabird community trends based upon ESAS survey data. Samples in the biotic plots B to D have been coloured according to the clusters in the abiotic plot A to highlight similarities between the respective analyses.

The eastern channel is included in the North Sea regional ecosystem area. Studies of the fish, cephalopod and macro-invertebrate assemblages in this area have identified four distinct community types that are determined by environmental factors such as depth, salinity, water temperature, seabed shear stress, and sediment type. Although these communities display significant interannual variation in overall community structure and composition, the different communities, and their spatial distribution, are persistent over time reflecting the relative stability of environmental conditions in the area. The different communities differ in their species diversity. Overall, however, species diversity over the entire region appears to have increased over the last two decades, and is highest in areas of soft sediment and wide variation in temperature and salinity (Vaz et al 2007).

3.8.3 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 fisheries 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). Recent estimates suggest that beam trawling in the southern and central North Sea beam trawl fleets removes 39% of standing-crop biomass on an annual basis and reduces benthic production by 15% relative to the unfished state (Greenstreet et al in press; Hiddink et al. in press),. In the northern North Sea the impact of otter trawling is less severe, with an estimate of the benthic invertebrate annual mortality due to fishing representing approximately 25% of the standing-crop biomass (Greenstreet et al in press). Historically trawling effort has not been homogeneous, with effort greatly concentrated in preferred historic fishing grounds (Greenstreet et al 1999; 2006; Jennings et al 1999; Greenstreet et al in press; Piet et al 2000; Piet et al in press Rijnsdorp et al 1998). 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 (Greenstreet et al in press). This should be taken into account when evaluating proposed closed areas or seasons.

The principal effects of fishing on the size and species composition of the North Sea fish community has been that as fishing mortality increased, the mean size of individuals in the community decreased, and species with larger body sizes formed a smaller proportion of community biomass (Gislason & Sinclair 2000; Jennings et al 1999; Greenstreet & Rogers 2006). 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. 1999; Daan et al., 2003, 2005). The changes in size composition of the fish community could change the predation mortality among species and sizes of fish. Changes in size composition of species and communities due to overfishing can also affect population fecundity both directly (reduction of larger, more fecund spawners), and indirectly (earlier maturation at smaller sizes).

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).

The way in which each type of fishing activity affects eight separate ecosystem components (habitats, nutrients, plankton, benthos, the fish community, commercial fish and shellfish, marine mammals, and seabirds) within the North Sea was described in detail by WGECO (ICES 2006). Two EC funded projects have compiled international fishing effort data bases for the major gear categories spanning the periods 1990 to 1995 and 1997 to 2004 (Jennings et al 1999; Greenstreet et al in press). These two studies indicate that the distribution of fishing activity has changed very little over the combined 14 year period. The pattern of impact on benthic and fish communities is likely to have varied very little across the North Sea. Any variation in impact will have been driven by overall changes in the levels of different types of fishing activity taking place across the whole North Sea. The MAFCONS data set suggests that fishing activity overall has declined markedly, by approximately 28%, since 1999. However, this overall decline masked very different changes taking place when each fishing activity category was considered independently. Beam trawl effort, otter trawl effort directed at fish and seine gear effort all declined by 31%, 44%, and 62% respectively, however, otter trawl effort directed at *Nephrops* increased by 65% (Greenstreet et al in press).

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3.9 The Baltic Sea

3.9.1 Ecosystem Components

3.9.1.1 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.

3.9.1.2 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 well-oxygenated water into all main basins of the Baltic Sea, including the Gotland Deep, Figure 3.9.1. Since 2003 there have been no major inflow events, and the waters in the deep basins of the Baltic are returning toward the relatively stagnant conditions in the late 1990s and early 2000s. Since the winter and summer inflows in 2003 temperature and hydrogen sulfide have increased, and salinity and dissolved oxygen have decreased in all the deep basins. Bottom temperature in Bornhold Deep is now 1.8 ^oC above the average 1970-1990 (7.96 vs 6.12), and at least 1 ^oC greater in all the other basins except Gotland Deep (0.3 ^oC warmer) (Helcom 2006)

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. Through the first part of this decade nutrient levels have remain persistently high and may be increasing further in most recent years (Helcom 2003, 2006). 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 continues, but at a slow rate, suggesting that some input of these compounds continue (Helcom 2002, 2006). 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.

3.9.1.3 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).

3.9.1.4 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 3.9.2). 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.

3.9.1.5 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).

3.9.1.6 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 3.9.3), 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 3.9.4) (MacKenzie *et al.* 2000). It increased somewhat following the 2003 inflow but has declined towards very low values in most recent years. 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).

3.9.1.7 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).

3.9.2 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.

3.9.2.1 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).

3.9.2.2 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).

3.9.2.3 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).

3.9.3 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.

3.9.4 Conclusions

3.9.4.1 Short term

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

3.9.4.2 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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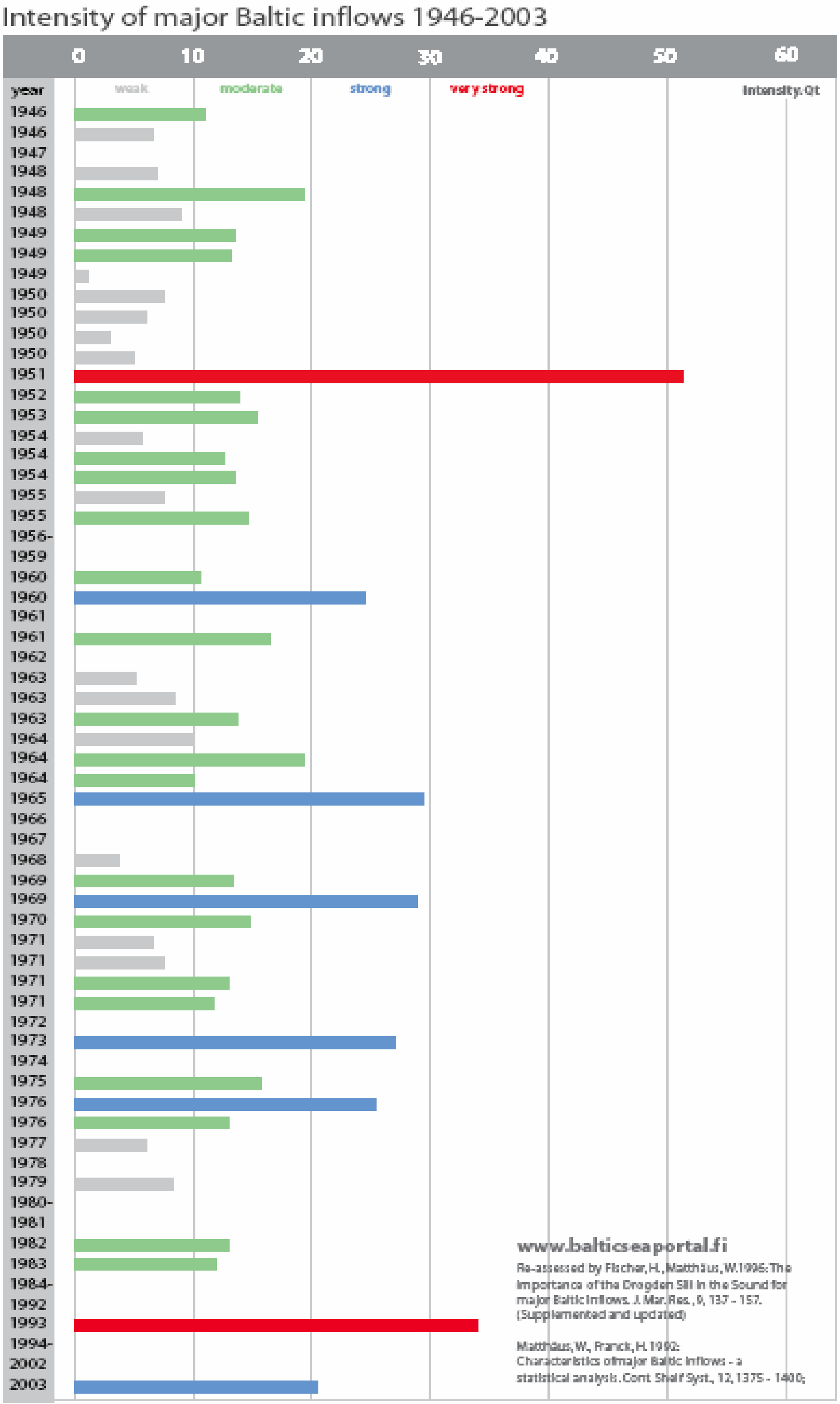

Intensity of major Baltic inflows 1946-2003

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Figure 3.9.1 Intensity of inflows to the Baltic, 1946-2003.

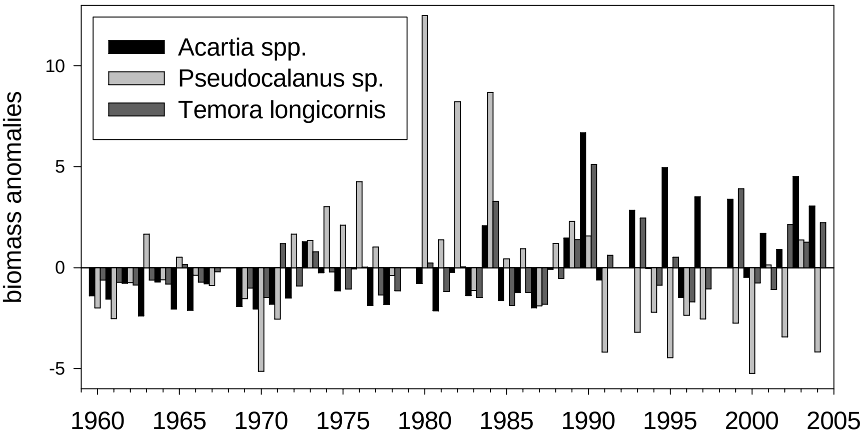

Figure 3.9.2 Time-series on spring biomass (mg*m-3) anomalies for the dominant mesozooplankton species in the Eastern Baltic, i.e. the calanoid copepods Acartia spp., Pseudocalanus sp. and Temora longicornis; data are from the Latvian Fish Resource Agency LatFRA in Riga.

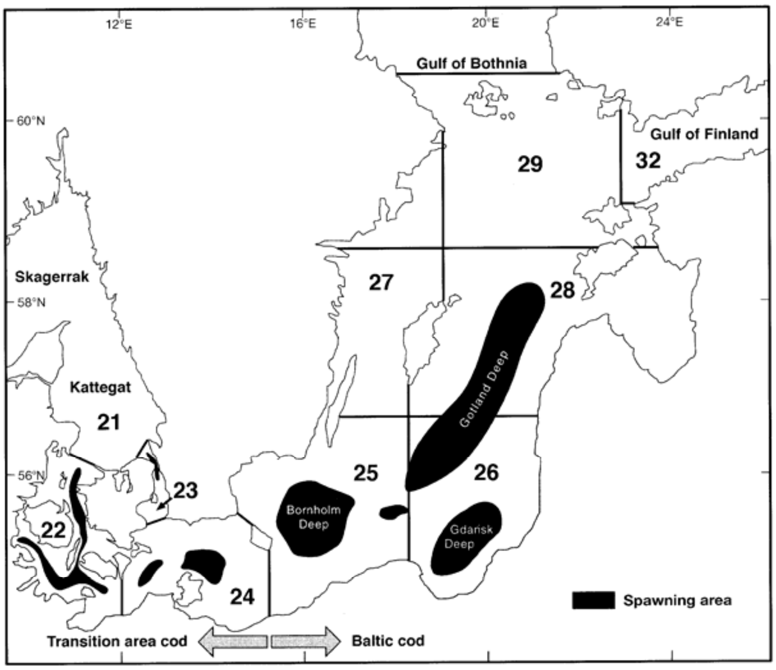

Figure 3.9.3 Historical spawning areas for cod in the Baltic Sea. From Bagge, O., Thurow, F., Steffensen, E., Bay, J. 1994. The Baltic Cod. Dana Vol. 10:1-28, modified by Aro, E. 2000. The spatial and temporal distribution patterns of cod (*Gadus morhua callarias*) in the Baltic Sea and their dependence 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.

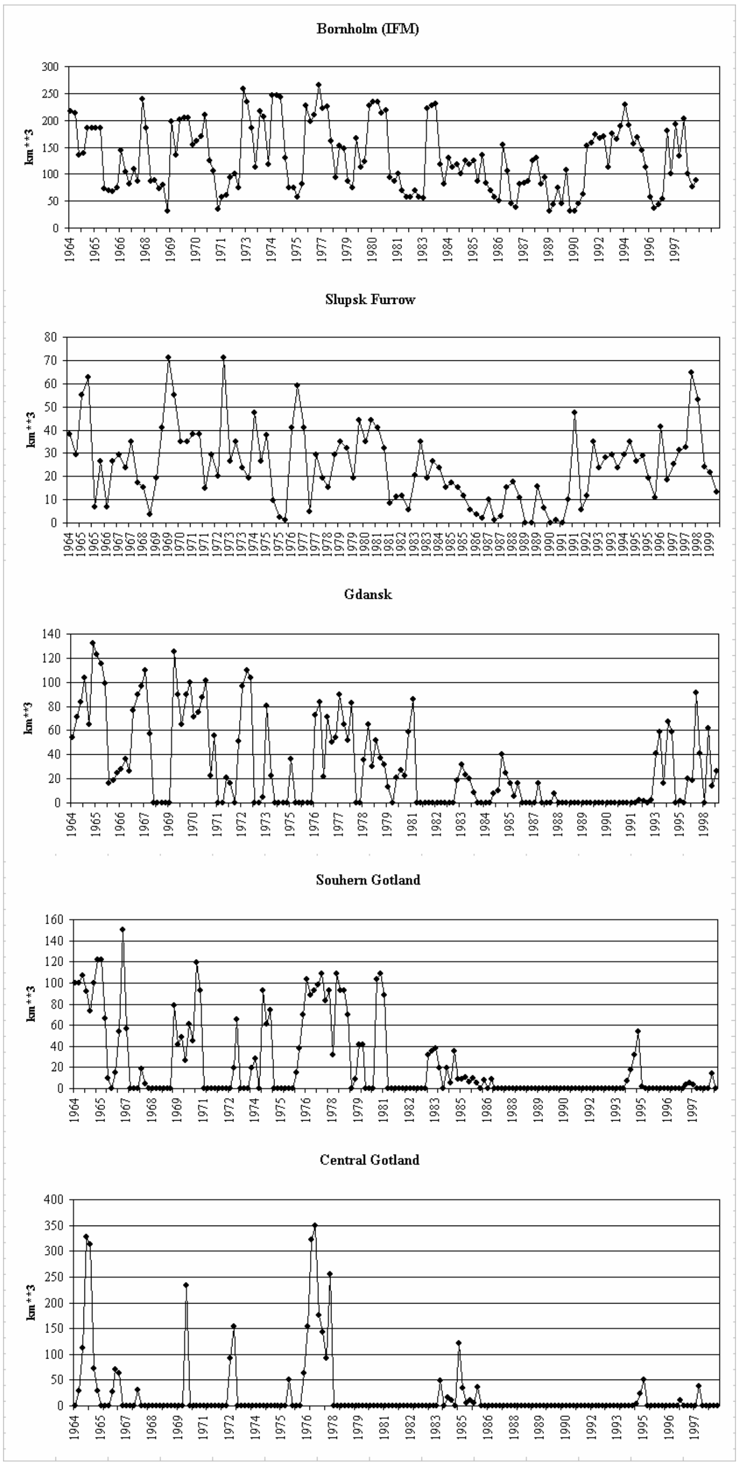

Figure 3.9.4 Time-series of reproductive volume for each spawning site. From MacKenzie, B. R., Hinrichsen, H.-H., Plikshs, M., Wieland, K., Zezera, A. 2000. Quantifying environmental heterogeneity: estimating the size of habitat for successful cod *Gadus morhua* egg development in the Baltic Sea. Marine Ecology Progress Series 193: 143-156. With updates by Maris Plikshs (Pers. Comm.).

3.10 Bay of Biscay and Western Iberia

3.10.1 Ecosystem Components

3.10.1.1 General description

The advisory region extends from west of Brittany (48°N) to the Gibraltar Straight (36°N). 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 3.10.1). 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).

3.10.1.2 Bottom topography, substrates, and circulation

3.10.1.2.1 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).

3.10.1.2.2 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 3.10.1 indicates the principal water masses and currents as explained by Mason et al. (2005).

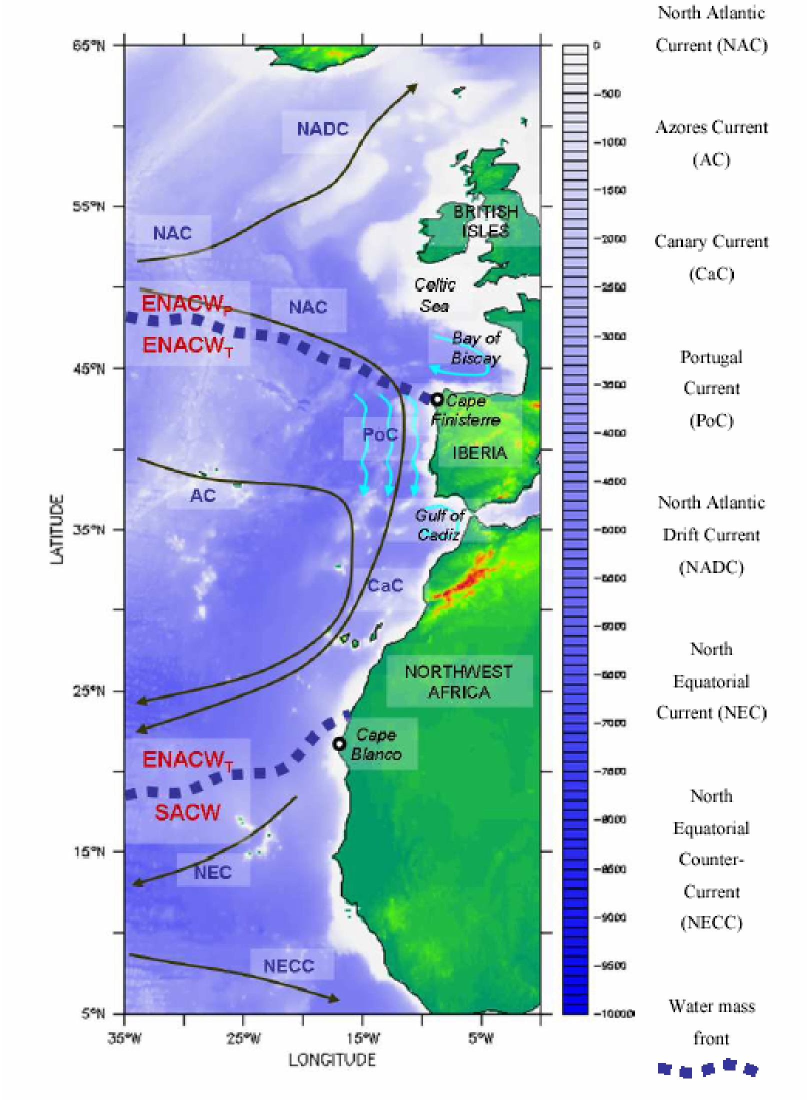

Figure 3.10.1. The main water masses in the Advisory region G are North Atlantic Central Water of sub-polar (ENACWp) and sub-tropical (ENACWt) origins and South Atlantic Central Water (SACW). The main large-scale surface currents are the North Atlantic Current (NAC), the Azores Current (AC), the Canary 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*., 2005). 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*., 2006). 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 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.*, 2004). 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.

3.10.1.3 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. 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).

Upwelling events are a common feature in Portugal, West of Galicia and in a narrow coastal band in western Cantabrian Sea, especially in summer (Fraga, 1981, Fiuza *et al.,* 1982, Blanton *et al.,* 1984, Botas *et al.,* 1990; OSPAR, 2000). In northeast Bay of Biscay, mainly in summer, upwelling events occur off South Brittany and the Landes coastline (Figure 3.10.2) and may induced low salinity lens detached from the river plumes (Puillat *et al.*, 2006; Lavin *et al.*, 2005).

In spring, the Bay of Biscay shelf hydrology is structured and one large central area characterized by vertical stability and low temporal variability seems to corresponds to an area of persistently low pelagic fish spawning activity (Planque *et al.*, 2006).There is no thermal stratification from January to April, stratification occurs from May to mid-September in a layer ~ 50m and disappear progressively in Autumn. In contrast, the haline stratification is strong from March to June (Puillat *et al.*, 2004).

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).

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 *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).

On yearly average, the French region received 2700 m^3 s^{-1} of run-off from the major rivers. The time series of the flow of Loire river (870 $m^3.s^{-1}$ of annual mean flow) shows that recent years have been below average (Figure 3.10.3).

Winter runoff and resuspension induce high non-living Suspended Particulate Matter(SPM) concentrations in the river plumes of the Bay of Biscay Shelf, these have important ecosystemic effects (Froidefond *et al.*, 2002). SPM extend over all the Bay of Biscay shelf during winter month with mean concentration around 3 $mg.m^{-3}$ (Huret, 2005, pp 62-63).

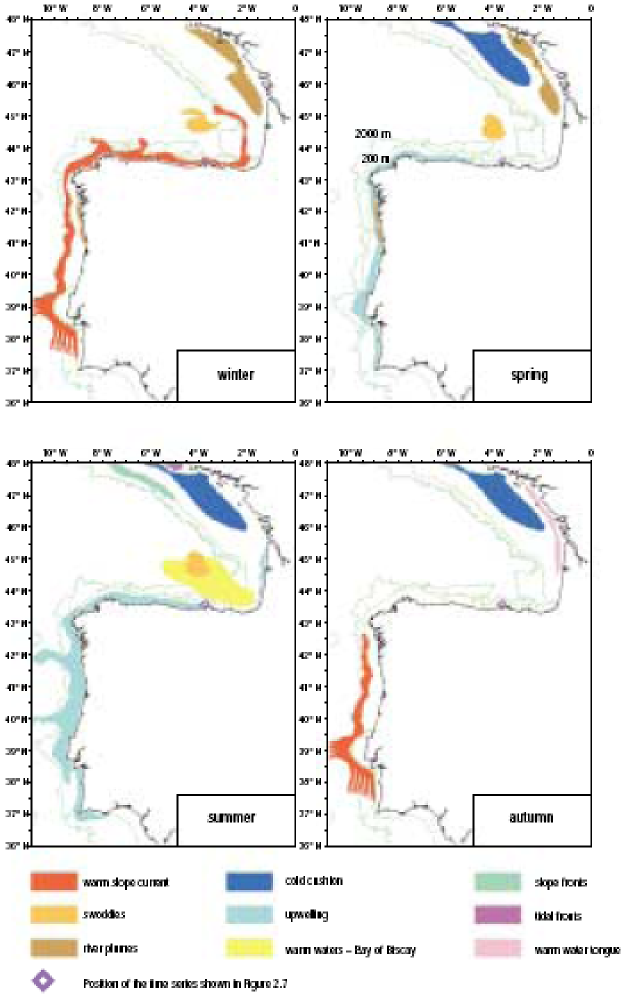

Figure 3.10.2. Seasonal variation in the main hydrographic features. Source: Koutsikopoulos and Le Cann (1996).

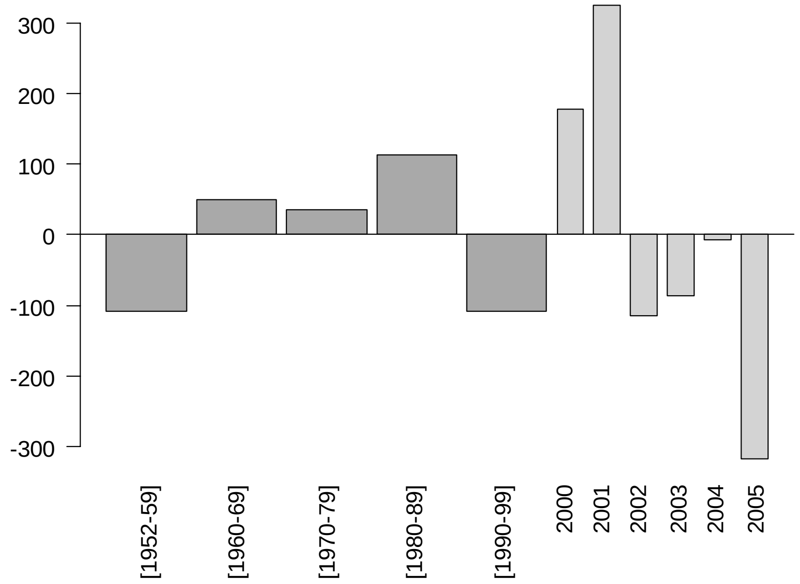

Figure 3.10.3. Variation of the river Loire yearly outflow ($m^3.s^{-1}$). Ten years period average from 1952-1999, yearly average for the 2000s. Data from the French data Bank on hydrology and hydrometry. http://www.hydro.eaufrance.fr/

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

Wind events and river runoff are drivers of the temperature and salinity distribution and variability (Puillat *et al.*, 2004; Villamor *et al.*, 2005).

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.

3.10.1.4 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) and in March in the Bay of Biscay (Huret, 2005, pp 64-65). By March-early April the spring bloom covers the entire off-shore region. From May onwards, chlorophyll drops sharply offshore, while strong blooms may still occur in the river plumes over the French shelf. Low chlorophyll values are observed in summer. The autumn bloom is variable, 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.

Hydrological features related to river plumes, and light availability, seem to be the two major factors regulating the winter to spring phytoplankton production in the Bay of Biscay (Labry *et al.*, 2001; Gohin *et al.*, 2003). Late winter phytoplankton blooms induce limitation in nutrients from March (Morin et al. 1991; Herbland *et al.*, 1998; Labry *et al.*, 2001). Phosphorous is the first limiting nutrient during these blooms (Labry *et al.*, 2002). Due to slope processes, blooms are regularly observed from satellite images over the shelf break from April to October, coccolithophorids being sometimes responsible (Lampert, 2002).

The average total primary production over the whole Bay of Biscay shelf, estimated from a primary production model coupled to a hydrodynamic model and using satellite data (Gohin *et al.*, 2005; Huret *et al.*, 2007) is 83 g C.m^{-2}.y^{-1} (6 year mean 1998-2003).

Along the southern Bay of Biscay and western Galician coasts 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).

3.10.1.5 Zooplankton

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 3.10.4) (Llope *et al.*, 2003).

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.

Three hundred species of zooplankton have been identified in the Bay of Biscay, among which 10% are copepods (Poulet *et al.*, 1996). In all the eco-region, copepods make up from 70 to 90% of plankton in number and only about ten species take a significant part in biomass and secondary planktonic productivity (D'Elbée, 2001).

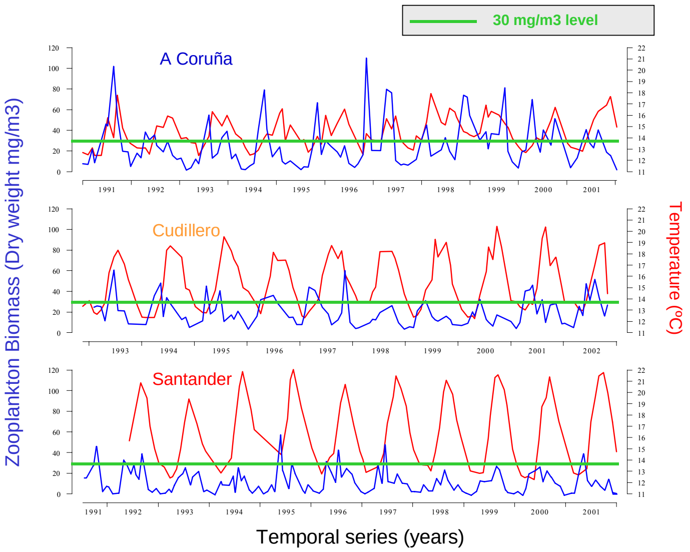

Figure 3.10.4 Variations in zooplankton biomass and temperature in the Cantabrian Sea. (Llope et al ; 2003, modified by Valdés).

The plankton community has changed over the last 50 years (Beaugrand, 2005). However, the change may be less pronounced that in more Northern areas like the North Sea.

3.10.1.6 Benthos

In the Cantabrian Sea, and 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 occurrence 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.*, 2006a). 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 and 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 decussatus*, cockle *Cerastoderma edule*, telline *Donax trunculus*). Some species were introduced for aquaculture purposes and some settled as wild populations (eg *Ruditapes phillipinarum*) are 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 substrate 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.

3.10.1.7 Fish community

3.10.1.7.1 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 organized 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). 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, monkfishes and sole. Most of these species are distributed all through the advisory region, although not evenly.

3.10.1.7.2 Trophic web

In the northern Iberian shelf, 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.*, 2006). 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; 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).

3.10.1.8 Mammals and birds

3.10.1.8.1 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 3.10.1. Detailed information on distribution and migratory patterns is restricted to the most common species.

Table 3.10.1 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

3.10.1.8.2 Birds

The Iberian Peninsula gives rise to large seabird populations due to its strategic geographical position regarding their migratory pattern.

Nesting seabirds in the area include European storm petrel (*Hydrobates pelagicus*), European shag (*Phalacrocorax aristotelis*), yellow-legged gull (*Larus michahellis*), lesser black-backed gull (*Larus fuscus*), kittiwake (*Rissa tridactyla*) and common guillemot (*Uria aalge*). Another group of 25 species are wintering or migrant seabirds along the North Spanish coast (Valeiras, 2003; Valeiras *et al.,* 2007). Most important species in terms of abundance are the northern gannet (*Morus bassanus*), the *Larus* spp. gulls (7 species), the Balearic shearwater (*Puffinus mauretanicus*), the Manx shearwater (*Puffinus puffinus*), the sooty shearwater (*Puffinus griseus*), the Cory´s shearwater (*Calonectris diomedea*), the razorbill (*Alca torda*) and the Atlantic puffin (*Fratercula arctica*).

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. Several studies of offshore seabirds in the the Gulf of Cadiz (ICES IXaS), Galicia (ICES IXaN), and Cantabrian Sea (ICES VIIIc) describe seasonal distributional patterns of species and their relationships with fishing discards availability and fishing boats distribution (Valeiras *et al.*, 2007). The spatial distribution of the scavengers generally was greatly driven by the distribution of demersal trawl fleet. The most common species showed high frequencies of occurrence at trawlers, ranging from 71 to 95% of the hauls.

3.10.1.8.3 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.

3.10.2 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). 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 *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). On the Bay of Biscay shelf, adult fish and eggs of sardine and anchovy distribution in spring were correlated to the distribution of 6 cluster of the hydrological and planktonic characteristics of sampled stations, however the consistency over years of the pattern is still unknown (Petitgas *et al.*, 2006).

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).

3.10.3 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 resuspension 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 were no fragile invertebrates (Blanchard *et al.,* 2004).

Based on bottom-trawl survey data Rochet *et al.* (2005), developed a diagnostic from indicators for 51 fish populations and the whole 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.

Preliminary effort analyses show that French fishing effort of both towed and fixed gears for demersal species increased in the Bay of Biscay since 1999, probably as a results of changes in effort geographical distribution.

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.*, 2005). 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 sized snipe-fish (*Macrorramphosus scolopax*) and silver pout (*Gadiculus argenteus*) and the medium sized blue whiting (*Micromesistius poutassou*). All these species are dead when discarded (Pérez *et. al,* 1996).

3.10.4 Other effects of human use of the ecosystem

3.10.4.1 Impact of oil spills

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).

Four 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.*, 2006; Serrano *et al.*, 2006b, Trujillo *et al.*, 2005).

The Erika oil spill, that occurred in December 1999, have had a varied impact among seabirds species. Among the most affected species (in terms of number of individuals found on beaches), some declined (razorbill, common scoter) whereas others stayed stable like the guillemot and the gannet, the two most affected species. By contrast, among the least often found species, some decreased very strongly in the north of the Bay of Biscay (Castège *et al.*, 2004).

3.10.4.2 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.

3.10.5 References

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3.11 Widely distributed and migratory stocks

3.11.1 Hydrography

Surface circulation and hydrography

The circulation of the North Atlantic Ocean is characterized by two large gyres: the *subpolar* and *subtropical* gyres (Figure. 3.11.1). The anticyclonic subtropical gyre owes its existence to the low-latitude trade winds and mid-latitude westerlies. Some of the water in the subtropical gyre is re-circulated to the west of the Mid Atlantic Ridge (MAR) and some water continues east and crosses the MAR in the Azores Current and the remainder forms the North Atlantic Current (NAC). The NAC looses its jet signature as it turns east and the waters are transported eastward in the Sub Polar Front (SPF), which is the boundary between the warm water in the subtropical gyre and the cooler and less saline water in the subpolar gyre to the north (Rossby, 1999). It crosses the MAR in 2 to 4 branches between 45°N and the Charlie Gibbs Fracture Zone (CGFZ, ~52°N; Harvey and Ahran, 1988). Sub surface (Bower et al., 2002) and surface drifters (Fratantoni, 2001) indicate that the northern branch that is tied to the CGFZ, is the main pathway for waters crossing the MAR from the western to the eastern North Atlantic. East of the MAR the SPF makes a sharp turn toward the north. On the cold side of the SPF low salinity Sub Arctic Intermediate Water is transported into the eastern North Atlantic.

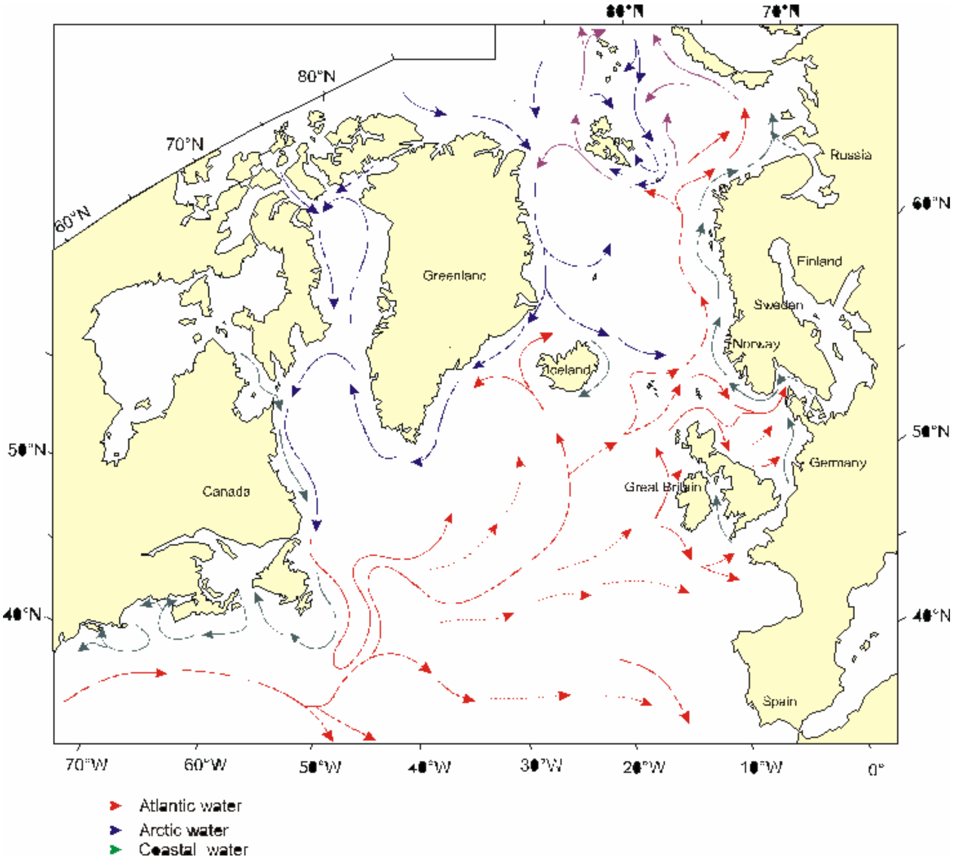

Figure 3.11.1. Surface current patterns in the North Atlantic (from Svein Sundby)

In the Iceland Basin there is a cyclonic circulation and relatively warm and saline water is transported from the eastern side of the North East Atlantic southwestward on the eastern side of the Reykjanes Ridge (Pollard et al., 2004). This water crosses the Reykanes Ridge and is transported northeastward on the western side of the ridge. Thus above the Reykanes Ridge relatively warm and saline modified North Atlantic Water is found whereas further west the waters are colder and less saline. The Rockall Through is an area of mode water formation and an 8-900 m thick layer of modified NAW is observed there. In the Iceland Basin the layer of modified NAW is about 500m. Further south there is a warm and saline upper layer that reaches a thickness of 8-900 m in the south. Along the eastern boundary there is a warm and saline slope current flowing northward from the Biscay to the Polar Ocean.

The circulation in the Norwegian Sea 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 general circulation pattern in the Barents Sea is strongly influenced by topography. Warm Atlantic waters from the Norwegian Atlantic Current defined by salinity higher than 35 flow in through the western entrance. 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 the northeast to southwest. The Atlantic and Arctic water masses are separated by the Polar Front, which is characterized by strong gradients in both temperature and salinity. In the western Barents Sea the position of the front is relatively stable, although it seems to be pushed northwards during warm climatic periods. In the eastern part the position of the 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 northern Barents Sea, while in the summer the whole Sea may be ice-free.

Recent oceanographic trends

The ICES Report on Ocean Climate (ICES, 2006a) provides summaries of long-term observations of environmental conditions to the end of 2005. The time-series from 29 standard stations and sections across the whole North Atlantic show generally rising trends in sea surface temperature (SST) and salinity. The increase in SST at several of the stations in the NE Atlantic is up to 3°C since the early 1980s. This rate of warming is very high relative to the rate of global warming.

Surface waters of the Rockall trough have been steadily warming for some years and are currently at an all time high. Hydrographic observations obtained during the blue whiting surveys uses mean temperature and salinity from 50 to 600m of all the stations in deep water west of the Porcupine Bank (ICES 2006b). This data show that after some years with temperatures around 10.1°C in the 1980s, an increase in temperature is seen after 1994 to a temperature above 10.5C in most of the recent years. In 2006, a new record has been set with 11.3°C, i.e. 0.5°C warmer than the previous record. Similar changes are seen in the other boxes, indicating that the box discussed above is representative for the region along the continental slope south of the Wyville Thompson ridge. The mean salinity in the box off Porcupine Bank is 35.51 this year. This is the highest value in the more than 20 years long time series.

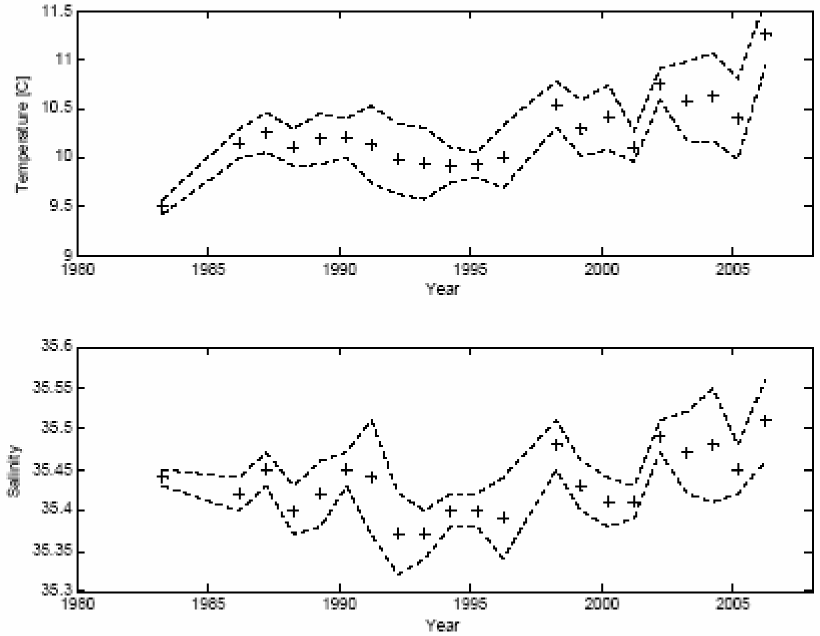

Figure 3.11.2. yearly mean temperature and salinity from 50-600m (crosses) of all stations in box with bottom depth>600m, west of Porcupine Bank bounded by 52 to 54 and 16-14W. Dotted lines are drawn at plus-minus standard deviation of all observations in each box, each year (from ICES 2006b).

In the Norwegian Sea, and especially in the eastern part, Atlantic water has been extraordinary warm and saline since 2002. During this period record-high values of both temperature and salinity have been observed. In 2006, temperature values were between 0,6°C and 1,1°C warmer than normal with highest anomaly in the north. The volume transport of Atlantic water into the Norwegian Sea increased considerably during 2005 and record-high transport values was observed during winter 2006.

The inflow of Atlantic Water to the Barents Sea was higher and warmer than ever recorded and the ice cover was the lowest on record for the winter of 2006. This record warm year confirms a warming trend seen in the Barents Sea, particularly the last 10 years.

3.11.2 Plankton

The ICES Report on Zooplankton Monitoring Results in the ICES Area (ICES, 2006c) provides an overview of recent changes in North Atlantic plankton. The Ecological Status report from SAHFOS (Edwards et al., 2006), provides standard time series of geographic and seasonal information on changes in phytoplankton and zooplankton back to 1946, with analysis of biogeographic shifts, changes in phenology and biodiversity and regime shifts, which are related to changes in fish populations.

Phytoplankton abundance in the NE Atlantic increased in cooler regions (north of 55°N) and decreased in warmer regions (south of 50°N). The effects propagate up through herbivores to carnivores in the plankton food web (bottom-up control), because of tight trophic coupling. Similar effects may be expected for other mid-latitude pelagic ecosystems, because the proposed mechanisms are general and the results for the NE Atlantic are consistent and based on very large scale, long-term sampling (Richardson and Schoeman, 2004).

Indicators of the zooplanktonic community have been developed over recent years (Beaugrand, 2005). Broad scale changes have occurred (figure 3.11.3) showing that over the last decade there has been a progressive increase in the presence of warm-water/sub-tropical species into the more temperate areas of the northeast Atlantic, with 2004 continuing with this trend.

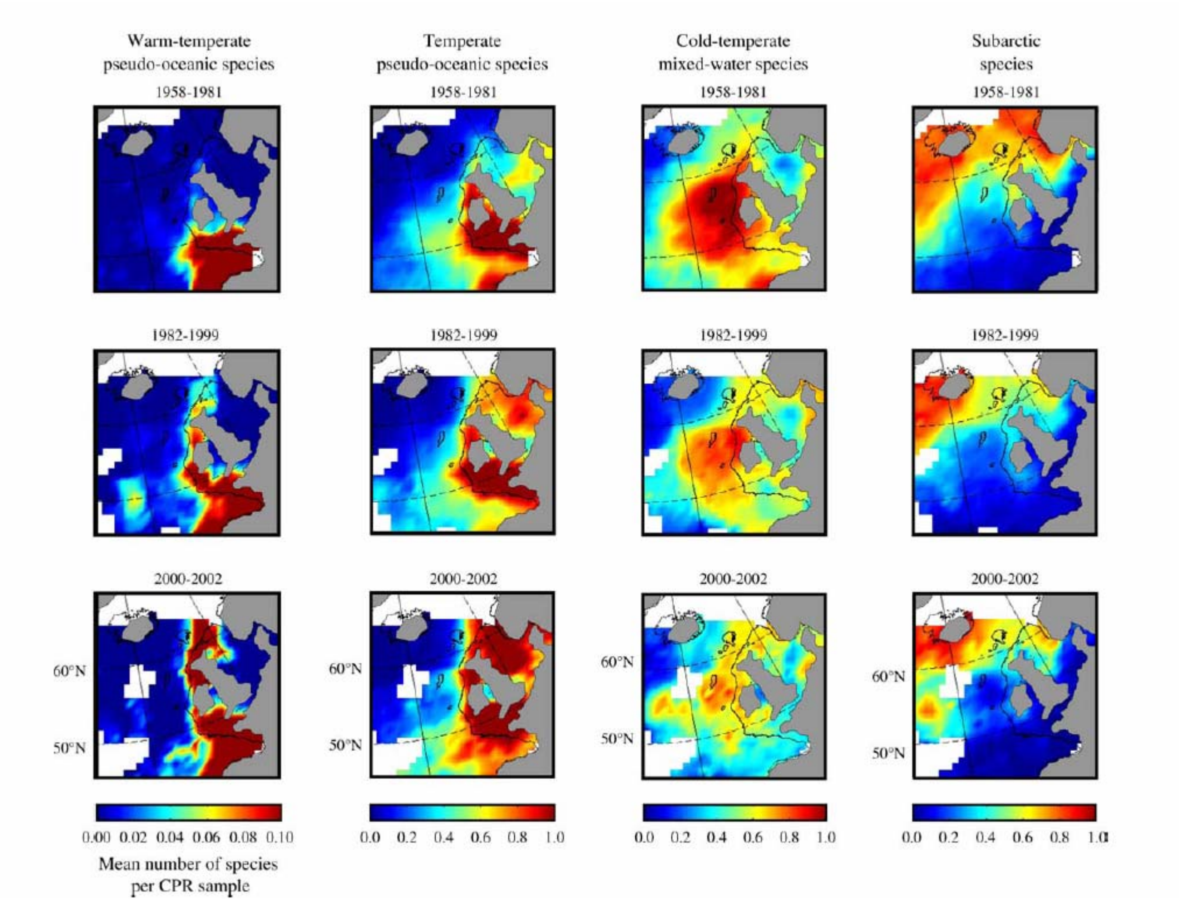

Figure 3.11.3 Long-term changes in the mean number of species per assemblage based on three periods: 1958-1981, 1982-1999 and 2000-2002 from Beaugrand et al. 2005)

3.11.3 Distribution of pelagic fish species

Blue whiting is distributed in European waters from the western Mediterranean Sea to the Barents Sea, around the Canary Islands and the Azores, in the North Sea, west of the British Isles, around the Faroes, east and south of Iceland, and westwards beyond Cape Farewell. The main spawning area extends from southwest of Ireland, over the Porcupine Bank and further north along the slope to north of the Hebrides. Spawning also takes place in the Rockall Bank area, in the Bay of Biscay and off the Iberian coast, and on a minor scale off the Norwegian coast, in Faroese waters and off the southern coast of Iceland (Monstad, 2004).

Spawning occurs at 300 - 500 m depth from January to June, earlier in the south than in the north. Mature fish migrate to the spawning grounds west of the British Isles during the winter months.

In spring-early summer, the post-spawning migration brings the adults back to the feedings areas. Exact migration patterns are not well known. Traditionally, the Norwegian Sea is considered as the main feeding area; also south of Iceland and along the continental shelf edge from Bay of Biscay to and into the Barents Sea. The northern stock component feeding in the Norwegian Sea disperses over large areas on the warm side of the polar front area. High concentrations may appear along hydrographic fronts (ICES, 2005ca).

From the spawning grounds west of the British Isles the hatched larvae drift northwards, towards the Norwegian Sea and Iceland, or southwards, towards the Bay of Biscay. The direction of drift depends on the spawning area; hydrographic modelling suggests that the separation line between northern and southern drift varies from year to year but is usually at the northern parts of the Porcupine Bank (Skogen *et al.*, 1999). By February the year after spawning, blue whiting probably originating from the main spawning area are found in surveys in the Barents Sea (Heino *et al.*, 2003). A part of the northward-drifting larvae enter the North Sea and fishery there by the fourth quarter of the year. The main nursery areas are in the Atlantic water in the Norwegian Sea, south of Iceland, southwest Barents Sea, and Bay of Biscay. Also the deeper parts of shelf areas around the Faroes and the British Isles function as nursery area.

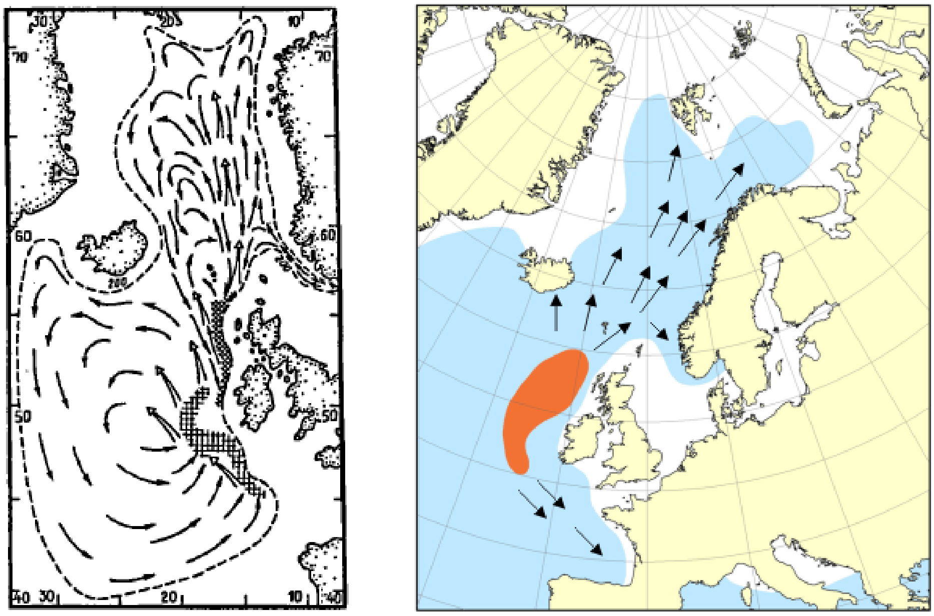

Figure 3.11.4 Migration of blue whiting. The left panel shows the migration pattern of adult blue whiting as suggested by Isaev *et al.* (1992). Hatched area shows the main spawning grounds. The current understanding does not fully support the pattern suggested for the component spawning around the Porcupine Bank by not accounting for the Bay of Biscay component. The migrations in the west are also virtually unknown. The right panel shows the current understanding on the drift patterns of blue whiting larvae (from ICES, 2005ca).

The **Norwegian Spring Spawning Herring** (NSS Herring) has its distribution area in the Norwegian Sea, the Barents Sea and along the Norwegian coast south to 59ºN. During long periods it has also been found north of Iceland during the summer. It is potentially the largest of the herring stocks in the northeast Atlantic (Holst et al., 2004).

Wintering has occurred in the open ocean to the east of Iceland (prior to the stock decline in the late 1960s) and off northern Norway, and in fjords at the west and north coast of Norway. Since the late 1980s until recently wintering has occurred in Vestfjorden, northern Norway. At present (winter 2006/2007) almost all of the stock contributed by recruits of the 1998–1999 year classes winters in the open ocean off the northern Norwegian coast. During wintering the herring is dispersed in layers both during day and night-time, deeper during day than night. Two different layers, with recruits in the upper and adult in the deeper layer, may occur. Migration from the wintering areas to the spawning areas starts in January (ICES, 2004).

Spawning occurs during February-April on the Norwegian shelf from 58ºN to 70ºN at bottom, on substrates like coarse sand, shell sand, gravel, stones and rocks, at depths of 30–250 m. The selection of spawning grounds and their extension is affected by the size and structure of the stock.

The hatched larvae drift northwards along the Norwegian coast. Some drift into fjord nurseries, but the major part of the larvae ends up in the Barents Sea (Holst and Slotte, 1998). The immature herring leaves the fjord and Barents Sea nursery areas to join the adults in the Norwegian Sea to feed during summer before the first spawning at ca. 28 cm length and ages 2–8 depending on growth.

It is believed that the recruits must learn from the adults the migration route to wintering, spawning and feeding grounds (Slotte, 2000). Changes in migration pattern usually take place during recruitment of strong year classes. There is a tendency for a year class to spawn farther south as it grows to be older (Slotte, 1999b, 2000). Reduced condition may cause a reduced migration distance compared with previous years. By modelling the size specific costs of migrating (Slotte, 1999a), and the benefits of larval survival farther south due to a drift through warmer temperatures, it has been demonstrated that it is optimal to spawn farther south with increasing size and condition (Slotte and Fiksen, 2000).

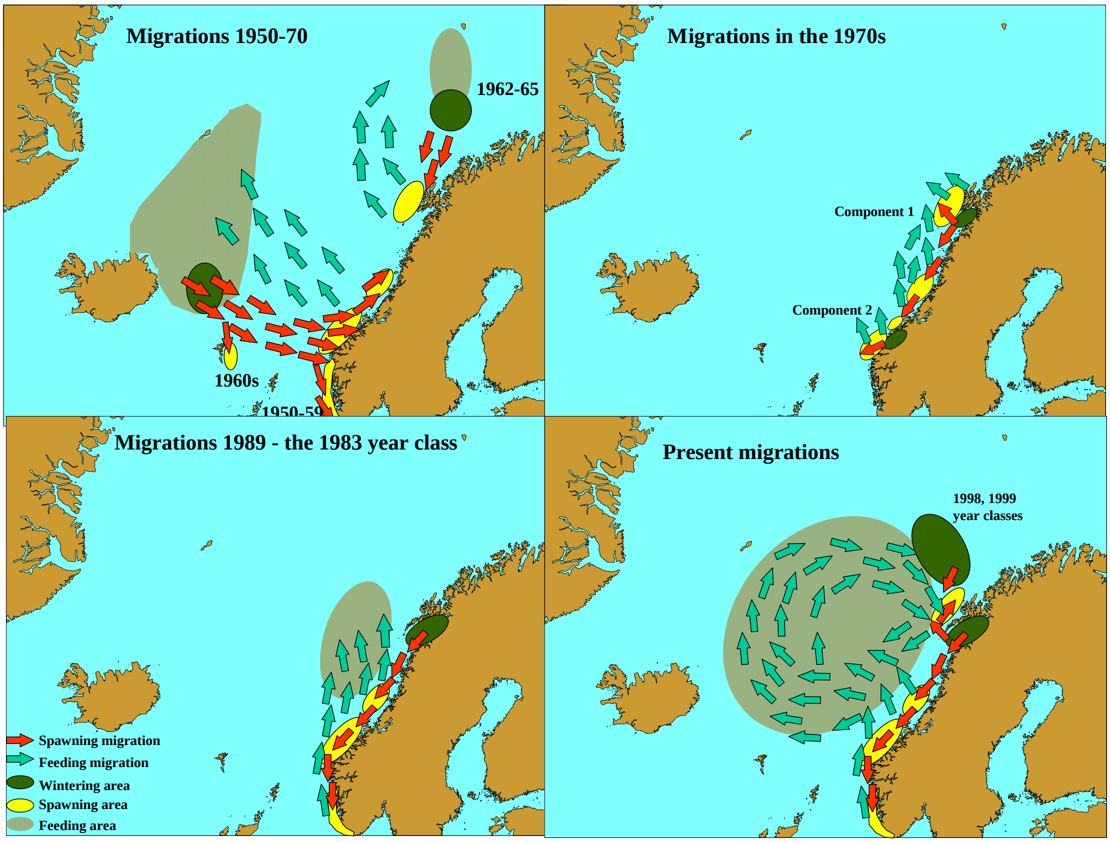

Figure 3.11.5. Schematic overview of historic changes in the adult NSS herring seasonal migration pattern (from ICES, 2004)

The overall distribution of the **North East Atlantic mackerel** stock ranges between the Iberian Peninsula and the Norwegian Sea and changes with life history stage and migration patterns. NEA Mackerel is divided into three spawning components depending on location of their spawning grounds. Spawning of the North Sea component is concentrated in the western and central part of the North Sea in June. The southern component spawns along the coast of the Iberian peninsula between January to May, while the western component spawns along the

European shelf between the Bay of Biscay and the west of Scotland. Timing of spawning is between March and July with peak spawning usually occurring in April to May. Spawning on the shelf is concentrated along the 200m contour line whereby mackerel are migrating northwards and progressively releasing their eggs. This latitudinal propagation of spawning appears to follow the increase of sea surface temperatures in the spring. Geographical changes in the centre of spawning along the western shelf have been observed over the last decades with peak spawning shifting west and northwards (Reid, 2001, Beare and Reid, 2002). Mackerel larvae are found close to the spawning grounds along the shelf edge but can drift and be retained onto the shelf and the Porcupine Bank. Transport and IBM models have shown that location of spawning and ambient circulation patterns influences larval survival (Bartsch, *et al*. 2004)

Nursery areas are generally on the shelf adjacent to coast lines. From south to north, juvenile mackerel have shown to aggregate in close to the Spanish/Portuguese border; Biscay (between 45 and 48° N); Celtic Sea/Cornwall; west and north of Ireland; West of the Hebrides and North edge of North Sea.

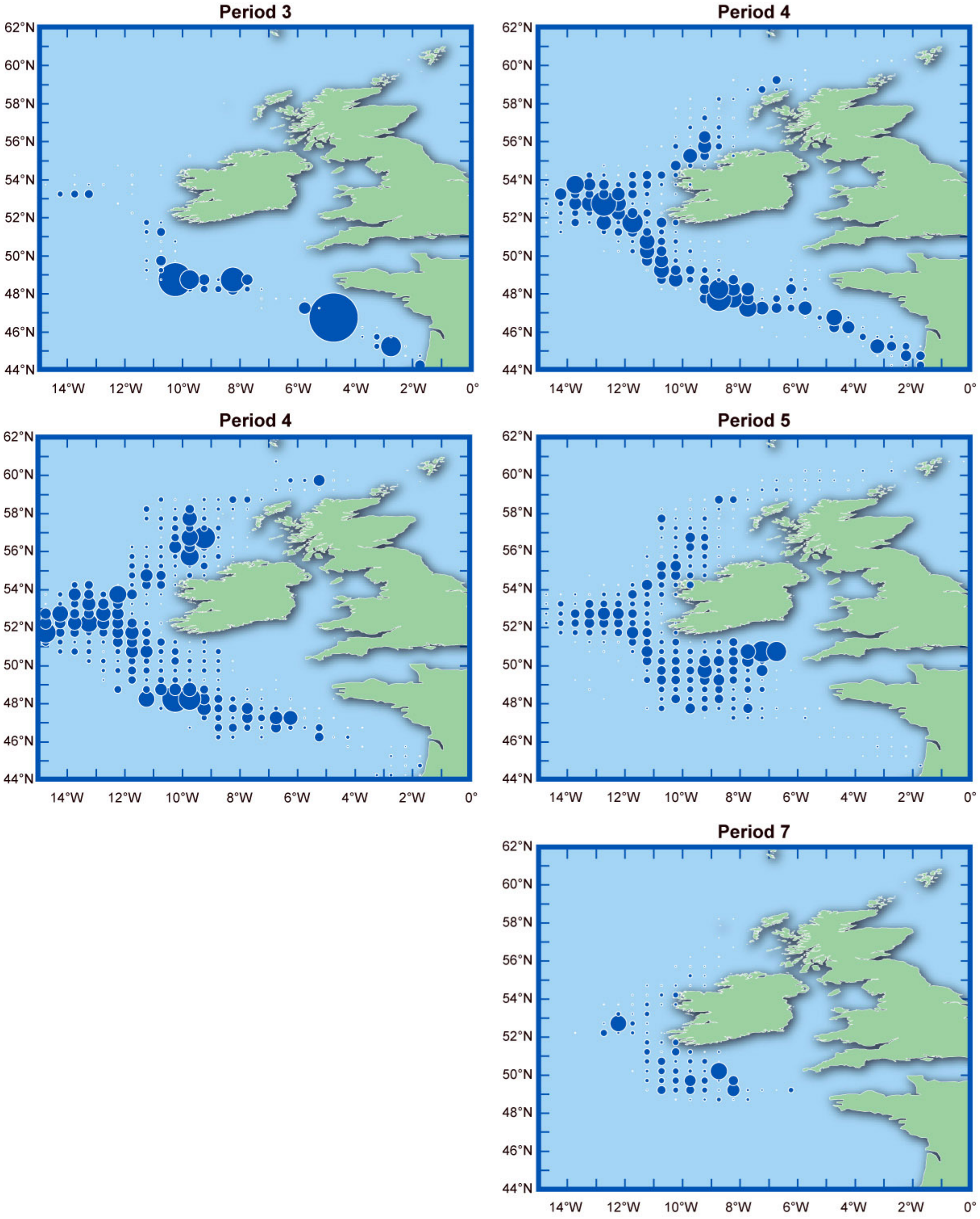

Figure 3.11.6 North East Atlantic mackerel, average distribution of stage 1 mackerel eggs, by period (approximately month) from the ICES international egg surveys showing the variable start in period 3 (March), the consistent distribution with northward movement through periods 4-6 and the end of the spawning south west of Ireland in period 7(July).

After spawning, mackerel migrate to the Norwegian Sea in July and August to their feeding grounds. Overwintering occurs in the northern North Sea before the prespawning migration recommences southwards towards the western shelf in January.

The **western horse mackerel** stock is distributed along the Bay of Biscay, south and west off the British Isles, in the western Channel, the northern North Sea, the Norwegian Sea and the western part of Skagerrak. Like NEA mackerel, western horse mackerel are closely connected to the shelf contour, and shows distinct areas for spawning, feeding and over-wintering. Spawning occurs along the shelf edge from the Bay of Biscay to the west of Ireland between April and July with peak spawning around June.

Migration might be mainly driven by water temperature. In autumn, at a temperature falling below ca. 10°C, T. trachurus retreat from the feeding areas in the southern Norwegian and the North Sea and migrate to the over-wintering areas further south. These are situated in the English Channel (Lockwood & Johnson, 1977, Macer, 1974 and 1977) and along the continental slope (Macer, 1977) in the Bay of Biscay and Celtic Sea (Eaton, 1983, Figure 3.11.7). In winter they form dense schools in deeper water. In spring the fish become far more dispersed (Polonsky, 1965) and migrate northward again with increasing water temperature (e.g. Chuksin & Nazarov, 1989).

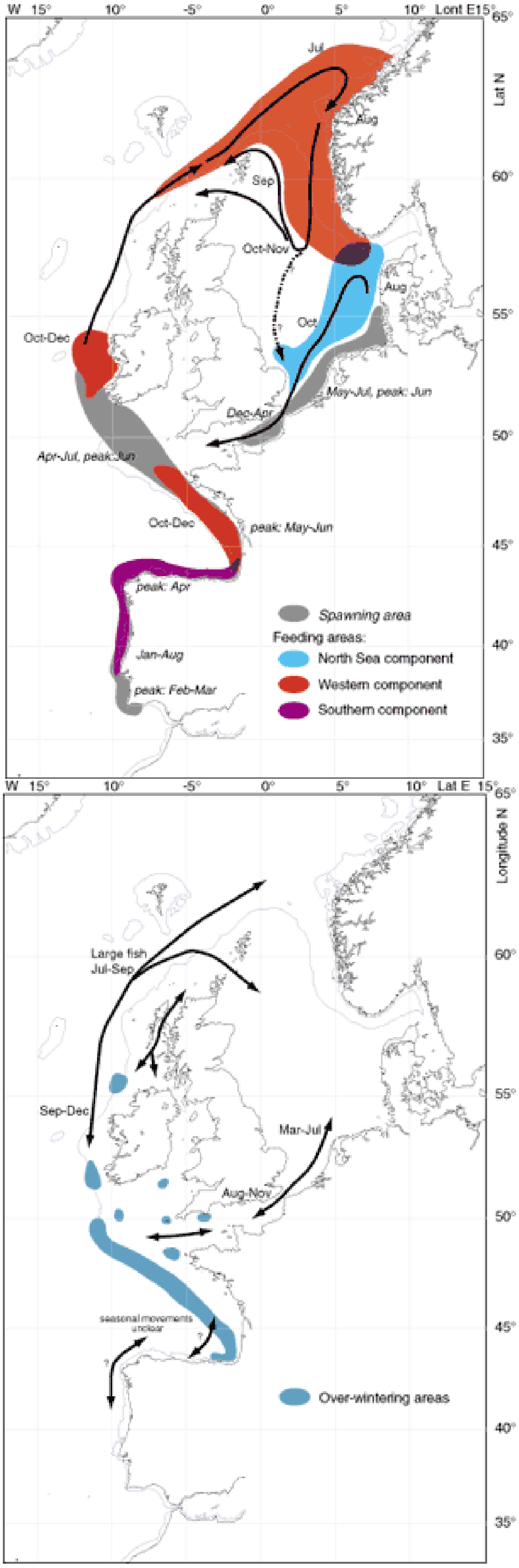

Figure.3.11.7 Schematic outline of assumed migration routes, spawning, feeding and over-wintering areas for the three Horse Mackerel stocks. Depth line drawn is the 200 m contour. For over-wintering areas see Fig. 3. (from www.HOMSIR.org and based on ICES, 1998 and Eaton 1983)

3.11.4 Feeding and school behaviour

The **Blue Whiting** occurs in loose layers or schools that show diurnal migrations; juveniles can occur in the surface waters during night. It feeds by snapping prey. The prey species are crustaceans (large copepods, amphipods, krill), small cephalopods, small fish and fish larvae (Bailey 1982; Monstad, 2004).

The **Norwegian Spring Spawning Herring** form schools of different sizes, or they may occur in scattering layers during day-time. During wintering they are dispersed in layers both during day and night-time, deeper during day than night. Two different layers, may occur, with recruits in the upper and adult in the deeper layer. During the spawning season they occur in dispersed layers close to surface during night, dense layers close to bottom or dense schools closer to the surface during periods of daylight (Slotte, 2001).

Feeding occurs from April to August, with May-June being the main feeding period. During the wintering period (September-January) and spawning season (February-April) they do not feed, but feeding starts immediately after spawning. They feed all over the Norwegian Sea at high stock levels and closer to the Norwegian coast during low stock levels. The feeding seems to occur in a clockwise manner starting in the south going west, north and east, ending up in wintering areas in northern Norway (Misund *et al.* 1998). Herring can feed both by snapping suitable prey and by filtering the sea water. The prey is mainly Calanus copepods, but also amphipods and other zooplankton are taken.

During summer feeding, **NEA Mackerel** cohabit with Norwegian Spring spawners in the Norwegian Sea, whereby their main feeding period is a month later than Herring. During feeding, mackerel occur in small schools near the surface where they feed predominately on *Calanus,* but also on other crustaceans, fish larvae and small adult fish. Recent feeding studies in June /July in the Norwegian Sea showed that *Calanus finmarchicus* was their principal prey item accounting for 53 to 98% of total stomach content by weight (Prokopchuk and Sentyabov, 2006). Mackerel remains as small high schools until aggregation in the overwintering area in the northern North Sea, in October, when it starts to form very large schools in 200m+ water at the western edge of the Norwegian Deeps.

Parts of the **Western horse mackerel** stock move to the southern Norwegian and the North Sea for feeding in July-August. Other parts feed in areas west of Ireland or at the Bay of Biscay continental slopes. Several investigations indicate that *T. trachurus* is a filter feeder, mainly ingesting zooplankton (e.g. Ben Salem, 1988). In the **English Channel** adult horse mackerel were found to forage to nearly 70% on crustaceans and only to 17% on fish, with monthly varying proportions (Macer, 1977). Recent work of Olaso et al.1999) for the **Bay of Biscay** on the diet composition in the southern Bay of Biscay showed seasonal differences: preying on crustaceans dominated during spring, while in autumn T. trachurus > 30 cm began to prey on fishes (blue whiting, gobiids, anchovy), which represented 45% of the food volume in this size-range.

3.11.5 Potential environmental influences

Environmental influences on the fisheries- Increasing temperature and changes in zooplankton communities 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.

Mackerel and **horse mackerel** migrations are closely associated with the slope current, and mackerel migration is known to be modulated by temperature (Reid *et a*l, 2001). Continued warming of the slope current is likely to affect the timing and the spatial extent of this migration. The southwards migration of Mackerel from wintering in the Norwegian Sea/North Sea to the spawning grounds west of Ireland, for example, commences when the temperature falls below a certain threshold (ca. 9C). Thus during warmer oceanographic conditions migration is only initiated once this threshold is reached and southwards movement can be delayed (Reid, *et al* 2001). The postspawning migration northwards to the Norwegian Sea has undergone changes in the last few decades with an earlier migration occurring in recent years (Reid *et al*, 2006).

Eggs and larvae of **Blue Whiting** may be influenced by hydrographic conditions during the spawning season which affect the relative amounts of eggs and larvae drifting to northern and southern nursery areas; a certain spawning area may seed northern areas in one year, southern areas in another (Skogen *et al*., 1999). There is a positive effect of the large inflow of warm Atlantic water to the Barents Sea (as indicated by a positive salinity anomaly on the Fugløya-Bear Island section) on abundance of blue whiting in the Barents Sea one year later (Heino *et al*., 2003).

The strength of year classes as 0-group in the North Sea is only weakly coupled to the strength of year classes in the main Atlantic stock. This suggests either local recruitment or variation in transportation of larvae into the North Sea. Increased inflow of Atlantic water into the Norwegian Sea through Faroe-Shetland Channel (as indicated by a positive temperature anomaly, e.g. Hátún *et al*., 2005) coincides with increased recruitment, although earlier warm periods have not witnessed a similar increase in recruitment.

For **Norwegian Spring Spawning** Herring the inflow of Atlantic water into the Norwegian Sea and Barents Sea (NAO-index) seems to influence the condition and hence fecundity of adult fish as well as the survival of larvae (Toresen and Østvedt 2000, Fiksen and Slotte 2002, Sætre *et al.* 2002). There is very good correlation between environmental changes locally at spawning grounds and nursery areas and the large-scale variations in Atlantic water inflow. The survival of larva is also influenced by changes in currents; some years retention areas may be stronger. It has been demonstrated that the tendency of retention may increase larval survival, i.e., the larvae stay for a longer period in warmer water, drifting slower towards the north (Sætre *et al.* 2002). The environmental conditions also affect the condition of the fish, which again may cause reduced fecundity (Oskarson *et al.* 2002). The strong year classes have occurred in periods of good condition and high temperatures.

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3.12 Oceanic and deep sea area

3.12.1 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 the latitude of Ireland southwards, further north sediment cover occurs to the west of the British Isles. To the west of Scotland, topography is variable with two portions of detached continental shelf – Rockall and Hatton Banks separated from the European continental shelf by the Rockall Trough. The north of this advisory region is marked by the Wyville Thomson and Iceland-Faroe Ridges. In the west, the major topography feature is the mid-Atlantic Ridge (MAR) that follows a sinuous course southwards from Iceland (where it is known as Reykjanes Ridge), to the Azores. At the ridge new oceanic floor is formed and the western and eastern parts of the North Atlantic basin are separating at a speed of 2-6 cm/year. The MAR has a rugged topography with numerous peaks of variable height occurring. Isolated seamounts occur over the whole basin. The European continental slope is comparatively gentle. The western part of the advisory region extends beyond the MAR over north-west Atlantic deep basin. Along the ridge, the Charlie Gibbs Fracture Zone (CGFZ) is a major transversal feature comprising a system of two main parallel deep rift valleys running perpendicular to the main MAR axis at about 52°N. The axis of the ridge south of the CGFZ is about 6° east of that of the ridge to the north. The main flow of deep-water between the western and eastern deep-sea basins of the North Atlantic occurs through these deep channels and affects the whole North Atlantic circulation (see http://www.mar-eco.no). If advisory region K were to be split in the future, the CGFZ might prove a suitable dividing feature.

The general circulation in the epipelagic zone (0-200m) is well understood. A warm current flows from the south-west North Atlantic towards Europe coast with several side branches. Cold currents flow south from the Labrador Sea and Irminger Sea (Figure 3.12.1) and also as a strong deep water flow between Shetland and the Faroes.

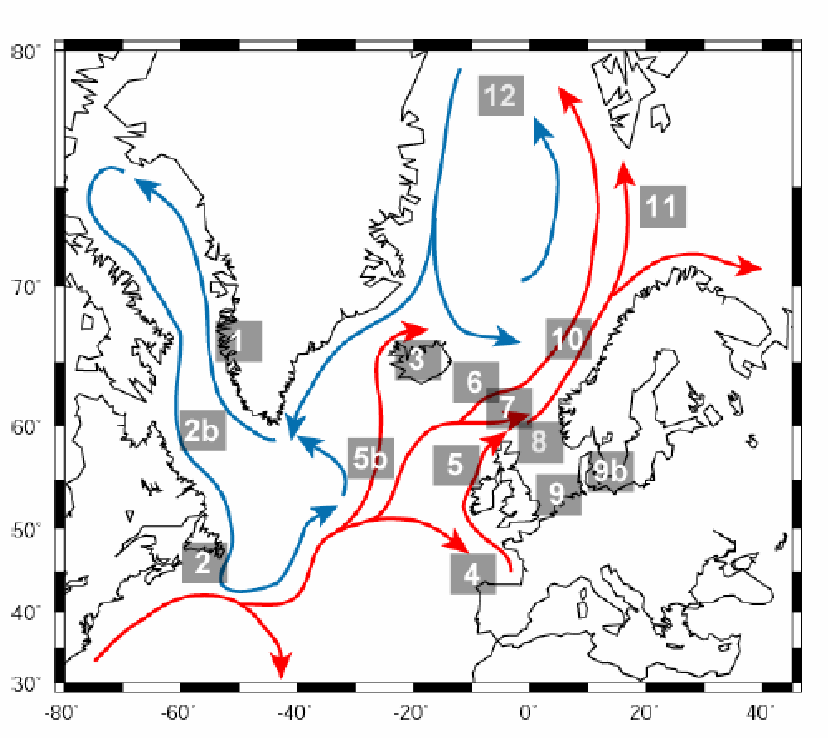

Figure 3.12.1. The general circulation of the North Atlantic in relation to the numbered areas presented in the Annual ICES Ocean Climate Status Summary 2004/2005 (ICES, 2005a). The blue arrows indicate the cooler waters of the sub-polar gyre. The red arrows show the movement of the warmer waters in the sub-tropical gyre.

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

Below about 700m there is little seasonal variation in temperature and spatial variations within the advisory region are small. Average temperatures are 7°C to 8°C at 1000m depth and less than 4°C below 2000m (Figure 3.12.2).

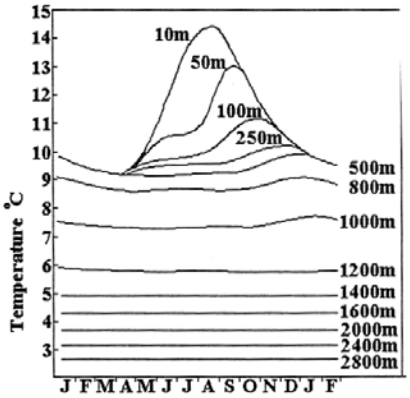

Figure 3.12.2. Seasonal variations of the sea temperature by depth in the Rockall Trough, west of Scotland (Gordon *et al.*, 1995).

At depth, primary production occurs only at hydrothermal vents and cold seeps from chemo-autotrophic bacteria and archaeas either as free cells or symbionts of larger organisms. This primary production is fuelled by the oxidation of fluids flowing from the seabed. Although this deep primary production supports exceptionally dense, diverse and unique communities including animals unknown in any other ecosystem (e.g. vestimentifer worms), these vents are not believed to produce a significant part of the total primary production at the advisory region’s scale.

Photosynthetic primary production at the surface is limited in many areas by nutrient availability. Exceptions exist near seamounts and other topographical features that cause upwelling from the nutrient rich deeper waters. Most primary production in the ocean is limited to the euphotic zone that reaches a maximum depth of 200m. A small proportion (1%-3%) of this surface production may eventually arrive back in deeper waters when phytoplankton and other particles sink forming ‘planktonic snow’ (Gage and Tyler, 1991). This process, together with rare falls of carcasses of large animals and particulate organic matter flowing down slopes from shelves and continental bring organic matter to the deep environment (Figure 3.12.3.). Flux of this organic matter varies both seasonally and from year to year.

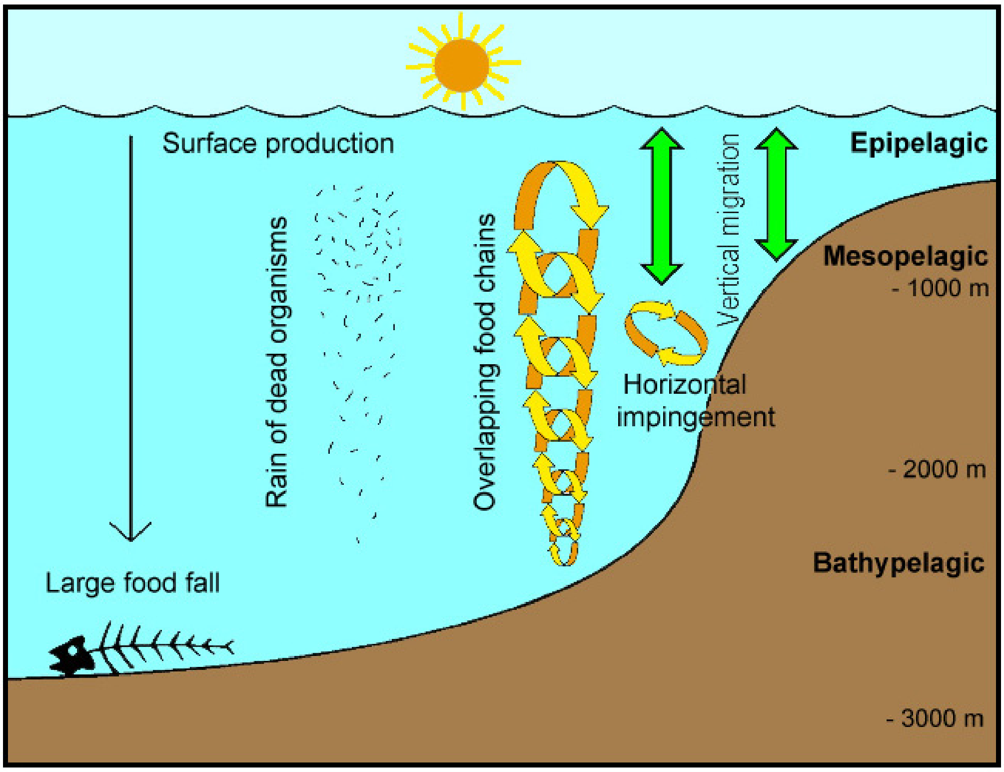

Figure 3.12.3: Trophic transport in the deepwater ocean (courtesy John Gordon, Scottish Association for Marine Science, see also Gordon, 1979).

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 at depth along the slope. 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 total biomass below (Koslow, 1997). Other processes bring food to the fish living along the slope, primarily from elsewhere in the oceans (Figure 3.12.3). Such processes are also involved in the distribution and density of deep water corals (Genin *et al.*, 1986). Fish over the slope feed on meso- and bathy-pelagic fauna brought to the slope by tidal currents (Gordon, 1979; Koslow, 1997).

3.12.3 Broad-scale climate & oceanographic features & drivers

The North Atlantic Oscillation (NAO) is known to control or modify three of the main parameters which drive the circulation in the ocean area covered by this summary (wind speed, air/sea heat exchange and evaporation/-precipitation). The Hurrell index of the NAO (Figure 3.12.4) is 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 an 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 (ICES, 2005a).

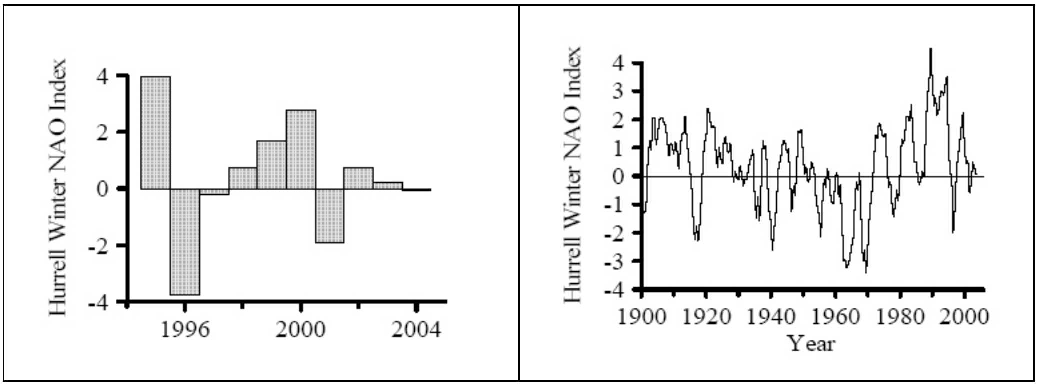

Figure 3.12.4. The winter NAO Hurell index (see text) in terms of the present decade (left) and the last 100 years (right–a two-year running mean has been applied), (from ICES, 2005a). The effect of the NAO on deep layers is poorly known.

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

There is little commercial exploitation of large invertebrates in this region. Deep-water trawling is known to have a small bycatch of cephalopods, the landings are often reported as miscellaneous cephalopods. The crab *Chaceon affinis* occurs at slope depths over the advisory region and is a by-catch of deep-water trawling and netting and a target of pot and net fisheries.

Biogenic habitat occur along the slope, the most well-known of these being formed by the scleractinian *Lophelia pertusa* a colonial coral, which locally forms large bioherms or reefs, along the slope, on the offshore banks (Rockall and Hatton), on the mid-Atlantic Ridge and on seamounts (Figure 3.12.5) (Freiwald, 1998; Rogers, 1999). Many areas remain to be surveyed for *Lophelia pertusa*. Some of these reefs are large, for instance, to the south and west of Ireland several reefs have built mounds of 150 to 200 m height and about 1 km wide are known. The base of these mounds are comprised of dead coral rubble with some infill; live corals grow on top of the mounds.

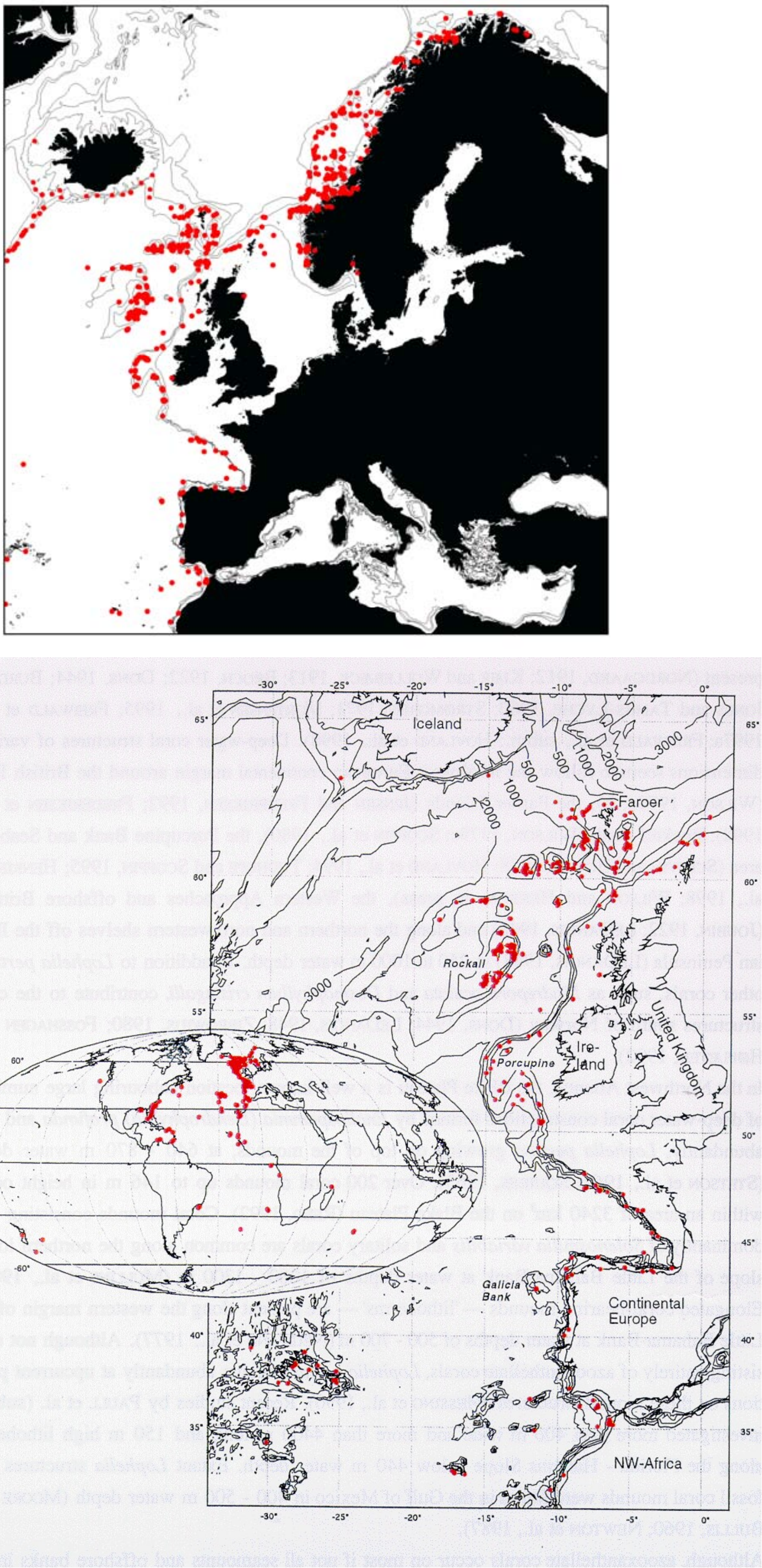

Figure 3.12.5. Distribution of deepwater *Lophelia* reefs in the North East Atlantic and wider (Freiwald, 1998).

A dense and diverse fauna is associated with *Lophelia* reefs. This includes fixed (e.g. anthipatarians, gorgonians) and mobile invertebrates (e.g. echinoderms, crustaceans). The species richness of fauna associated with 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 around corals but possible functional links between fish and coral have proved difficult to demonstrate (Husebo *et al.*, 2002).

3.12.5 Fish community

Large pelagic fish (tunas, swordfish, some sharks) are not considered in this section.

In the advisory region the two major small pelagic species are blue whiting *Micromesistius poutassou* and greater argentine *Argentina silus*. Both occur mainly over the slope and at the shelf edge. Blue whiting is a major prey of some deepwater (e.g. black scabbard fish *Aphanopus carbo*) and shelf (e.g. hake *Merluccius merluccius*) fish.

The mesopelagic zone (200-1000 m) has a high diversity of small fish species with striking morphological characters and adaptations such as large mouths, light organs and specialised 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 a sample catch. The most diverse (number of genus and species) families are Myctophidae and Stomiidae. Many, if not all, mesopelagic fish migrate to feed on pelagic prey in upper water layers during the night. They return to the depths during daytime probably in order to avoid epipelagic predators. This is another mechanism by which nutrients reach deeper water layers (Figure 3.12.3).

A similar, but less abundant, fauna is found in the bathypelagic zone (1000-3000m). Bathylagidae is the most common family, other common families are Platytroctidae and Searsidae.

The demersal deep water fish community includes several larger species. Species composition primarily depends on depth and most deepwater species have large areas of distribution, some being found in both hemispheres and in the Atlantic, Pacific and Indian Oceans (e.g. orange roughy, Alphonsinos., several deep water squalid sharks and smaller non-commercial species such as *Halagyreus johnsonii*).

In this deep water region, dominant commercial species at 200-2000m include species such as ling, tusk, roundnose grenadier, orange roughy and deep-water sharks and chimaeriforms (Table 3.12.1) and other species such as redfish, monkfish and Greenland halibut that are dealt with elsewhere. 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 and most larger deepwater demersal fish are assumed highly vulnerable to over-exploitation, having a low reproductive capacity. For example, the maximum sustainable exploitation rate of orange roughy is estimated between 1 and 2% of the unexploited biomass (Koslow *et al.*, 2000). Most stocks of the larger species are overexploited. Orange roughy, which forms dense aggregations (Koslow *et al.* 2000; McClatchie *et al.*, 2000; Lorance *et al.*, 2002) was depleted in the early 1990s in some ICES areas, in particular off west Scotland and Ireland (Lorance and Dupouy, 2001; ICES, 2004). The blue ling, exploited on the upper slope, was depleted by the 1980s. 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.

Table 3.12.1 Broad distributional description of some important deep water fish in the North Atlantic

SPECIES	LATITUDINAL DISTRIBUTION	DEPTH DISTRIBUTION (M)	OTHER INFORMATION
Blue ling *Molva dypterygi*	79°N - 48°N	150 – 1000m	Found mostly from 350-500 m depth on muddy bottoms
Ling *Molva molva*	75°N - 35°N	100 – 1000m	Occurs mainly on rocky bottoms in fairly deep-water, usually 100- 400 m
Tusk *Brosme brosme*	83°N - 37°N	18 – 1000m	Far from the shore, near the bottom, mostly 150-450 m
Roundnose grenadier *Coryphaenoides rupestris*	67°N - 20°N	400 – 2200 m	Bentho- to bathypelagic in about 400-1200 m depth. Large schools at 800-1000 m
Orange roughy *Hoplostethus atlanticus*	65°N - 56°S	180 – 1809 m	Inhabits deep, cold waters over steep slopes, ocean ridges and sea-mounts.
Black scabbardfish *Aphanopus carbo*	69°N - 27°N	200 – 1800 m	Occurs on slopes from 200m off the British Isles to 1,800m off Madeira
Black dogfish *Centroscyllium fabricii*	68°N - 51°S	180 – 1600 m	Found on the outermost continent. shelves and upper slopes, mostly below 275 m
Portuguese dogfish *Centroscymnus coelolepis*	64°N - 48°S	150 – 3700 m	Commonly found on continental slopes and abyssal plains.
Leaf-scale gulper shark *Centrophorus squamosus*	69°N - 54°S	145 – 2400 m	Found on or near the bottom of continental slopes.

Many demersal slope species are not commercial because they do not reach sufficient size while the alepocephalid are large but have a low palatability due to the high proportion of water in their flesh. At 1000m-1500 m *Alepocephalus bairdii* is the dominant species by 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).

3.12.6 Birds & Mammals

The only breeding birds in the advisory region are on the Azores where, the main species are Cory's shearwater, *Calonectris diomedea* (189000 pairs), 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). These deep offshore waters are visited by migrant birds breeding elsewhere outside their breeding seasons, most are Procellariformes and include northern fulmar *Fulmarus glacialis*, from colonies around the North Atlantic and sooty *Puffinus griseus* and great *P. gravis* shearwaters from the South Atlantic.

The most common among the approximately 30 marine mammals species that occur in the advisory region are common dolphin *Delphinus dephis*, striped dolphin *Stenella coeruleoalba*, long-finned pilot whale *Globicephala melas*, Risso’s dolphin *Grampus griseus*, fin whale

Balaenoptera physalus and sperm whale *Physeter macrocephalus*. Those abundance estimates that exist for these species have wide confidence intervals.

3.12.7 The major environmental impacts on the ecosystem dynamics

The deep sea environment is considered to be less variable than surface systems. Moreover, due to the long life span of exploited species, variations in annual recruitment have a relatively minor effect on the standing biomass so short-term variability in the environment is unlikely to have great effects on stocks. The North Atlantic Oscillation may influence the composition of the deep sea fauna over time. It has been suggested that an outburst of sea cucumbers and brittle stars on the abyssal plain of the North Atlantic might be linked to the extremes of NAO seen in these years. It is not known how global warming might change the deep seas in the longer term.

3.12.8 The major fishery effects on the ecosystem

Modern fishing fleets are capable of causing a very significant reduction in demersal deep water fish biomass in just a few years; a consequence of this has been the collapse of several fisheries (Koslow *et al*., 2000). Along the MAR, roundnose grenadiers were depleted by fisheries in the 1970s (Merrett and Haedrich, 1997).

Populations of large fish that aggregate on oceanic bathymetric features such as seamounts are particularly sensitive to overfishing, due to low productivity and high catchability. On the southern part of the MAR and adjacent seamounts, populations of alphonsinos were depleted also in the 1970s. More recently, longline fisheries appear to have depleted seamounts populations of “giant” redfish on seamounts of the northern MAR (Hareide and Garnes, 2001).

These depletions of dominant species lead to major changes in demersal deep sea fish communities due to the loss of their larger predators and 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 discarded catch is made of smoothheads (Alepocephalidae) because of their high abundance (Allain *et al*., 2003).

Deep-water trawling damages deep sea benthic communities. Over recent years attention has focussed on the impact of trawling on *Lophelia* reefs. Measures to reduce these impacts and to protect some areas have been taken.

Passive gears may also have effects. At least under some conditions (long soak time, hundreds of km of net, deployment over coral reefs) deep-water set nets can also have an impact, both on the fish community due to ghost fishing and targeting vulnerable species such as sharks (Hareide *et al*., 2005). As a consequence, deepwater netting was banned in ICES divisions VIa,b, VIIb,c,j,k and part of sub-area XII in 2006. Long-line fishing can have effects through breaking off branches of coral and overturning large sponges. Long-lines can also have a relatively high bycatch of seabirds.

3.12.9 Concluding remarks

Over the last 15 to 20 years, the deep-water ecosystem has been significantly impacted by fishing as fisheries have extended into deeper waters, driven partly by the overexploitation of shelf stocks. Deepwater stocks typically have a low productivity and therefore sustainable levels of exploitation are much smaller than those of shelf stocks. Many stocks have therefore been over-exploited and depleted within a few years of a fishery opening.

Towed fishing gears have severe impacts on benthic communities; this is a major problem on structurally complex habitats, including biogenic reefs, which have long recovery times. Static netting can also be undesirable as it can generate (i) habitat disturbance, (ii) ghost fishing by dumped and lost nets and (iii) overfishing if too much net is deployed. Therefore deepwater trawling should be restricted primarily to sedimentary bottoms and where possible fisheries should shift to long-lining and closely managed netting (away of coral areas). This switch has occurred in some southern hemisphere fisheries (e.g. the fishery for Patagonian toothfis, *Disostichus eleginoides* around South Georgia and South Shetland Islands).

There are some large gaps in the knowledge of exploited stock structure and biomass. For EU fleets, this may improve with the revision of the EU Data Collection Regulation (Council Regulation (EC) 1543/2000) and the improved on-board observer programme (Council Regulation (EC) 2347/2002). Better reporting of catches and effort data is necessary especially in international waters (NEAFC regulatory area). VMS (Vessel Monitoring System) data for all fleets should be made available to National Research Institutions.

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4 Major environmental events of relevance to fisheries advice

In response to the term of reference

b) 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;

The Working Group decided that there had been little payoff from past efforts in area (see discussion in sections 5 and 6). Rather, it chose to discuss a major overall environmental trend of major significance for many ICES assessments and much of its advice.

4.1 Recent trends in North Atlantic ocean climate and in plankton

The ICES Report on Ocean Climate 2005 (ICES CRR 280) provides summaries of long-term observations of environmental conditions to the end of 2005. The time-series from 29 standard stations and sections across the whole North Atlantic show generally rising trends in sea surface temperature (SST) and salinity. The increase in SST at several of the stations is up to 3^{o}C since the early 1980s. This rate of warming is very high relative to the rate of global warming and probably explains why distribution changes for fish and plankton in the NE Atlantic have been particularly rapid over the past 30 years. Matching increases in salinity indicate that advective processes play a part in the warming.

The North Atlantic Oscillation index during the winter of 2005/2006 was slightly negative. It is possible that the prolonged period of positive NAO which lasted from 1980-2002 is now over, but incomplete data for the winter of 2006/2007 are close to the long-term mean. The NAO is an indicator of temperature and other environmental conditions for the coming spring and summer and therefore influences survival of early life stages of cod (Stige L.C et al., 2006) and other species. In the longer term, most climate models simulate some increases in the winter NAO index in response to increasing concentrations of greenhouse gases (Gillett et al. 2003)

Norwegian waters have never been as warm as present. High temperatures in the North, Norwegian and Barents seas have been observed the last 5-10 years and in 2006 several record-high temperatures were observed. The warming is a result of both higher air temperatures and warmer Atlantic inflow. The result of record high temperatures in the inflowing Atlantic Water is illustrated by the temperature timeseries at 200 m in a coastal station off the Lofoten Islands. The mean temperature in the period from October to December (4. Quarter) along the south-western coast was the highest observed since 1936 caused by a very warm summer and mild autumn weather.

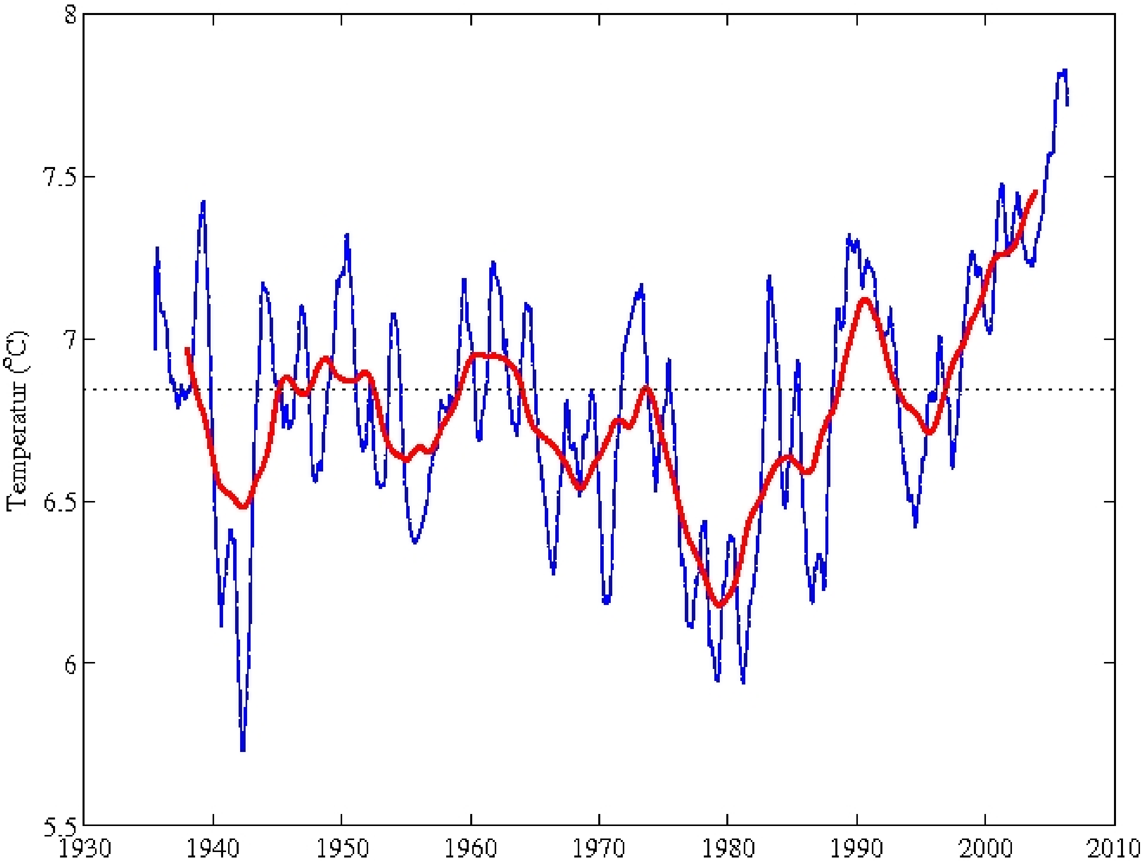

Figure 4.1. Temperature at 200 m depth at Eggum (Lofoten Islands). One year (blue line) and five year moving averages are shown.

[*Comments on presentation, data gaps and updating*. The inclusion of more long-term observation sites for areas such as the Baltic and SW British Isles would help to fill out the picture. Updated information on ocean climate information can be obtained from a number of sources, such as NORSEPP and BSH. It would be very useful to obtain timely updates in future. Daily updates of the NAO are available on-line and much of the winter period index is completed by late February, when this WG meets].

The ICES Report on Zooplankton Monitoring Results in the ICES Area, Summary Status Report 2004/2005 (ICES CRR 281 provides an overview of recent changes in North Atlantic plankton. The Ecological Status report from SAHFOS (Edwards,M.; Johns,D.G; Licandro,P; John,A.W.G. & Stevens,D.P. 2006. Ecological Status Report: results from the CPR survey 2004/2005. SAHFOS Technical Report, 3:1-8. ISSN 1744-0750) provides standard time series of geographic and seasonal information on changes in phytoplankton and zooplankton back to 1946, with analysis of biogeographic shifts, changes in phenology and biodiversity and regime shifts, which are related to changes in fish populations.

Phytoplankton abundance in the NE Atlantic increased in cooler regions (north of 55°N) and decreased in warmer regions (south of 50°N). The effects propagate up through herbivores to carnivores in the plankton food web (bottom-up control), because of tight trophic coupling. Similar effects may be expected for other mid-latitude pelagic ecosystems, because the proposed mechanisms are general and the results for the NE Atlantic are consistent and based on very large scale, long-term sampling (Richardson and Schoeman, 2004).

In the North Sea the population of the previously dominant copepod species, *Calanus finmarchicus* declined and was replaced by southern species (Beare et al., 2002). The seasonal timing of plankton production also altered in response to recent climate changes. This has consequences for plankton predator species, including fish, whose life cycles are timed in order to make use of seasonal production of particular prey species (Edwards and Richardson, 2004). The survival of young cod in the North Sea appears to depend on the abundance, seasonal timing and size composition of their prey. Changes in all of these since 1958 resulted in increased survival and good recruitment of cod throughout the 1960's and 70's and then a progressive decline over the past thirty years (Beaugrand et al., 2003) .

[*Comments on presentation, data gaps and updating.* The time taken to process plankton samples means that data from plankton monitoring are likely to remain at least one year behind until more automated methods of identification and quantification are developed. The data coverage has improved greatly, but could be improved further. It is unfortunate that the Norwegian Sea is not covered by a CPR route.]

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4.2 What this means for fisheries

Implications of the widespread warming (etc) for fisheries assessments and advice

As documented above, the warming in the Northeast Atlantic is widespread from southwest Europe up to the Barents Sea, although less strong in some areas, such as around the Faroes. It is present in more than just the temperature signal, appearing also in many plankton records, reflecting the impact of large-scale forcing by the NAO. What is implied for fisheries assessment and management by a signal this strong, and widespread in space and across lower trophic levels?

Because of the trend and extreme values in temperature and other indices, the full time series of data on exploited stocks in the areas most strongly affected may not be the most reliable guide to the current dynamics of these stocks. Rather, data collected during periods of similar biological and physical oceanographic conditions are likely be a better source of information on current stock dynamics. The last period of intense warming for the North Sea and adjacent areas was in the 1930s and early 1940s. However the history of exploitation of the marine resources in these ecosystems was very different prior to that warm interval. Consequently, the warm regime may have occurred when biomasses of exploited stocks were much larger, and species-interaction processes involved in maintaining community structure and function may have been functioning more strongly as regulating factors. As a result, there is justification to be cautious about assuming that population dynamics parameters from the earlier warming period are the best indicators of the parameters to assume under the present environmental conditions.

As an alternative, it is noted above that a number of environmental indictors suggest that the current warming began by 1985 in at least the southern areas, and even the more northerly areas by the mid 1990s. The mid 1980s were a time when a number of information sources suggest that there was a "regime shift" in at least the North Sea. Hence sound practice in the assessments for the Northern Shelf, North Sea, Channel, Celtic Seas, Norwegian Sea and Barents Sea, would be, where data allow, to examine the components of productivity of each stock – recruitment, growth, maturation, fecundity, and natural mortality - for trend since 1985 in the case of the North Sea, and the comparable year when the warming trend became clear in environmental data from other areas. If evidence is found of a trend or step-change in any of the parameters of productivity, then the continuation of the trend or more recent values would be considered more appropriate assumptions than long-term averages for those parameters. In several areas of the northeast Atlantic, oceanographic variables are currently outside the range of historic observations. In those areas of unknown stock dynamics even extrapolating well documented trends beyond the range of past observations is a risky and uncertain practice – although simply assuming the trend has ceased by using the more recent or more extreme values for the dependent also has its risks and uncertainties.

As noted in Section 4.1 this warming has been noted for some time, and investigations are already underway into some of its possible biological consequences. In the coming year more results are expected to come available, adding substantially to our understanding of its consequences for these marine ecosystems and their components. However some insights are already coming available for consideration.

In particular, evidence to date indicates that where it has been studied, the changing environmental regime is having a greater impact on recruitment than on growth or natural mortality. Moreover, the effects of the environmental change on recruitment appears to be strongest for stocks in the southern end of the ranges of species with generally more northerly distributions. Several of these stocks appear to have been experiencing consistently poor recruitment in recent years. Research is underway to clarify the mechanisms linking the recruitment trends to the oceanographic ones, but predictive models currently produce highly uncertain forecasts of recruitment. At this time direct survey indices of incoming recruitment are considered more reliable than model-based predictions of recruitment, particularly when the models are merely statistical fits of trends in recruitment to trends in temperature or other environmental variables.

Another major response of fish populations to changing temperature regimes – or responses of plankton populations to the temperature changes - is simply changes in distribution. Although causal mechanisms are not fully worked out, sections 3.9 and 3.11 contains examples of changes in the distribution of some species in the northeast Atlantic that seem to be consistent with responses to changes in temperature regime. For example, there is clear evidence that mackerel have altered their spawning grounds in recent years, and the timing of migration, and both can be related to the changing water temperatures to the west and north of western Europe (see section 3.11).

There are also major changes in fish species composition in the area, such as the dramatic increase in the abundance and northward distribution of Snake pipefish (*Entelurus aequoreus*) since 2003, with its area of distribution now including the Atlantic water along the west coast of Spitsbergen and in the Barents Sea (Harris *et al.* 2006). In this case, though, the the linkage between the increase in abundance and the increase in temperature of the Atlantic water is less clear. Outbreaks of snake pipefish have occurred in the past, without similar anomalously warm water conditions. However, that does not mean the current warming conditions have not been a factor in the present outbreak. However changes of this nature are important to an ecosystem approach to management and advice. For example snake pipefish seem to be taken by a wide range of seabird species, but seems to be associated with poor breeding success in UK breeding colonies (Mavor *et al.* 2005, 2006, as cited by Harris *et al.* 2006).

Implications for fisheries advice and management really require case specific knowledge that is rarely available. For example, sardine and anchovy are being taken in commercial quantities in the southern North Sea and even the Baltic in 2006. Are these catches part of the productivity that is supposed to be supporting the yields advised for the traditional fisheries in Divisions VIII and IX, or is it "new production" that is not accounted for in the ICES assessments and advice?

WGRED has no answer to that question, but its answer is important for the advice on these stocks. A precautionary approach would indicate that until there is evidence that the harvests in these new areas are not from the production estimated for the "historic" stock, they should be included in the total harvest from the assessed population. The example highlights that management regimes need to be adaptive and flexible, sometimes on time scales as short as within a fishing year, in order to respond to new circumstances that may arise from stocks that have changed distribution, catchability, or productivity in response to the changes in the ocean environment. The management regime has to be genuinely precautionary, as well, in the sense that it must react proactively to evidence of change. Management should act to ensure risks of harm to stocks are kept low,, without waiting for science to provide definitive advice with full documentation of the causes of the observed changes and complete analyses of all their implications.

Another consequence of fisheries on stocks whose distribution has changed in response to changing environmental conditions is that the ecological footprint of the fishery may change, even if the yield is properly attuned to the current productivity of the stock. By fishing a stock in a different place, or in different seasons, mixed species aspects of fisheries advice and management may have to be changed, to reflect the catch composition of the relocated fishery. The footprint does not stop with the mixed fishery considerations, either. If a fishery moves to chase a stock responding to new temperature conditions, the composition and magnitude of bycatches may be different, as may the effects of gears on habitat features and communities. These impacts could be quite large if the fishery moved into new areas that do not have a history of being fished with the gears that will be used in the relocating fishery ICES currently has no framework for advising on these larger aspects of fisheries, although WGECO has been developing components of such a framework for some time. However, the effects are likely to be real, and will need to be considered in when ICES begins to provide integrated advice.

There is a final consideration in the implications of changing temperature regimes for fisheries advice and management. In the past century, other warm periods have come and gone, and the fish communities have persisted without any documented irreversible changes. This is taken as evidence of some resilience of the communities to environmental perturbation. However, past warm periods preceded the major reductions in biomass, age composition, and possibly spawning subpopulation structure of many of the commercially exploited stocks. The full degree to which excessive fishing in the recent decades has reduced age and size composition of exploited stocks, and the diversity of spawning and feeding areas is still being documented. However, if the past resilience of the fish community and individual stocks to environmental anomalies depended in part on the broad age composition and diversity of spawning units, their resilience to the current extreme warm event (or trend) may be much lower than observed in the past. This concern again suggests a highly precautionary approach to management would be justified, until there is more evidence about the resilience of these systems.

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5 Harvest Control Rules that Consider Environmental Variation

The Term of Reference was to:

> 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.

When this Term of Reference was developed, there was no expectation that WKEFA would be established and meet in 2007, and it had been announced that SGMAS would be taking an extended break. Given the mandate and plans of WKEFA and the expectation that SGMAS will convene in 2008 to consider the results of WKEFA however, WGRED concluded that it would be premature to provide specific recommendations for harvest control rules taking account of environmental factors. WGRED still believes that control rules taking account of environmental conditions are likely to be necessary for many stocks, if ICES is to conduct its work efficiently and provide its advice in an ecosystem content. However the results of WKEFA and the subsequent take-up by SGMAS will provide a more focused and sound basis for developing such rules than is available now.

WGRED did consider the harvest control rule for northeast Arctic cod, capelin and herring, as described in Tjelmeland (2005). The "rule" is actually a complex multispecies fishing strategy, where optimal exploitation rates for cod and capelin depend on the state of the herring stock, as well as each other's state. The rule is supported by a complex simulation model where cod stock dynamics is modelled with functional relationships to predation on early life history stages by herring, feeding conditions for juvenile and adult cod, cannibalism, and ocean climate. There was neither time nor expertise to critique the underlying model in depth, nor was such a detailed review considered necessary for the needs of WGRED. Rather, it was agreed that such a model illustrates that it is feasible to develop simulation models and control rules that do include effects of both environmental conditions and biotic relationships, bringing substantial ecological knowledge into the exploration of management strategies, assessment of stock dynamics in a multispecies context, and producing results that are directly applicable to management needs.

WGRED did note that development of the current generation of the assessment model (BIFROST) and control rule is the result of some 20 years of dedicated effort by its developer. Similarly, the progress made by the GLOBEC team reviewed in section 6 required a full-time scientific coordinator for nearly 10 years, and substantial contributions of collaborative effort by scientists throughout the ICES community. REGNS also must have required in aggregate at least two decades of scientific person-years of effort, spread among the many participants. Both REGNS and GLOBEC have reached the point where their results can be picked up by those bringing ecological relationships into assessment models and control strategies, but neither project has actually even made that step. It is possible that had there been more emphasis placed on having these large research teams give priority to applying the knowledge that they were acquiring to assessment and harvest management questions, we would be somewhat farther along, but there would have slower progress elsewhere in the project as a consequence.

WGRED discussed the spectre that a message from these projects is that whereas it is feasible to bring ecological knowledge of the dynamics of sets of stocks to the point where it can be applied in assessment and management, each case would take comparably massive investments of scientific effort and expertise. With the ICES scientific community, including WGRED, in agreement that process-based explanations of patterns are much preferred to correlations as a basis for scientific advice, does this mean that progress on implementing an ecosystem approach in ICES will be actually as demanding and slow to progress as some critics of the concept have claimed? WGRED expresses cautious optimism that from these major initiatives, some generalizable lessons are being learned. Just as the classic approach to single species assessment and advice did not have to be reinvented for every stock, perhaps we are on the verge of learning tactics and strategies from these intensively explored cases that will make application to additional stocks, species, and ecosystems move much more swiftly. But that is optimism, however cautious, and not a certainty. Moreover, it was noted that these comparative successes are all "good case" scenarios, because some of the environmental relationships are particularly strong (especially for the Barents Sea case), or there many replicate stocks for comparative work (GLOBEC) and the cases are comparatively data rich compared to many other areas.

It is clear that if ICES is serious about placing its assessments and advice into an ecosystem context, that is not going to happen by having most of ICES continue business as usual while a few working groups somehow develop and apply new suites of much more complex – but scientifically equally sound – tools for ecosystem approaches to each step in developing advice. ICES – and the national laboratories - have to fully commit to this framework as the foundation for their science efforts, if the policy commitments that have been made to the ecosystem approach in the Bergen Declaration, the Common Fisheries Policy, the EU Marine Strategy, and many other policy documents including ICES own centennial Copenhagen Declaration are to matched by practices in science and management. It is important to make these commitments real, but it is also important to step back and consider what really matters in the short term.

In the short term many fisheries and ecosystems in the ICES area face serious problems, sometimes crises, that require urgent action. Many of the necessary actions do not require waiting for the scientific framework for an ecosystem approach to be ready. ICES advice has been stressing that for many stocks Fishing Mortalities are too high and Spawning Biomasses are too low. Every year more stocks require recovery plans, and not enough recovery plans are leading to "rapid and secure recovery" – which was to be their goal when they were developed. Poor fishing practices, including discarding, and misreporting contribute to depleted or declining stock status. Based on discussions in section xx, it is likely that the "downstream" effects of the fisheries on the ecosystem may be a much greater concern than the "upstream effects" of the environment on stock dynamics for many stocks. Significant progress can be made on all these major and urgent fisheries problems without waiting for an ecosystem approach to assessments and harvest control to be fully developed.

WGRED concludes that whatever else ICES does in terms of continuing to build the scientific foundations for an ecosystem approach to management of human activities in the seas, ICES advice should begin to focus on thorough, professional, and balanced treatments of some of these major issues in conservation and sustainable use of marine ecosystems. WGRED **recommends** that the Advisory Committee(s) start in 2007 to pick one major issue each year as a focus for work by Expert Groups during the coming year and as an introductory section of the annual Advice. WGRED further **recommends** that the first such theme be overfishing, where "overfishing" is defined broadly to include the total mortality being inflicted on the stocks by the fisheries as reported catch, un-reported catch, discards, and other ways that the fishery causes mortality to the stock. WGRED would play a central role in pulling together the document of the "upstream" aspects of the issue; in the case of overfishing, consolidating all the evidence on what Fs and total removals really have been across stocks and regions, and how biomasses have trended. WGECO would play a central role in providing an evaluation of the effects of the excessive fishing mortality (or other issue) on the marine ecosystems. Depending on the issue many other Expert Groups in ICES could make significant contributions to give the Advisory Committee(s) the scientific foundation for its discussion of the issue and provision of advice as needed to address it.

Such a focus of ICES advice on major issue would not create unnecessary public controversy. Public debate of these issues is necessary, appropriate and is already going on. Unfortunately, it is often fed by science "advice" with a strong advocacy bias for some preferred outcome. ICES would provide the invaluable service of providing the type of balanced and sound advice needed for informed dialogue on the complex bmanagement decisions that really matter.

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6 Implications of GLOBEC work for other ICES Expert Groups

For the Term of Reference

> e) "Review the progress made by the Cod and Climate Change iniative 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."

When this Term of Reference was developed, there was no expectation that WKEFA would be established and meet in 2007. Given the mandate and plans of WKEFA, however, WGRED concluded that it would be premature to provide specific recommendations for changes to existing Terms of Reference for Expert Groups, or new ones, to guide Assessment and other Expert Groups in taking more direct account of environmental considerations in their assessments and support for advice. WGRED still believes that changes or addition to Terms of Reference are likely to be necessary for ICES to conduct its work effectively and provide its advice in an ecosystem context, but the results of WKEFA will provide a more focused and sound basis for making such changes than is available now.

The GLOBEC CCC project has provided many results that need to be taken into account in ICES assessment and advisory practices, with regard to how environmental conditions may affect recruitment, growth, survivorship, and maturation of cod. Many of these results have already been published in the scientific and technical literature, and a list of websites where some of the key documents can be downloaded is provided below. WGRED was informed that some of the case histories planned for WKEFA will be cod stocks that have been studied in the CCC project, providing a mechanism to go from research to practice.

The emphasis of GLOBEC on studying processes and not just documenting correlations is valuable. It provides a scientific basis for assessment and advice on management taking ecological processes and relationships into account, rather than just assuming that observed trends will continue. There are some precedents already for assessment models including life history and ecological processes in their algorithms, for example Northeast Arctic cod and capelin (see Section 5), and this seems a natural pathway of advancement for placing assessments and advice into an ecosystem context. Such development can be made taking account of the general GLOBEC CCC results that effects of environmental conditions on stock productivity dynamics are more pronounced and important for stocks on the extremes of the species' range than stocks near the center of the species' range. That general rule of thumb might help keep the assessment models as simple as possible without being so overly simple that they leave out crucial components of stock dynamic. By focusing on the ecological aspects of the population processes in building the new generation of assessment models, it might also increase the likelihood that “the environment” is thought of in broad and integrated manner, rather than simply as set of covariates (or just the single covariate of temperature) to relate statistically to other terms in the assessment model.

However, putting more realistic ecological processes into assessment algorithm is not the only possible pathway for including effects of environmental conditions on stock dynamics in assessments and advice. The growing use of Management Strategy Evaluations to develop control rules and harvest strategies provides another pathway that is at least likely (or more so) to improve ICES practices and advice. As already acknowledged in past reports of SGMAS (2005), WGECO (2006) and WGRED, environmental considerations should be part of the Objectives which the management strategy is trying to achieve, the Operating Models and Assessment Models that are being explored, and the factors against which robustness of different management rules are tested. Again, WKEFA will be looking at all these aspects of Management Strategy Evaluations in terms of environmental considerations, so it is premature to make specific recommendations for practice in this area as well. However, it is appropriate to stress that serious attention should be given to exploring control rules that may include trigger points for states of the environment, such that one harvesting strategy or exploitation rate may be applied for one set of environmental conditions, whereas when the environmental conditions move beyond some limit, a different strategy or exploitation rate would be applied.

Such a conditional control rule approach does provide a new focus for interrogating the large data sets of time series of environmental variables and measures of stock status. When Limit Reference Points were being sought for Spawning Stock Biomass (SSB), fitting a stock-recruit functional relationship to all the historic data, by itself, rarely solved the problem of selecting an appropriate reference point (ACFM 2002). Other more specific analyses of stock productivity at low biomass were usually necessary. In a similar way, looking for an overall relationship between an environmental feature and properties of stock productivity may not be a particularly efficient way to determine where to locate a trigger point for switching a control rule. Rather, this approach encourages analyses that directly ask how risk of something undesirable (poor recruitment, poor growth, increased non-fisheries mortality, altered catchability or bycatch rates, etc) varies with environmental conditions. If risk of very poor (or good) productivity does increase markedly under certain environmental and/or biological conditions, these conditions could be effective trigger points for conditional control rules. Such rules would be more effective in ensuring that ICES advice is robust to the occasional environmental anomaly; circumstances where advice based on assuming “typical” conditions could go badly wrong with severe consequences for the resource.

There is another pathway that WGRED also feels is worth exploring, with regard to bringing environmental considerations more effectively into assessments, advice, and management of fisheries. Spatial management tools are becoming used frequently in fisheries management, and as the EU Habitats Directive and general considerations of protecting sensitive and vulnerable habitats grow in importance for fisheries management, they are likely to become even more common. From the outset, science advice on their size, location, and management measures within them should developed in the broadest possible context. Combining knowledge of the life histories of both target and non-target species with knowledge of the bathymetry, hydrography, and species composition of the whole area in which management is occurring may help to guide the application of spatial management tools to address at least partially a number of fisheries problems, including mixed catches, discarding of small fish, and environmentally related changes in distribution, plus the effects of the fishery on the ecosystem itself.

One more message emerged clearly from the WGRED discussion of the results of the GLOBEC CCC results (e.g. Brander 2005; Ottersen et al. 2006) Without question the environment does affect the productivity of fish populations, but the effects will be subtle and/inconsistent for many stocks. Most will take substantial time to document fully, and many will be hard to incorporate readily in assessment algorithms and sometimes even harvest control rules. Where the effects are fairly small, or only manifest infrequently under anomalous environmental conditions, if stock biomasses were large and exploitation was at sustainable rates, the stocks would be resilient to such effects. With a resilient stock the risk of dealing with the environmental conditions reactively (i.e. – just deal with them once we see that they have occurred, which is the *de facto* strategy at present for ICES assessments and advice) would be small. The stock might suffer a drop in productivity and a brief increase in exploitation rate, but for a healthy stock being exploited at a cautious (not even precautionary) rate, these negative effects would not be serious and should be readily reversible in the short term. Under current stock sizes and exploitation rates for many stocks in the ICES area, however, there is little margin for assessment or management error without harm to the resource that is potentially serious and difficult to reverse. Hence one clear message from this review is to reinforce a message that ICES has already been sending – reduce F and allow stocks to rebuild to large and resilient spawning biomasses.

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SGMAS report – 2005

WGECO Report 2006

7 Additional matters for ICES consideration

During the deliberations of WGRED, and joint meetings with AMAWGC and PGWKEFA, several matters arose that WGRED would like to have considered within ICES.

7.1 The value of some specific indicators / information from other ICES Expert Groups

The form and content of the Overviews prepared or updated annually by WGRED are maturing, as we benefit from wide feedback on the usefulness and clarity of the Overviews, and learn from each other's good ideas. At this meeting we noted that there is potential for confusion because in trying to report recent status and long-term trends in some key ecosystem components, it is very difficult to find trend indicators that are developed in comparable ways across the different ecoregions.

The inconsistencies are particularly acute for indicators of primary production, which we think is particularly valuable to report in the overviews. Differences in productivity across ecoregions help to scale many other differences which we would like to discuss in an integrated, basin-wide Overview, and changes in productivity over time within an ecoregion are signals that are important to discuss. With input from regional experts we can locate indicators of primary productivity for most ecoregions, but the nature of the indicators vary widely – some total production, some new production; some for a local monitoring area, some from integration of satellite measures over large areas; some annual, some for restricted parts of the year. Even if we were not doing any integration across ecoregions in our Overviews, the situation invites misinterpretation by clients reading multiple overviews.

WGRED considers that it would add noteworthy value to the quality and consistency or our Overviews if the ICES Expert Group considered most qualified (we hear that WGPE is being re-established) were tasked to provide an annual value of primary productivity for each of the ecoregion.

WGRED stresses that it does not intend to create large new workloads for scientists in other Expert Groups, but suspects that somewhere in the scientific community, work towards that end is done anyway. Our preference would be for an annual indicator of total primary productivity (new and regenerated), considered more or less representative of trend and scale at the ecoregion level. Our discussions are always about major anomalies from average or recent trend, and major differences among ecoregions. Hence we do not need exceptionally high accuracy, precision, and spatial resolution, simply something good enough to discuss major patterns. Were an appropriate Expert Group to agree on such an indicator, provide a recent historic time series, and then update it on an annual basis, the content and consistency of our Overviews would be improved greatly.

WGRED considers the same deficiency exists for an indicator of status and trend in whatever constitutes the major zooplankton taxa in each ecosystem. WGRED recognizes that an indicator of "zooplankton" for a whole ecoregion, that can be compared to indicators of "zooplankton" for other ecoregions, is an ambitious and possibly vague concept. However, we are well aware of the critical role that zooplankton play in the status of any ecosystem, and that exceptionally high or low productivity at that level would be a significant ecosystem signal. It would be a great value to WGRED to at least have WGZE, or another expert group as appropriate, discuss this need in our Overviews, and provide their suggestions for how it could best be treated by WGRED. If there is some preferred way to report annually on status of zooplankton (production above all, from our perspective) in each ecoregion, using values that can be compared for trend over time within each ecoregion, and ideally have some meaning when compared across ecoregions within a year, that would be useful. It would be even more useful if the proper Expert Group of ICES not only identified the preferred way(s) to report annually on status and trends in "zooplankton" but provided the necessary values for our use each year.

WGRED also noted the significant value of the report on status and trends of hydrographic conditions that is produced by WGOH. This report is invaluable in allowing the Overviews to contain concise and up to date information on the core physical oceanographic features in each ecoregion and to present that information in ways that allow informed contrasts to be made across years and ecoregions. WGRED does call attention to the need for this information specifically on the scale of the "Celtic Seas" (Irish Sea, west of Scotland, west of Ireland and Celtic Sea) and for "Greenland" (as defined for the Overviews), since coverage for these regions is presently somewhat limited. Some possible sources of additional temperature and salinity time-series data for these particular regions has been included in this years WGRED Overviews, for example long-term sampling stations in Ireland, the UK and Isle of Man.

WGRED also notes that a particularly informative trend indicator would include both the long term mean and measures of the confidence intervals or standard errors around the mean. That way events that moved "significantly" outside the range of historic information would be strongly highlighted, facilitating discussion in the narrative, and among readers of the overviews.

7.2 Consequences of the conclusion of REGNS

WGRED found the products from REGNS to be extremely valuable as a source of information and figures for the North Sea Overview. More importantly WGRED found the REGNS products to be a source of insight into how to achieve the sorts of integration of diverse pieces of information that make the Overviews most meaningful and informative. WGRED considers the process and products of REGNS clearly justify the major investment of scientific expertise and effort that was invested in it. However, REGNS is now over, and that poses several concerns to WGRED.

7.2.1 Custodianship of the final REGNS databases.

A large amount of the effort expended in the REGNS process was identifying what time series were available or could be constructed and how they could be structured to be sufficiently inter-compatible that integrative analyses and comparison could be conducted. Now that those data bases of time series exist, they will rapidly lose value if a process is not instituted for keeping them up to date. The effort needed for this task is very small compared to the effort required to construct them, but there are no mechanisms in place to ensure that the time series will be updated and kept available to the scientific community for the many more uses that can be made of them. WGRED discussed several options for ensuring the effective custodianship of these databases, and did not settle on a single preferred option. However WGRED agreed strongly with the importance of ensuring that arrangements are made for keep the existing data base of time series up to date and accessible. WGRED **recommends** that Consultative Committee, MCAP, and the Secretariat treat this matter as a high priority and develop such a plan and implement the necessary mechanisms this year.

REGNS produced several products in their integrative work that have been taken into the WGRED Overviews for the North Sea. These products are expected to continue to be central to the Overviews, as the type of concise and integrative information that the Overviews strive to convey. These figures will rapidly become obsolete if the analyses are not repeated annually (or close to annually). Actually conducting the analyses would be straightforward for an appropriate group of experts, as long as the databases were being kept up to date (see above). However the proper Expert Group to conduct the periodic updated reanalyses is not straightforward. WGRED could certainly conduct and interpret the analyses as part of their annual work to update the Overviews. However the changes being proposed for the entire advisory process pose the possibility that a great deal of the integration that will be in the advice will be done at the level of what are now the Assessment Working Groups. If that is the case, then it would also be reasonable to expect the Expert Group for the North Sea to conduct these analyses, as an activity central to ensuring that their products were indeed integrated. WGRED **recommends** that ConC and MCAP discuss these two options in the context of the changes in the advisory processes, and ensure that one or the other (or an alternative that is superior to either) is implemented for 2008 and beyond.

In its consideration of the REGNS products WGRED agrees that REGNS took the task of advancing the capacity to conduct integrated assessments of the North Sea marine ecosystem as far as could be gone with the data bases, tools, and ideas available at the time. The products and final analyses can be taken as “best practice” for an integrated assessment of the North Sea under the present conditions, and should repeated periodically as noted in xxx.b. However, science is an iterative process, and the process and products of REGNS are expected to prompt more science, more discussions, and more analyses. Additionally there are always advances in monitoring and new data sets coming available. Some replacement for REGNS is a priority, to ensure that work on further developing integrated assessment approaches for the

North Sea do not cease. The follow-up initiative is not expected to be as resource demanding as the REGNS process, at least in the coming years, but the momentum developed by REGNS should not be lost. WGRED **recommends** that ConC ensure some provision is made within the ICES Expert Groups to ensure that progress continues to build on the strong foundations built by REGNS.

In addition, the data sets and analyses provided by REGNS provide significant opportunities for many other Expert Groups in ICES to draw on new data, information, and insights; increase the scope of their investigations and activities; and add further value to their own work and the work of REGNS. WGRED **recommends** that ConC and MCAP ensure that as many Expert Groups in ICES as possible be encouraged to consider the final REGNS Report and products in detail, with regard to what uses they can make of the REGNS work, and what opportunities they see for follow-up to maximize the benefits of the investments made in the REGNS process.

As noted in c) REGNS has been completed for the North Sea, and many valuable lessons have been learned. WGRED considers the exercise to have justified similar attempts at integrated assessments, and notes the on-going work towards those ends in the overall BSRP initiative. WGRED concludes that it is very unlikely that the final analytical approaches settled on by REGNS for the North Sea could be transferred directly to any other ecoregion. There will always be differences in the types and amounts of information that is available, and in the dynamic processes and relationships that determine the major properties of the system, that are important enough to warrant thorough consideration in planning and developing the best approach to an integrated assessment of the system. However, WGRED feels that with each success lessons are learned that makes the next integrated assessment more tractable and less demanding of developmental resources, although development of a credible integrated ecosystem assessment will always require a commitment of time from a diverse team of experts collaborating for more than just a few workshops. Without question, however, the ends justify the investment, especially if ICES and its clients are serious about adopting an ecosystem approach to their work. WGRED **recommends** that planning commence within ICES to develop an integrated ecosystem assessment for another ecoregion within the ICES area, building as fully as possible on the experiences with REGNS and BSRP. With the information available to its meeting, WGRED considers it likely that the Norwegian Sea and/or Barents Sea would be particularly amenable to be the next initiative of this type for ICES.

7.3 Maps of fishing activity.

In preparing the sections of our overviews on ecosystem effects of human activities, we noted the value of a map of fishing activity that was available for the Barent's Sea, based on VMS data on vessel activities. It would add greatly to preparation of the Overviews if similar maps could be provided for fishing activity of each major gear type in all ecoregions. The ideal would be one map per gear type per ecoregion, integrating fishing activity across the entire year. Sources would include VMS data, and all the other sources of information that are available on intensity and location of fishing activity. The integration of effort within a gear type across an entire year and ecoregion should ensure compliance with all national and European provisions of confidentiality of information about individual fishing vessels.

7.4 Analysis of the footprint of fishing

WRED noted the analysis of the total footprint of fishing activity (that is all the direct and indirect consequences of fishing on the whole ecosystem) in the North Sea that was done by WGECO. It was a valuable source of information for preparing the North Sea Overview, and will be mined more fully in future Overviews. WGRED would strongly encourage that similar analyses be undertaken for the other ecoregions. WGRED sees value in the analyses being done next in the Celtic Seas, the Bay of Biscay and western Iberian Seas, and to north in the Norwegian and Barents Seas. Noting the work involved we do not expect them all to be done at once, and our preliminary discussions suggest that the necessary information might be available most readily for the Norwegian and Barents Sea.

7.5 Terms of Reference for next year.

Given the direction in which ICES seems to be heading with WKEFA, SGMAS, SGRAMA and the activities of the assessment Expert Groups, WGRED is seeing relatively little value returned for effort in continuing to emphasis identification of "major annual events", although we would continue to do so when something really noteworthy happens. We would see much more value in being tasked to prepare key inputs to the annual "Issue Discussion" that we recommend in Section 5, should MCAP agree with such an addition to the annual integrated advice. We would also see substantial value in follow-up work to whatever comes from the WKEFA report, although it is premature to specify a particular term of reference until the workshop has completed its work.

With regard to our Term of Reference e)

> "e) Review the major on-going research projects in the ICES area, including but not exclusively ones funded by EU-funding sources, whose results are likely to be relevant to including environmental and ecosystem considerations in assessments and fisheries advice, and develop and report on a schedule for conducting work similar to ToR d) for the other research projects".

WGRED considers BECAUSE and EFEP to be particularly appropriate for review in 2008. The new Working Group on Multispecies Assessment Methods (WGMAM) is tasked in 2007 with evaluating the potential utility of the various models which emerge from BECAUSE. Additional work will be required however, following WGMAM to help define how such information and knowledge might be translated into a form which could contribute to the annual advisory process.

Annex 1: List of participants

WORKING GROUP FOR REGIONAL ECOSYSTEM DESCRIPTION

ICES Headquarters

19 February – 23 February 2007

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Annex 2: Recommendations

We suggest that each Expert Group collate and list their recommendations (if any) in a separate annex to the report. It has not always been clear to whom recommendations are addressed. Most often, we have seen that recommendations are addressed to:

- Another Expert Group under the Advisory or the Science Programme;
- The ICES Data Centre;
- Generally addressed to ICES;
- One or more members of the Expert Group itself.

RECOMMENDATION	ACTION
1. WGRED **recommends** that the Advisory Committee(s) start in 2007 to pick one major issue each year as a focus for work by Expert Groups during the coming year and as an introductory section of the annual Advice.	
2. WGRED further **recommends** that the first such theme be overfishing, where "overfishing" is defined broadly to include the total mortality being inflicted on the stocks by the fisheries as reported catch, un-reported catch, discards, and other ways that the fishery causes mortality to the stock.	
3. WGRED **recommends** that Consultative Committee, MCAP, and the Secretariat treat this matter as a high priority and develop such a plan and implement the necessary mechanisms this year.	
4. WGRED **recommends** that ConC and MCAP discuss these two options in the context of the changes in the advisory processes, and ensure that one or the other (or an alternative that is superior to either) is implemented for 2008 and beyond.	
5. WGRED **recommends** that ConC ensure some provision is made within the ICES Expert Groups to ensure that progress continues to build on the strong foundations built by REGNS	
6. WGRED **recommends** that ConC and MCAP ensure that as many Expert Groups in ICES as possible be encouraged to consider the final REGNS Report and products in detail, with regard to what uses they can make of the REGNS work, and what opportunities they see for follow-up to maximize the benefits of the investments made in the REGNS process.	
7. WGRED **recommends** that planning commence within ICES to develop an integrated ecosystem assessment for another ecoregion within the ICES area, building as fully as possible on the experiences with REGNS and BSRP.	

After submission of the report, the ICES Secretariat will follow up on the recommendations, which will also include communication of proposed terms of reference to other ICES Expert Group Chairs. The "Action" column is optional, but in some cases, it would be helpful for ICES if you would specify to whom the recommendation is addressed.