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Contents

1 Opening of the meeting

The meeting was opened at 10:00 on Monday, February 25, by the Chairman, Dr. Jake Rice, of Canada. The Secretariat briefed the Working Group on new procedures within ICES, including the use of Sharepoint as a major site for document preparation and management. With several members experiencing difficulties accessing the Sharepoint site, much of the business through the week was conducted on the ICES W:\\ drive, which remains a vital part of operations for Expert Groups meeting at the Secretariat.

2 Adoption of the agenda

The agenda, reflecting the Terms of Reference assigned to the working group, were adopted, Joint meetings were planned with AMAWGC on Monday afternoon and Thursday morning. The schedule focused on work on the overviews on the first days, and treatment of the other terms of reference later in the week. The Terms of Reference for 2008 were:

a) Consider, following reform of the ICES advisory process, what environmental information is needed for integration by expert and review groups to ensure that environmental forcing is taken into account in drafting fisheries advice; (Section 4).

b) Based on a), make recommendations for relevant activities by ICES working groups; (Section 4).

c) For each Eco-region to be used in the 2008 ICES advice, review, improve and update drafts of Ecosystem Overviews; (Section 3).

d) 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 2008, and to the extent possible recommend ways in which this information could be used by Expert Groups and Advisory Committees. (Section 5).

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;

Advisory region overviews

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 bycatch 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

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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.

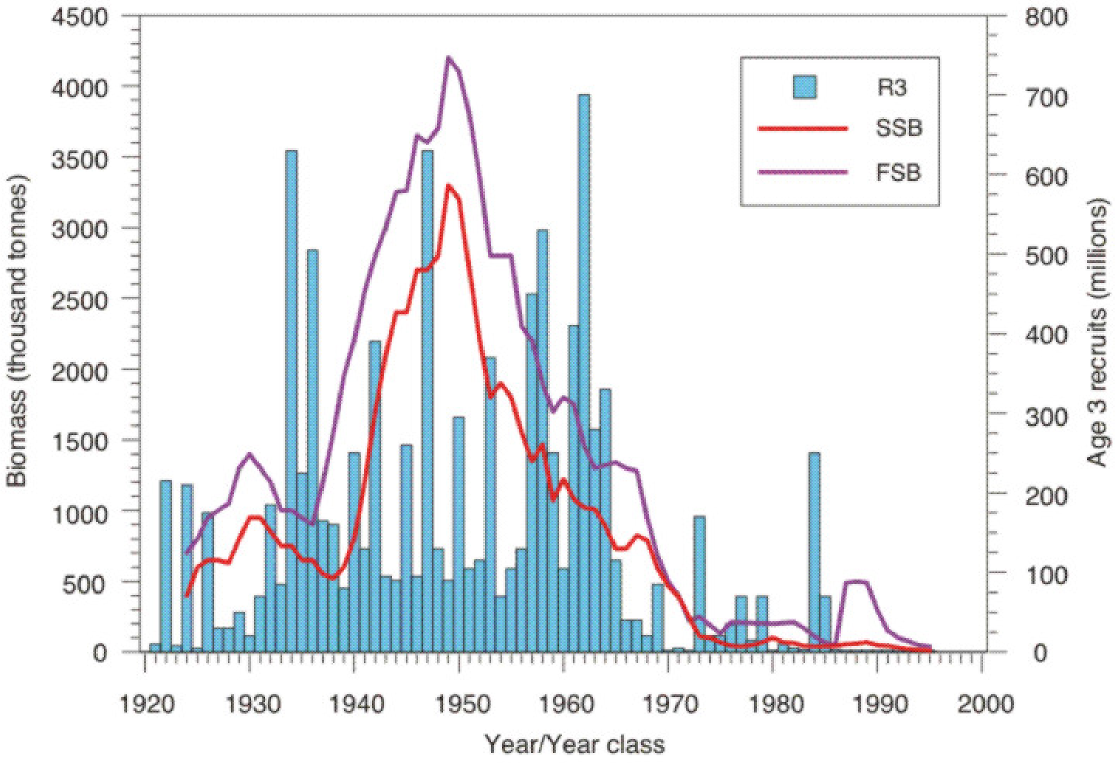

Figure 2.1. Recruitment at age 3, spawning biomass and fishable biomass of cod off West Greenland.

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 northIcelandic 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 and oceanographic features & drivers

As pointed out above the NAO has some 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 during the late 1990s it changed to near average conditions at the turn of the 21st. century. The position and strength of the Icelandic Low during the past two years 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*) (Gislason and Astthorsson, 2004). 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, 2005). In 2005 and 2006 zooplankton biomass north of Iceland was again above long term average while in 2007 it decreased again. To the south the zooplankton biomass has been below the long term average since 2003. (Anon., 2008).

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 has 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 inshore 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, haddock and whiting.

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 northwest and southeast 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 southeastIceland (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 south, west and north coasts of 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 northwest, north and east 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. In recent years the stock size of capelin has decreased from about 2000 Kt in 1996/97 to about 1000 Kt in 2006/07 (Anon., 2007). 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 and 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 one quarter of the total number and biomass of seabirds within the ICES area (ICES, 2002). Auks and petrel are most important groups comprising almost three fifths and one quarter 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 (> 80 cm) 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.

Two species of seals, common seal (*Phoca vitulina*) and grey seal (*Halicoerus grypus*) breed in Icelandic waters, while 5 northern vagrant species of pinnipeds are found in the area (Sigurjonsson and Hauksson, 1994; Hauksson, 1993, 2004). The common seal is observed in coastal areas all around the country, while the grey seal is mainly found off the west, northwest and southeast coasts.

The seal populations at Iceland have been harvested through the centuries, both for food and fur. Hunting of both species combined is currently limited to about 1000 individuals annually, well below the level of ca. 6000 animals of several decades ago. Regular surveys of the common seal and grey seal populations have been undertaken in Icelandic coastal waters since 1980 and 1982, respectively (Anon., 2007). Stock estimates for both species have declined considerably since initial surveys, common seals from about 30 000 individuals to about 10 000 and grey seals from about 9000 to 6000. The steady decrease in population size of both species is mainly considered to be due to over exploitation (Anon., 2007).

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 1º 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 west Iceland (the same has been observed off southeast 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 2007 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 May-June 2007 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, along with a possible decrease in the stock size of capelin has resulted in a lower food 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., 2007). 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*)). In fact mackerek has in recent years been found in the waters to the east of Iceland in considerable quantitites leading to a fishery in the Icelandic EEZ of more than 30 thousand tonnes in the summer of 2007. 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 bycatch in these fisheries is not available.

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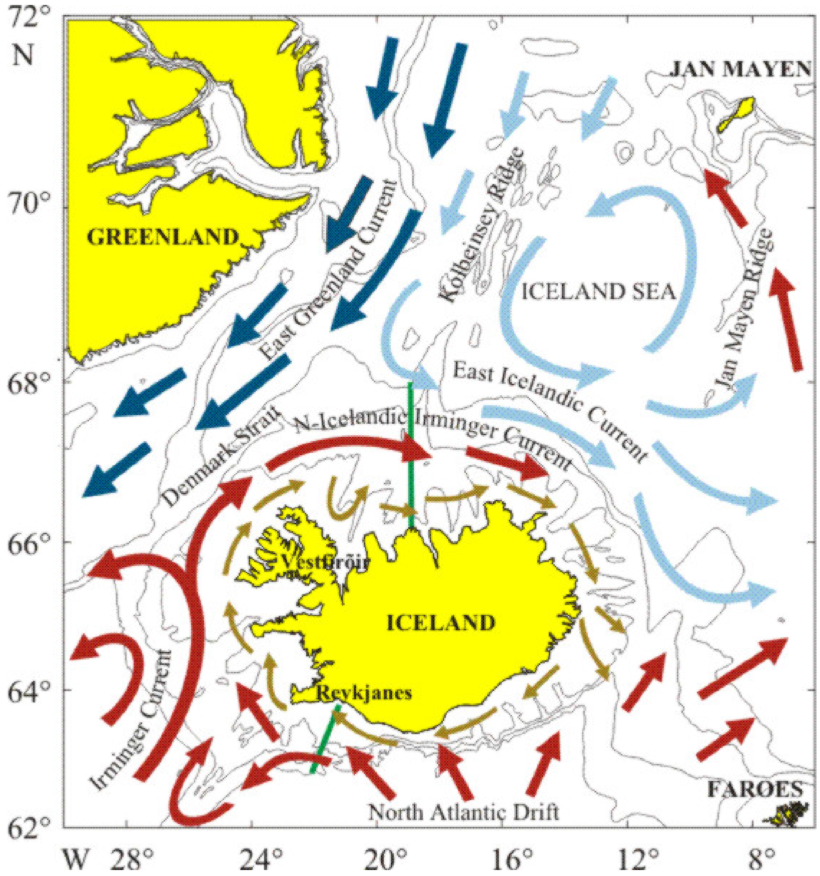

Figure 3.1. The system of ocean currents around Iceland and in the Iceland Sea.

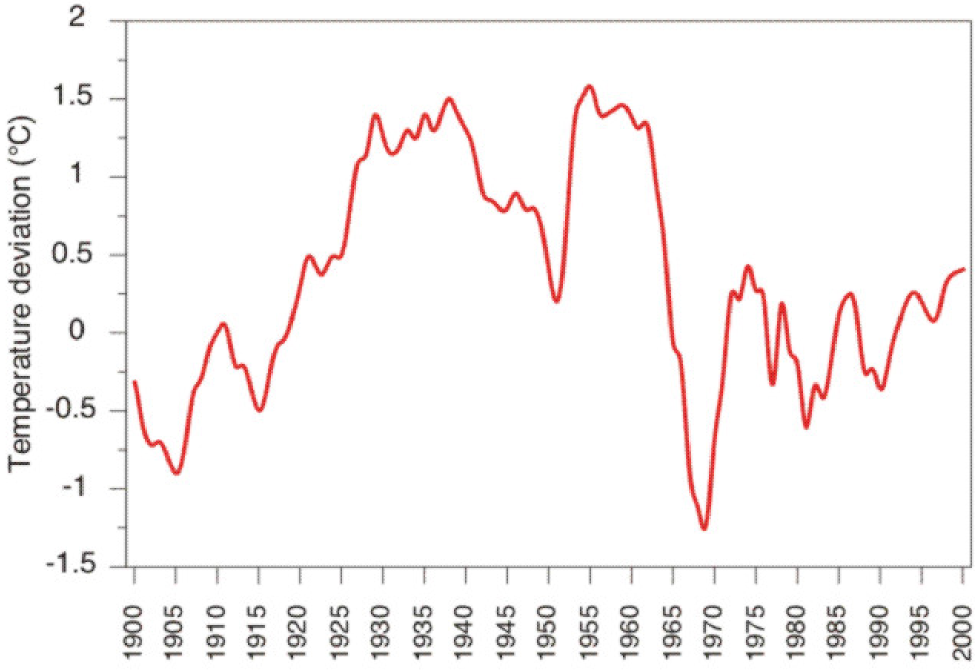

Figure 3.2. Temperature deviations north of Iceland 1900–2000, five year running averages.

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 km^2, 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 flows 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°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).

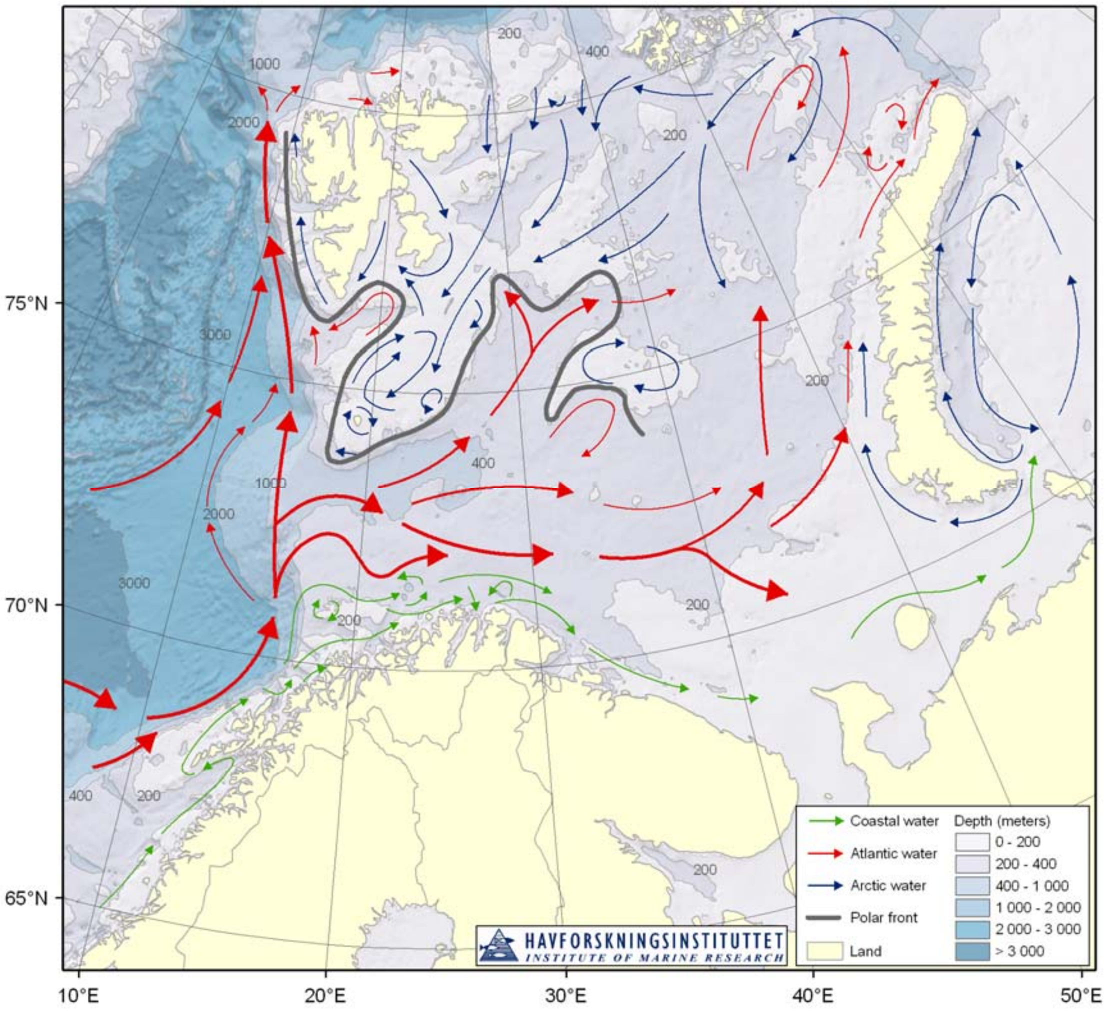

Figure 3.1.1. Bottom contours and current systems in the Barents Sea.

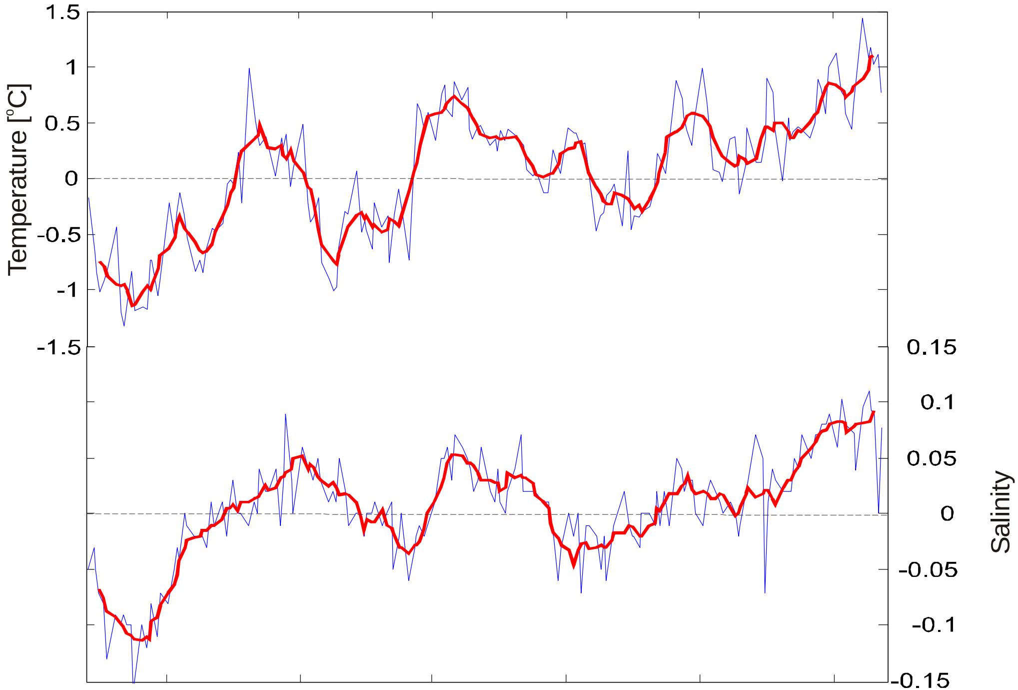

Figure 3.1.2. Temperature (upper graph) and salinity (lower graph) anomalies in the Fugløya-Bjørnøya transect during the period 1977–2006.

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 seven pinnipeds (seals), twelve large cetaceans (large whales) and five 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* 5400; humpback whales *Megaptera novaeangliae* 1200; sperm whales *Physeter macrocephalus* 4300 (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 bycatches in gillnet fisheries (Bjørge and Kovacs, 2005). In 2004 Norway initiated a monitoring program on bycatches 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 bycatch, but also increases fish catch, as bait loss is reduced. This way there is an economic incentive for the fishermen, and where bird bycatch 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 2000 m. The Norwegian Sea is divided into two separate basins with 3000 m to 4000 m depth, with maximum depth 4020 m. 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.

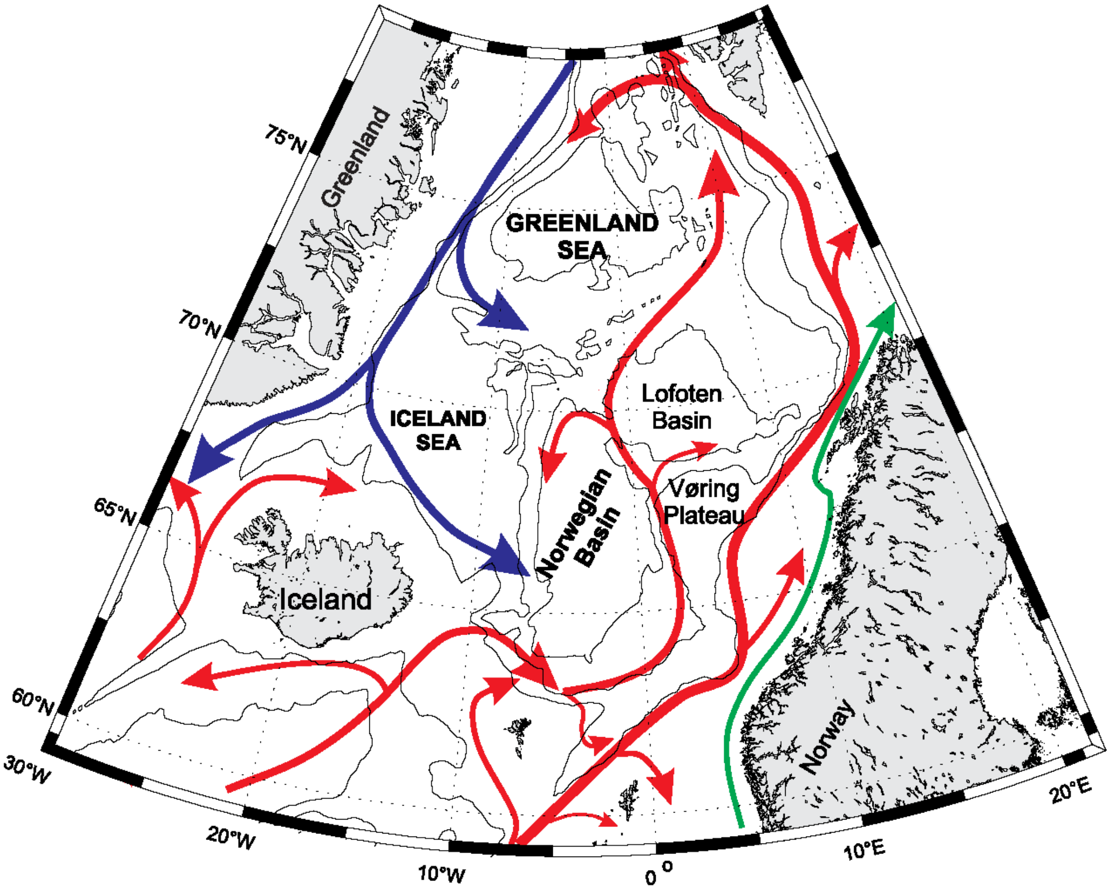

Figure 3.5.1. Norwegian Sea main circulation pattern. Red lines indicate warm currents, blue lines indicate cold currents and green lines show low salinity coastal water.

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 have 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 (1970s) 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 is 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 5000 fin whales in the Norwegian Sea. Of the other baleen whales, humpback whale, Megaptera novaeangliae, is quite common with its 1000 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 6000 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 1960s. 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.

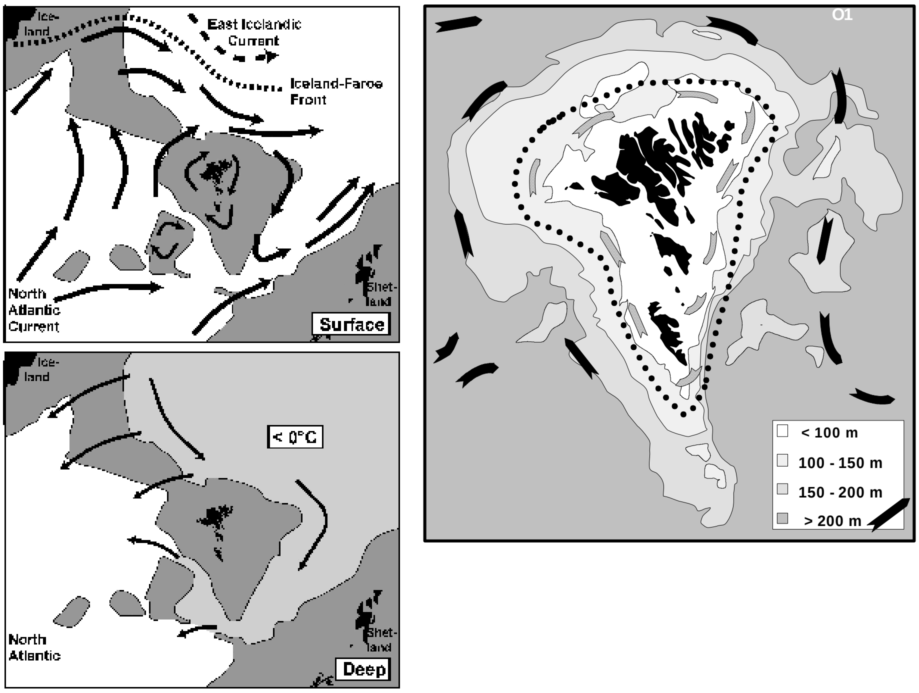

Figure 3.6.1. Bottom topography, circulation and water masses at the surface (top left panel), at depth greater than about 500 m (bottom left panel) in the area around the Faroes and on the Faroe shelf (right panel). Dashed lines indicate fronts.

3.6.1.2 Temperature

Due to the strong tidal currents on the Faroe shelf the temperature is constant from surface to bottom in the shallow shelf areas. The temperature ranges from around 6°C in March to 10–11°C in August-September.

In the Northeast Atlantic there has been a general salinity and temperature increase since the early 1990s. The salinity now reaches the previous maximum last observed around 1960, and temperature values exceed records (Holliday *et al.*, 2008). This trend has also been observed on the Faroe shelf, where temperature monitoring since 1992 has revealed a mean annual temperature increase of about 0.07°C year^{-1}, resulting in a temperature increase of about 1°C during this period.

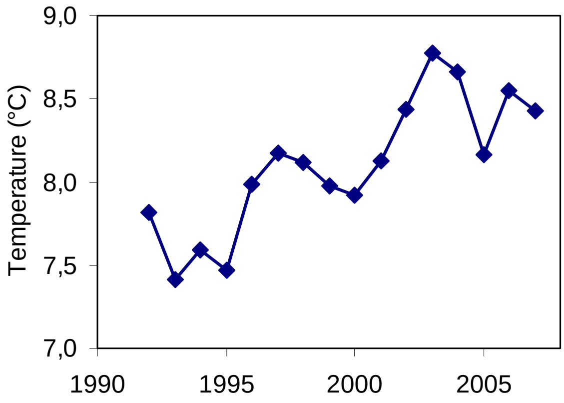

Figure 3.6.2. Mean annual temperature on the Faroe shelf, 1992–2007.

3.6.1.3 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 3.6.3). 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, Nielsen, 2007).

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.*, 2008a).

In 2007 the biomass increase occurred early in spring. However, it decreased already in beginning of June and remained low for the rest of the season.

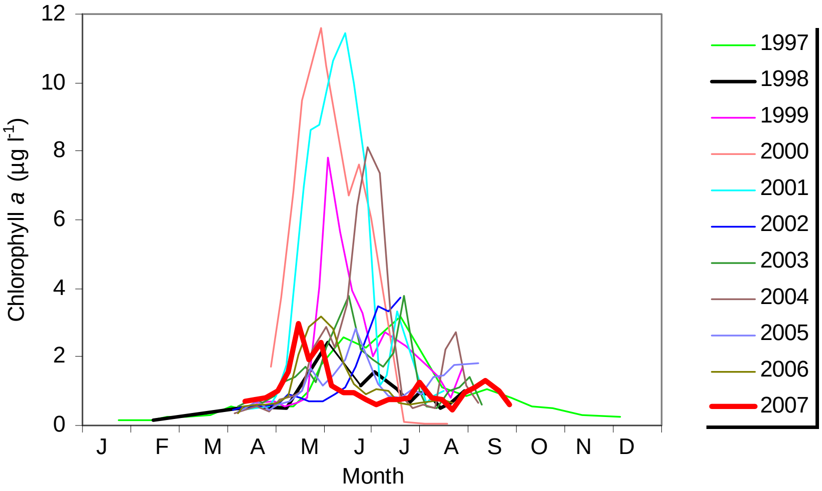

Figure 3.6.3. Chlorophyll *a* concentrations on the central shelf, 1997–2007.

The mean annual primary production on the shelf is around 160–200 gC m^2 of which about 50% is estimated to be new production (Debes *et al.*, 2008a). There is a very high interannual variability primary production (Gaard, 2003, Eliasen *et al.*, 2005), and from 1990 to 2007 the new primary production (from spring to mid summer) has fluctuated by a factor ~5 (Figure 3.6.4). The index for 2007 was slightly below the 1990–2007 average and has been so for the last three years. With exception of 2004 the phytoplankton production index has been below average since 2002 (Figure 3.6.4).

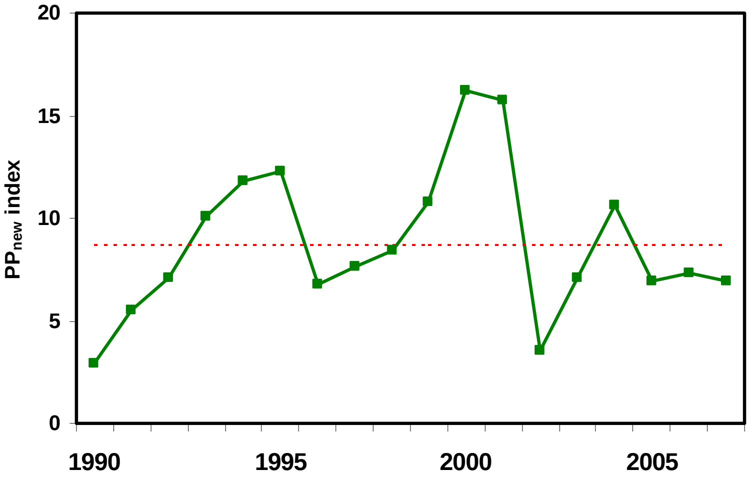

Figure 3.6.4. Index of new primary production from spring to mid-summer on the Faroe shelf since 1990. The horizontal line represents the average index during the 1990–2007 period.

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 *et al.*, 2008a) 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 biomass increase and the primary production.

The variability in primary production between years (Figure 3.6.4) 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 year ahead.

3.6.1.4 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 off-shelf 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.*, 2008b). This variability affects feeding conditions for fish larvae and pelagic juveniles in general on the shelf (Gaard and Steingrund, 2001, Gaard and Reinert, 2002, Kristiansen, 2007, Nielsen, 2007).

3.6.1.5 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 3.6.5. 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.

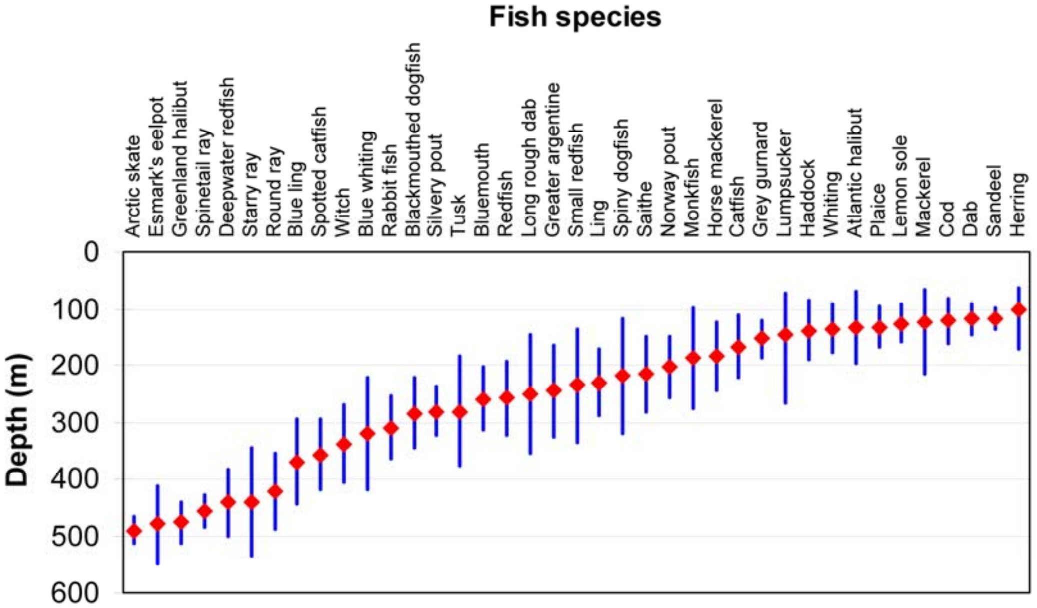

Figure 3.6.5. Typical depth distribution of fish in areas deeper than ~65 m on the Faroe shelf and in the ocean around the Faroes.

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.

Sandeel recruitment and abundance has been low since the productive years 1999–2001, and is still at a low level. This seems to have affected the growth rates and abundance of cod, and apparently of haddock too.

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 2007, Steingrund and Gaard, 2005).

Due to low cod recruitment on the Faroe shelf in the resent years the stock has decreased to the same low level as in the early 1990s. The haddock stock is close to average but is decreasing.

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.

3.6.1.6 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 3.6.6).

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).

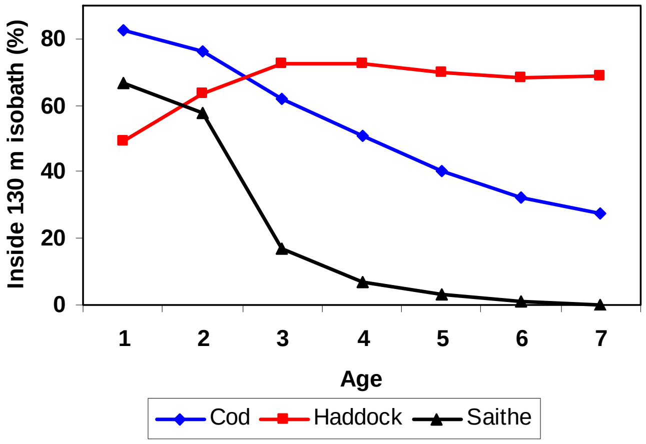

Figure 3.6.6. Proportion of cod, haddock and saithe caught inside the 130 m isobath during summer groundfish surveys 1996–2003. (From Steingrund and Gaard, 2005).

3.6.1.7 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 3.6.7) (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 in setting biological reference points-although it is no guarantee for recruitment success.

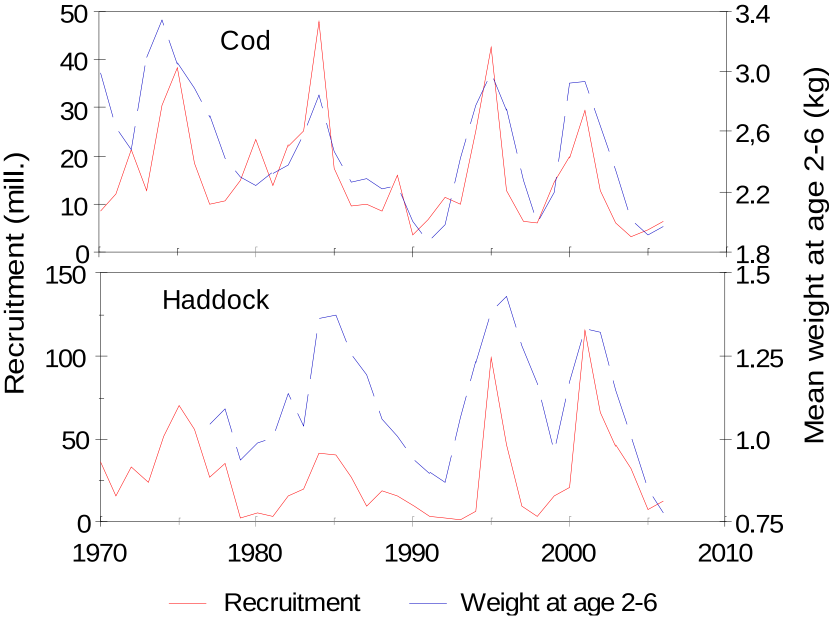

Figure 3.6.7. Relationship between recruitment of 2 years old cod and haddock and the mean weight of 2–6 years old cod during 1970–2006 and haddock during 1977–2006 on the Faroe shelf.

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.

3.6.1.8 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 3.7.8). The growth rates are mainly affected by the highly variable food production. The causal mechanism seems to be a positive relationship between phytoplankton production, zooplankton production and production of food organisms for cod and haddock (e.g., benthic crustaceans, polychaets, 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 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 3.6.8).

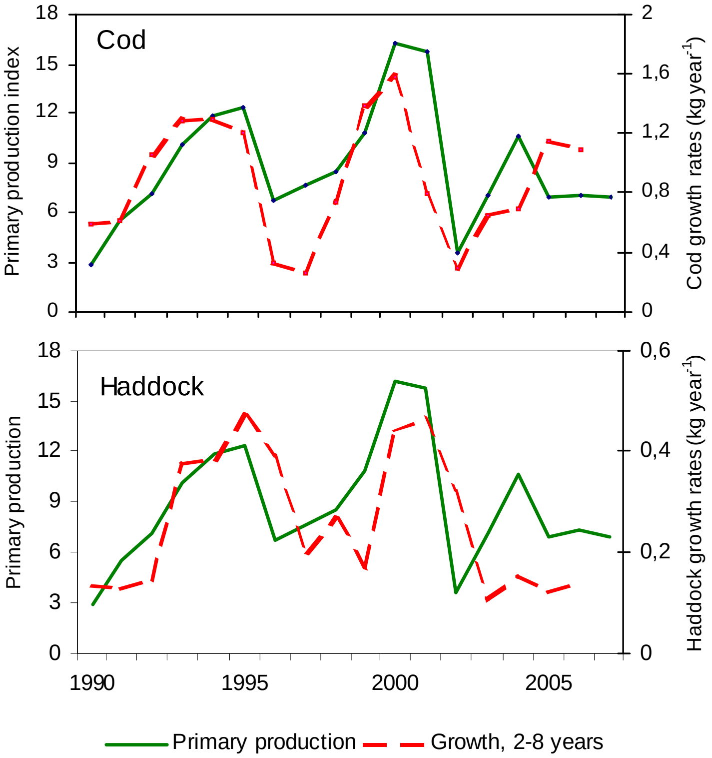

Figure 3.6.8. Index of new primary production and mean growth rates since the year before, for cod (upper panel) and haddock (lower panel) since 1990.

As pointed out in Section 3.6.1.5 sandeel recruitment and abundance has been at a low level since the productive years 1999–2001. This has affected feeding conditions for especially cod and most likely haddock too.

Weight-at-age for cod and haddock are at present at a very low level (Figure 3.6.7). During the last two years it has stabilized for cod but decreased for haddock in 2006. Consequently, the average growth rate of cod has been slightly higher than expected from the primary production index alone, possible due to the very low cod abundance.

3.6.1.9 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 relatively well with primary production (Figure 3.6.9). When comparing primary production with production of cod haddock and saithe combined, the correlation is even better.

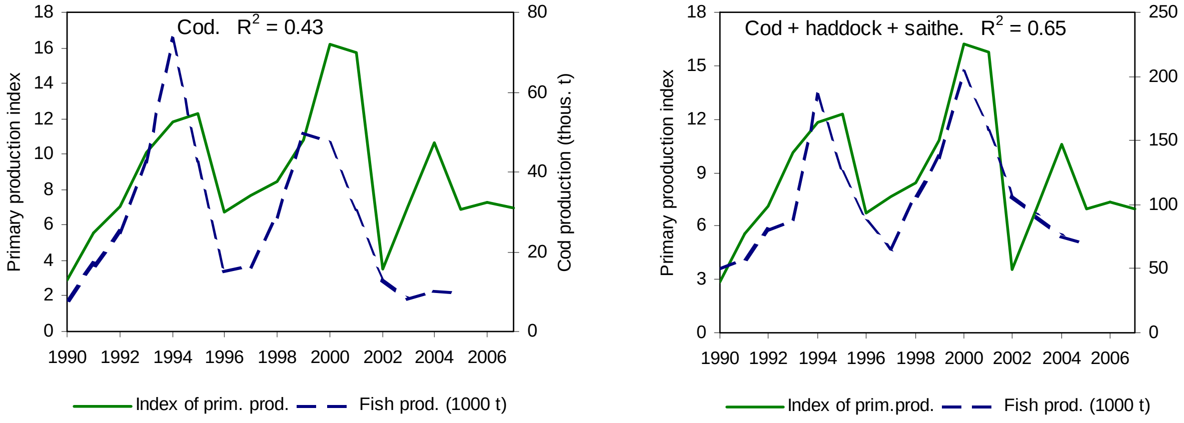

Figure 3.6.9. Index of new primary production on the Faroe shelf and corresponding production one year ahead, of cod (left panel) and cod + haddock + saithe (right panel).

Since young age groups are the most numerous (mainly in the productive years) the observed variability in cod production in Figure 3.6.9 largely is due to variable abundances of recruits (Figure 3.6.10). The production variability is, thus, affected by variable recruitment (uncertain for the last year) and fishing effort. By combining Figures 3.6.8, 3.6.9, and 3.6.10, the low cod production during the last years seems to be due to low cod abundance and not low growth rates. 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 3.6.6), 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.

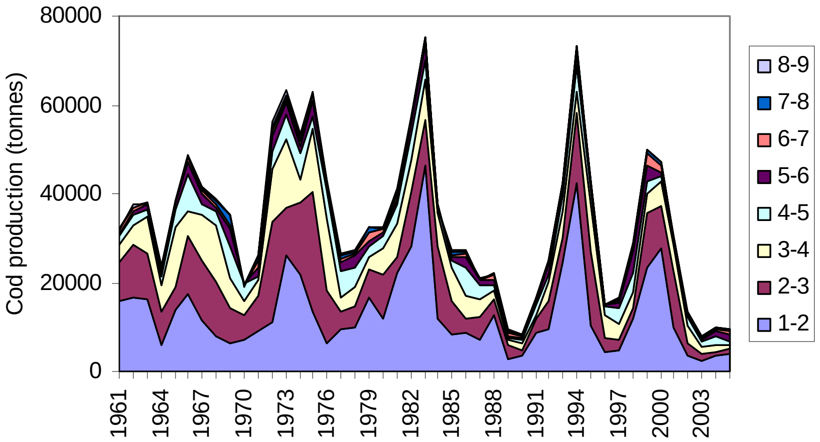

Figure 3.6.10. Production of Faroe Plateau cod, split into age groups.

3.6.1.10 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 significant reduction of 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 bycatch 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 3.6.8). The cod growth rates seem to be negatively correlated with the catchability of longlines, suggesting that cod prefer longline baits when natural food abundance is low. Since longliners usually take a large proportion of cod catch, the total fishing mortality fluctuates in the same was as the longline catchability and there is thus a negative relationship between cod growth and mortality.

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

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

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

The catchability analysis reported above suggests that natural factors may have a large influence on longline catchability for cod and haddock. In 2007 the primary production was below average.

3.6.4 References:

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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 100 m. 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 rockier pinnacle areas to the east. The Irish Sea is shallow (less than 100 m deep in most places) and largely sheltered from the winds and currents of the North Atlantic. The English Channel is a shallow (40–100 m) 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).

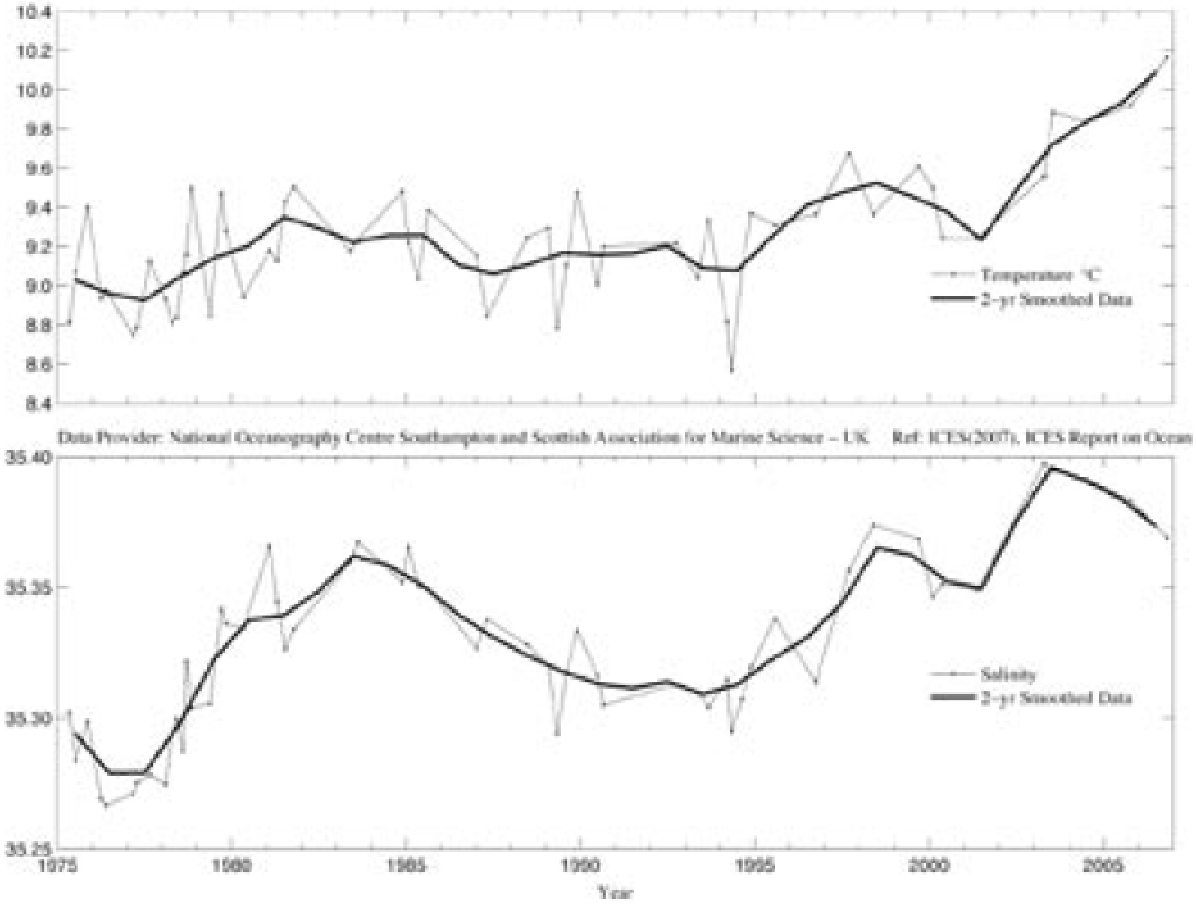
On the shelf, tidal mixing and thermo/saline fronts occur at several locations immediately to the west of Britain, including the Ushant Front in the English Channel, the Celtic Sea front at the southern entrance to the Irish Sea, and the Islay Front between Islay and the coast of Northern Ireland. The 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, 2007).

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. In 2006, the warm and saline conditions persisted in the upper ocean of the Rockall Trough, though salinity has been decreasing since a peak in 2003. The notable decrease in mean salinity in 2006 was caused by the presence of fresher water between the Anton Dohrn Seamount (11°W) and the Rockall Bank (13°W); however, the shelf edge current (at 9°W) had persistently high salinities. Temperatures once again reached record levels, though most of the additional warming since 2005 was confined to the upper 400 m. Upper ocean temperatures (0–800 m) were 0.8°C and salinity 0.04 above the long-term mean (1975–2000).



Data Provider: National Oceanography Centre Southampton and Scottish Association for Marine Science – UK Ref: ICES(2007), ICES Report on Ocean

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 (ICES, 2006b).

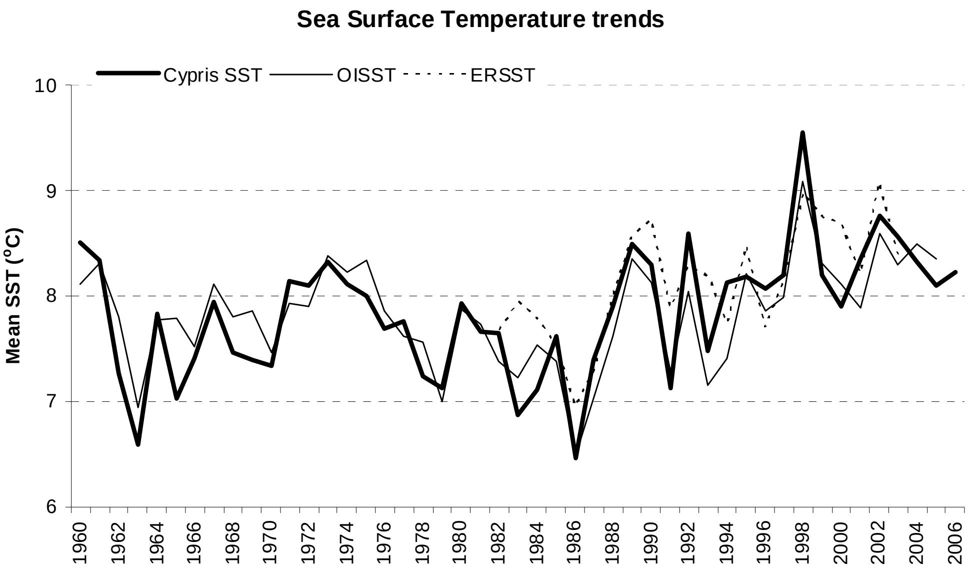


Figure 3.7.2. Sea surface temperature in the Irish Sea from 1960 to 2006 (ICES 2006b).

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).

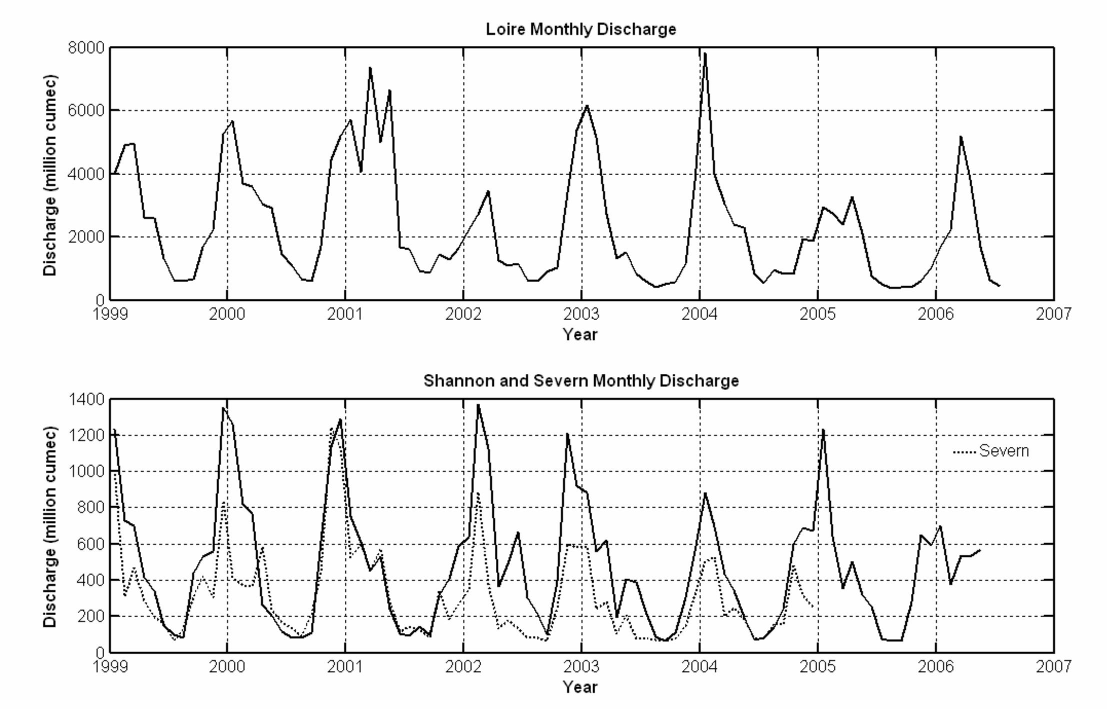


Figure 3.7.3. Discharges from rivers affecting the western Irish Shelf, river Loire (upper panel) and rivers Shannon and Severn (lower panel). Note different scales on Y axes.

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 2005 were 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 and 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: 66–232 m) 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 assessments 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).

Demersal elasmobranchs

The Celtic Seas eco-region covers west of Scotland (VIa), Rockall (VIb), Irish Sea (VIIa), Bristol Channel (VIIf), the western English Channel (VIIe), and the Celtic Sea and west of Ireland (VIIb-c, g-k), although the south-western sector of ICES Division VIIk is contained in the oceanic northeast Atlantic eco-region. This eco-region broadly equates with the area covered by the North-western waters RAC. Whereas some demersal elasmobranchs, such as spurdog *Squalus acanthias* and lesser-spotted dogfish *Scyliorhinus canicula,* are widespread throughout this region, there are some important regional differences in the distributions of other species. Other than spurdog and tope, the main species of shark taken in demersal fisheries in this eco-region are lesser-spotted dogfish, smooth-hounds *Mustelus* spp. and greater-spotted dogfish *Scyliorhinus stellaris*. Sixteen species of skate and ray are recorded in the area, the most abundant skates being thornback ray *Raja clavata*, cuckoo ray *Leucoraja. naevus*, blonde ray *R. brachyura*, spotted ray *R. montagui,* undulate ray *R. undulata,* common skate *Dipturus batis*, shagreen ray *L. fullonica* and smalleyed ray, *R. microocellata*. Other batoids (stingray *Dasyatis pastinaca*, marbled electric ray *Torpedo marmorata* and electric ray *T. nobiliana*) may be observed in this eco-region, although they are more common in more southerly waters. These are generally discarded if caught in commercial fisheries and are not considered in this report.

Landings of rays appear as a series off peaks and troughs, with lows of approximately 14 000 t in the mid-1970s and 1990s, and highs of just over 20 000 t in the early and late 1980s and late 1990s. While landings have fluctuated considerably over the time series, they have been in a constant decline since 2003, and the 2006 landings of approximately 10 000 t are the lowest in the time series. This decline in landings is thought to be mainly due to a combination of increased regulation and changes in consumption (ICES, 2007).

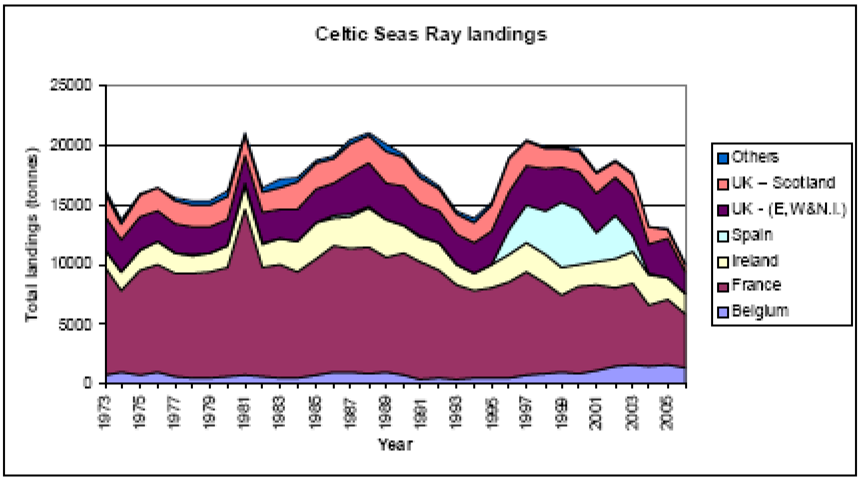


Figure 3.7.7. Demersal elasmobranchs in the Celtic Seas. Total landings (tonnes) of Rajidae by nation in the Celtic Seas from 1973–2006 (Source: ICES).

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 and 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 and 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 and 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 and 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. 4000) 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 and 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 and 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 and 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.

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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 (50–100 m) central part that runs north along the British coast. The central northern part of the shelf gradually slopes down to 200 m 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 500 m. 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 (Figure 3.8.2). 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.

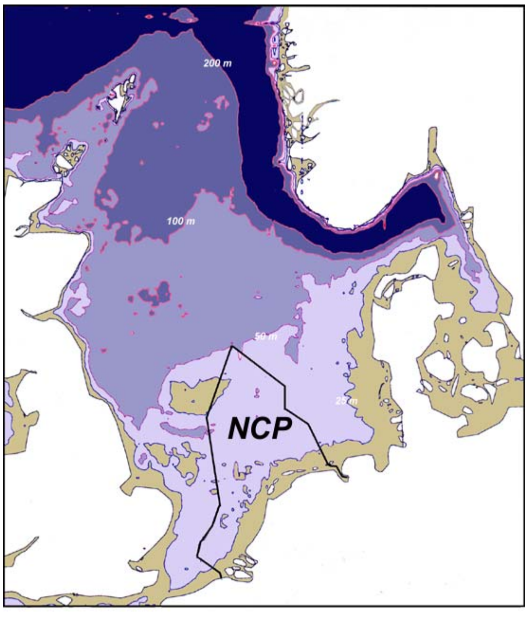


Figure 3.8.1. Bathymetry of the North Sea (source-RIVO-alternative from ICES).

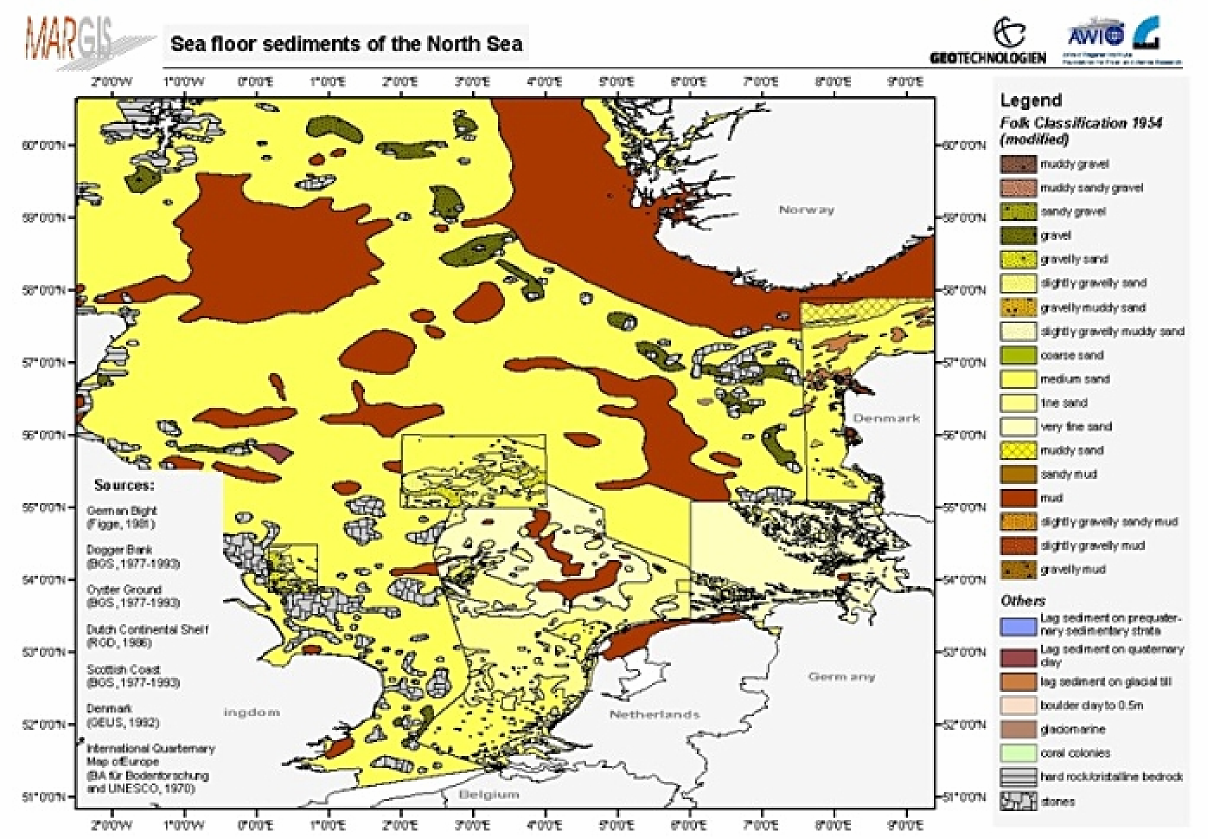


Figure 3.8.2. Seabed sediment types. http://www.awi-bremerhaven.de/GEO/Marine_GIS/Margis%20homepage/index.html

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 and 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 and 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 3.8.3.

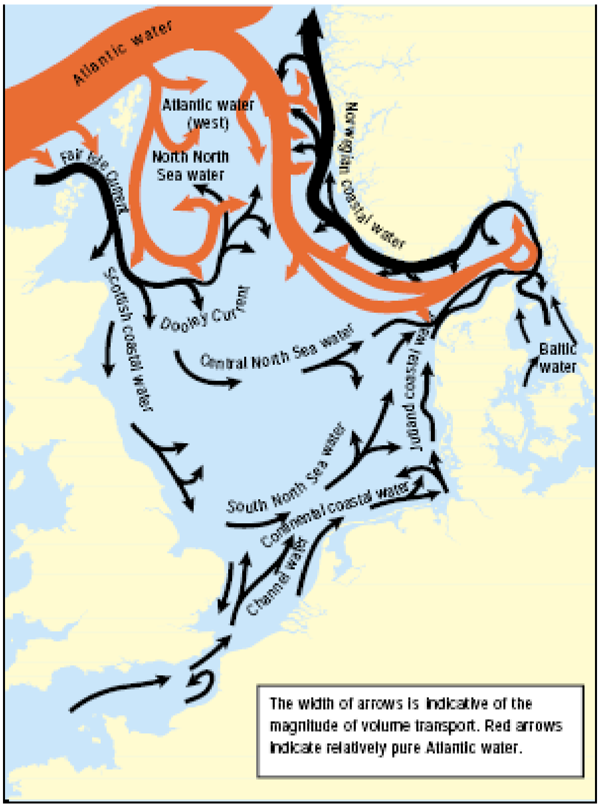


Figure 3.8.3. General circulation pattern in the North Sea. Copied from Regional QSR II (after Turrell *et al.*, 1992).

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 3.8.4. shows average bottom temperatures in winter and summer for 1997–2002.

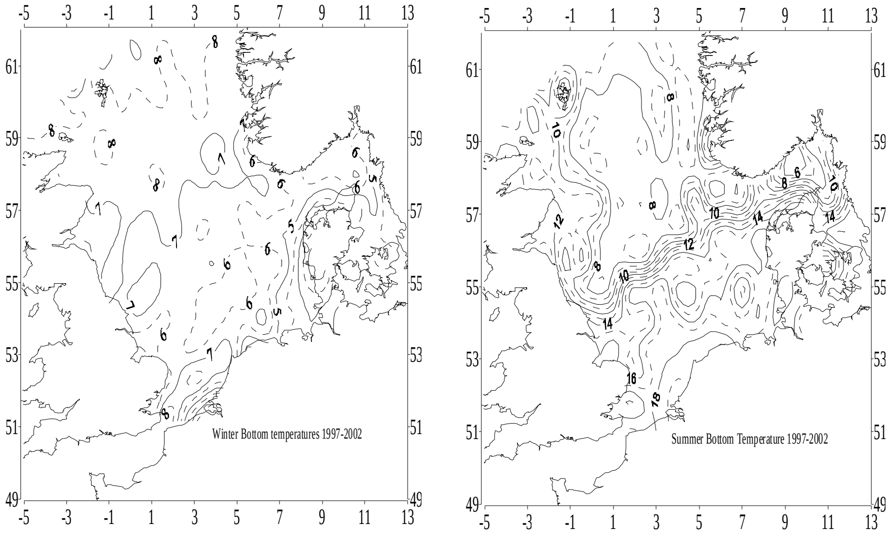
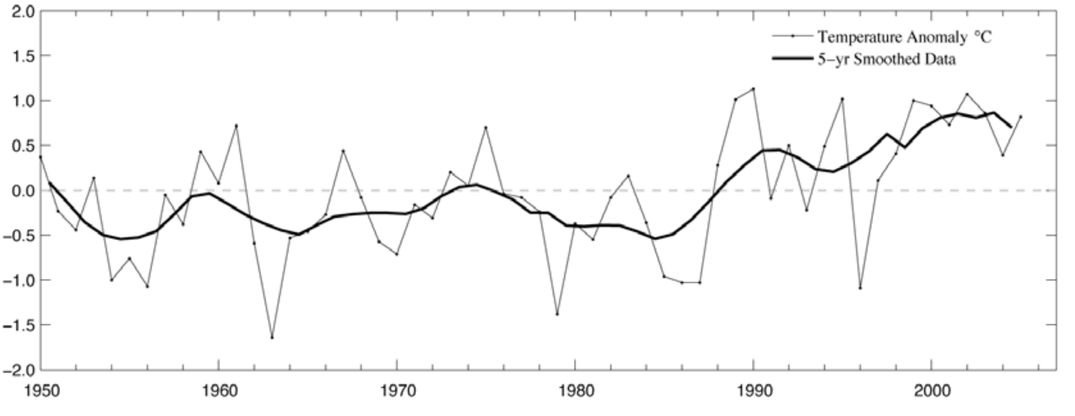


Figure 3.8.4. Average distribution of winter (left) and summer (right) bottom temperatures.

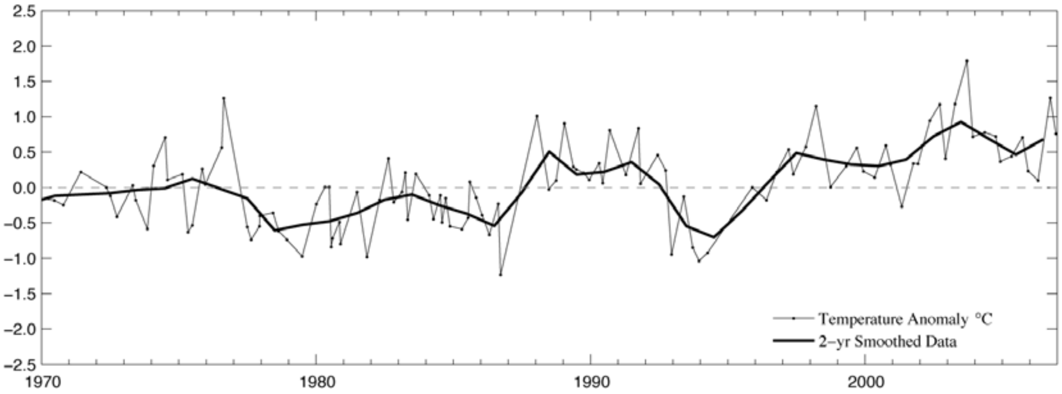
The salinity and the temperature variations generally reflect the influence of the North Atlantic Oscillation (NAO) on the movement of Atlantic water into the North Sea and the ocean-atmosphere heat exchange. Numerical model simulations show strong differences in the circulation depending on the state 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 (e.g. 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.

Results presented in (ICES, 2007) show the area-averaged sea surface temperatures of the North Sea have been increasing since June 2001 (Figures 3.8.5 and 3.8.6). The vegetation period (primary production) was much longer than usual in 2006. The Helgoland Roads standard station demonstrates that, since the cold winter of 1996, sea surface temperature has been above the 30-year mean (1971–2000), with positive anomalies of 0.5–1.0°C. In 2006, March and April revealed negative anomalies up to -1°C, but positive anomalies exceeded 1°C continuously from June to December, with maximum anomalies of 2.7°C in October and 2.3°C in December.



Data Provider: AWI/BAH (Alfred–Wegener–Institut / Biologische Anstalt Helgoland) – Germany Ref: ICES(2007), ICES Report on Ocean Climate 2006

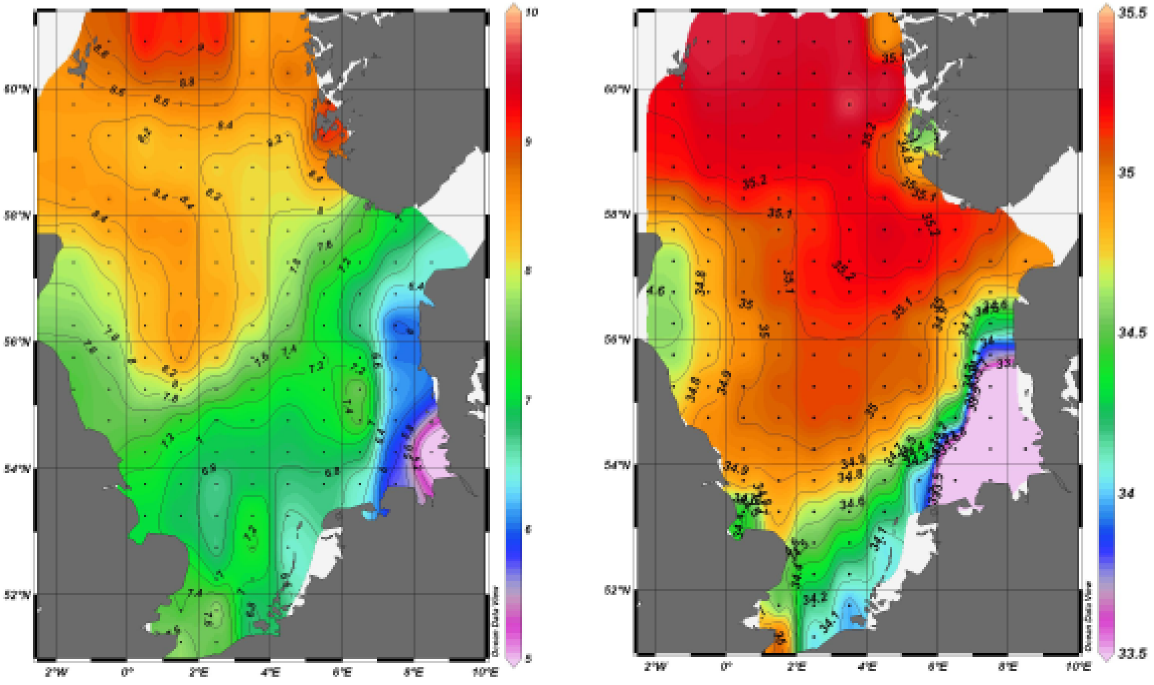
Figure 3.8.5. Southern North Sea. Annual mean surface temperature anomaly at Station Helgoland Roads.



Data Provider: Fisheries Research Services – Aberdeen – UK Ref: ICES(2007), ICES Report on Ocean Climate 2006

Figure 3.8.6. Northern North Sea. Temperature anomaly in the Fair Isle current entering the North Sea from the North Atlantic.

The warm conditions in the North Sea that had lasted since the summer of 2006, continued in the second quarter of 2007. The temperature anomalies in the first quarter were positive by 0–1 Co in the northern North Sea and by 2–4 Co in the southeastern part. These high positive anomalies persisted in April but were somewhat reduced to 1–2 Co in the southeastern area in June. Seasonal stratification started in April in the waters west of Denmark and by May the waters north of the Dogger Bank were markedly stratified. SST data from the 1st qtr. IBTS 2007 survey are presented in Figure 3.8.7.



(a) (b)

Figure 3.8.7. Winter (January-February) bottom-water temperature (a) and salinity (b) for the North Sea, collected during ICES International Bottom-Trawl Surveys in 2007 (from Skjoldal, 2007).

The continued and significant increase in seawater temperatures was also observed at Arendal on the Norwegian Skagerrak coast (ICES, 2007b). Daily recordings of sea surface temperatures at Arendal from January 2006 to December 2006 are shown in Figure 3.8.8. The temperature during the 4th quarter in 2006 remained above average, most of the time about 2 SD above the long-term average (climatology). This situation continued during the 1st quarter in 2007, with sea surface temperatures 1.5–2 SD above the long-term average in January and March. This was interspersed by a cooling of the sea surface to close to average conditions in late February.

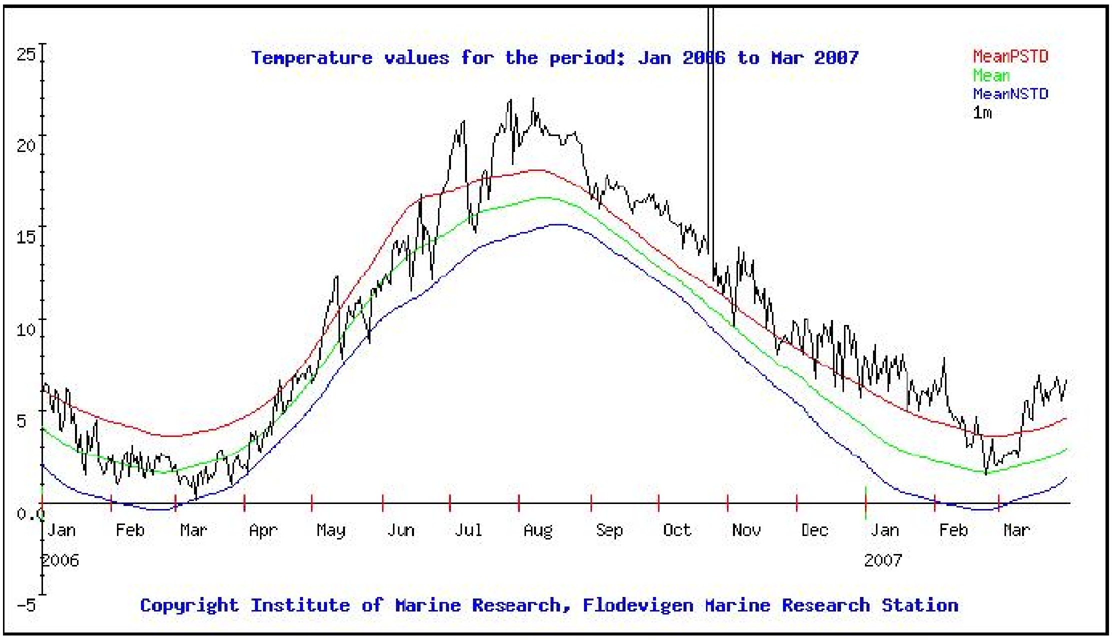


Figure 3.8.8. Daily sea surface temperature recordings at Arendal on the Norwegian Skagerrak coast from January 2005 to December 2006. Also shown is the long-term average temperature +/- 1 SD (standard deviation). Data from Institute of Marine Research (IMR).

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 3.8.9).

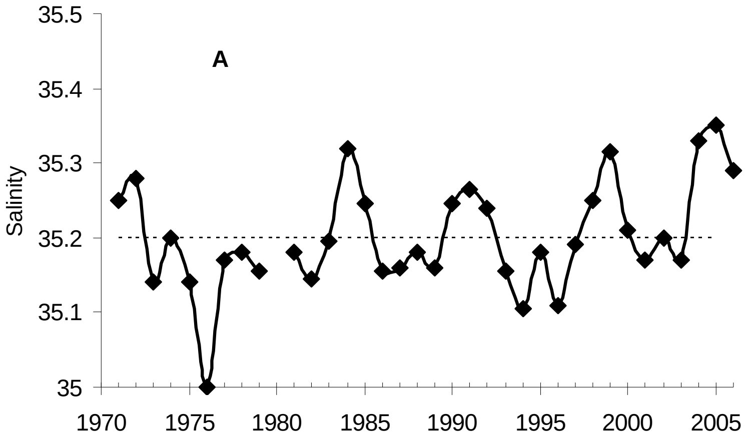


Figure 3.8.9. Salinity near bottom in the north-western part of the North Sea in the summers of 1970–2006.

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.

3.8.1.2 Major climatic and ecosystem features

The water circulation through the North Sea is generally counter-clockwise, with most of the water entering in the north over the North Sea plateau and exiting through the Norwegian Trench along the coast of Norway. The inflow of Atlantic water shows large seasonal and interannual variability, driven by winds and pressure gradients along the continental slope (Pingree, 2005) which vary from year to year known as the North Atlantic Oscillation (NAO). The NAO winter index, which is a measure of the air pressure gradient between the Azores High and the Iceland Low, has undergone both long-term and short-term fluctuations. High or positive NAO index conditions typically drive strong inflow and transport through the North Sea, while weaker flows are associated with negative NAO anomalies (Reid *et al.*, 2003). The index decreased through the mid-part of the last century to a minimum in the 1960s. This coincided with the “Great salinity anomaly” which was a signal of low salinity water that propagated around the subarctic gyres of the northern North Atlantic (Dickson *et al.*, 1988, Blindheim and Skjoldal, 1993). The anomaly arrived in the North Sea in the late 1970s, manifested as pronounced minima in salinity and temperature and subsequently the NAO index shifted to high values from the late 1980s through the first part of the 1990s, followed by a marked drop to a strong negative anomaly in winter 1995/96. These were very marked climatic events that have been associated with changes in plankton composition (Planque and Batten, 2000, Beaugrand *et al.*, 2002, Beaugrand, 2003, Reid *et al.*, 2003), fish populations and other biota in the North Sea (Reid and Edwards, 2001, Reid *et al.*, 2001, Edwards *et al.*, 2002, Reid and Beaugrand, 2002).

Modeled inflow of water (Skogen and Søiland, 1998) into the North Sea through the northern boundary between Orkneys, Shetland and the west coast of Norway during the 1st quarter of the year, was low in the late 1960s and late 1970s, while increasing substantially in the late 1980s and early 1990s (Figure 3.8.10), corresponding to the low and high NAO index situations described above. These changes in flows have been related to changes in plankton abundance and composition in the North Sea and characterized as cold-biological and warm-biological events (Reid *et al.*, 2003) and also the variance in recruitment or distribution of 5 major North Sea fish populations with data for the time period 1971-1991 (Svendsen *et al.*, 1995). Climate forcing was thought to be the most likely explanation for the “gadoid outburst” in the 1960s, which was a period with favorable recruitment conditions for several of the gadoid groundfish species in the North Sea (Cushing, 1984). Although significant environmental events have had an impact on the status of the North Sea ecosystem, including its fishery, time series data on the spawning stock biomass (SSB) of six important demersal fish stocks (ICES, 2007) reveals considerable variation (Figure 3.8.11), reflecting the combined influence of the environment and impact from fishing. North Sea haddock, cod and saithe were at high biomass levels in the late 1960 and early 1970s, reflecting the gadoid outburst, followed by subsequent declines to low levels in the first part of the 1990s. Haddock and saithe have since recovered whereas the decline of cod has continued. Fishing pressure (fishing mortality) in the 1990s was so high that the stock was predicted to collapse based upon theoretical considerations (Cook *et al*., 1997). The warm climate and low zooplankton abundance (particularly of *Calanus finmarchicus*) have also been implied in the decline, and lack of recovery, of North Sea cod (Planque and Frédou, 1999, Beaugrand *et al*., 2003, Drinkwater, 2005, Rindorf and Lewy, 2006).

Pelagic, plankton-feeding fish are another important component of the North Sea ecosystem. North Sea herring declined due to overfishing to a very low level in the 1970s (Figure 3.8.12), but subsequent recovery efforts have allowed the stock to increase to a level within safe limits. North Sea mackerel stocks were also fished to unsafe levels in the 1970s and for the North Sea stocks they have not recovered. However, mackerel from the western stock (in the NE Atlantic) is abundant and uses the northern North Sea as part of its feeding area. Other important pelagic fish species in the North Sea ecosystem are sprat, sandeels, and blue whiting.

Pelagic fish are likely to provide a pressure on the plankton which constitutes their food as seen by observations in the Barents Sea ecosystem (Skjoldal and Rey, 1989, Dalpadado and Skjoldal, 1996) and the North Sea (Reid *et al*., 2000). *Calanus finmarchicus* (a cold-water artic-boreal species of copepod) has fluctuated inversely with *Calanus helgolandicus* (a warm water temperate species of copepod), being abundant under negative NAO index conditions. The strong inverse correlation between *C. finmarchicus* and *C. helgolandicus* broke down after 1995, presumably reflecting less *Calanus finmarchicus* in the inflowing water originating in the Norwegian Sea (Planque and Reid, 1998, Reid *et al*., 2003), and possible increased predation pressures arising from increased pelagic fish stocks and their resumed migration to feed in the Norwegian Sea (Holst *et al*., 2004).

In addition, recruitment conditions for blue whiting were exceptionally good for several years starting in 1995, leading to a marked increase in the stock of young fish feeding in the Norwegian Sea (Monstad, 2004, Skjoldal and Sætre, 2004). It has been suggested that predation by these two very large pelagic fish stocks, herring and blue whiting (each of them producing between 5 and 10 million tons of fish landings each year) could have lowered the amount of *Calanus*, thereby indirectly influencing the adjacent North Sea ecosystem (Skjoldal and Sætre, 2004).

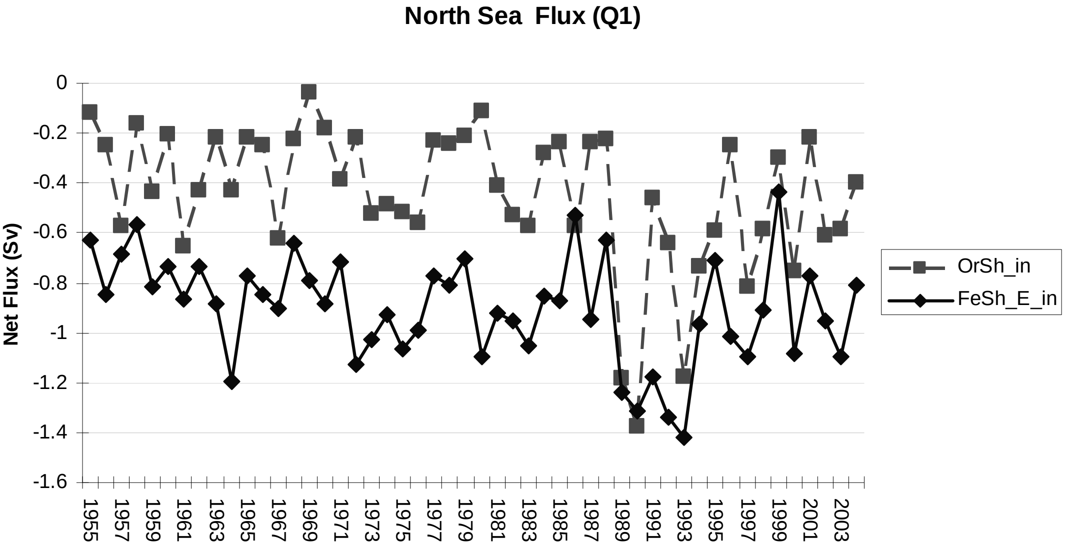


Figure 3.8.10. The annual Q1 average net flux of seawater across two boundaries into the northern North Sea, namely; the Orkney/Shetland transect and the Faeroe/Shetland transect. Both show a large negative flux in 1989 which is associated with a step increase in the North Sea temperature as the amount of cold deep water entering from the North East Atlantic was particular low at this time (Skogen and Søiland, 1998).

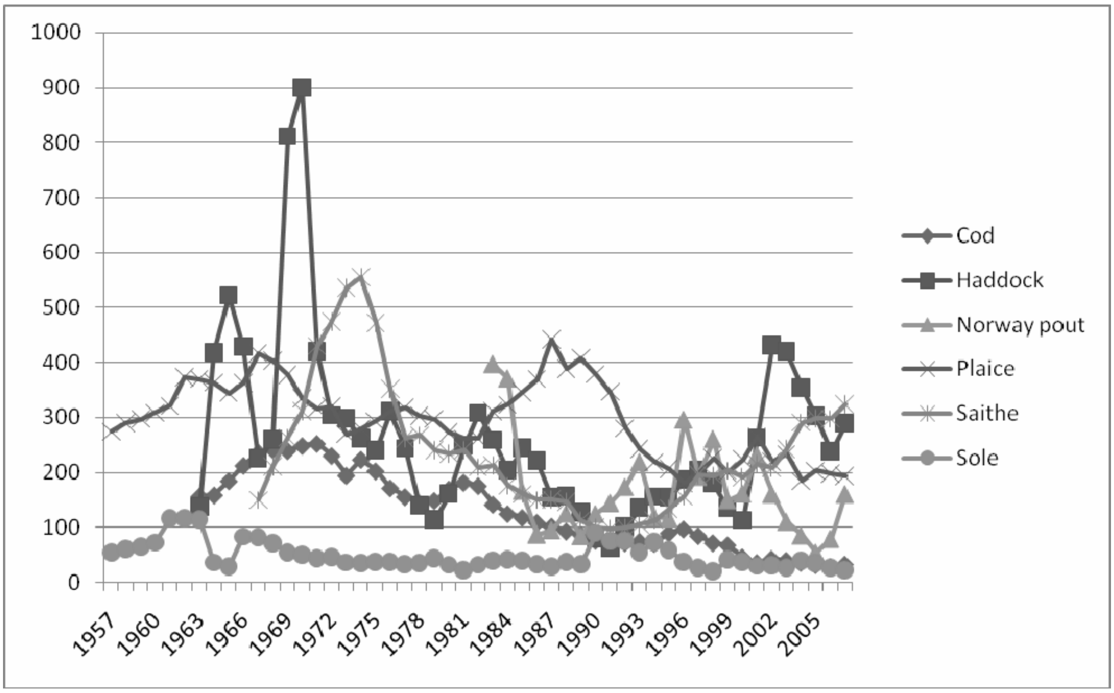


Figure 3.8.11. Total North Sea Spawning Stock Biomass of the 6 most commercially important demersal species between 1957 and 2006. Values are 1000's of tons.

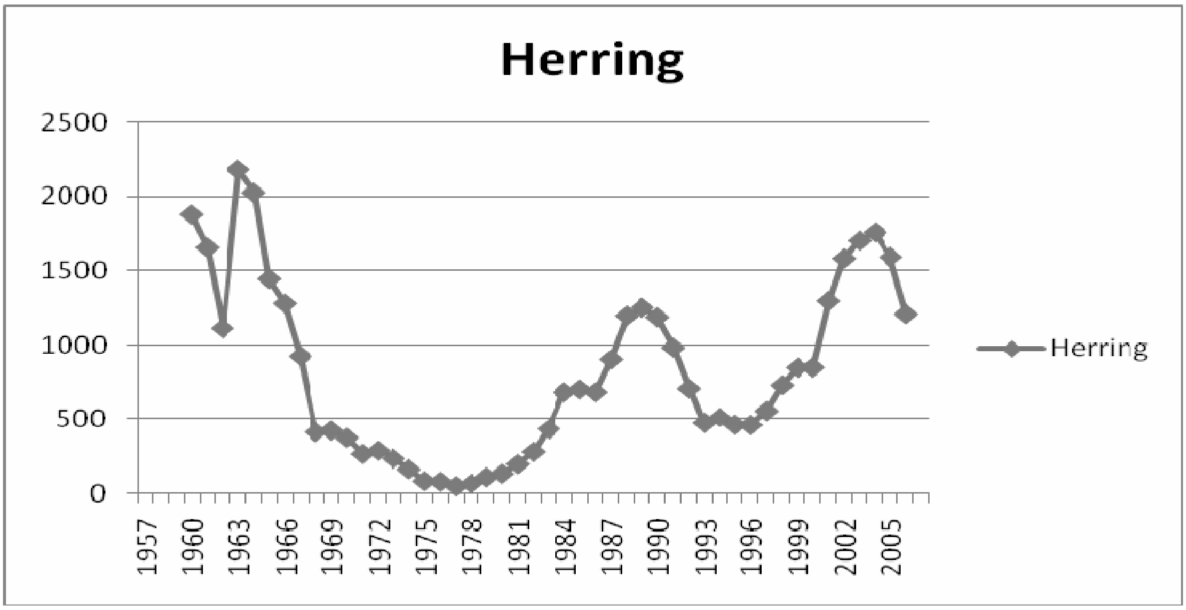


Figure 3.8.12. Total North Sea Spawning Stock Biomass of herring between 1957 and 2006. Values are in 1000's tons.

3.8.1.3 Plankton Status

Effects of climate on zooplankton and their consequences for marine food webs are clear. Beaugrand *et al*. (2003) showed from CPR data and cod catch data in the North Sea that a decreasing abundance of *Calanus finmarchicus* and concomitant shift toward the warmer water *Calanus helgolandicus* was clearly associated with a reduction in cod recruitment. This study demonstrated the critical importance of zooplankton in the marine food web, fisheries yields, and their sensitivity to climate change. Likewise, Corten (2000) showed that the distribution of herring depends on the persistence of suitable food organisms, in particular abundance of *Calanus finmarchicus*. Using PCA, Beaugrand *et al.* (2003) found strong relationships between NAO, SST, phytoplankton, *Calanus finmarchicus*, and salmon. Sims and Reid (2002) found parallel declines in *Calanus* and Basking sharks. Sea birds are strongly impacted by the abundance of sand eels which in turn is determined by abundance of zooplankton and phytoplankton (Frederiksen *et al*., 2006).

Planque and Froementin (1996) found a strong relationship between *Calanus finmarchicus* and NAO from 1958–1995, but the correlation was not as strong after 1996 (Planque and Reid, 1998; Pershing *et al*., 2004). Beaugrand *et al*. (2002) found a decrease in abundance of cold-water and arctic zooplankton species and an increase in warmer water ones in the NE Atlantic and N Sea.

In analyzing CPR data from the North Sea between 1960 and 2003, Hays *et al.* (2005) observed a clear decrease in abundance of *Calanus finmarchicus*, and an increase in *C. helgolandicus*, and a marked overall decrease in both species combined. Over the whole NE Atlantic, Edwards *et al.* (2006) found a distinct decrease in copepod abundance from 1946–2004. In addition to copepods, phenological studies of invertebrate larvae (decapods and echinoderms) in the North Sea reveal a clear trend toward earlier seasonal peaks in abundance, indicating the effects of a warming environment. There have also been clear shifts in community structure in the North Sea, from a low-diversity boreal community during the late 1970s to a higher-diversity warmer water community during the 1990s to present day.

The spring bloom in the Southern Bight and the Channel occurred somewhat later in 2007 than in the two preceding years, and vigorous blooms with high chlorophyll content developed in coastal waters in April and May. On the Norwegian Skagerrak coast the spring bloom occurred in late March, which is later than usual. Chlorophyll levels were low in May and June. Based on satellite-observations of chlorophyll, the spring bloom started first (March) in the stratified waters of Kattegat and Skagerrak and in the clear waters of the Dogger Bank, and latest (May–June) in the northwestern part of the North Sea and in the western Channel.

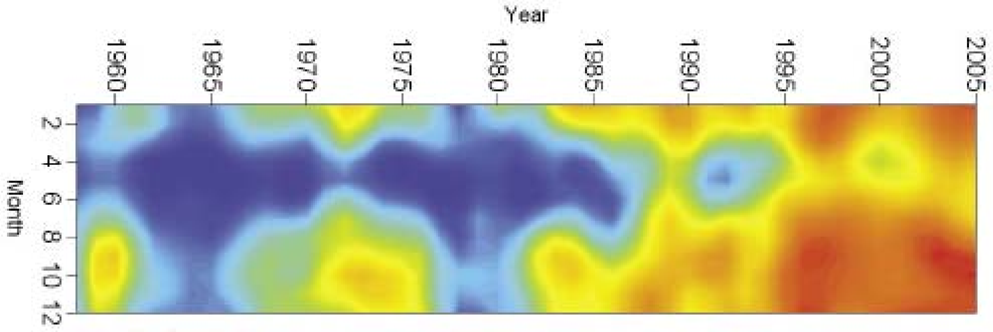


Figure 3.8.13. A simple ratio between a warm-water species (*Calanus helgolandicus*) and a cold-water species (*Calanus finmarchicus*) per month from 1958–2005. Red values indicate a dominance of the warm-water species and blue values the dominance of the cold-water species. (0 = total C. finmarchicus dominance, 1 = total C. helgolandicus dominance). Data from North Sea. (Edwards *et al.*, 2007. Ecological Status Report: results from the CPR survey 2005/2006. SAHFOS Technical Report, 4: 1–8. Plymouth, UK).

3.8.1.4 Benthos and larger invertebrates

The 50 m, 100 m, and 200 m 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 the benthic invertebrate species *Nephrops norvegicus, Pandalus borealis* and brown shrimp *Crangon crangon*.

It was concluded in ICES, (2007c) that in general the spatial distribution of the macrofaunal communities in 2000 was rather similar to that in 1986, as described by Künitzer *et al*., 1992. The decrease in total abundance found in the northern North Sea (>100 m) was influenced by the use of different mesh sizes in 1986 (0.5 mm) and 2000 (1 mm) as well as the spatial resolution of the station grid. The increase in species number in this region in 2000 might be the result of improved taxonomic precision. Thus "real" changes in community structure between 1986 and 2000 can be more confidently discussed for the southern North Sea. Changes in community structure north of the 50 m depth contour may be related to changes in the hydroclimate caused especially by changes in the North Atlantic Oscillation (NAO) which, in positive mode, results in an increase in SST, changes in sediment structure, and food availability, as described by Reid and Edwards (2001) and Kröncke *et al*. (1998). Wieking and Kröncke (2001) described the NAO-influenced changes in hydrography, especially north and south of the Dogger Bank. The increase in inflow of Atlantic water masses through the Fair Isle channel strengthened the frontal system north of the bank creating a "strong" border between northern and southern water masses. High current velocities in the northern part of the Dogger Bank (Siegismund and Schrum, 2001) in addition to a seasonal jet (Brown *et al*., 1999), limit the accumulation of particulate organic material in seabed sediments. Klein *et al*. (1999) showed that, during storms, fine sediments at the seabed are mobilized at a depth of up to 60 m at the northern slope of the Dogger Bank. Thus, the decrease in total species number and the increase in species such as the small polychaete *Paramphinome jeffreysii*, as well as the dominance of the interfacefeeding polychaetes *Myriochele* spp. and *Spiophanes bombyx* north of the 50 m depth contour, provide supporting evidence for a change in hydrodynamics affecting sediment structure and stability, as confirmed by changes in the median grain size in this area associated with changes in food availability (Wieking and Kröncke, 2001). Since *P. jeffreysii* and *Myriochele* spp. are considered to be cold-temperate species, their increase in abundance north of the 50 m depth contour might be a hint of colder northern water masses north of the frontal system. Changes observed in the communities at the offshore stations in the southwestern North Sea towards the English Channel and the eastern part of the Frisian Front indicate similar environmental influences. The decrease in the polychaete *Ophelia borealis* in these regions might be influenced by an increase in SST (*O. borealis* is a cold-temperate species) as well as by changes in the sediment composition as found by Wieking and Kröncke (2001) at the Dogger Bank. However, there was no evidence of a systematic change in sediment particle sizes between the 1986 and 2000 surveys. At the coastal stations in the southwestern North Sea towards the English Channel and at the western part of the Frisian Front, an increase in interface-feeding polychaetes such as *S. bombyx*, *Magelona* spp., and *Lanice conchilega*, as well as the bivalve *Spisula* spp., might be caused by greater food availability at the Flamborough and Frisian Fronts owing to an NAOinduced increase in SST and hydrodynamic forces. Owing to frontal conditions and enhanced primary production, food supply to the benthos (quality and quantity) will be higher than in non-frontal areas at comparable depths. In the eastern North Sea in 2000, the increase in phoronids and other interface-feeding species such as the polychaete *S. bombyx* and the bivalves *Fabulina fabula* and *Corbula gibba* also indicate an NAO-induced increase in food availability owing to higher primary production in the German Bight, as described by Reid *et al*. (1998) and Reid and Edwards (2001). Current induced changes in the sediment structure might have caused the increase in the brittlestar *Amphiura brachiata* and the sea urchin *Echinocyamus pusillus*, which prefers coarser sediments, but *A. brachiata* is also a warm-temperate species (Wieking and Kröncke, 2001)

3.8.1.5 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 and 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.

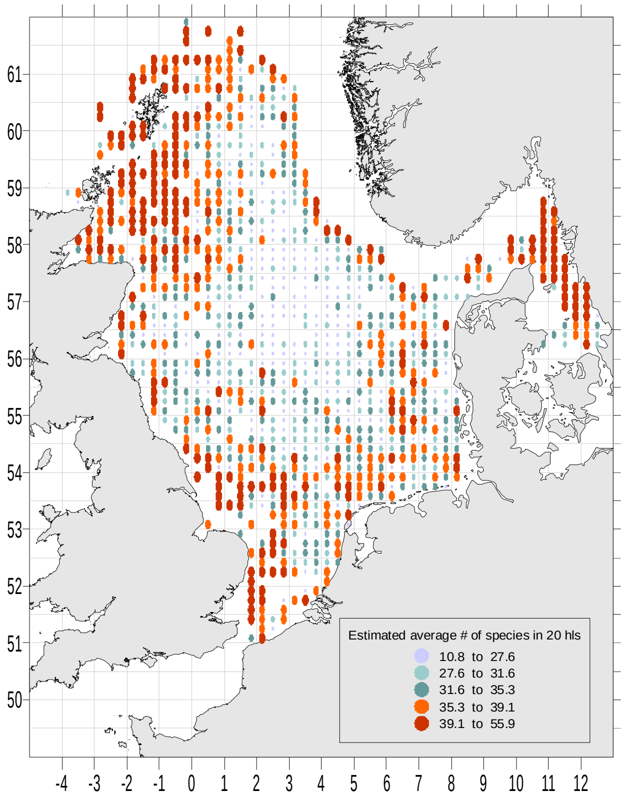


Figure 3.8.14. Spatial indices of species richness for all species.

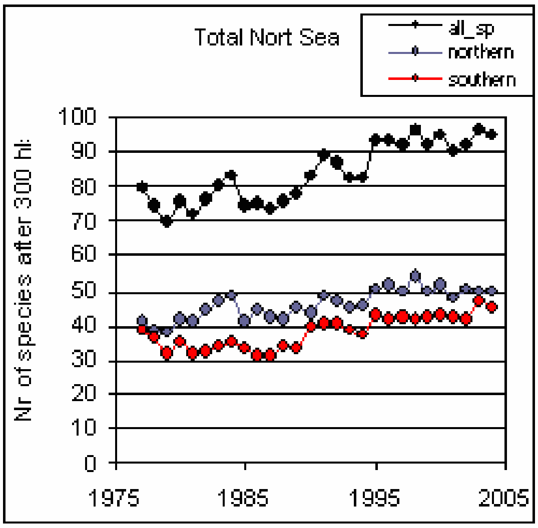


Figure 3.8.15. Species richness based on IBTS surveys.

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 and Sinclair, 2000; Jennings *et al.*, 1999). This is reflected in the slopes of size spectra becoming steeper (Rice and Gislason, 1996), reductions in the abundance of large species with low intrinsic rates of increase, such as many elasmobranches, (Walker and Heessen, 1996; Walker and Hislop, 1998), and increases in abundance of many smaller species (Greenstreet and Hall, 1996; Heessen and 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 and Furness, 1996; Wanless *et al.*, 1998) and marine mammals (Hammond and 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 and 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 and Heessen, 1996). Spatial management measures have been proposed, and in some cases implemented to protect the remaining stocks.

Fish population structure

Recent tagging studies suggest that the Skagerrak coast and the Kattegat may function as nursery area for North Sea cod, and that return migration to the North Sea are commonplace (Svedäng and Svenson, 2006; Svedäng *et al.*, 2007). The existence of separate subpopulations in the Kattegat in relation to putative subpopulations in the Skagerrak and the North Sea has also been further corroborated by genetic surveys, supporting the proposition of a spatially segregated stock structure in the eastern North Sea region (Stenseth *et al.*, 2006; Carl André, pers.com). 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 and Svedäng, 2004). However, remnants of the collapsed Kattegatt population (ICES, 2007) still spawn in the southeastern Kattegatt (Vitale *et al.*, in press).

Demersal elasmobranchs

In the North Sea about 10 skate and ray species occur as well as seven demersal shark species. Thornback ray *R. clavata,* is probably the most important ray for the commercial fisheries. Preliminary assessments for this species were presented in ICES (2005). The trends in total international landings of rays and skates for AreaIV are shown in Figure 3.8.16 (ICES, 2007).

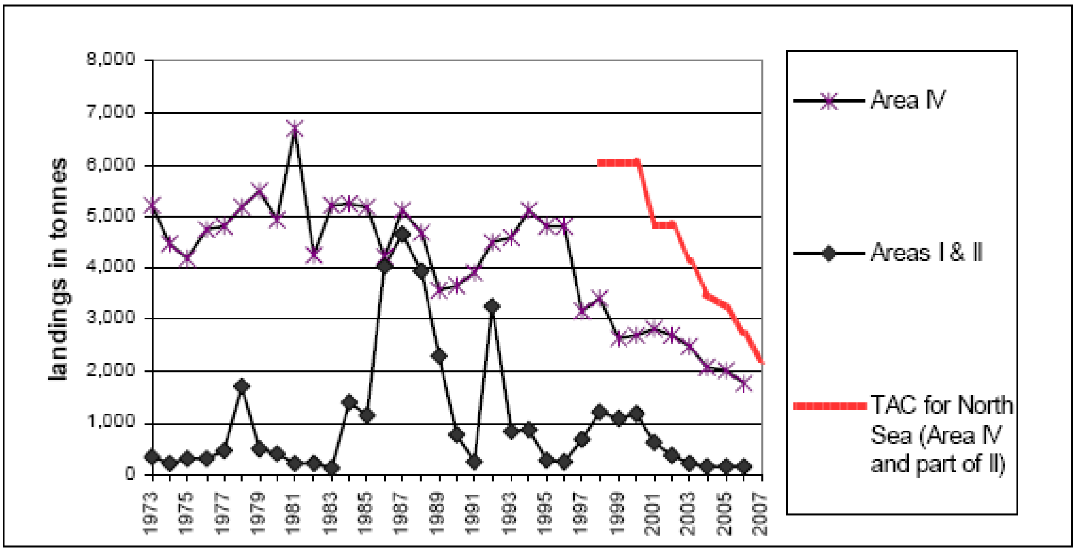


Figure 3.8.16. Demersal elasmobranchs in the North Sea, Skagerrak, Kattegat and eastern Channel: total international landings of rays and skates from areas IV and I & II, and EC TAC for the North Sea.

Raja clavata: is restricted mainly to the south-western extent of the North Sea Survey indices of abundance increased during the 1980s, followed by a decline to the mid 1990s, and with a recent increase (Figure 3.8.17). The manner in which total area occupied (AO) changed over time, fluctuating but lower after the mid-1990s bore little resemblance to the pattern of abundance. Most of the abundance is concentrated in a small area to the southwest of the survey area. Present total AO is only 44% of the extent of the species in the 1980s.

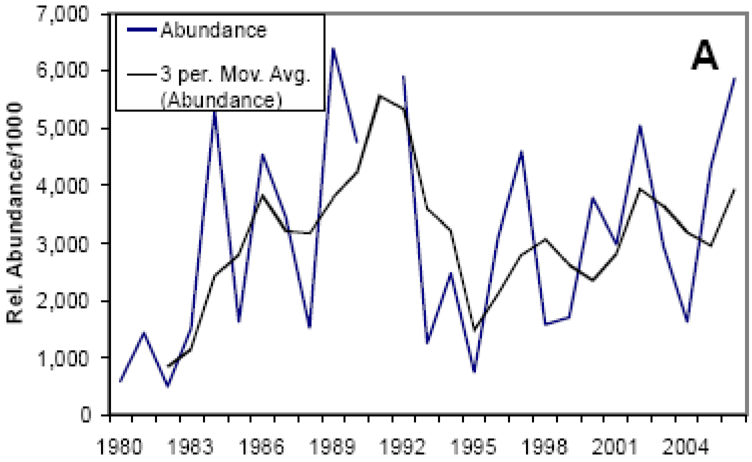


Figure 3.8.17. R. clavata in the North Sea. Annual estimates of relative abundance using SPANdex. A 3 year running average is represented to smooth the high inter-annual variation of the estimates.

All four skate species appear to have maintained or increased their abundance since 1980. However, for at least two species, the area occupied (AO) has varied in a manner quite different from changes in abundance. In all cases high density AO (at the centre of mass) corresponded more closely to the observed abundance changes. Total AO, reflecting extent of the distribution of a species is often used as one metric of population status (IUCN, 2001). However, it is clear, from this comparison of spatial dynamics in relation to changes in abundance of four species of skates in the North Sea that total AO may be misleading. Total AO may not reflect population changes and therefore should be used with caution when being used to assess the status of species. A clear example of this is the large decline in total AO of *R. clavata* which did not match changes in abundance. *R. clavata* has become more concentrated at the centre of mass. This type of pattern should however be regarded with caution particularly if the species is becoming more concentrated where fishing effort is high.

3.8.1.6 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).

3.8.1.7 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 (8300 t), haddock (6500 t) and plaice (5200 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 (6600 t) and dragonets (1900 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 bycatch in fishing operations and effects of contaminants. Specifically, the large bycatch of harbour porpoise in gillnet fisheries has led to management measures.

Porpoise

The harbour porpoise is the most commonly encountered and widely distributed cetacean species in the North Sea but there are few sightings south of 47ºN. Overall abundance of harbour porpoises in the North Sea and adjacent areas has not changed between the two SCANS surveys (1994 and 2005). Harbour porpoise numbers in the whole area were estimated to be 386 000 (Coefficient of variation, CV=0.20). Porpoise density was lowest in strata along the outer shelf to the west of Britain and Ireland and off the Atlantic coasts of France, Spain and Portugal (<0.1 animals/km2). It was highest in the south central North Sea and coastal waters of northwest Denmark (~0.6 animals/km2). Elsewhere there was relatively little variation in porpoise density. Harbour porpoise distribution, however, has undergone a southward shift with a two-fold increase in the number of porpoises in the southern North Sea strata while porpoise numbers in the northern North Sea strata have halved (Figures 3.8.18 and 3.8.19). The reasons for this southward shift of harbour porpoise distribution are unknown; however, a change in distribution and availability of prey species is considered the most likely explanation, although other explanations are possible.

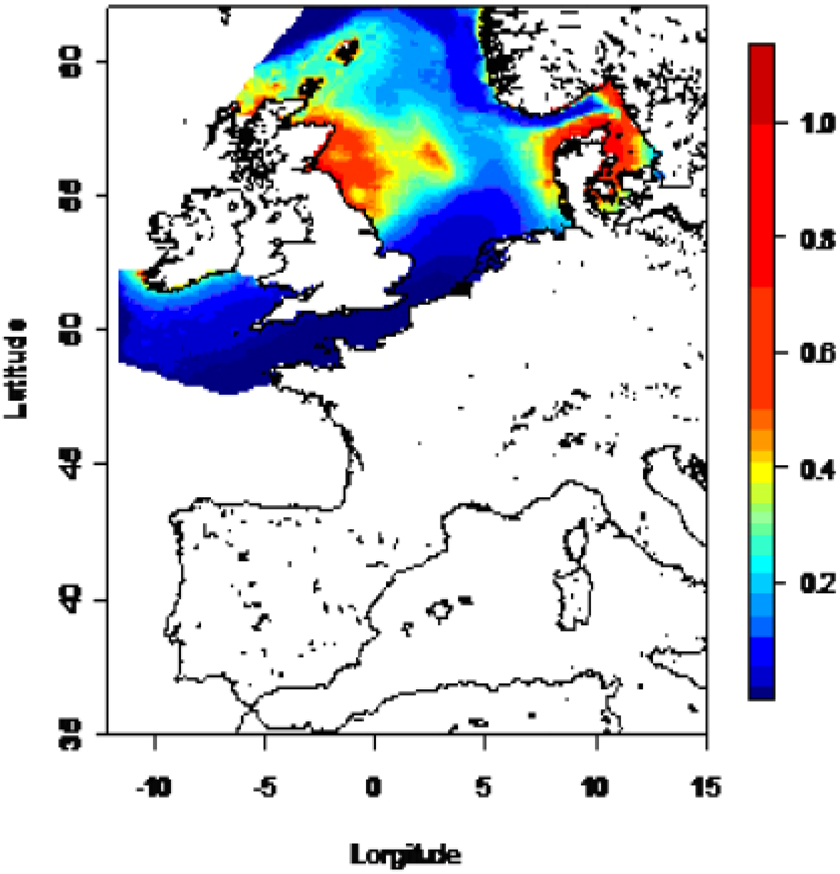


Figure 3.8.18. Density surface of harbour porpoise abundance from the SCANS I survey in 1994 (animals.km^{-2}). Note the main concentrations off East Scotland and north-east England and around Denmark. Surveys were not conducted in the Irish Sea and west of Scotland.

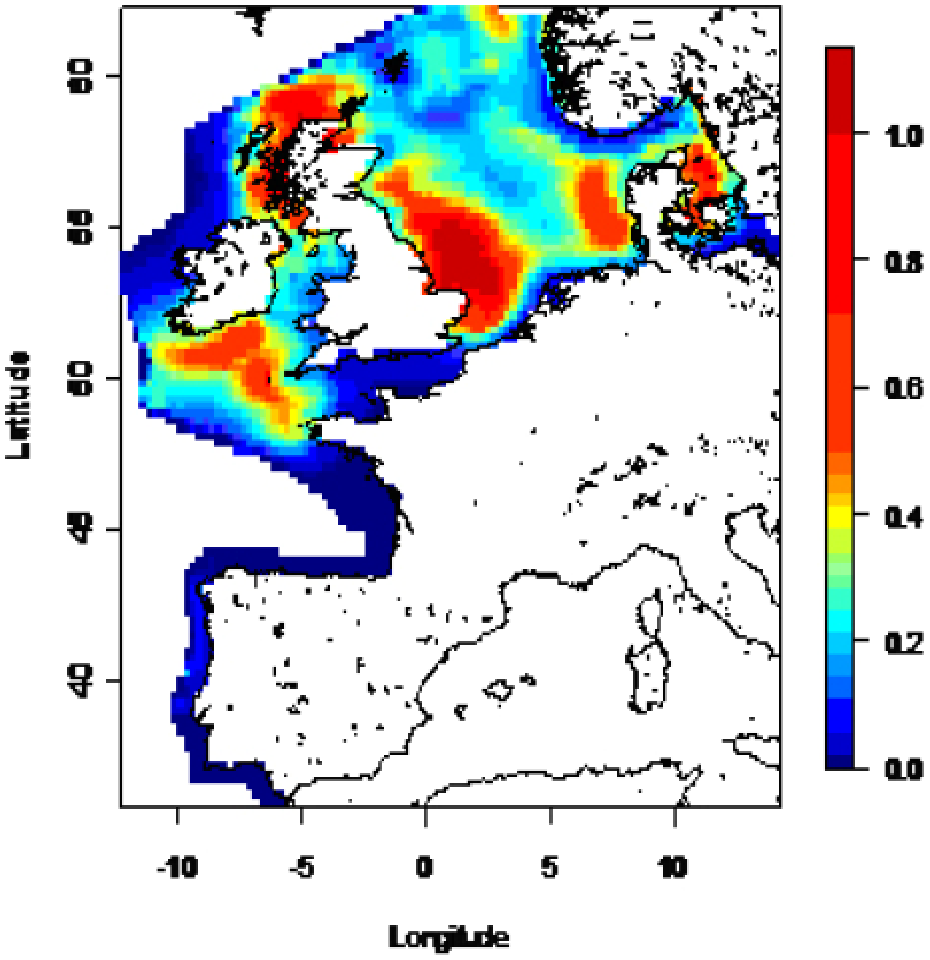


Figure 3.8.19a. Density surface of harbour porpoise abundance from the SCANS II survey in 2005 (animals.km-^{2}). Note that the main concentration in the North Sea is now off East England and North Scotland, also the increased densities on Celtic Shelf. The concentration to the west of Denmark is further offshore.

Evidence of increased numbers of porpoises in the southern North Sea has continued to accumulate (Figure 3.8.19). From sightings during two aerial observation flights (modified pollution control flights) performed by MUMM (Management Unit of Mathematical Models for the North Sea, in Brussels) it was (roughly) estimated that the average density of porpoises in Belgian waters in March and April 2004 was between 0.2 to 0.6 per square km, or 650 to 2100 animals (Haelters and Jacques, 2006). Numbers of porpoises in Belgian waters in summer and autumn are much lower. Long-term passive acoustic monitoring has been conducted in the German Baltic Sea from August 2002 to December 2005 with porpoise detectors (T-PODs). Results show seasonal as well as geographical variation in harbour porpoise presence (and therefore abundance), with decreasing detections from west to east and more porpoises in the summer months than in winter (Verfuß *et al.*, 2007). 2006 data show similar results (Verfuß, pers. comm.).

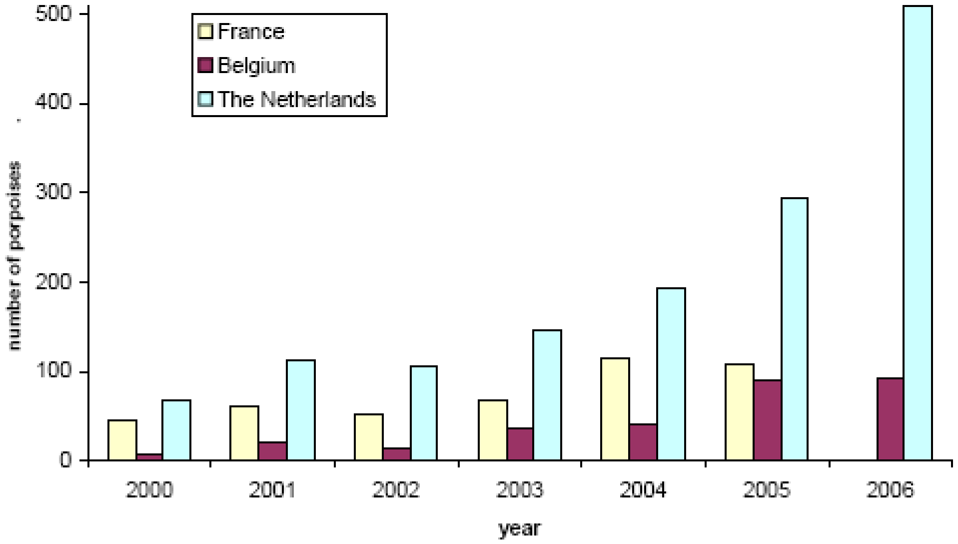


Figure 3.8.19b. Increase of porpoises strandings on the French, Belgian and Dutch coasts between 2000 and 2006 (no data for the French coast for 2006 available yet) (compiled from RBINS/MUMM, unpublished; ASCOBANS, 2007).

3.8.1.8 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 2007. 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.

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). Vast oyster beds were described from the open North Sea by Olsen (1883) and the Wadden Sea by Hagmeier and Kändler (1927) and Linke (1937) that no longer exist. Early, preindustrial trawl fisheries in the North Sea targeted oysters already in the 1700 century and overexploitation is important in explaining the early extermination of these populations (Reise, 1982; Neudecker, 1990).

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 and Sinclair, 2000; Jennings *et al.*, 1999; Greenstreet and Rogers, 2006). This is reflected in the steeper slopes of size spectra (Rice and Gislason, 1996), reductions in the abundance of large species, such as many elasmobranches, with low intrinsic rates of increase (Walker and Heessen, 1996; Walker and Hislop, 1998), increases in abundance of many smaller species (Greenstreet and Hall, 1996; Heessen and 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).

3.8.4 Links between North Sea plankton, fish stocks, fisheries and seabirds

This description builds upon the existing knowledge available on the structure and function of the North Sea marine ecosystem (Jones, 1982 and Heath, 2005). For example, it is known that energy, in the form of carbon and nutrients, flows between the trophic levels as a result of predator-prey interactions and that these interactions to a large extent are size based such that numerous small animals tend to be eaten by rather fewer larger animals creating complex foodwebs (Jones, 1982; Heath, 2005 and Steele *et al.*, 2007). Also the recycling of carbon and nutrients by micro-organisms ensures energy passes back down the foodweb as a series of microbial feedback loops and that coupling between the pelagic and benthic ecosystems is maintained.

To illustrate the changes in energy cycling in the North Sea foodweb two 11 year periods were distinguished 1983–1993 (Figure 3.8.20) and 1993–2003 (Figure 3.8.21).

For the earlier period (1983–1993) the results suggest a system mainly top-down regulated, as indicated by generally higher relatedness at the top than at the bottom of the foodweb. Significant top-down fishing pressure was indicated by the highest relatedness value occurring between demersal fishing pressure and demersal stock (0.8), but also high relatedness between the pelagic fishery and pelagic stock (0.5). For both the demersal and pelagic ecosystems the predominant pressure acting on the North Sea ecosystem (as represented by the ecosystem components described) was from fishing and not environmental forcing. Indeed, during the 1980s a doubling of the annual sandeel landings was witnessed from 0.5 million tonnes in 1983 to 1.1 million tonnes in 1989; landings of demersal fish such as cod were in steady decline which is usually attributed to both climate and mainly otter trawl fishing. Beam trawling effort also increased significantly over this period putting further pressure on the system (Jennings *et al.*, 1999). In addition, there is a significant and high degree of relatedness between seabirds and both pelagic and demersal fisheries and fish stocks. In this respect it is noteworthy that the highest value is between the demersal fishery and seabirds (0.7) possibly reflecting the increase in discards associated with the demersal fishery compared to the pelagic fishery (Furness, 2003).

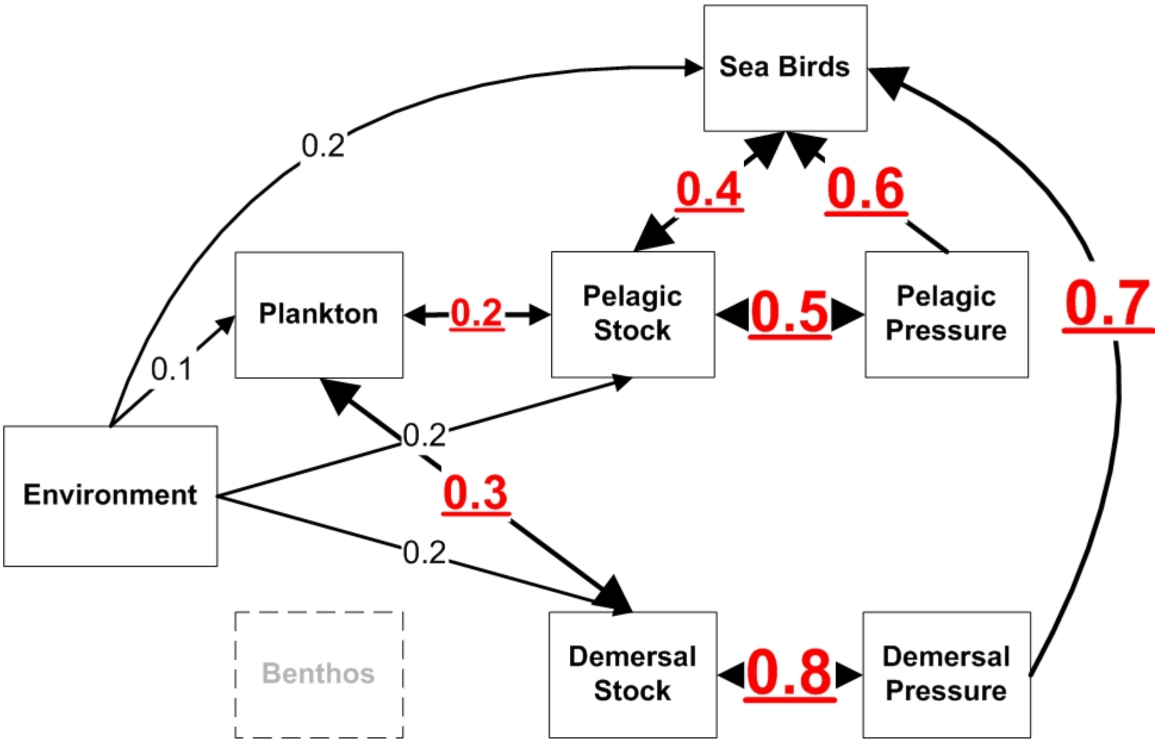


Figure 3.8.20. The relatedness (or degree of connection) between ecosystem components of the North Sea for the period 1983 to 1993, highlighting a significant possible top-down pressure as a result of fishing. Numbers underlined indicate a significant correlation.

By contrast the period 1993 to 2003 (Figure 3.8.21) shows the pelagic foodweb to be bottom-up regulated with a highest value between the abiotic and plankton components (0.6) and decreasing values further up the food chain. This system is arguably more sustainable and favourable for the maintenance of ecosystem integrity and fisheries. However, for the benthic ecosystem the relatedness between the demersal fishery and demersal fish stock components remains significantly high, albeit lower than in the pre-1993 period, suggesting top-down fishery pressure remains significant, and greater than the environmental forcing. In addition, it is noteworthy that the degree of relatedness between the seabirds and both fisheries and fish stock components has decreased over this period compared to the period 1983 to 1993, which is perhaps to be expected given the overall decline in fish discards (as inferred from the overall decline in demersal fish landings) over the assessment period. Interestingly a similar decline has been described in the seabird populations in the North Sea particularly for the northern fulmar and black-legged kittiwake (Parsons *et al.*, in press).

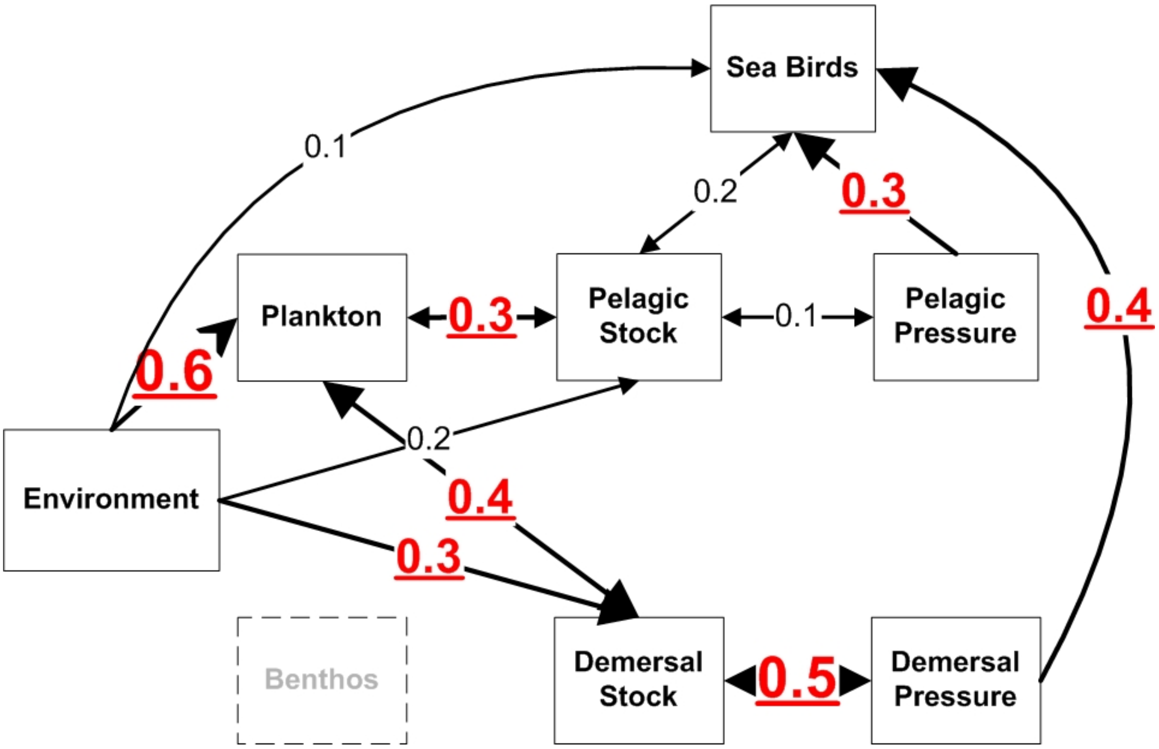


Figure 3.8.21. The relatedness (or degree of connection) between ecosystem components of the North Sea for the period 1993 to 2003, highlighting a significant bottom-up pressure for the pelagic ecosystem and top-down pressure for the benthic ecosystem. Numbers underlined indicate a significant correlation.

3.8.5 References

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3.9 The Baltic Sea

In addition to WGRED, the newly established ICES/HELCOM Working Group on Integrated Assessments of the Baltic Sea (WGIAB) had its first meeting in March 2007 (ICES, 2007). The aim of WGIAB is to conduct and further develop Integrated Assessments for the different subsystems of the Baltic Sea, as a step towards implementing the ecosystem approach in the area. Key to the implementation of an ecosystem approach to the management of marine resources and environmental quality is the development of an Integrated Assessment (IA) of the ecosystem. WGIAB decided on 3 major goals to be accomplished within the 3 next years, which are (i) to regularly conduct RIEAs (Regional Integrated Ecosystem Assessments), (ii) develop adaptive management strategies and (iii) incorporate modelling into the assessment work.

WGIAB conducts RIEAs for four subregions (systems) of the Baltic Sea (i) Central Baltic Sea;, including the three deep basins, Bornholm Basin, Gdansk Deep and Gotland Basin; ii) Gulf of Riga; iii) the Gulf of Finland; iv) Bothnian Sea). For all systems multivariate analyses have been conducted using matrices of time-series representing the ecosystems and their environments. All four investigated subsystems displayed pronounced changes in the last 2–3 decades with a series of Reg*ime Shifts* (RS) identified in all multivariate datasets. Climate-related hydrographic change in the Baltic, i.e. decreases in salinity and oxygen and increase in temperature, have been identified as the main drivers of the ecosystem changes.

For more details see the reports of WGIAB (ICES, 2007). WGRED will continue to give an overview about the Baltic Sea as a whole.

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. Marine landscapes and habitats have recently been compiled for the whole Baltic Sea in the project BALANCE (www.balance-eu.org).

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 the 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. Some recent baroclinic inflows in 2006 changed the deep water temperatures and improved the oxygen situation in the southern Baltic. Recent investigations in July 2007 have shown that the huge vertical extension of the layer containing hydrogen sulphide remained (Helcom, 2007).

The sea surface temperature of the year 2006 was characterized by comparatively warm months, July, Octobers and Decembers and in the annual average 2006 was the warmest year of the period 1990–2006 (Helcom, 2007). Meanwhile, near-bottom temperatures have exceeded the long-term mean again as a consequence of the baroclinic inflow of 2003, and are raising further in 2007 due to the baroclinic inflows of 2006 (Nausch *et al.*, 2007). The northern and western Gotland Basin is only indirectly affected by the baroclinic events of 2006. Bottom temperature in the Bornhold Deep is now 2.7 ^{o}C above the average 1971–1990 (8.80 vs 6.12), and 2–3^{o}C warmer than in all other basins (Helcom, 2007). A recent report by HELCOM (2007) states: "In summary, a climate warming is reflected in time series data on the maximum annual extent of sea ice and the length of the ice season in the Baltic Sea. On the basis of the ice extent, the shift towards a warmer climate took place in the latter half of the 19th century. During the past ten years, all ice winters have been average, mild, or extremely mild. The length of the ice season showed a decreasing trend by 14–44 days during the 20th century, the exact number depending on the location around the Baltic Sea. The ice extent, the date of ice break-up, and the length of the ice season show a correlation with the NAO index." Ice coverage in the Baltic is lagging behind the mean development by several weeks in the winter 2007/2008. The ice conditions in winter 2006/2007 were normal for a mild winter. However, taking the amount of ice reports as an indicator for the length of the ice season 2006/2007, this was the shortest ice season since 1960. (Bundesamt für Seeschiffahrt und Hydrographie, Baltic Sea Ice Services, http://bsis.eisdienst.de/index.shtml).

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).

Furthermore, hypoxia in shallow coastal waters seriously affects biodiversity especially in the archipelagos of the northern Baltic Sea. These irregular events are caused by local topography, hydrography and drifting algal mats. (Helcom, 2002).

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). Annual emissions of dioxins and furans in HELCOM countries have decreased during the period from 1990 to 2005 by 24% (Helcom, 2007).

Pollution of the Baltic Sea includes POPs, such as PCBs and other organochlorines e.g. dioxins are efficiently transferred through trophic levels which often results in higher concentrations in top consumers and fat rich species e.g. sprat, herring and salmon. Contaminant levels in northern Baltic herring and salmon are so high that consumption is being regulated (Helcom, 2002, 2004). Concentrations of PCBs in fish vary between years and species. In herring muscle concentrations were high in the late 1960s to early 1970s and have declined since that time. Similarly, in cod liver the concentrations have declined by 4–5 fold during the 1980s to 1990s. However, after the early 1990s the levels have remained stable or risen slightly. These trends mirrors the ban of PCBs but also indicates that PCBs are still available and cycled through trophic levels despite the ban and much lowered supply to the Baltic from direct emissions and other processes such as riverine input and deposition. The largest pool of PCBs in the Baltic Sea is in the sediment which also acts as an important source for PCB in biota (Wania *et al.*, 2001). MacKenzie *et al.* (2004) showed that the standing stock of the most important fish species in the Baltic Sea is an important sink for PCBs that, through fisheries, removes a significant part in comparison to other budget components. The study highlights that fisheries has a role in the recycling of contaminants and suggests that banning the discard of contaminated organs such as cod liver could be part of pollution management (MacKenzie *et al.*, 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 and 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 (Hagen and Feistel, 2005).

3.9.1.3 Baltic Sea food-web

The Baltic Sea food-web shows a relatively low species diversity, compared to fully marine systems (Sandberg *et al.*, 2000), but includes all trophic levels from primery producers to marine mammals as top predators (Harvey *et al.*, 1997, Jarre-Teichmann, 1995). The lowest trophic levels are occupied by primary producers (phytoplankton, and\or macrophytes in costal areas). The intermediate trophic levels (2–2.8 TL) is covered by Micro- and Mesozooplankton as well as benthic fauna. Fish (demersal and pelagic) as well as carnivore invertebrates occupy the trophic levels from 3.4 to 3.7 (Sandberg *et al.*, 2000). Marine mammals (seals and harbour porpoises) form the highest trophic levels.

Despite of spatial environmental gradients, the classical food web structure is fairly similar on geographical scales; however the estimated primary production varied significantly between basins (Sandberg, 2007). The overall carbon flows are highest in the Baltic proper, somewhat lower in the Bothnian Sea and much lower in Bothnian Bay. A clear difference could be found in the average trophic levels in the food web between basins. The average trophic level was lower for demersal fish in the Bothnian Sea and higher for macrofauna in the Bothnian Bay, compared to the other basins (Sandberg *et al.*, 2000).

As described by Harvey *et al.* (1997) biomass changes at higher trophic levels caused either by fishing, trophic interactions, and/or variable recruitment also influence lower trophic levels. Also Osterbloom *et al.* (2006, 2007), confirm that cascading effects in the Baltic food web and fish population dynamics are related to fisheries management strategies and the level of productivity.

The south-eastern Baltic coastal ecosystems are highly productive, channelling a large proportion of their primary production into exploitable fishery resources. Local nutrient sources influence phytoplankton primary production, but retention of primary production in sheltered areas with favourable hydrographical conditions is the most important factor determining food availability to the pelagic and benthic food web (Tomczak *et al.*, 2005).

3.9.1.4 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 7000 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). The spring bloom was higher in 2007 than in the previous year in the Gulf of Finland, the Northern Baltic Proper and Arkona Basin. No rising trend can be detected from 1992 to 2007 in the Gulf of Finland, the Northern Baltic Proper or the Arkona Basin (Helcom, 2007).

3.9.1.5 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.

3.9.1.6 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).

3.9.1.7 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, flounder, plaice, turbot, 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 impaired recruitment 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.*, 2003). 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 (Köster *et al.*, 2005). 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.

Egg predation intensity by clupeids depends on ambient hydrographic conditions. In stagnation periods, when oxygen and salinity are low, the vertical overlap between predator and prey is high, while opposite conditions release cod eggs from clupeid predation. Furthermore, egg predation pressure depends on predator abundance. Herring stock sizes declined throughout the 1980s and 1990s (Köster *et al.*, 2003), while sprat stock size increased to the highest levels on record in the mid-1990s, mainly because of favourable thermal conditions for reproduction (MacKenzie and Köster, 2004). Timing of spawning defines the major predator species, late spawning enhancing the horizontal overlap with herring, but releasing predation pressure by sprat. The shift of the cod spawning season to summer during the first half of the 1990s has thus been an advantage for cod reproductive success. (Köster *et al.*, 2005).

The commercial fish community changed from cod-to sprat-dominated during the recent decades. The cod stock declined due to climate-induced recruitment failure and a continuously high fishing pressure (Köster *et al.*, 2005). The sprat stock increased meanwhile to record levels during the 1990s being a result of climate-induced recruitment success and lower predation pressure by cod (Köster *et al.*, 2003; MacKenzie and Köster, 2004). Herring biomasss decreased mainly due to reduced growth (Möllmann *et al.*, 2005), but also lower recruitment.

3.9.1.8 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; Österblom *et al.*, 2007). 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 weakening cod recruitment and subsequently generating favourable recruitment conditions for sprat (Köster and Möllman, 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, but importantly also by the release of sprat from cod predation (Harvey *et al.*, 2003). The dominance shift was supported by the continued high fishing pressure on cod (Jarre-Teichmann, 1995, ICES, 2007). The dramatic increase of sprat has had a negative effect not only on the growth and abundance of predators and zooplanktivores (sprat and herring; Cardinale and Arrhenius, 2000; Cardinale *et al.*, 2002; Casini *et al.*, 2006) and the breeding success of the fish-eating common guillemot (Österblom *et al.*, 2006), but has also had cascading effects on zooplankton (Casini *et al.*, 2006) and phytoplankton (Casini, pers.com.).

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. However, parallel with the shift in the offshore ecosystem, the landings of the main coastal predators perch and pike have declined during the last two decades in coastal areas of the Baltic Proper, most likely due to recruitment failure caused by larval starvation (Ljunggren *et al.*, 2005; Nilsson *et al.*, 2004).

3.9.2.1 Bycatch of fish

The total bycatch of fish in the Baltic fisheries is presently unknown. The EU has supported several very recent studies of bycatch, 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 bycatches. The less important smaller fisheries can have a high proportion of bycatch (Helcom, 2002).

The occurrence of lost net have been surveyed in areas where gillnet fishing are practiced and lost nets are frequent (compiled in Brown and Macfadyen, 2007. 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 bycatches 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 bycaught 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 2007) 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.

3.9.3.1 Non-native species

The current status of being a non-native species refers to a position in evolutionary history but does not qualify as an ecological category with distinct and consistent properties. However, the next invasion by a non-native species may be the first with profound consequences on the ecosystems affected and therefore, precautionary measures should be taken to avoid any introduction (Reise *et al.*, 2006). The American comb jellyfish *Mnemiopsis leidyi* was first recorded in the Baltic Sea in 2006 (Javidpour *et al.*, 2006). In the Black Sea, *M. leidyi* showed to be a dangerous invader, feeding intensively on early life stages of commercial important pelagic fish species, thus impacting on fish stocks as well as causing dramatic cascading effects on the whole food-web (Shiganova *et al.*, 2001). In a recent investigation, Haslob *et al.* (2007) investigated the potential consequences for fish stock recruitment in the Baltic Sea, focussing on the Bornholm Basin, which serves as the major spawning ground for cod and sprat. It could be shown that the diet of *M. leidyi* is composed of fish eggs. The vertical overlap coefficient with cod eggs was more than 4 times higher than with sprat eggs. Based on an observed temporal and spatial overlap with cod eggs, *M. leidyi* should be considered a potentially important predator of cod (Haslob *et al.*, 2007).

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 cascaded down the food web resulting in a shift in zooplankton and phytoplankton, which as well 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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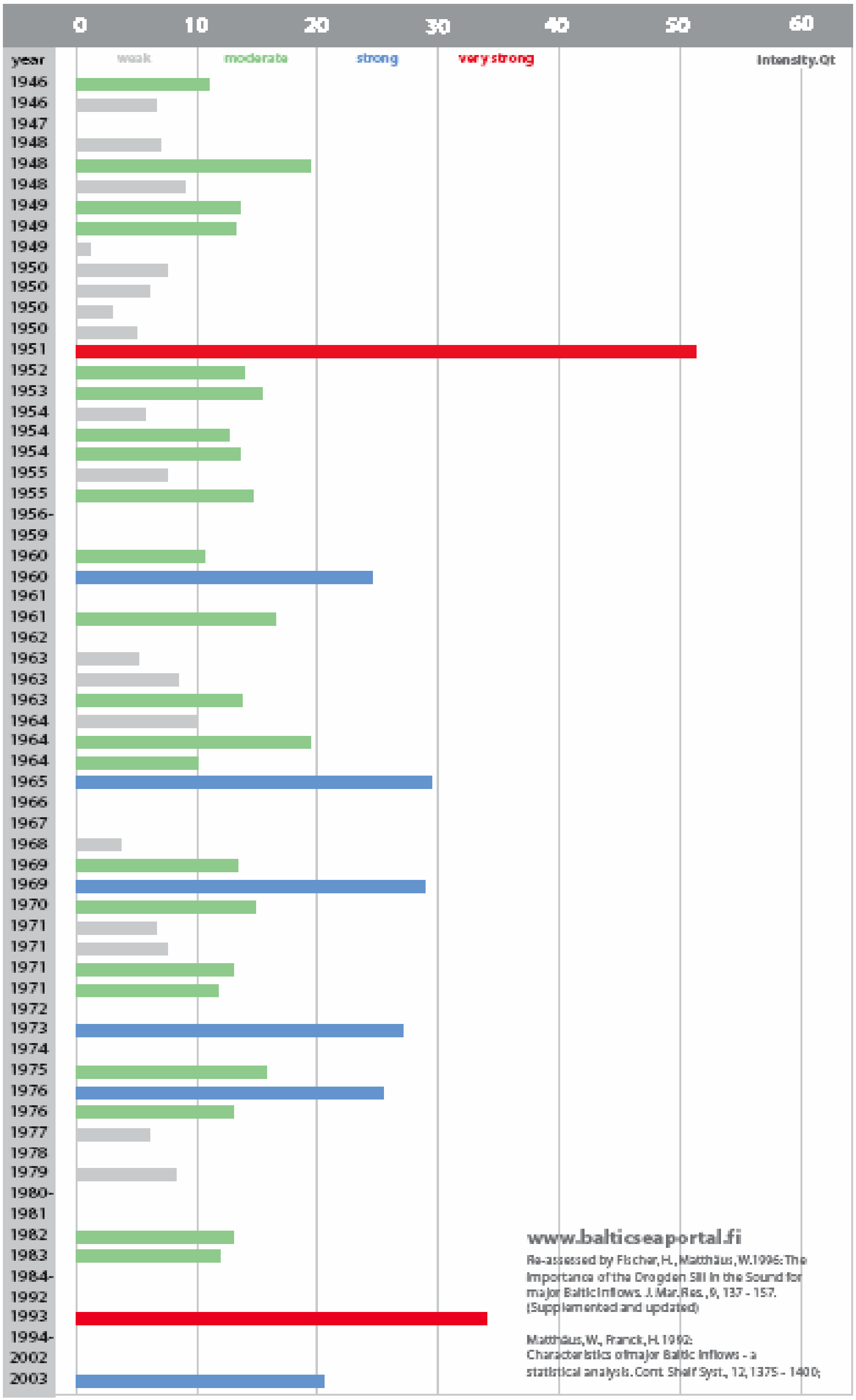
Intensity of major Baltic inflows 1946-2003



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Re-assessed by Fischer, H., Matthäus, W. 1996: The importance of the Drogden Sill in the Sound for major Baltic inflows. J. Mar. Res., 9, 137 - 157. (Supplemented and updated)

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

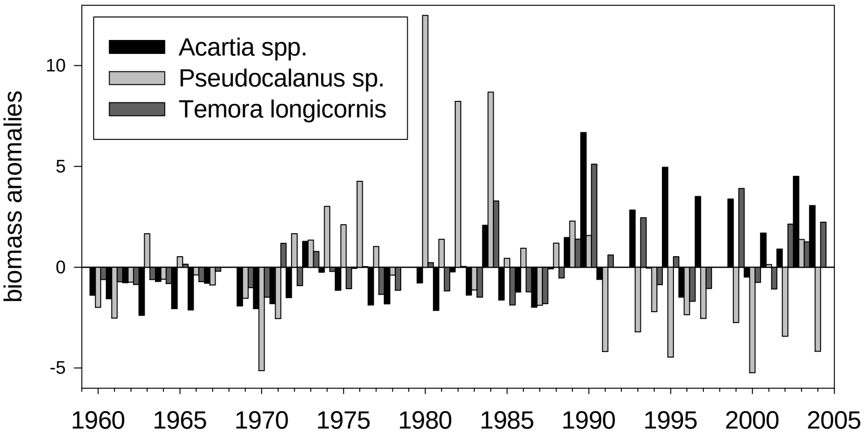

Figure 3.9.2. Time-series on spring biomass (mg*m-3) anomalies for the dominant mesozooplankton species in the Eastern Baltic, i.e. the calanoid copepods Acartia spp., Pseudocalanus sp. and Temora longicornis; data are from the Latvian Fish Resource Agency LatFRA in Riga.

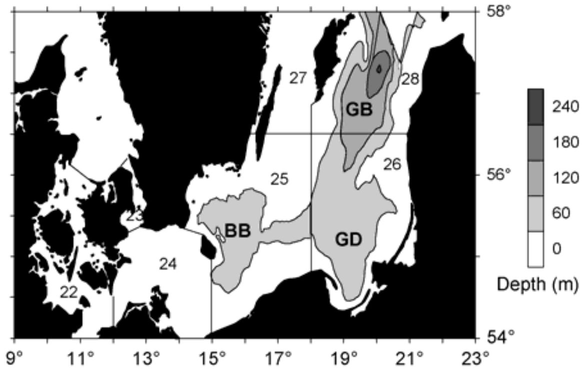

Figure 3.9.3. The southern and central Baltic with spawning areas of the eastern Baltic cod stock in ICES Subdivisions 25 (BB: Bornholm Basin), 26 (GD: Gdansk Deep), and 28 (GB: Gotland Basin). From Köster *et al.*, 2005: Baltic cod recruitment-the impact of climate variability on key processes. ICES Journal of Marine Science, 62: 1408–1425.

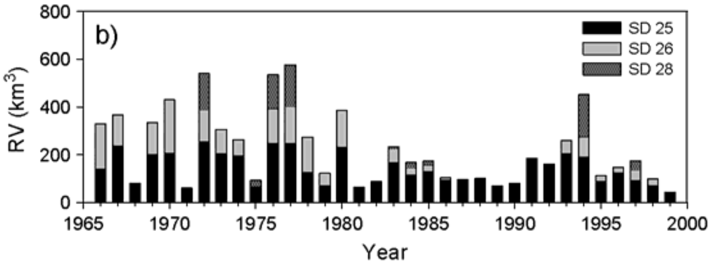

Figure 3.9.4. Time-series of reproductive volume (RV) in Subdivisions 25, 26, and 28. Modified from Köster *et al.*, 2005: Baltic cod recruitment-the impact of climate variability on key processes. ICES Journal of Marine Science, 62: 1408–1425.

3.10 English Channel

3.10.1 Ecosystem components

3.10.1.1 General geography

The English Channel is a shallow epicontinental sea separated from the Atlantic by the Celtic shelf. It stretches over 500 km (about 77 000 km^2) from the Dover strait to the east to an arbitrary limit with the Celtic Sea to the west. It is characterized by its particular morphology (causing a strong Atlantic influence to the west) and a diversified coast line.

Toward its western limit, the depth is about 100 m (at longitude 5°W) reaching 180 m in its central trench which extent into this zone. It then diminishes towards the east (40 m in the center of the Dover Strait (Figure 3.10.1). The Channel can also be defined as a biogeographical transition zone for numerous species as it is situated between Lusitanian (to the south) and boreal (to the north) provinces. This transition status enables the early detection of trends in ocean climate between the two provinces.

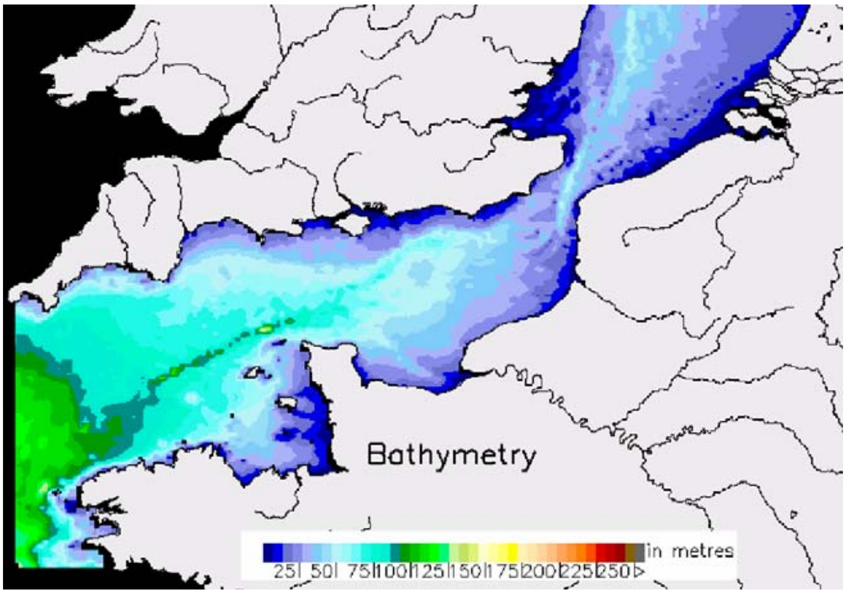

Figure 3.10.1. Bathymetry of the Channel (source IFREMER, http://www.ifremer.fr/cersat/facilities/browse/del/roses/browse.htm) .

3.10.1.2 General oceanography

The Channel is a forced passage for the water masses between the Atlantic and the North Sea and its configuration (bathymetry, coastline) causes the formation of particular structures (fronts, gyres) that control advection and dispersion of suspended material. Hydrology and tidal conditions are also very particular with medium to large amplitude tides (from 5 to 12 m) and varying tidal current speeds that can reach 3 to 10 knots along the French coasts (due to Coriolis force) making the Channel predominantly a macro-to megatidal area. In the Dover strait, which is a narrow (bottom neck) between France and UK at the boundary between the Channel and the southern North Sea, the tidal currents increase dramatically.

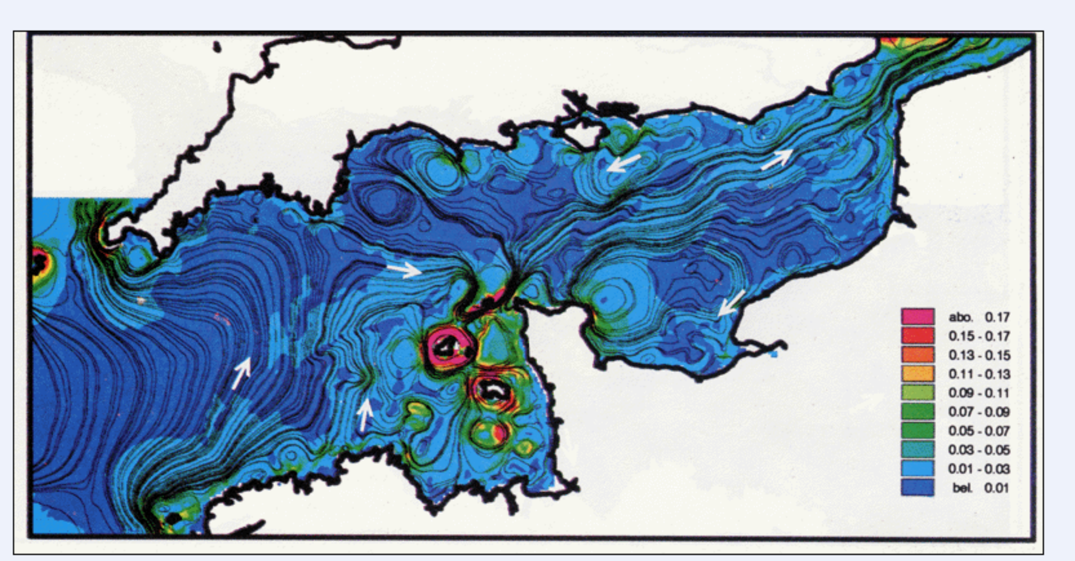

Figure 3.10.2. Residual lagrangian trajectories (average vertical speed for tide coefficient 70 in the absence of wind, after Salomon and Breton, 1991).

The study of the residual tidal currents highlights marked retention, dispersion and advection areas (Figure 3.10.2). The long term displacement of the water masses is illustrated by a 600 km long axial water stream progressing at ca. 2 cm.s^{-1} towards the Dover strait and by gyres generated by the topography. Depending on their flow speed, these structures may resist strong wind events for some time (Salomon and Breton, 1993). In the Dover strait, the residual tidal circulation contributed up to 30% to the total flow rate (on average 120.103 m^{3}s^{-1}) entering the North Sea. Although the general progression of Atlantic waters towards the North Sea are determined by tides, eastern wind regimes lasting several days may induce an inversion of the general flow direction.

The bedstress (Figure 3.10.3) resulting from tidal currents determine a sediment succession from gravels and pebbles in areas with strong currents to fine sediments locked in bays and estuaries. Because of the relatively large tidal forcing (bed shear stress), rocky and gravelly bottoms dominate in the Channel (Figure 3.10.4).

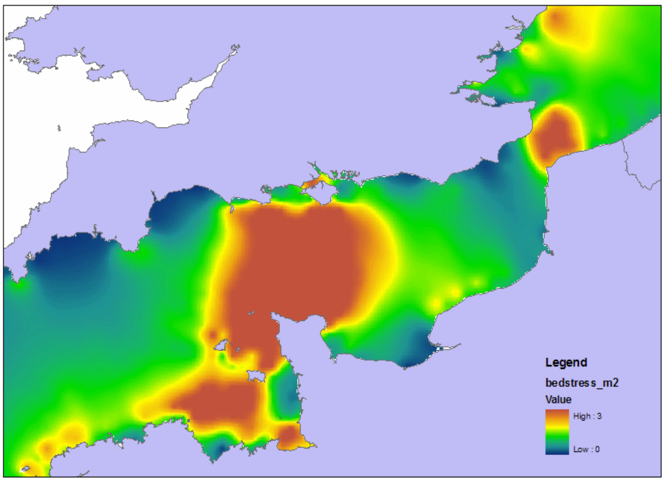

Figure 3.10.3. Estimates of bed shear stress (in N m-2) came from an 8-km resolution hydrodynamic model (Aldridge and Davies, 1993).

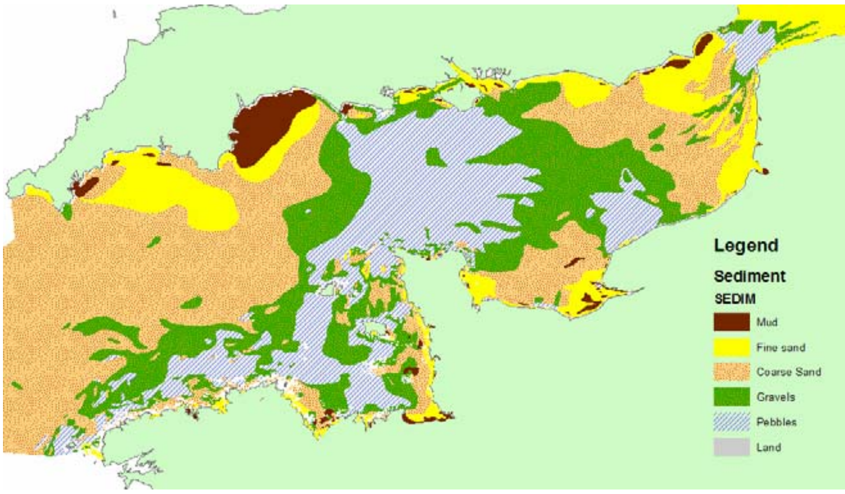

Figure 3.10.4. Seabed sediment types extracted from a digital version of the sediment map of the English Channel developed originally by Larsonneur *et al.* (1982).

The hydrological conditions are not identical in the western and eastern part of the Channel. In the shallower eastern part of the Channel, the bed-shear stress resulting from the tidal currents and the winds mix the water column. Fresh water inflow from coastal rivers pour into a "coastal flow" parallel to the French coast and situated north to the Seine River (Figure 3.10.5).

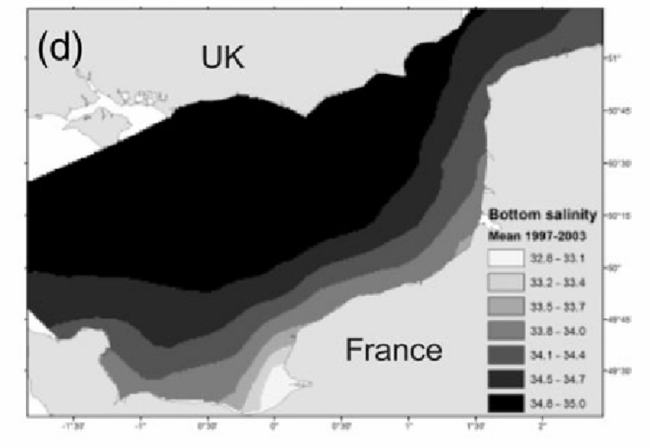

Figure 3.10.5. October mean bottom salinity from 1997 to 2004 (source Vaz *et al.,* 2007).

To the west, where the depth increases, a summer thermocline may establish (Figure 3.10.6). This results into a marked thermal gradient between the western side under oceanic influence and the eastern side under continental influence (Figure 3.10.7). The temperature pattern in the Channel is also influenced by the seasonal fluctuations of the coastal waters temperature as well as rivers inflow (Castel *et al.*, 1997).

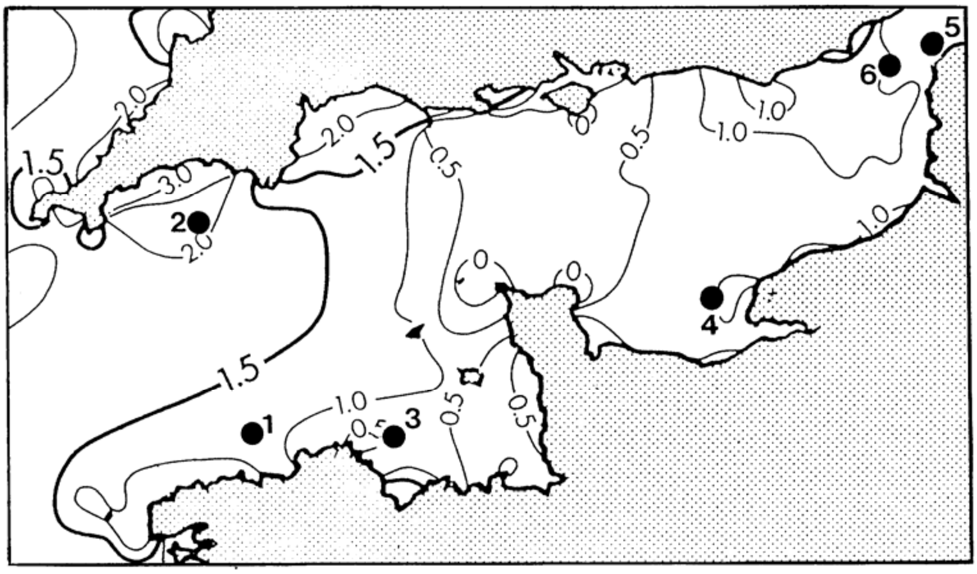

Figure 3.10.6. Stratification index in the Channel (values <1 illustrate permanent vertical homogeneity, 1.5 isoline marks the emplacement of the thermal front (from May to September) (after Pingree, 1980).

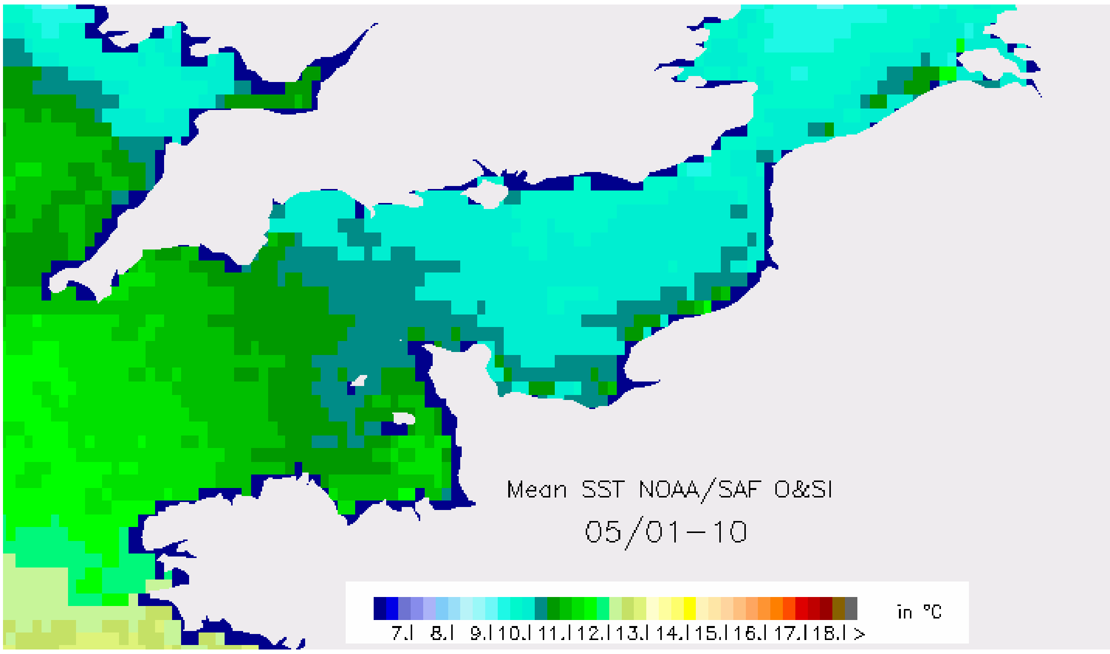

Figure 3.10.7. SST climatology in May (10 day average of satellite images over several years, after Faugere *et al.*, 2001, source http://www.ifremer.fr/cersat/facilities/browse/del/roses/browse.htm).

The warming of the Channel area regionally is consistent with the global warming signal observed over the whole North East Atlantic over the last decades (Castel *et al.*, 1997, Woehrling *et al.*, 2005). Figures 3.10.8 and 3.10.9 illustrate the sea surface temperature evolution in Western and Eastern Channel.

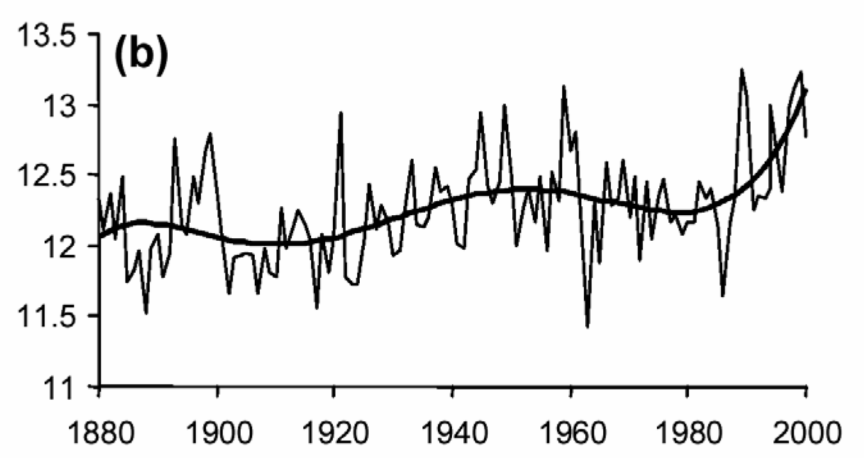

Figure 3.10.8. Mean annual sea surface temperature in western English Channel off Plymouth (from Hawkins *et al.*, 2003).

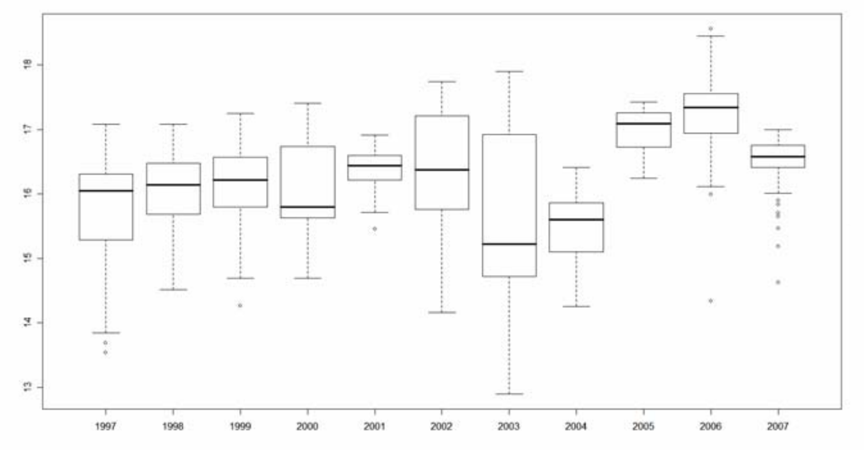

Figure 3.10.9. Surface temperature in the Eastern Channel in October from 1997 to 2007 (observed during the Channel Ground Fish Survey onboard the Ifremer RV "Gwen Drez").

Currents also contribute to the turbidity of the coastal waters by favoring the re-suspension of mineral and organic particles and the diffusion of continental intake (Figure 3.10.10). This turbidity limits the light penetration into the water column and alters the light energy both quantitatively and qualitatively (Frontier & Pichot-Viale, 1995).

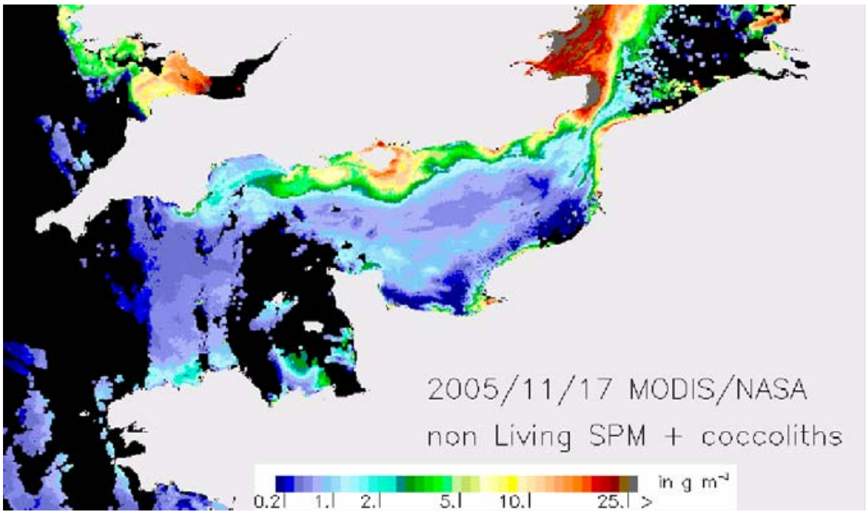

Figure 3.10.10. Suspended matter distribution in November 2005 from satellite images (calculated after Frondefroid *et al.*, 2002, source http://www.ifremer.fr/cersat/facilities/browse/del/roses/browse.htm).

More generally, three large hydrographical entities may be distinguished in the Channel: the western Channel under Atlantic water influence with a stratified NW part in summer and low continental intake; the Normand-Breton Golf where eddies slow the water renewal and with low continental intake and the eastern Channel up to the Dover Strait receiving through the Seine estuary most of its continental intakes with increased turbidity (Figure 3.10.11).

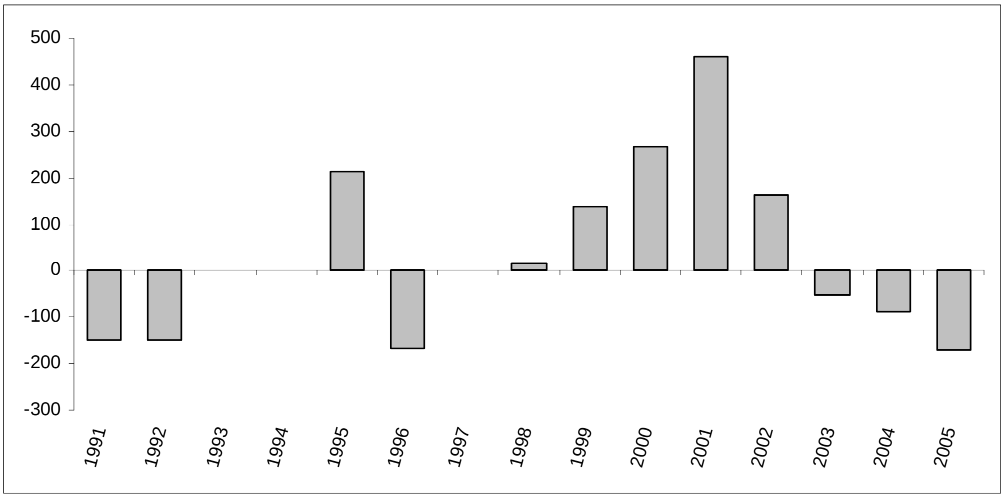

Figure 3.10.11. Variation of the river Seine yearly outflow (m3.s-1). Interannual outflow average being 6666 m3.s-1 Data from the French data Bank on hydrology and hydrometry. http://www.hydro.eaufrance.fr/.

Figure 3.10.12 shows the sea surface salinity evolution in October in the Eastern Channel over the last decade. These illustrate salinity decline correlated to the large river Seine outflow from 1999 to 2001 followed by a relative stability of the salinity in recent years.

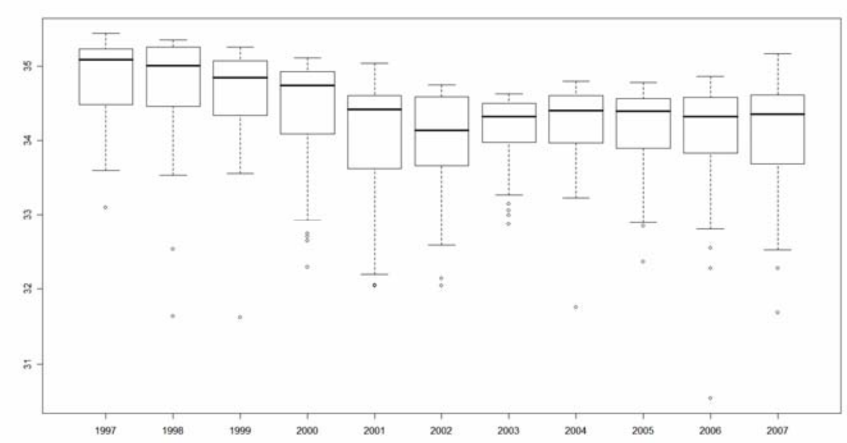

Figure 3.10.12. Sea surface salinity in the Eastern Channel in October from 1997 to 2007 (observed during the Channel Ground Fish Survey onboard the Ifremer RV "Gwen Drez").

3.10.2 Phytoplankton

Among the identified microalgae in the Eastern Channel are diatoms (genus Nitzschia, Thalassiosira, Rhizosolenia, Chaetoceros, Skeletonema and Gyrodinium, Gymnodinium, Ceratium for dinoflagelates). For the areas of the Seine and Somme estuaries, diverse marine , brackish and fresh water population of diatoms are mixing some being planktonic and others benthic. In the Channel, some toxic and harmful species form blooms with direct effect on marine animals (eg: Dictyocha speculum, Prorocentrum minimum and P. micans, Gymnodinium cf nagasakiense) and human consumption (Dinophysis and Alexandrium) (Belin and Martin-Jézéquel, 1997). The spatial distribution of the primary production may vary largely seasonally but is often concentrated along the coasts (Figure 3.10.13).

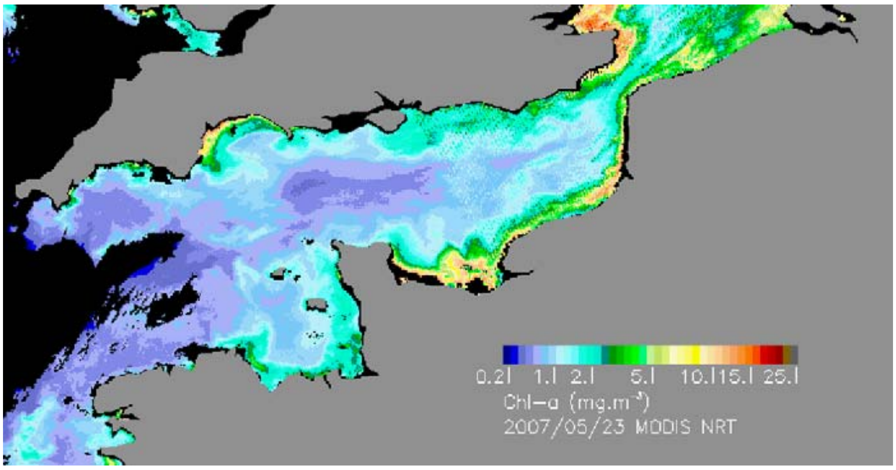

Figure 3.10.13. Chlorophyll a concentration in May 2007 from satellite images (calculated after Gohin *et al.*, 2002, source http://www.ifremer.fr/cersat/facilities/browse/del/roses/browse.htm).

3.10.3 Zooplankton

In the Eastern Channel, the stability of the hydrological structure orientated along the coast gives rise to a specific coastal ecosystem slowly drifting northward with a characteristic coastal and offshore assemblage of plankton. These two ecosytems are separated by a relatively narrow front (Brylinski and Lagadeuc, 1990).

The most represented groups are the copepods, *Sagitta setosa* (chaetognathe), cladocera and jellyfish as well as numerous benthic invertebrate larvae (Cirripedia, Annelidae and Echinodermae). In the western Channel, the zooplankton is subject to the influence of Atlantic water mainly in areas deeper than 50 m. Fauna is more diversified than in the eastern part of the Channel and an offshore (central western channel) assemblage may be distinguished from a coastal assemblage (<30 m) (Le Fèvre-Lehoërff *et al.*, 1997).

3.10.4 Benthic habitats

Large tidal currents and the associated increased seabed stresses give rise to coarse seabed sediment conditions with associated characteristic sessile epifauna. In inlets and bays, where the tidal stresses are weaker fine sediments accumulate giving rise to dominant infauna communities (Castel *et al.*, 1997). Along this gradient, associated benthic assemblages often follow the same repartition (Cabioch, 1968; Gentil, 1976; Retière, 1979) (Figure 3.10.14).

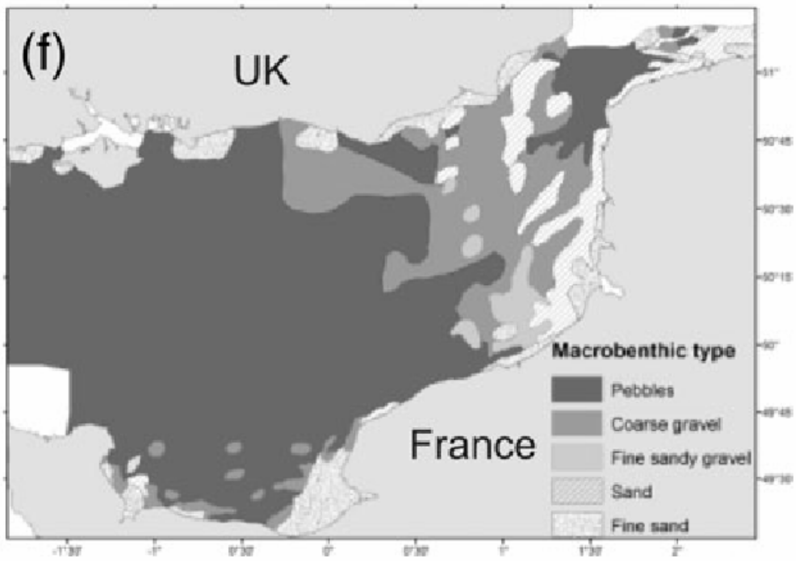

Figure 3.10.14. Macrobenthic community distribution in the Eastern English Channel (modified by Carpentier *et al.*, 2005 after Sanvicente Anorve, 2002).

In the western Channel, due to its particular tidal conditions, intertidal and subtidal zones characterised by a large variety of habitats occur. This translates into a very large faunistic and floristic species richness.

3.10.5 Fish communities

Most European commercial species are present in the Channel. Of the 100 (or so) species that contribute to the catches, about 40 species constitute 90% of the landed biomass. It is unusual to have so many species contributing to the bulk of the commercial landings, This is possibly due to the relative shallowness and large variety of habitats in the area, but also it may be related to the structure of the local fishery which supports a large number of small coastal vessels exploiting diversified resources to meet a varied demand in consumption with less reliance on large pelagic fisheries as experienced elsewhere. Large life history traits (benthic, demersal, pelagic) and taxonomic diversity may be noted as flat fish (sole, plaice,…), gadoids (cod, whiting, hake…), elasmobranches (skates, sharks, dogfish), crustaceans (crabs, spider crab, lobster), cephalopods (squids and cuttlefish), shellfish (scallops, whelk) and algae may all be found in the area (Guitton *et al.*, 2003). Some species are considered as resident as particularly attached to some Channel biotopes (scallops, whelk, algae), others are seasonal, following their migration (mackerel) or reproductive cycle (herring, seabass, cuttlefish). Most are species with a larger geographic distribution that may be found indiscriminately in the Channel or in adjacent areas. (sole, whiting,…), some displaying some Atlantic preference (hake, squids, anglerfish) or rather some North Sea attachment (Cod, herring). Numerous spawning and nursery grounds as well as migratory routes of many species occur in the Channel.

Populations are distributed along the main ecological gradients resulting in a combination of cold and temperate water species, the Channel being the thermal partition limit for some of them (southern limit for cod and whiting, and northern limit for hake and anglerfish).

The spatial distribution of some species has been recently described over the last two decades in the Eastern English Channel (Carpentier *et al.*, 2005, http://charm.canterbury.ac.uk/). This distribution was strongly structured by the local abiotic environment most of which have remained stable over this period. 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 (Figure 3.10.15). From 1997 to 2004, some 25% of overall community structure variance could be related to the available environmental descriptors and 20% to persistent factors such as depth, seabed shear stress, sediment, and macro-invertebrate community type. The different communities differ in their species diversity and are highest in areas of soft sediment and wide variation in temperature and salinity (Vaz *et al.*, 2007).

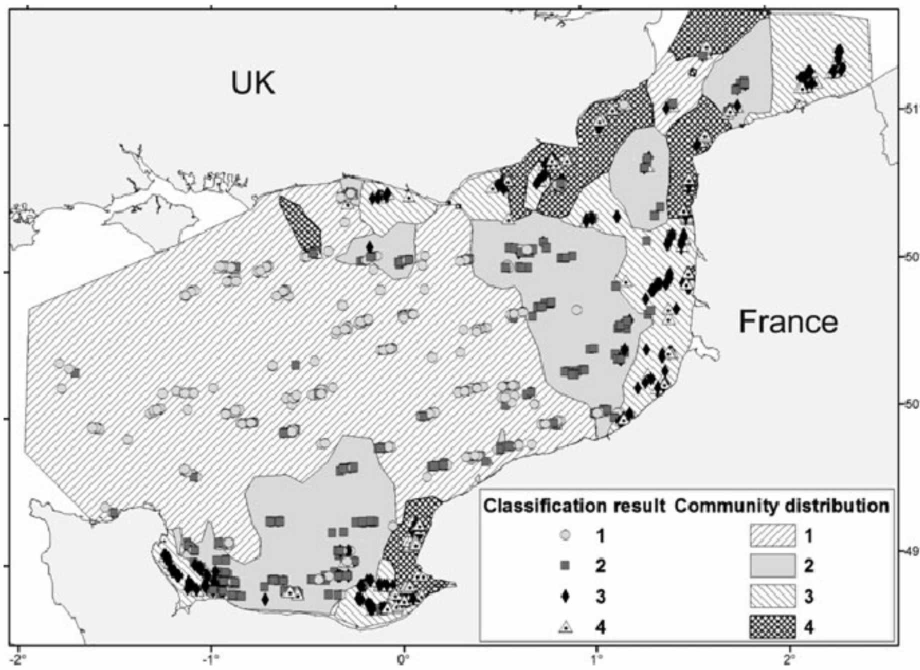

Figure 3.10.15. Spatial distribution of fish sub-communities in the Eastern Channel from 1988 to 2004. Gradation from open sea community to coastal and estuarine communities is shown (Vaz *et al.*, 2007).

Rochet *et al.* (2005) assessed two estuarine communities (Seine and Somme estuaries) identified as nursery areas for commercially important stocks exploited elsewhere in mixed fisheries. In both estuaries, no significant evolution trends were found. They also concluded that overall the fish stock populations of the Eastern Channel were not deteriorating.

This result was also supported by recent studies showing that although the Eastern Channel fish communities displayed significant inter-annual variation in both structure and composition over the last two decades, the different communities, and their spatial distribution, are persistent over time reflecting the relative stability of environmental conditions in the area (Vaz *et al.*, 2007). Overall, however, species diversity over the entire region appears to have increased over the last two decades, (Vaz *et al.*, 2007). The figures produces in this paper were updated by the authors and are presented below.

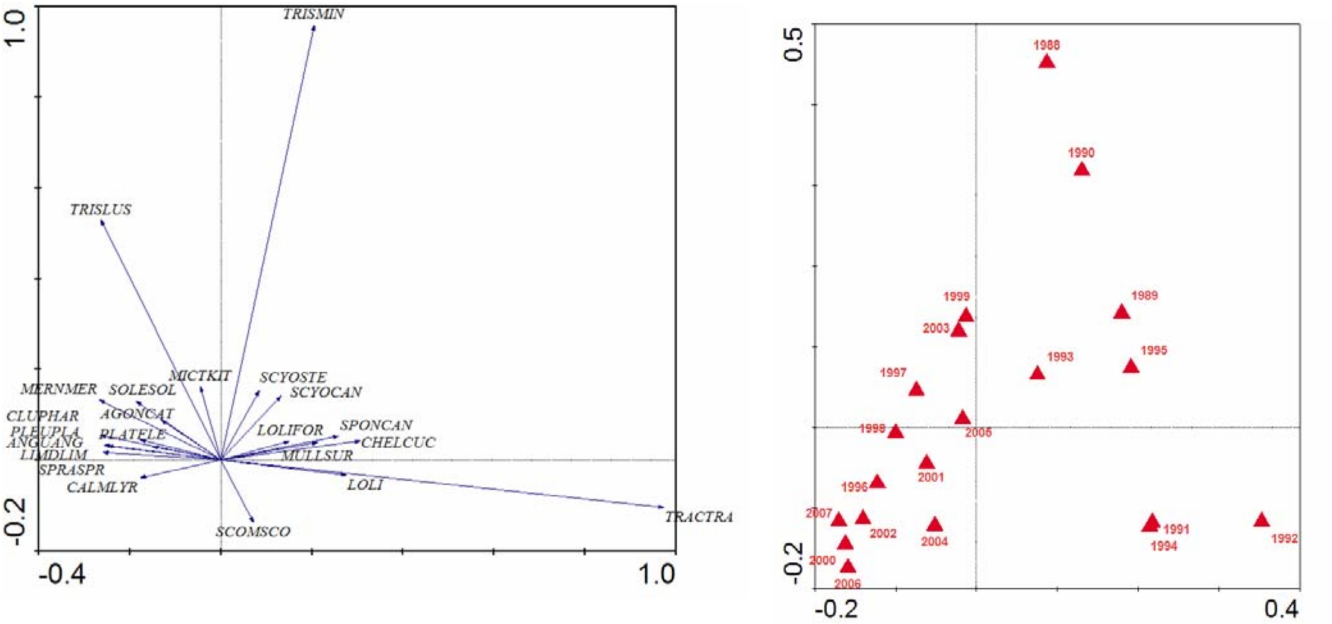

Figure 3.10.16. Principal Component Analysis on CGFS community data from 1988 to 2007 (first and second eigen-values account for 53.4% variation, data were corrected to account for spatial extent and sampling intensity changes in the survey design).

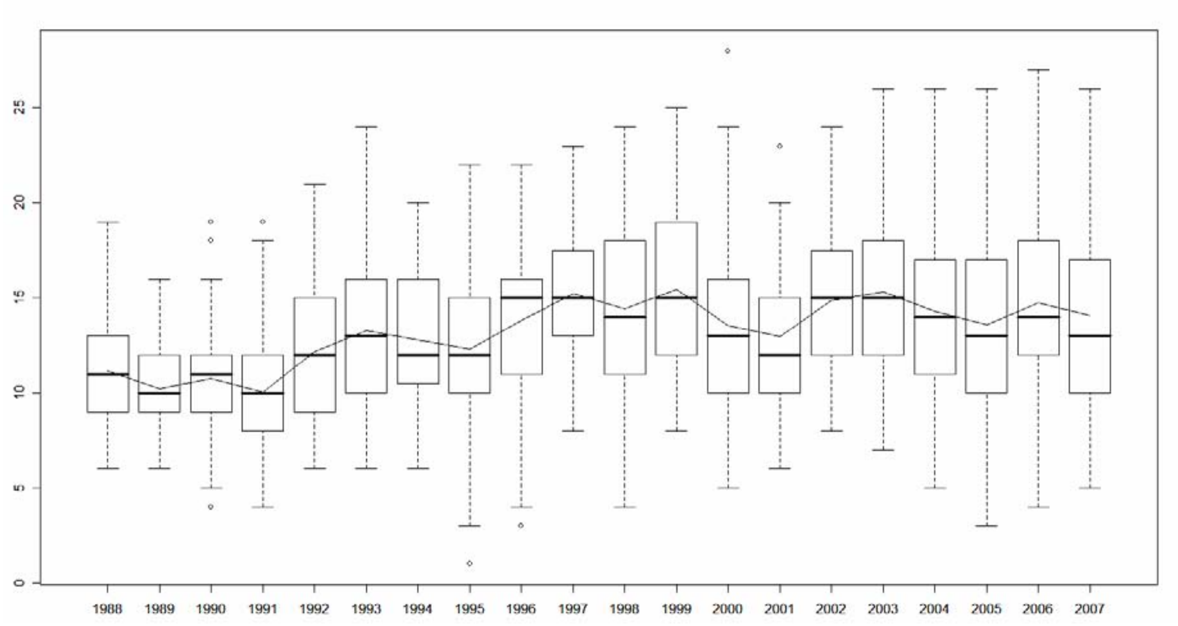

Figure 3.10.17. Species richness per haul (the line represents the average) The species richness evolution from 1988 to 2007 is significant (p<0.001).

The community appears to be slowly shifting towards species assemblages dominated by flatfish, whiting, sprat and dragonet (Figure 3.10.16). These species are characteristic of species rich coastal assemblages well adapted to changing temperature and salinity conditions. This pattern is correlated to an overall increase in species richness at the level of the haul translating an increase in the species co-existence (Figure 3.10.17). This may be induced by higher spatial heterogeneity and more variable conditions.

3.10.6 Knowledge gaps

Primary and secondary production data in the Channel originate mainly from very coastal areas. These data are too restricted temporally and spatially to be extrapolated to the whole region (Lacroix *et al.*, 2007). Also primary production and large functional group of phytoplankton have been modeled with success in the Channel (Menesguen *et al.*, 2007), these models still require field data or satellite imagery to be better calibrated. Secondary production patterns are still not well described.

The sediment and benthic invertebrates distribution are over 30 years old and these data certainly need updating. A better understanding of the overall effect of aggregate extraction activities over the whole system (sediment dynamic, coastline erosion, benthic invertebrates, fish) is also required to anticipate possible adverse effect of mineral resources exploitation in the Channel.

There is gaps in the knowledge of fish distribution and abundance evolution in the Western Channel. CEFAS historic and future surveys may enable to close these gaps in the future.

Synthetic information of seabirds and marine mammals are available but often aggregated to adjacent regions. These need to be added to account for upper trophic levels.

3.10.7 Major significant ecological events and trends

Hawkins *et al.* (2003) reviewed the changes in marine life abundance recorded in the Western Channel off Plymouth and related them to environmental change and human activity. They have shown that, from the 1920s to the 1950s, there was a period of warming of the sea, with increases in abundance of species of fish, plankton and intertidal organisms that are typically common in warmer waters to the south of Britain. This period was followed by a cooler period where northern cold-water species became more abundant but over-exploitation prevented them to return to abundance levels close to those observed at the beginning of the century. Since the 1980s regional sea-surface temperature has warmed again and abundances of warm-water species are increasing.

Some warm-water species, in particular red mullet and common squid, exhibited a strong evolution in their abundance over the last few years. The following figures are indices computed by IFREMER (Franck.Coppin@ifremer.fr) from the Channel Ground Fish Survey observed abundance in October in the Eastern Channel onboard the Ifremer RV "Gwen Drez". These indices include all age classes and may translate strong recruitment (Figures 3.10.18 and 3.10.19). In both cases, a new fishery is developing.

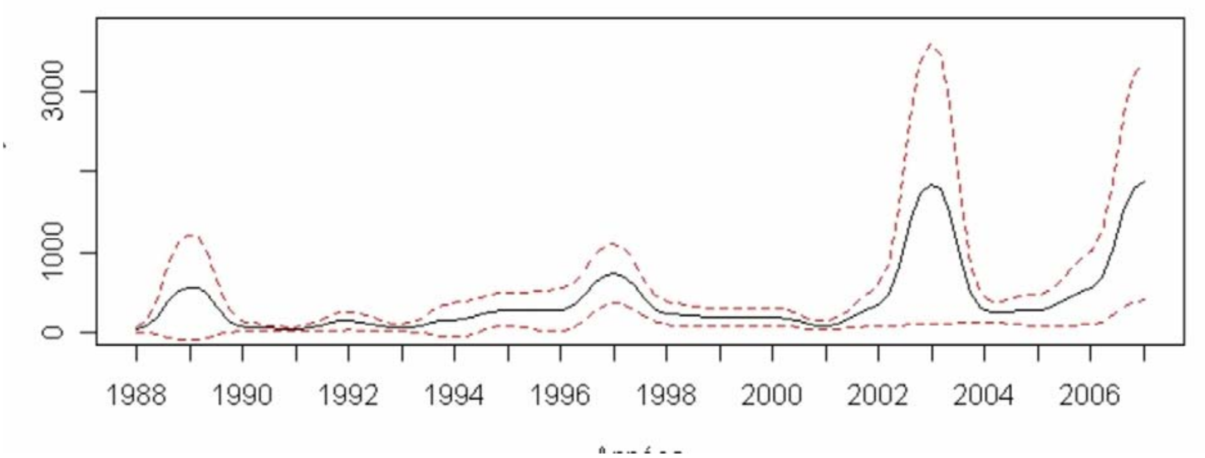

Figure 3.10.18. Red Mullet (Mullus surmulletus) average density (nb/km^2) with 95% CI..

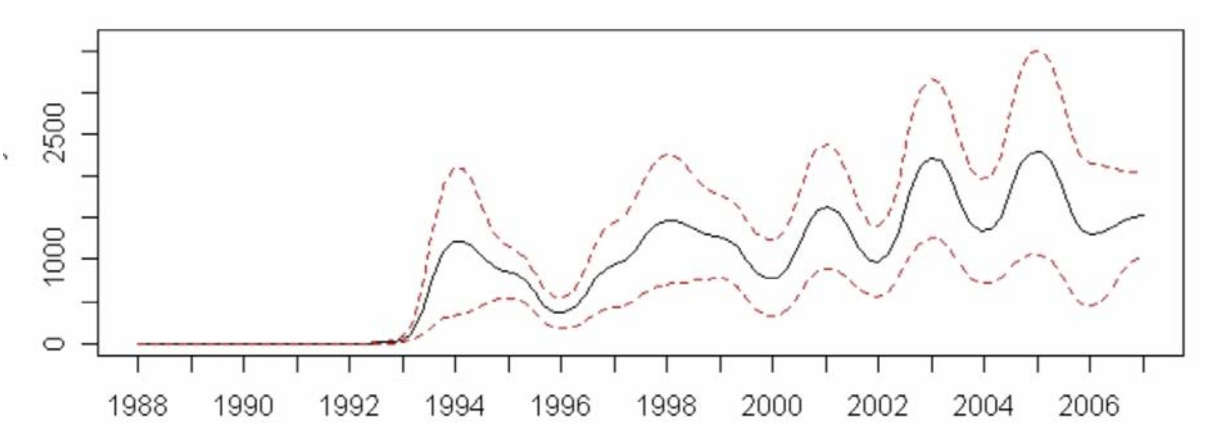

Figure 3.10.19. Common squids (*Loligo vulgaris*) average density (nb/km^2) with 95% CI.

3.10.8 Human impact on the ecosystem

3.10.8.1 Fisheries effects on benthos and fish communities

Fishery activities are dominated by trawlers (over 200 000 Kw total power in 2003 in the French Fleet), followed by netters (30 000 Kw total power in 2003 in the French Fleet). They are characterized by a large number of métiers and mixed fishery strategy with a majority of boats being less than 12 m and operating in coastal areas (source: Leblond *et al.*, 2004)). Living resources of the area are also exploited by several fleets from other EU countries (UK, Belgium, Netherlands, Germany, Denmark). The resulting intensive trawling pressure may have an adverse effect on the benthic invertebrate and fish assemblages in the area.

As the cod spawning biomass is below safe limits in the Eastern Channel and North Sea, it is the object of a recovery plan in this area. Similarly the sole in the Western Channel is the object of a management plan for the same reason. These plans however have not yet produced any clear improvement of these stocks. Plaice in the North Sea (and in the Eastern Channel) is at risk of reduced reproductive capacity. A new management plan for North Sea plaice is under development. The plan is scheduled to be endorsed by the Council of Ministers in EU.

3.10.8.2 Other human activities

The Channel eco-region (ICES VIId, e areas) has, for a long time, supported important human activities and is submitted to a large number of users. It is one of the most intensively used sea areas in the world. It is also an important economic area for numerous activities such as tourism, leisure, maritime traffic, international ports and harbors, exploitation of mineral resources and offshore windfarms, all contributing to pollution pressures in the region. It must be noted that the constitution of RAC (Regional Advisory Council) at the European scale and in particular of the Channel sub-group (part of the North Western Waters RAC) have the ambitious task of bringing scientists and managers together to evaluate and propose new management solutions for the area.

The Channel concentrates sea freight activities from the Atlantic to the large northern ports such as Rotterdam, with regulated fluxes through traffic separation systems (Figure 3.10.20). Links between the continent and the British Isles generate a very large flow of passenger freight between French and English ports in particular in the Dover Strait. For the same reason, numerous communication and power cables as well as gas transport installations are set in the Channel in all possible directions.

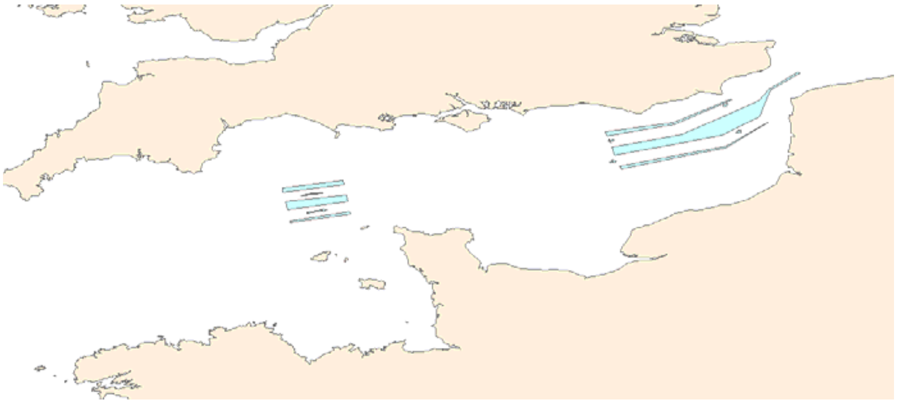

Figure 3.10.20. Traffic separation system in the Channel.

The coastal areas increasingly attract new human implantation and receive the outflow of heavily populated catchment basins that capture various pollution. The numerous mineral resources have been listed and are already partly exploited if not the object of increasing and pressing demand on both side of the Channel (Figure 3.10.21). Shellfish farming is also an important activity in many areas. Some physical and climatic characteristics (tidal and wind regime, shallow depth and sandy bottoms) make it a potential area for developing sustainable power production. These uses, along with fisheries are often competing for access (both in space and time) and each of them generates its own interaction (and risk) with the local ecosystem.

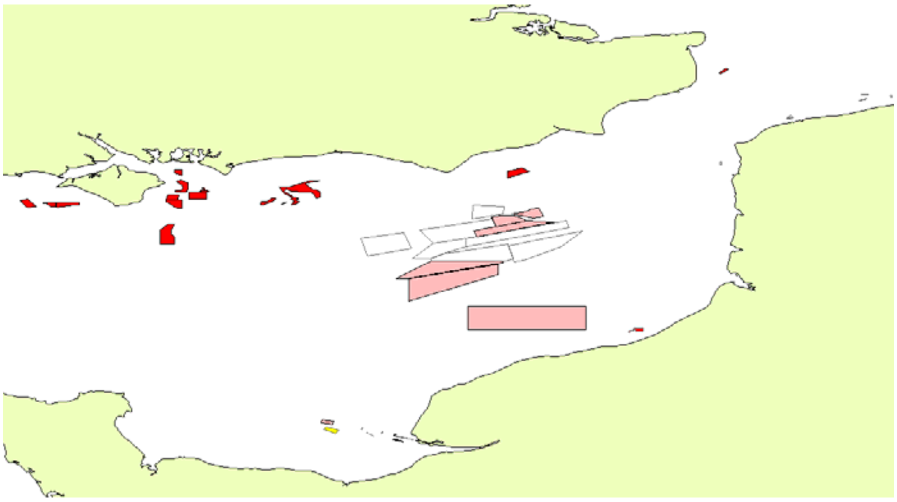

Figure 3.10.21. Aggregate extraction sites in the Eastern Channel: in red are exploited sites, in pink are licence demands, in yellow are blocked exploitation licences, hollow sites are of unknown status (source IFREMER, this layer was produced in 2001 and is not up to date).

Some of these uses are strongly increasing and may reflect national stakes (such as mineral resource or power supply). It is important to take into account and start evaluating the potential risks generated by these activities.

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3.11 Bay of Biscay and Western Iberia

3.11.1 Ecosystem components

3.11.1.1 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).

3.11.1.2 Bottom topography, substrates, and circulation

3.11.1.2.1 Bottom topography and substrates

The continental shelf in the northern Bay of Biscay is about 140 km wide; it becomes 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. On the southern border of the Bay of Biscay, the continental shelf of the Cantabrian sea is as narrow as 12 km. Seamounts such as Le Danois Bank and Galicia Bank (up to 450–600 m depth) form deep canyons with the close Iberian continental shelf, influencing the local circulation of the water masses. The Iberian Basin comprises the Iberian Abyssal Plain and the Tejo Abyssal Plain; it is limited to the north by the Galicia Bank; and to the south by the Tore Madeira Ridge and the Gorringe Sea Mount (at locations shallower than 200 m). The western limit of the basin is at approximately 16_ºW (taking the Tore Madeira Ridge as the western end) and the eastern limit is the meridionally aligned margin of Western Iberia. The main connection linking the basin and the Gulf of Cadiz is a passage (4000 m) that runs between the Gorringe Sea Mount and the coast. (Peliz *et al*., 2005).

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 (500 m–800 m) 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. 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 shelf/shelf break areas have predominantly muddy substrate. One major sedimentary area off South West Brittany is known as Grande Vasière (large muddy area).Muddy sediments are also present in the Galician inner shelf associated with the large estuarine systems of the "*rias*" (López-Jamar *et al.*, 1992, Serrano *et al.*, 2008). Contouritic deposits occur in the Cantabrian Sea and in the Gulf of Cadiz. In the latter, the slope is composed by muddy sands full enriched by hydrates, that triggers fluid escapes and cold seeps (Díaz-del-Río *et al.*, 2005).

3.11.1.2.2 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*. (2006).

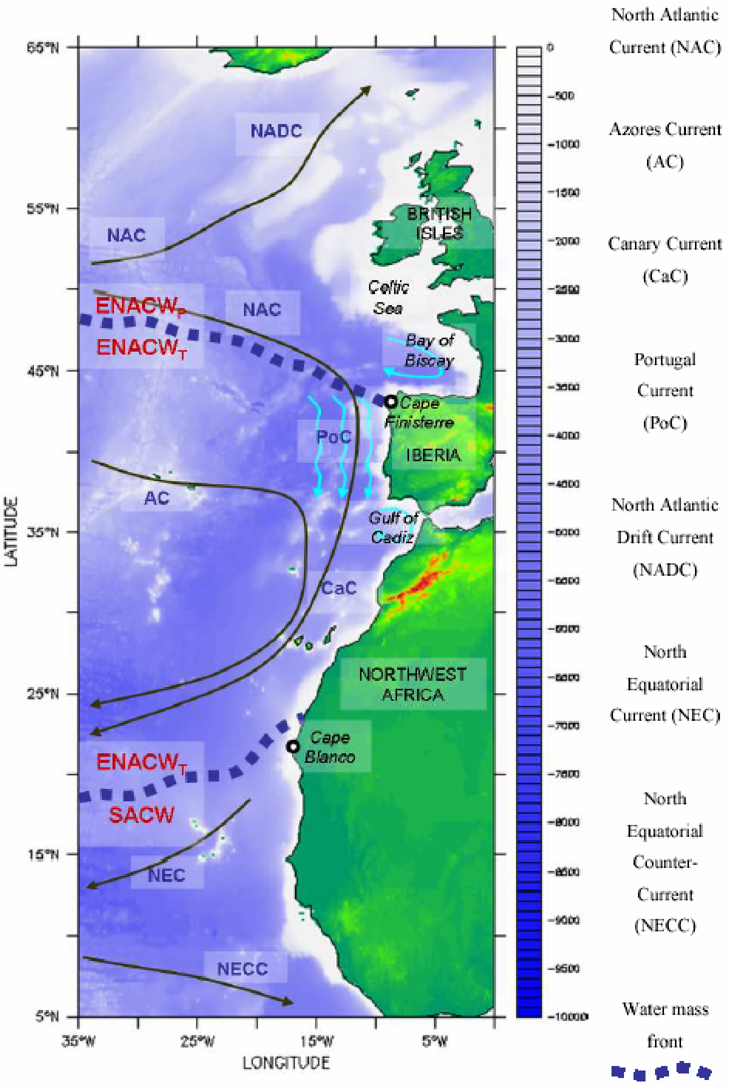

Figure 3.11.1. The main water masses in the Advisory region G are North Atlantic Central Water of sub-polar (ENACWp) and sub-tropical (ENACWt) origins and South Atlantic Central Water (SACW). The main large-scale surface currents are the North Atlantic Current (NAC), the Azores Current (AC), the Canary 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.* (2006).

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 and Le Cann, 1990). 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 shelf and slope (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 current 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) (Figures 3.11.2 and 3.11.3). In the Cantabrian Sea the surface currents generally flow eastwards during winter and early spring and change westwards in late spring and summer following the wind forcing (Lavín *et al*., 2006).

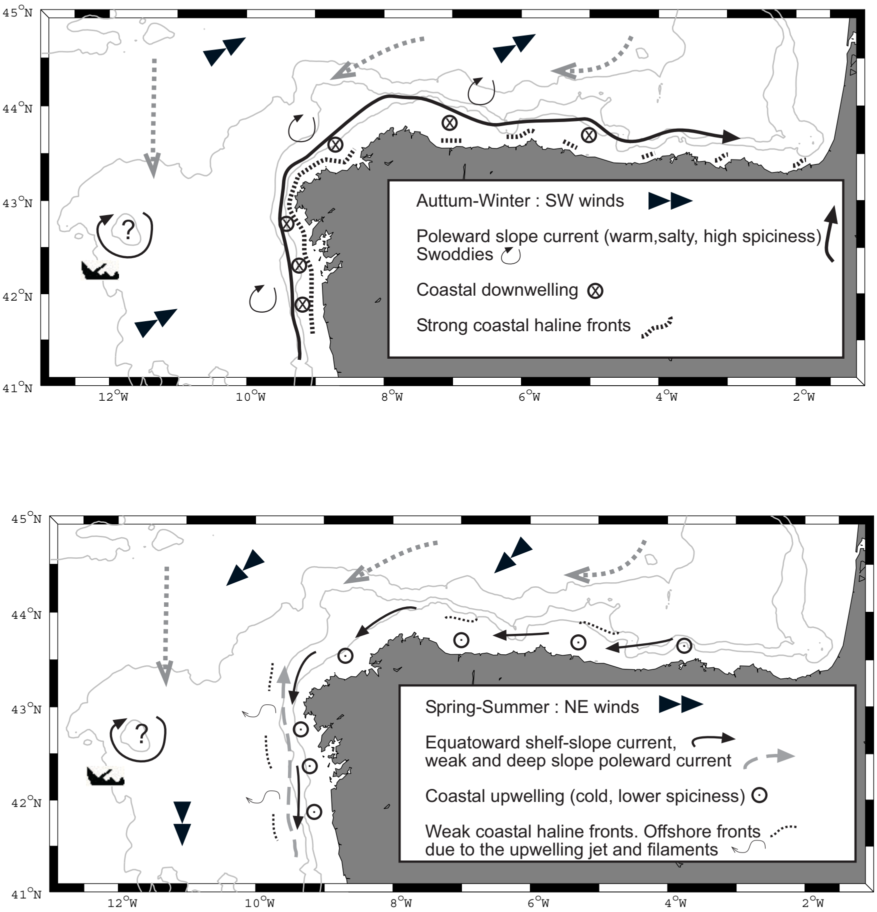

Figure 3.11.2. Schematic circulation during typical upwelling (spring and summer) and downwelling (autumn-winter) seasons. Offshore current is dominated by the Portugal current, which is represented by a gray dotted arrow. Note that a typical season is a simplification and the system is subject to event variability that can dominate the response of the system. (From Ruiz-Villareal *et al.*, 2006).

In autumn and winter, the surface circulation is predominantly northwards, partially driven by southwards winds and meridional alongshore density gradients (Peliz *et al.,* 2003a, b), and transporting higher salinity, nutrients-poor and warmer (subtropical) waters over the shelf break (Frouin *et al.*, 1990; Haynes and Barton, 1990; Pingree and Le Cann, 1990; Ruiz-Villareal *et al.*, 2006) (Figures 3.11.2 and 3.11.3). These waters (the Iberian Poleward Current) (Peliz *et al.,* 2003b) contribute to fronts over the shelf that determine the coastal distribution of plankton, fish eggs and larvae (Fernández *et al.,* 1993; González-Quirós *et al.,* 2003) in western Iberia and the Cantabrian Sea (Villamor *et al.*, 2004). Another important feature 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.

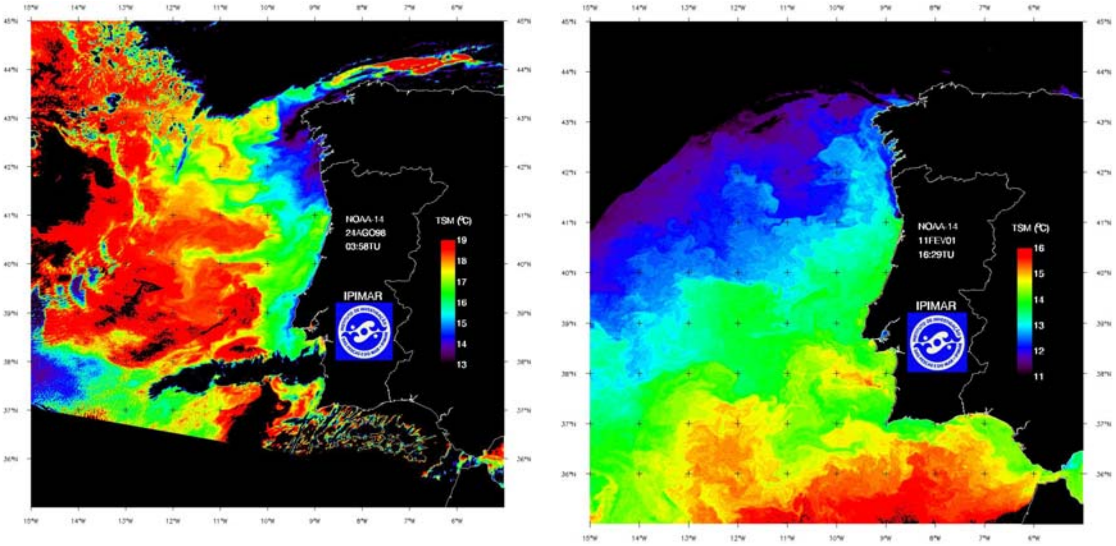

Figure 3.11.3. Satellite images showing typical winter (left) and summer (right) circulation in the Iberian basin. In winter coastal convergence, low salinity plumes and a warm surface poleward current are visible whereas in summer coastal upwelling with long filaments up to >200 km offshore are present (courtesy of A. M. Santos, IPIMAR).

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.

3.11.1.3 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 100 m 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 and may induced low salinity lens detached from the river plumes (Koutsikopoulos and Le Cann, 1996; Puillat *et al.*, 2006; Lavín *et al.*, 2006). (Figure 3.11.4).

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 ~ 50 m 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 2700m^{3} s^{-1} of run-off from the major rivers. The time series of the flow of Loire River (870m^{3}.s^{-1} of annual mean flow) shows that recent years have been below average (Figure 3.11.5).

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 ecosystem effects (Froidefond *et al.,* 2002). SPM extend over all Bay of Biscay shelf during winter month with mean concentration around 3 mg.m^{-3} (Huret, 2005, pp 62–63).

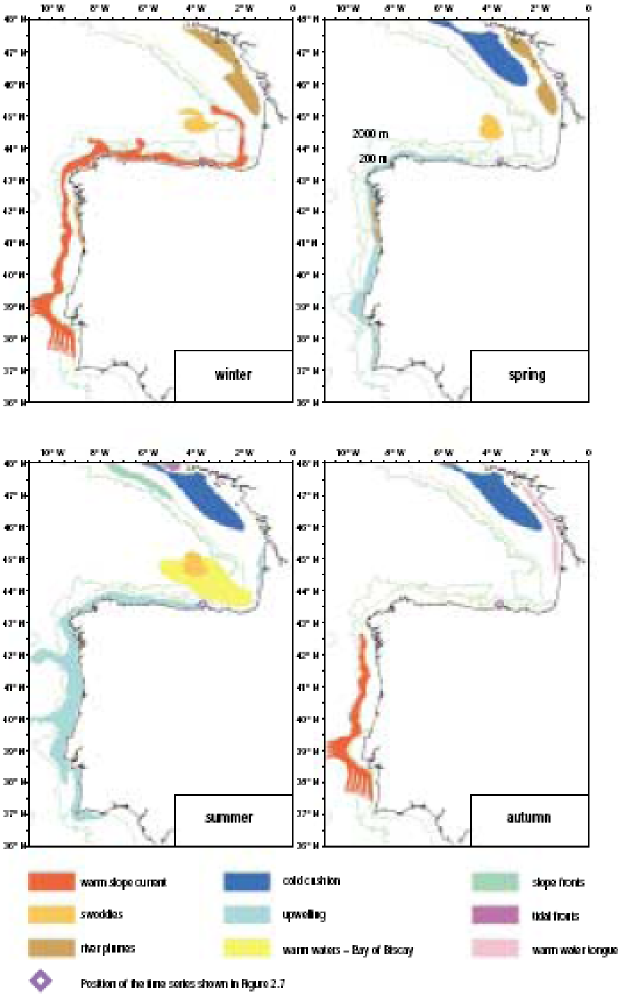

Figure 3.11.4. Seasonal variation in the main hydrographic features. Source: Koutsikopoulos and Le Cann (1996).

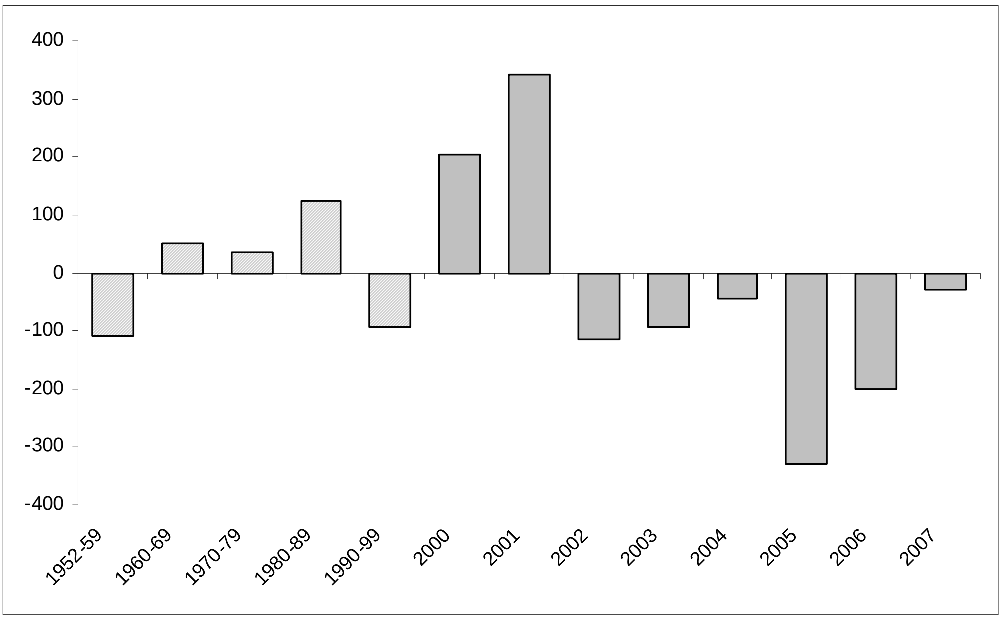

Figure 3.11.5. Variation of the river Loire yearly outflow ($m^3.s^{-1}$). Ten years period average from 1952–1999, yearly average for the 2000s. Data from the French data Bank on hydrology and hydrometry. http://www.hydro.eaufrance.fr/ .

3.11.1.3.1 Broad-scale climate and oceanographic features & and drivers

Large positive values of the NAO index are associated with higher dominance of the middle-latitude easterly wind flow during winter that can lead to increased winter upwelling episodes. Dickson *et al.* (1988) related the decline in zooplankton and phytoplankton in the North Atlantic and in the catch of sardines off Portugal with the increase in northerly winds during the 1970s. These increased winter upwelling episodes related with large positive NAO indices were also observed during the 1990s (Borges, *et al.*, 2003).Following a long period of increase from an extreme and persistent negative phase in the 1960s to a most extreme and persistent positive phase during the late 1980s and early 1990s, the Hurrell NAO index underwent a large and rapid decrease during the winter preceding 1996, followed by positive values during 1999 and 2000, since then the NAO index has been fairly weak but mainly positive except for the winter preceding 2001, 2004 and 2006 (ICES, 2007).

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

3.11.1.4 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).

3.11.1.5 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 3.11.6) (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).

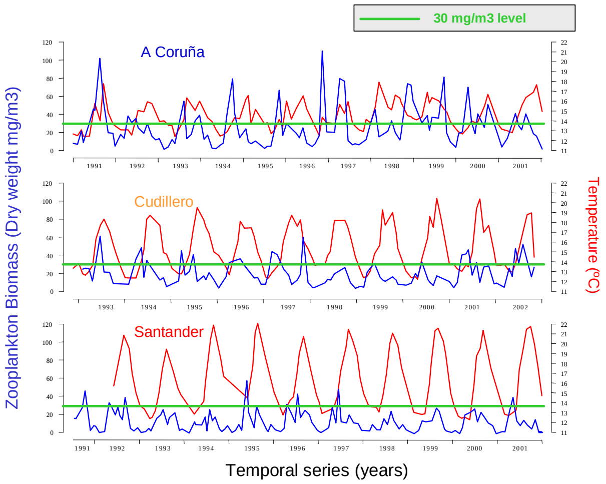

Figure 3.11.6. Variations in zooplankton biomass and temperature in the Cantabrian Sea. (Llope *et al.*, 2003, modified by Valdés).

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.

3.11.1.6 Benthos

In the Cantabrian and Galician shelf, and most probably in the whole region, depth and sediment characteristics (grain size and organic contents) are the main factors controlling the distribution of both epibenthic an endobenthic communities (Sánchez, 1993, Serrano *et al.*, 2008).The mean fish species richness shows a progressive decrease with depth while the inverse phenomena appears in invertebrates, which prefer deeper water and muddy substrates due to their predominantly detritivorous feeding habits (Olaso, 1990). 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. The latter are abundant on rocky bottoms together with echinoderms (Serrano *et al.*, 2006a). In some areas bioherm, such as maerl beds occur in shallow waters. *Lophelia* formations are known to be present in the Cantabrian Sea on the slopes at depth ranges that coincide with the Mediterranean Outflow Water (Alvarez-Claudio, 1994).

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.

3.11.1.7 Fish community

3.11.1.7.1 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. Immature northern bluefin tuna (*Thunnus thynnus*) migrates to the feeding areas in the inner most part of the Bay of Biscay, from late spring to mid-autumn, returning to the Gulf of Cadiz and Atlantic Moroccan coasts in winter (Rodriguez-Marín *et al.*, 2007).

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 and Serrano, 2003).

Off Portugal richness decreases slightly with depth, from the coastline to the shelf break (200–300 m), steadily increasing afterwards down the slope. Based on bottom trawl surveys richness was higher in the winter compared to the summer and autumn (Sousa, *et al.*, 2006). On the upper slope the fish community is dominated by blue whiting (*Micromesistius poutassou*). Horse mackerel (*Trachurus trachurus*) is more important in autumn assemblages whereas the boarfish (*Capros aper*) dominates in summer. 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). 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 trawl and longline tuna, swordfish and scabbardfish 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.

3.11.1.7.2 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 and 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).

3.11.1.8 Mammals, birds and turtles

3.11.1.8.1 Mammals

Seven species of mysticeti, twenty-three species of odontoceti and seven species of pinnipeds have been reported in the eco-region. The main habitat and status of these species is summarised in Table 3.11.1. Detailed information on distribution and migratory patterns is restricted to the most common species.

Table 3.11.1. Main marine mammal 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

3.11.1.8.2 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.

3.11.1.8.3 Turtles

Two marine turtle 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.

3.11.2 The major effects of the ecosystem on fisheries

A general mechanism emerges in the region: there is an alternation of periodical quasi decadal dominance of boreal fresher and colder water and sub-tropical warmer and saltier water, and in accordance with the biogeography of the region, this will favour the productivity of each species' life-traits differently. (ICES, 2007).

Significant inter-annual trends in climatic, oceanographic and ecosystem variables are indicative of global warming in the region since ca. 1950. Quasi-decadal scales are characteristic of climatic, oceanographic and fish abundance indices, but plankton indices display shorter periods. Sardine and Anchovy showed synchrony in positive and negative phases up to 1978, they increased and decreased simultaneously. This pattern was broken and moved to asynchrony thereafter, when sardine and anchovy have opposite phases. Sardine catches are negatively correlated with northwesterly winds and these are strongly and positively correlated with NAO. Sardine catches showed periods of 20–29 years, and 10 years of cyclic variation. The Bay of Biscay anchovy recruitment is significantly correlated with local downwelling and upwelling events that can be measured at 45º N and 2ºW and follow a seasonal pattern: During winter the water column has almost no stratification due to convergence and downwelling from western poleward currents bringing warmer and saltier water of sub-tropical origin. During summer water column stratification increases when northern winds dominate and mechanisms of divergence and stable stratification prevail, bringing colder and less saline water of sub-polar origin to the Bay of Biscay. This weak upwelling gives a stable stratification that favours good recruitment. Nevertheless if Spring-Summer northern winds induce gales and storms disrupting the stable stratification this is detrimental for anchovy success. (ICES, 2007; Uriarte, *et al.*, 2002; Allain *et al.*, 2001).

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). During Autumn 2007 surveys covering the Portuguese region it was noted that *Trachurus picturatus* dominated and that *Trachurus mediterraneus* was present in higher quantities than usual. *Scomber japonicus* continued to be observed in abundance in the Portuguese area, likewise during 2006.

Lavín *et al*. (2007) have explore the impact of climatic and oceanic variables on the dynamic of oceanic (albacore *Thunnus alalunga*) and coastal (horse mackerel, *Trachurus trachurus*) species in the Bay of Biscay and Western Atlantic. Albacore catches were negatively correlated with the Gulf Stream index and positively with the wind component. Analysis confirmed that environmental conditions explained the availability of age 3 albacore to the surface fisheries for the period 1975–1999.

3.11.3 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 a habitat change may have adverse effect on sedimentary facies and burying animal such as *Nephrops*. Nevertheless, the participation of natural (storms) and anthropogenic (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).

3.11.4 Other effects of human use of the ecosystem

3.11.4.1 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, 23 000 birds (6000 alive and 17 000 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).

There has not been a clear effect of this event on the demersal and pelagic domains of the Iberian shelf. An initial abundance decrease of some benthic species (e.g. four-spot megrim, Norway lobster and other benthic decapod crustaceans) in 2003 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 has had a varied impact among seabird 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).

3.11.4.2 Incidental catch of cetaceans

Some incidental catches of mammals were recorded in seabass, tuna and herring 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.

3.11.5 Major significant events

The anomalous winter of 2005 in south-western Europe (extremely cold and dry) caused the lowest temperature record of the time-series 1993–2005 for the surface waters in the southern Bay of Biscay, and the mixed layer reached unprecedented depths greater than 300 m. The isopycnal level 27:1 classically used to analyze ENACW variability (Figure 3.10.1) disappeared (outcrops further south) and as a result the hydrographical structure of the upper layers of the ENACW was strongly modified remaining in summer 2006 completely different than what it was in the previous decade. This change in the mixed layer could be important in the ecosystem (González-Pola, *et al*., 2006).

3.11.6 References

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3.12 Widely distributed and migratory stocks

3.12.1 Hydrography

Surface circulation and hydrography

The circulation of the North Atlantic Ocean is characterized by two large gyres: the *subpolar* and *subtropical* gyres (Figure. 3.12.1). 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.

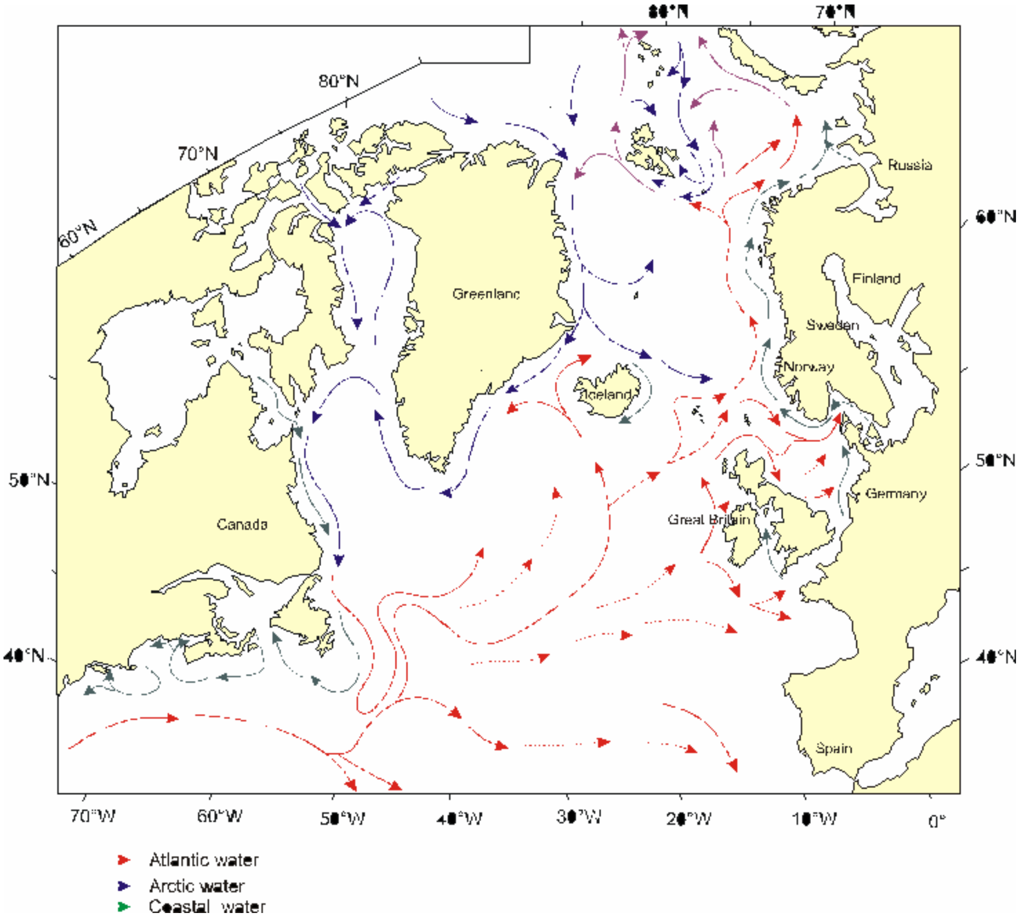

Figure 3.12.1. Surface current patterns in the North Atlantic (courtesy of Svein Sundby).

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 500 m. 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, 2007a) provides summaries of long-term observations of environmental conditions to the end of 2006. 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 600 m of all the stations in deep water west of the Porcupine Bank (ICES, 2006a). 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 10.5°C 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.

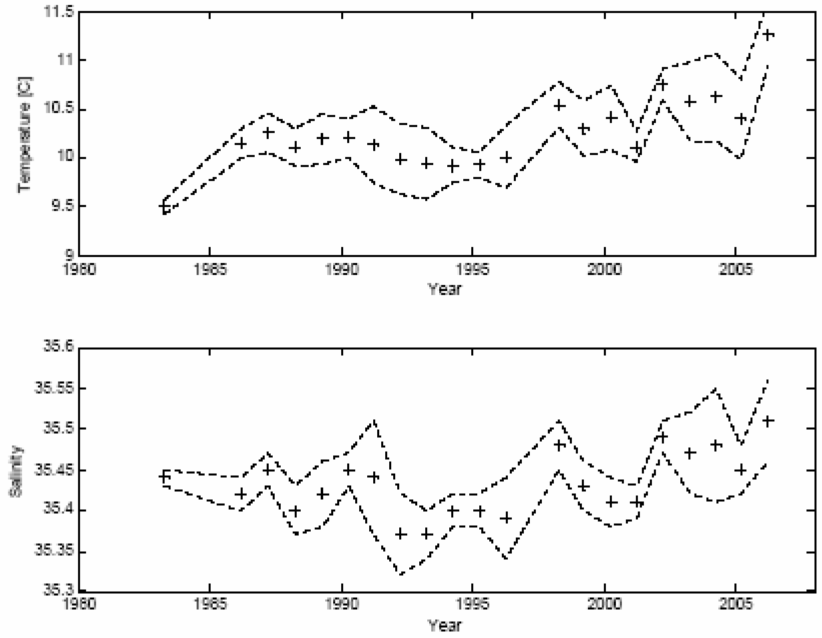

Figure 3.12.2. Yearly mean temperature and salinity from 50–600 m (crosses) of all stations in box with bottom depth>600 m, west of Porcupine Bank bounded by 52 to 54 and 16–14 W. Dotted lines are drawn at plus-minus standard deviation of all observations in each box, each year (from ICES, 2006a).

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. In 2007 the temperature in the inflowing water is colder and less saline than in the previous year and at about the same level as 2005, but still above the long term average.

3.12.2 Plankton

The ICES Report on Zooplankton Monitoring Results in the ICES Area (ICES, 2006b) provides an overview of recent changes in North Atlantic plankton and the ICES PGNAPES reports on zooplankton biomass in wider feeding areas for migratory stocks in the Norwegian Sea (ICES, 2007b). 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 3.12.3) 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.

In the Norwegian Sea the total zooplankton biomass in May was the lowest on record since 1997. In the area west of 2°W (cold water mass) the biomass equalled the mean for the time series while it in the eastern region (warm Atlantic water) was low, as was the case in 2006 (ICES, 2007b).

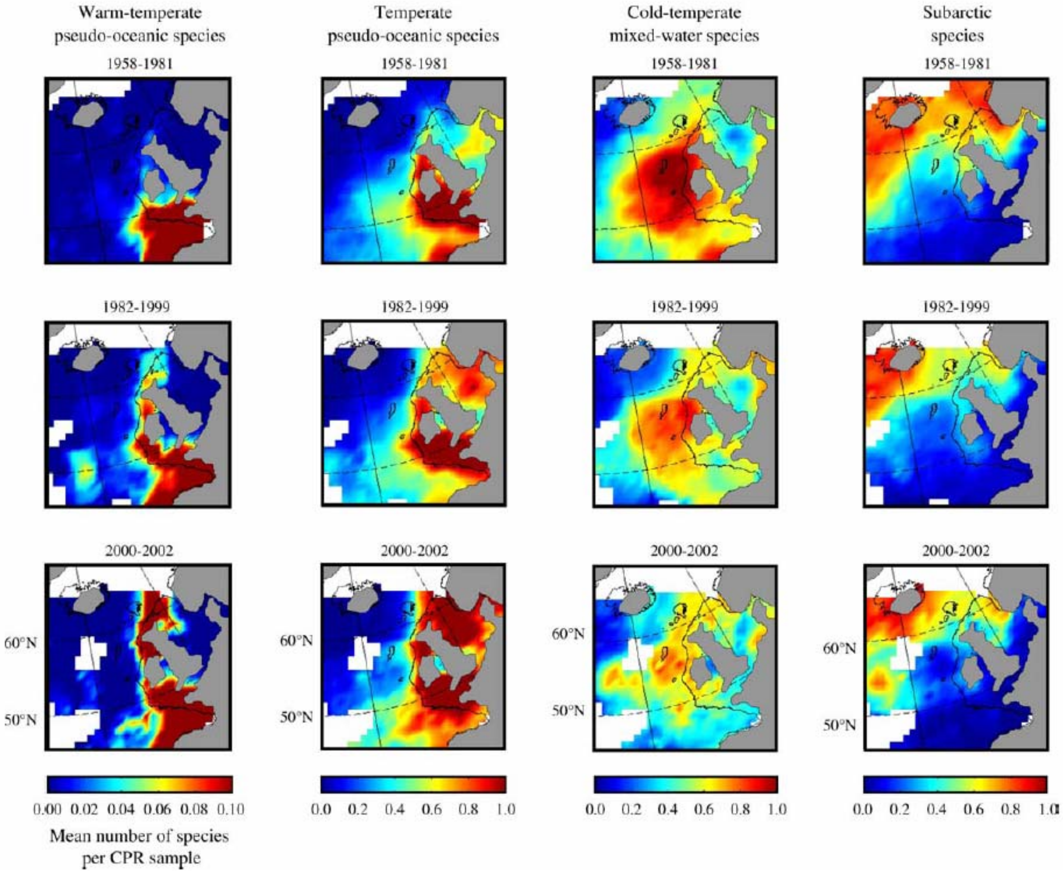

Figure 3.12.3. Long-term changes in the mean number of species per assemblage based on three periods: 1958–1981, 1982–1999 and 2000–2002 from Beaugrand *et al.*, 2005).

3.12.3 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.

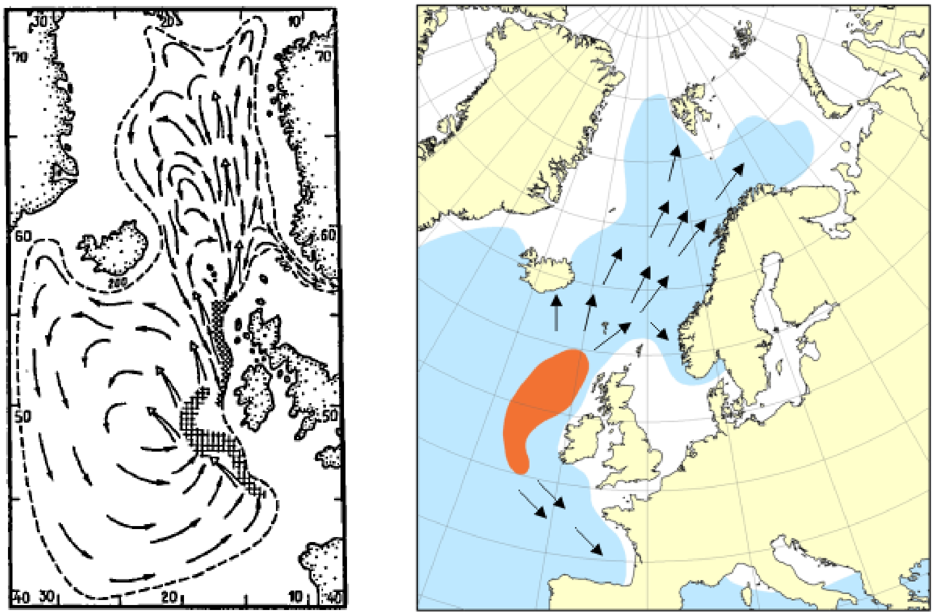

Figure 3.12.4. Migration of blue whiting. The left panel shows the migration pattern of adult blue whiting as suggested by Isaev *et al.* (1992). Hatched area shows the main spawning grounds. The current understanding does not fully support the pattern suggested for the component spawning around the 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 2007/2008) 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 (Huse *et al.*, 2002). 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).

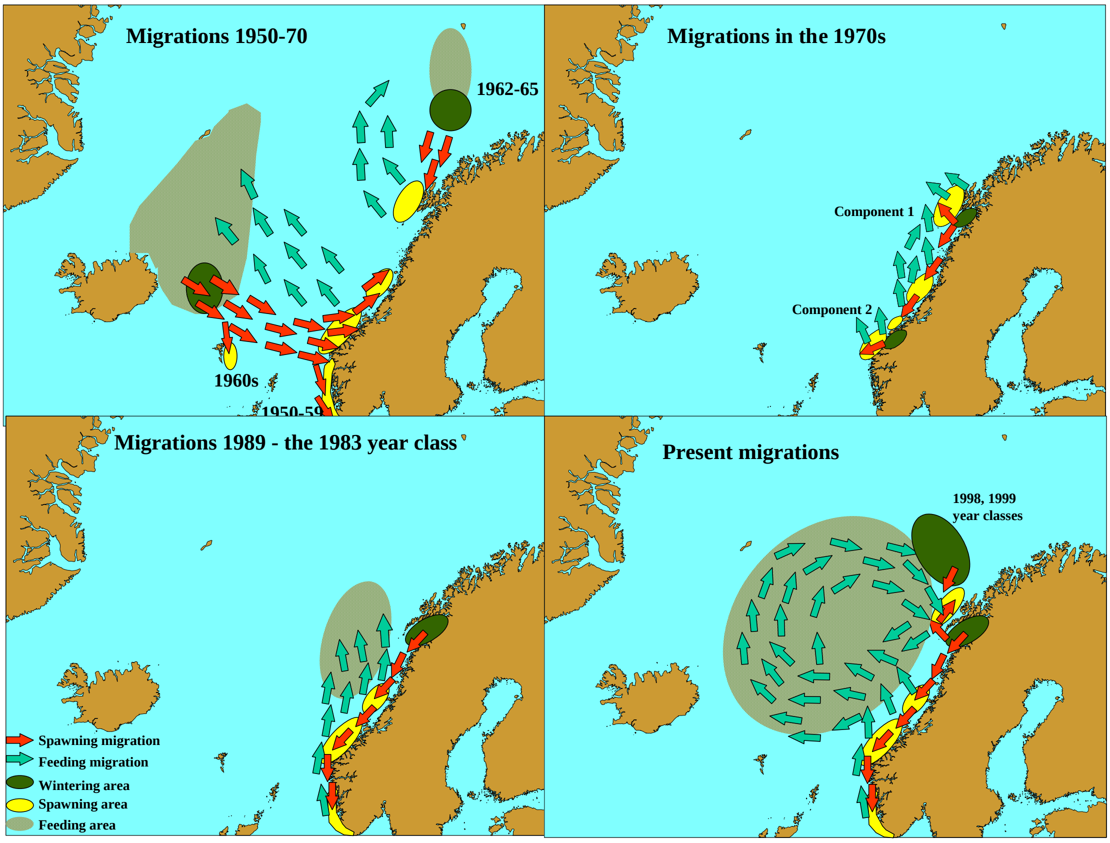

Figure 3.12.5. Schematic overview of historic changes in the adult NSS herring seasonal migration pattern (from ICES, 2004).

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 200 m 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 48oN); Celtic Sea/Cornwall; west and north of Ireland; West of the Hebrides and North edge of North Sea.

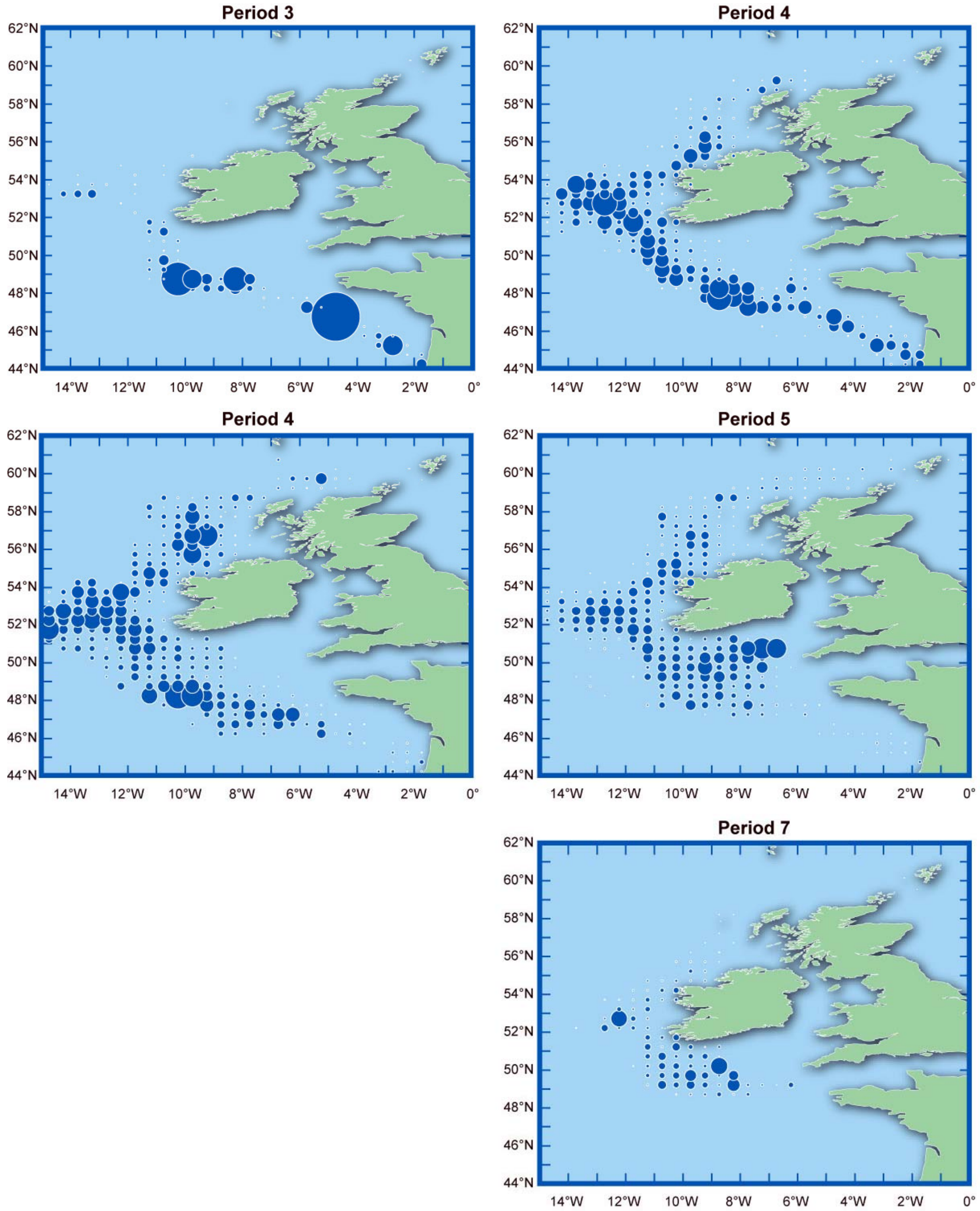

Figure 3.12.6. North East Atlantic mackerel, average distribution of stage 1 mackerel eggs, by period (approximately month) from the ICES international egg surveys showing the variable start in period 3 (March), the consistent distribution with northward movement through periods 4–6 and the end of the 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.

Data from a coordinated ecosystem survey in the Norwegian Sea in July-August 2007 showed a significant increase in the western and northern distribution area of adult mackerel. Furthermore, juvenile mackerel from the 2006 year class where present for the first time in relatively large quantities up to 66ºN and constituted about 10% of the sampled specimen (ICES, 2007c).

The ICES WGMHSA has put forward a hypothesis that an overall northerly shift in the distribution of NEA mackerel has taken place in 2005–2007. There is also a westerly shift in the northern part of the spawning and feeding areas. If such a large-scale change in distribution and migration pattern really has occurred it is assumed this may have substantial consequences for future abundance, spawning, growth and recruitment of the NEA mackerel stock.

The reasons to the observed changes in distribution are likely to be found in recent changes in the hydrographic conditions in the spawning area. It is well-known that there have been large changes in the size and distribution of blue whiting stock since the mid 1990s, especially in the western distribution area (ICES 2007/ACFM:29). Mackerel uses more or less the same areas to spawn, thus it is likely that these large-scale changes in the environment would also affect mackerel. Changes in the oceanic environment in the Porcupine/Rockall/Hatton areas have been shown to be linked toe the strength of the so-called subpolar gyre (Hátún *et al.*, 2005). In recent years the area has been dominated by the more warm and saline Eastern North Atlantic Water (origination from the south), thus giving favorable conditions for spawning over a relatively wide area (Hátún *et al.*, 2007). However, it remains to be shown whether there is a causal relationship between hydrographic conditions and recruitment of mackerel.

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 3.12.7). 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 and Nazarov, 1989).

The **Southern Horse mackerel** (*Trachurus Trachurus*) stock (ICES, 2007c; Abaunza *et al.*, 2004) is distributed within the West Iberian Atlantic with relative stability along the year. This might be explained by the coincidental location of spawning and feeding grounds. Old adults after spawning migrate northward for feeding. Spawning takes place during the winter predominantly along the shelf break (Farinha and Borges, 1994), well adjusted to the seasonal upwelling timing of the West Iberian system (Santos, *et al.*, 2001). In the Autumn, when the peak of recruitment takes place (Borges and Gordo, 1991) the juveniles are more abundant in the northwest region (Borges, 1991; Murta and Borges, 1994). Ontogenic migrations of horse mackerel along the Iberian region inferred from autumn surveys indicated juveniles and adults moving along the area but not undertaking long migrations outside northwest Iberia region (Murta *et al.*, 2008).

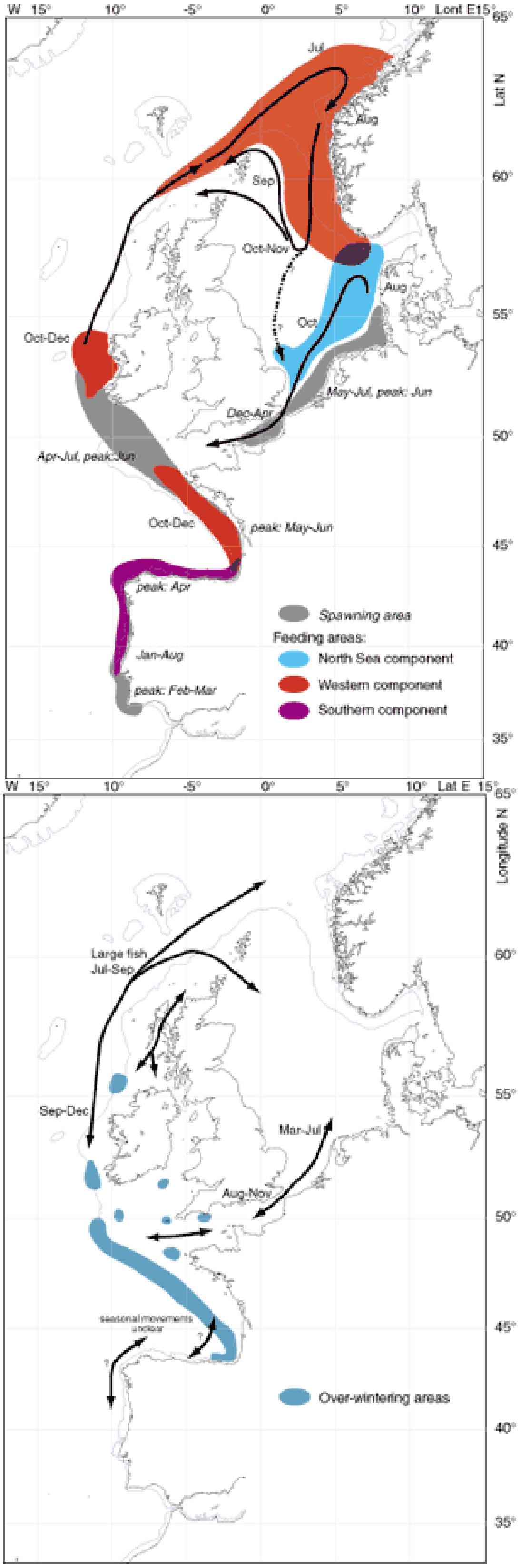

Figure.3.12.7. Schematic outline of assumed migration routes, spawning, feeding and over-wintering areas for the three Horse Mackerel stocks. Depth line drawn is the 200 m contour. For over-wintering areas see Figure 3. (from www.HOMSIR.org and based on ICES, 1998 and Eaton 1983).

3.12.4 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 200 m+ 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.

3.12.5 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* *al.*, 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. 9°C). 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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3.13 Oceanic and deep sea area

3.13.1 Bottom topography, substrates, and circulation

Most of the surface of the advisory region K is abyssal plain with average depth >ca 4000 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-ockall 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 m/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 3.13.1) and also as a strong deep water flow between Shetland and the Faroes.

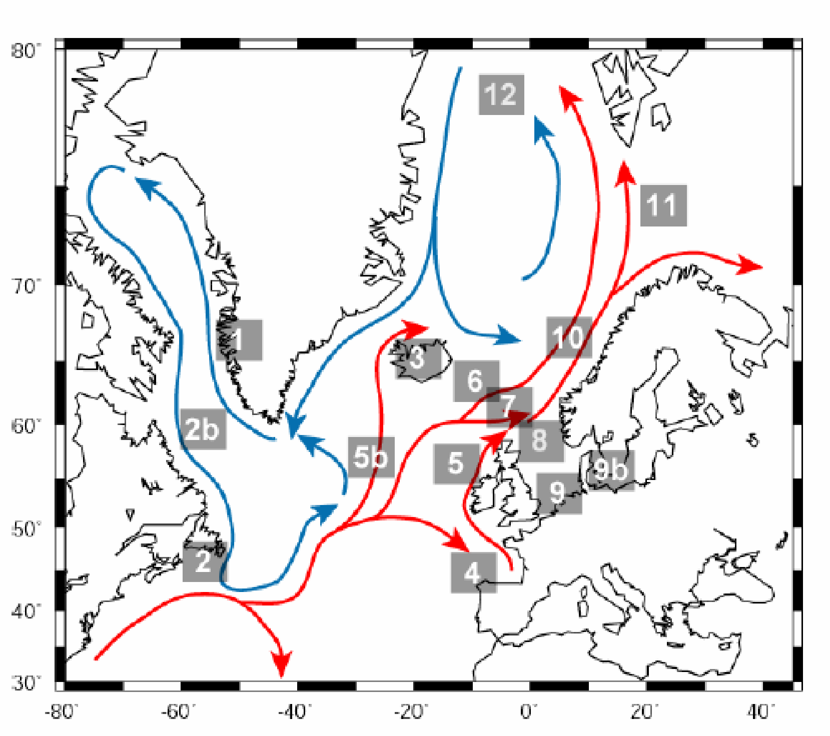


Figure 3.13.1. The general circulation of the North Atlantic in relation to the numbered areas presented in the Annual ICES Ocean Climate Status Summary 2006/2007 (ICES, 2007a). The blue arrows indicate the cooler waters of the sub-polar gyre. The red arrows show the movement of the warmer waters in the sub-tropical gyre.

3.13.2 Physical and chemical oceanography (temperature, salinity, nutrients)

Below about 700 m 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 1000 m depth and less than 4°C below 2000 m (Figure 3.13.2).

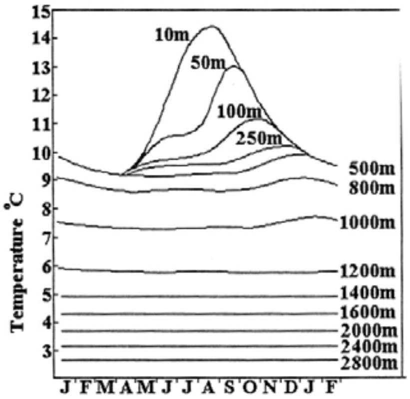


Figure 3.13.2. Seasonal variations of the sea temperature by depth in the Rockall Trough, west of Scotland (Gordon *et al.*, 1995).

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 200 m. 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 3.13.3.). Flux of this organic matter varies both seasonally and from year to year.

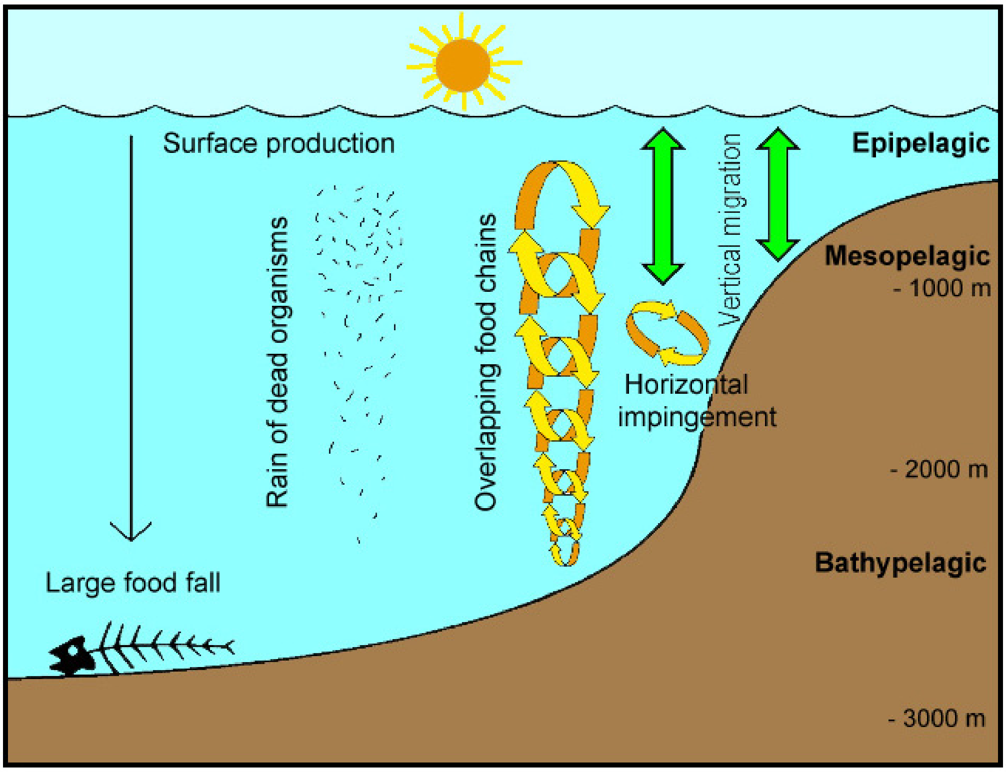


Figure 3.13.3. Trophic transport in the deepwater ocean (courtesy John Gordon, Scottish Association for Marine Science, see also Gordon, 1979).

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 1200 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 3.13.3). 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).

3.13.3 Broad-scale climate & oceanographic features and 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 3.13.4) 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, 2004 and 2006 (ICES, 2007).

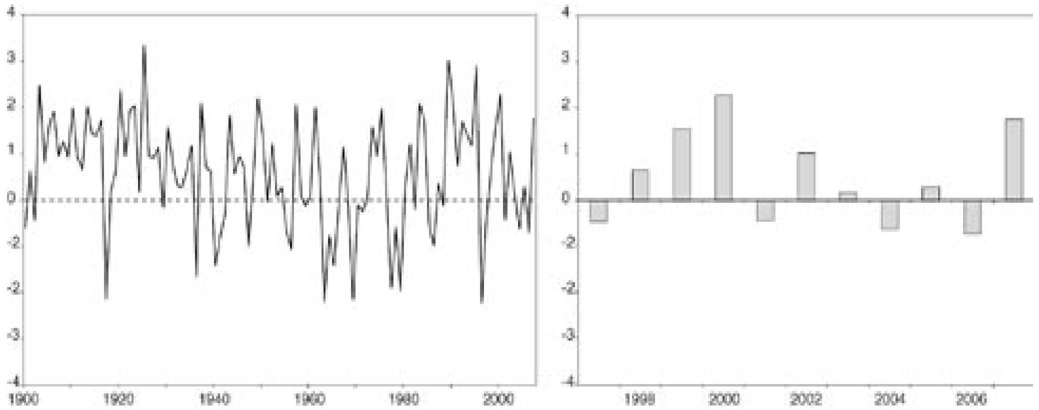
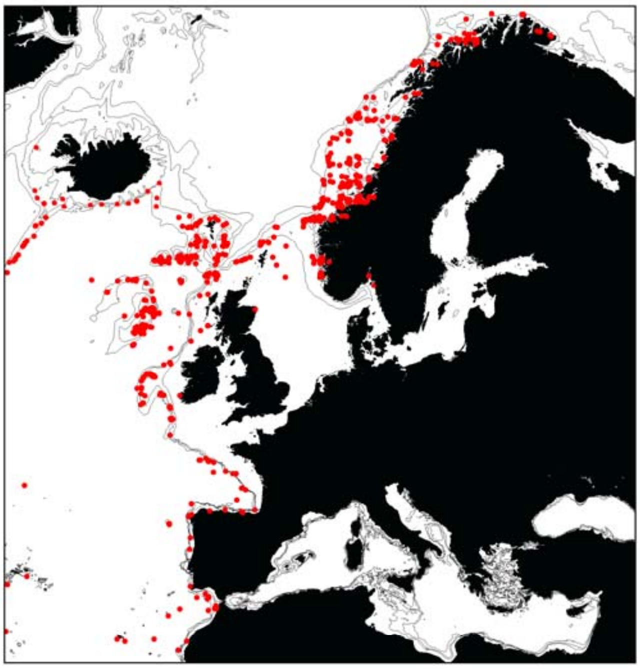


Figure 3.13.4. The winter NAO Hurrell index (see text) in terms of the present decade (left) and the last 100 years (right-a two-year running mean has been applied), (from ICES, 2007). The effect of the NAO on deep layers is poorly known.

3.13.4 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 bycatch 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 3.13.5) (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 bases of these mounds are comprised of dead coral rubble with some infill; live corals grow on top of the mounds.



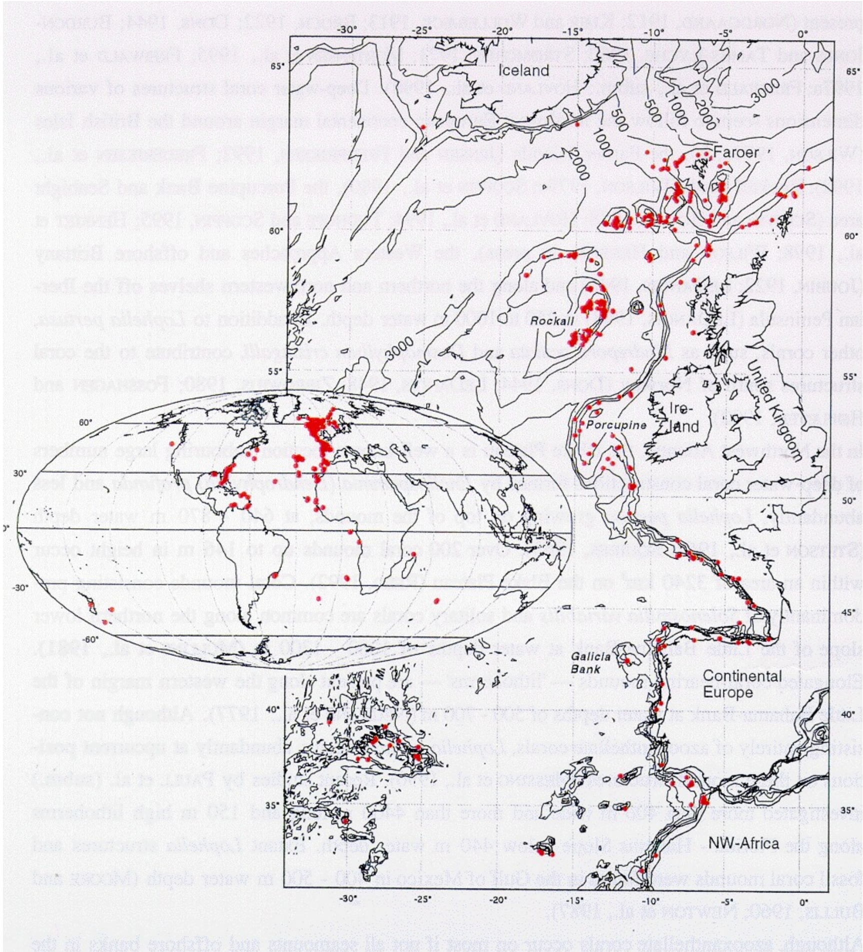


Figure 3.13.5. Distribution of deepwater *Lophelia* reefs in the North East Atlantic and wider (Freiwald, 1998).

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).

3.13.5 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 3.13.3).

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 3.13.1) 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 3.13.1. 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 1800m 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 1000 m–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).

3.13.6 Birds and mammals

The only breeding birds in the advisory region are on the Azores where, the main species are Cory's shearwater, *Calonectris diomedea* (189 000 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 mammal 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.

3.13.7 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.

3.13.8 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 bycatch 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.

3.13.9 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 deep water 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 What is needed for integration by expert and review groups to ensure that environmental forcing is taken into account in drafting fisheries advice?

4.1 What are the challenges and opportunies?

WGRED discussed how the integration of ICES advice should occur within the new ICES advisory structure. Discussions were informed by the revised advisory process as adopted by the Council in February, and took note of both past discussions in the 2006 and 2007 Reports of WGRED and WGECO.

First, it is important that planning be done for FOUR separate but often interacting aspects of "integration".

a) The consideration of environmental forcing and species interactions on the dynamics of fish populations ("fish populations" and "fish stock assessment" should be interpreted broadly throughout to include single-species assessments of that status and trends of any marine population.

b) The consideration of the effects of individual human activities such as a fishery on other parts of the ecosystem, whether directly via for example, bycatch or impacts of gear on habitats, or indirectly through the alteration of relationships among species, due to direct effects on their abundance, size composition, etc.

c) The consideration of the cumulative and aggregate effects of multiple human activities in the sea on marine ecosystems, populations and habitats.

d) The conduct and interpretation of Integrated Ecosystem Assessments (as defined in WGECO 2007) to provide insight into what is linked to what in the ecosystem, and their use in subsequent assessment or advisory tasks.

The reasons for addressing each type of considerations in ICES advice has been made strongly and clearly in past reports of WGRED, WGECO, and ACE, and need not be repeated yet again. However, WGRED does stress that the new draft EU Marine Directive dispels any remaining uncertainty about the need for ICES to provide integrated advice, and advice integrated in all four aspects.

Overarching Policy Objectives provide a unifying concept for thinking about and communicating about integrated advice. There are some overarching global policies for human activities in the Ocean, including (Agenda 21 of the Rio Convention (UN 1992) and several parts of the Johannesburg Convention (UN 2002), and UN Fish stocks agreement). These guide the higher level policy objectives expressed by the various clients of ICES (EU, OSPAR, HELCOM, member states) determine the nature of the advice. In order for the ICES advisory process to prepare for the tasks ahead we made an inventory of the type of objectives and how they are phrased based on excerpts of a selection of such policy documents:

- Common Fisheries Policy (CFP) Council Regulation Nr 2371/2002 on the conservation and sustainable exploitation of fisheries resources under the Common Fisheries Policy

  "Precautionary approach shall be applied in taking measures designed to protect and conserve living aquatic resources, to provide for their sustainable exploitation and to minimise the impact of fishing activities on marine ecosystems. It shall aim at a progressive implementation of an ecosystem based approach to fisheries management."

- Marine Strategy Directive SEC(2005) 1290 establishing a Framework for Community Action in the field of Marine Environmental Policy

  "with the overall aim to promote sustainable use of the seas and conserve marine ecosystems."

  "The end objective of the proposed Directive is to achieve good environmental status of the marine environment by 2021. "

- Maritime Policy Blue book COM (2007) 574 final. An Integrated Maritime Policy for the European Union

  "Fisheries management must take more into account the welfare of coastal communities, the marine environment and the interaction of fishing with other activities. The recovery of fish stocks will be energetically pursued, requiring sound scientific information and reinforcement of the shift to multi-annual planning. The Commission will take action to ensure that the Common Fisheries Policy reflects the ecosystem-based approach of the Strategy for the Marine Environment, and will work to eliminate Illegal, Unreported and Unregulated fishing in its waters and on the high seas."

  "Managing fish stocks at Maximum Sustainable Yields will provide a better future for the European fishing community and ensure its contribution to Europe's food security; this should be achieved by 2015 in line with international commitments."

- Bergen declaration, Ministerial declaration of the fifth international conference on the protection of the North Sea, Bergen Norway 20–21 March 2002

  "fisheries policies and management should move towards the incorporation of ecosystem considerations in a holistic, multiannual and strategic context. While the transition towards a full ecosystem approach to fisheries management should be progressive and concomitant with the enhancement of scientific knowledge",

  "the current state of scientific knowledge, coupled with a sound application of the precautionary principle, allows the immediate setting of certain environmental protection measures."

  "encourage the appropriate authorities to promote those fishing activities having less impact on the ecosystem"

In each of these policy documents there is the explicit mentioning of "the ecosystem". In WGECO (ICES, 2006, 2007) the different ecosystem components that make up an ecosystem were identified and even though no concrete operational management objectives have been formulated for each of these ecosystem components this is supposed to happen in time. This implies that achievement of objectives related to the target stocks will need to be balanced against objectives related to a wide array of other ecosystem components such as the conservation of the "size structure of the fish community", "biodiversity of the benthic invertebrate community" or "abundance of marine mammal population".

For the past decade ICES advice on fisheries has been structured around a small suite of fishery-based objectives set explicitly or implicitly for each target stock separately-advice that has a high probability of keeping spawning biomass of a stock at or above B_{pa} and fishing mortality at or below F_{pa}. Policies may evolve to alter these fishery-based reference points, such as the CFP redefinition of the high level fisheries objectives in terms of MSY rather than just healthy stocks and sustainable fisheries, and these changes would implications for ICES assessments and advice. However, the integration as implied in point s A-D above have even greater implications for how the assessment and advisory content would have to change. Integrated advice will be structured around a suite of objectives differing in two ways from the current narrow pair per stock. First, existing B_{pa} and F_{pa} (and B_{lim} and F_{lim}) for target species may be changed to take account of environmental forcing and species interactions (A), and possibly to take account of some affects on the fish community or ecosystem (B). Second, integrated advice dealing with the ecosystem effects of fishing (B) will almost certainly include adding additional ecosystem-based objectives to the suite of objectives which provide the structure for ICES advice, as may the integrated ecosystem assessments (D). In addition, cross-sectoral integration of advice (C) may change the types of analyses and presentations of results necessary to develop recommended management options (such as the current catch options tables) that link the population (and sometimes community) analyses to the suites of ecosystem objectives.

4.2 What are the parts?

To plan for the provision of integrated advice ICES needs to acknowledge the different types of Expert Groups combined in one box in the original Flow Chart for the new advisory process (Figure 1). We refer to these types of EGs by the name of an existing group, to make clear what type of groups we are discussing. However we stress in all cases we are discussing the *class* of expert groups and not the single one whose name we are using. Specifically, there are:

4.2.1 Assessment type Working Groups

In the past Assessment-type EGs evaluate fish stock status (or, for groups reporting to ACME or ACE, some other ecosystem property) and fishing mortality (or rate of impact of some other human activity) against a pair of objectives for SSB and F. The changes needed for integrated advice are possible changes in analytical methods used by the assessment EGs and likely changes in the suite of objectives which the steps must address. They require significant changes in the make-up of the groups at each step. Assessment EGs *must* have participation by marine ecosystem ecologists with strong analytical backgrounds, and often some expertise in hydrography and the biology and population dynamics of species other than exploited fish stocks, in addition to the traditional fish stock assessment experts. These experts are needed to ensure these more ecosystem-based analytical results are interpreted appropriate right from the start.

4.2.2 SGMAS type Expert Groups

SGMAS has provided exceptional leadership in evaluating methods and developing capacity to conduct Management Strategy Evaluations. However, in integrated advice structured around a broad suite of objectives, MSE work must deal with management strategies that are robust to uncertainty from environmental drivers, and management strategies which try to maximize the likelihood of achieving ecological objectives that are not associated with the status of the target stock(s) of the fishery nor only the pressure of fisheries. SGMAS-type groups must be created or given a much wider mandate to focus on management strategies addressing the expanded suites of objectives.

4.2.3 SGPRISM type Expert Groups

ICES has supported a number of EGs that addressed both conceptual and computational issues associated with inclusion of environmental drivers in analytical assessment work of the core EGs. For example SGPRISM and SGGROMAT addressed the "how to" questions, and groups like SGRECVAP and WKLTSWE, addressed "if" and "why" it should be done. Key products are recommendations on both of these types of questions, which have to be incorporated in the practices of the Assessment-type EGs, and sometimes the Objectives structuring the assessments. Continuing this approach is necessary, and processes need to be established to ensure that the products of these EGs actually make it into practice in assessment and advice.

4.2.4 WGECO type Expert Groups

ICES has supported groups such as WGECO, and WGEXT for some time, looking at the ecosystem effects of specific human activities. These groups have a signficant profile in the overall advisory process, forming the foundations for most ICES advice on ecosystem effects of human activities, including cumulative effects and interactions. It is expected that more activity-specific EGs are likely to need to be created, such as the recent EG to consider the ecosystem consequences of sound in the sea. The major changes for these groups would be in the pathway through the advisory process, rather than the nature of what they are doing. Products of this type of EG have traditionally gone to ACE or ACME, and been passed directly on to relevant clients. Some products, in response to generic questions such as "What are the effects of mobile bottom-contacting fishing gears on benthos" would still go through the review process to ACOM for release. They would also produce guidance/recommendations for practice of the assessment-type EGs, in how to take account of particular ecosystem effects in the regular advisory process. Such recommendations for changes to ICES assessment and advisory practices would be in the forms of recommendations to either adjust reference points for existing objectives (such as a different B_{pa} to allow for dependent predators or competitive interactions) or for new objectives to be added to the suite of objectives guiding the analyses and advice formation of the regular assessment processes (such as status and bycatch mortality rate for a non-target but vulnerable species).

4.2.5 REGNS/WGIAB-type Expert Groups

ICES invested significant planning to deliver the integrated ecosystem assessment of the North Sea by REGNS, and the one for the Baltic Sea underway from WGIAB. Such periodic integrated ecosystem assessments play an important role in synthesising information about the ecosystem relationships, trends, and human pressures and impacts; particularly with regard to how different components and pressures (both human and environmental forcing) interact. Groups like REGNS and WGIAB should become established EGs for each region, responsible for keeping both the culture and infrastructure (methods and data) for such integrated ecosystem assessments alive between their periodic assessments. Furthermore there would be clear benefits if these regional groups maintained operational conceptual models for the different ecosystems and to promote the development of simulation models of ecosystems such as ECOPATH or ATLANTIS. Ecosystem models can be valuable for studying energy flows and interactions between the different components of the ecosystem. The modelling will complement the integrated ecosystem assessment and allow for simulation experiment to address "what-if" questions related to ecosystem structure and functioning, and management.

In addition to the Expert Groups discussed in previous sections, there are other types of Groups with essential roles in producing integrated advice. These include:

4.2.6 ACOM and Advice Drafting Groups

No significant changes in function or operations are envisioned for these groups, although it is not obvious that the planning for these highest-level parts of the advisory process has really thought in depth about how they will handle truly integrated advice and the process that produces it.

4.2.7 Review Groups

The reports and products of all the EGs above require peer review and quality assurance. The existing proposal has Review Groups (RG) filling this role for assessment-type EGs, and it is consistent with the thinking behind the overall that the other types of EGs would have RGs as well. They would serve the same general function wherever they occurred in the process, but their make-up could vary substantially, to be most appropriate for a particular set of EG reports and products to review.

With the Assessment EGs addressing a more diverse set of objectives for structuring their assessments, the RG would have to have a much broader disciplinary expertise and familiarity with a wider range of analytical methods than is likely to have been planned for. This is particularly true for the RG for WGECO-type, and REGNS/WGIAB-type Review Groups, and the RGs for the Benchmark Workshops. However, even for the RGs for the assessment-type EGs, strong ecological knowledge would be necessary.

4.2.8 Benchmark Workshops

These become a cornerstone in making the integration of advice real, by ensuring the initial analyses and interpretation of results by the assessment-type EGs starts off being planned for integration. Recommendations for changes to practice, either in terms of analytical methods or structuring objectives, from SGMAS-Type, WGPRISM-type, WGECO-type, and REGNS/WGIAB-type EGs, if accepted by the advisory process (generally via ACOM) would become implemented as part of the assessment approach(s) here. The Benchmark Workshops would consider the direction and guidance from ACOM, relevant reports of all these other types of EGs, and the information (both data and biological knowledge) available, and identify analytical methods considered most appropriate for the assessments of status relative to the full suite of objectives. Each Benchmark Workshop *must* have a good representation of marine ecosystem ecologists, with strong analytical backgrounds, in addition the traditional fish stock assessment experts and some expertise in management strategy evaluation. This ecological expertise is needed to ensure that the Benchmark Workshop gives appropriate attention to the full spectrum of factors needed in integrated advice.

4.2.9 Data Groups

Assessments and advice that addresses environmental forcing, species interactions and/or interactions among human uses requires diverse data sets to exist, to be easily accessible, and to be readily integrated. ICES has always included a few Expert Groups with responsibilities for planning or coordinating the management of data (e.g. SGMID and WGDIM), and in various ways the ICES Secretariat has maintained some data-bases directly, and interacted regularly with some other institutions that maintain other types of databases. For the advisory process to produce integrated advice, it is necessary that focused and reliable Expert Groups exist and work with the Secretariat on data availability and compatibility. Otherwise the work of the

REGNS/WGIAB-type Groups would be nearly impossible, and any real integration in the analyses of the assessment-type EGs would be highly inefficient and often not practical. Some regional structure to these groups would be logical, and options should be explored as part of Section 4.3.

4.2.10 Science Expert Groups

These are not structurally part of the advisory process. However, the advisory process depends critically on the science EGs (e.g. WGFE, BEWG). Without effective linkages between the two processes, ICES advice, integrated or otherwise, ceases to be the best science advice possible given the information available, and the science community of the ICES area is not being used effectively. Science EGs need to pay attention to questions that are crucial to the quality and effectiveness of ICES advice; Advisory EGs need to take up new science knowledge swiftly. The absence of any reference to the science processes and EGs of ICES in the early flowchart was a major gap.

In reality, there is a gradient in the EGs and other groups associated with the advisory process, from groups with roles and duties almost exclusively within the sphere of the advisory process, to ones almost exclusively within the sphere of the science processes of ICES. This reflected in Figure (2) which illustrates the gradient from science (blue) to advice (yellow), with the mixed identity of many of the EGs demonstrated. Specifically:

- Purely Advisory: ACOM, Drafting Groups, Many Review Groups
- Mostly Advisory: Assessment WGs and Benchmark Workshops (more science than Assessment-type EGs)
- Both Advice and Science: SGMAS-type, WGECO-type and SGPRISM-type (and their Review Groups)
- Mostly Science: REGNS/WGIAB-type Groups, Data Groups, All other Science EGs and Committees

4.3 How do the parts interact?

Advice will be integrated and ICES will work efficiently, only if all the parts above understand their roles, understand what is needed from them by other groups, and communicate frequently and effectively to ensure messages are clear and useful. The flow-chart in Figure 2 has a few of the key linkages, but it is not possible to put all the necessary arrows in such a figure, without it becoming too cluttered to follow. Instead, Table 4.1 contains a cross-tabulation of what products are produced by each group, and what group(s) receives them. In the caption for the table there is an intentional use of a few different nouns and verbs to convey the degree of emphasis or obligation associated with a particular product, as explained in the table caption. Note ACOM may give guidance and direction to EGs with both science and advisory roles. ConC may also give guidance and direction to such groups. As in the past with MCAP, interaction between ACOM and ConC should resolve any differences of views or priorities before either gives guidance or direction contradicting the other. Note that Table 4.1 also leaves out the Review Groups in the passage of products, but their quality assurance role is assumed as a necessary step before any products are passed through the process.

4.4 Considerations in implementation

Not everything can be done at once. During the transition phase, from time to time an EG is likely to find a product that it needs from some other group is not available. The process is designed to address those circumstances. For example, a WGRECO-type group may recommend that a new type of Ecosystem Objective be part of the assessment responsibilities for an assessment-type EG. Before that can happen an SGMAS-type EG may have to undertaken appropriate work and the data-based EGs ensure the necessary data would be available to the assessment EGs. In those cases the loop would go from the WGECO-type group producing the recommendation to ACOM for consideration and guidance to SGMAS-type and data EGs for action, and finally their products would go to the Benchmark Workshops for inclusion in practice.

The availability of the proper ecological experts may be serious constraint on implementation. This expertise is likely to be in short supply, and rarely have such experts been sent to the assessment-type expert groups, at least those doing fisheries assessments. Success of this-or any other-approach to integration of advice (except artificially at the very last stages of its preparation) depends on Lab Directors sending a different mix of experts to these assessment-type EGs, and possibly these meetings attracting some participation from non-traditional sources such as universities. Failure to send the right mix of experts will ensure the assessment-type EGs will not succeed in integration of their analyses and interpretation of results. Howeve having the right mix of experts does not guarantee success, unless the working procedures of the assessment-type EGs change to include this broader expertise fully in their work. This will mean, among other things, doing some different types of analyses with different types of outputs as part of the core analytical basis for advice. These changes have to start with some different Terms of Reference being assigned to the assessment-type EGs, such that it will be clear that these different types of analyses and results really do address the charge by ACOM to the EGs, and will have to be supported in the periodic guidance received by the Assessment-type EG from the Benchmark Workshop (those, too, having received some different Terms of Reference). Looked at this way, 2008 can only be viewed as a transition year, with many changes to the culture of the assessment-type expert groups only likely to be possible from 2009 onward, when there has been adequate planning of the right terms of reference for the right groupings of topics to be assessed and interpreted together.

If availability of expertise is a limiting factor on potential progress, it may be necessary to have a small number of EGs specifically tasked with certain subsets of all the analyses arising from Benchmark Workshops, rather than have Assessment-type EGs do the integrated analyses for full suites of Objectives that belong together ecologically or functionally. These specialised ecosystem assessment EGs would meet periodically, and might conduct their assigned analyses to complement the work of a number of different assessment-type EGs in one sitting. A review group with appropriate expertise would consider their products and the integration of their drafted advice with the drafted advice from the appropriate assessment-type EG. It is expected that at least occasionally the advice from the two perspectives would not be readily reconciled. ACOM would have to develop practices to address such situations.

The groupings of fish stocks and related issues that are assessed or otherwise addressed in individual expert groups need to be reconsidered carefully. This proposal is founded on fish stock assessments occurring in conjunction with assessments of other related ecosystem components and pressures. Consideration must be given with regard to what provides the most effective groupings to facilitate advice that is integrated across appropriate ecosystem components and human activities on appropriate regional scales.

There could be efficiencies gained from assessing at the same time groups of stocks whose dynamics are likely to be affected by a similar environmental forcer, or even by a particular type of forcer (for example land-based nutrient run-off) that may occur in widely separated parts of the ICES area. There could be efficiencies gained by assessing groups of stocks exploited by fisheries with a common type of ecosystem impact of great concern. Assessing all the stocks and other parts of the ecosystem affected by an individual fishery might be a very reasonable grouping. Where species interactions are considered an important driver of the dynamics of a set of stocks, these stocks would almost certainly have to be assessed together. It could even be that where two or more different human activities are both important and interacting pressures on a particular ecosystem, options to achieve a suite of ecosystem objectives can only be considered reasonably in light of both activities at once, and one assessment EG should assess the status of the suite of ecosystem components and impacts of both activities.

United Nations 1992. United Nations Convention on the Environment and Development http://www.unep.org/unep/partners/un/unced/home.htm

United Nations 2002. Plan of Implementation-World Summit on Sustainable Development. New York 44 pp.

Table 4.1. Identification of the nature of the communicaton and products between the types of Expert Groups and other Groups in the integrated advisory process. Note that specific nouns and verbs are used to represent different levels of emphasis and obligation with regard to what is being communicated or transmitted.: “Suggestion” and “Question”-Soft; one group thinks something is a good idea, a concern or is curious about something, and thinks the other group(s) could do something useful with it. “Guidance”-Stronger than a suggestion, but leaves scope for discretion by the group receiving the guidance about how to act on it. “Recommendation”-Strong; a group is pretty confident that a conclusion is sound and should be the basis for action by another part of the process. “Direction”-Very Strong. ACOM is telling a group that something should be done; the equivalent of assigning a Term of Reference. “Basis for advice”-Strong, these are the science-based products and text that ACOM should consider releasing as ICES advice.

From

To

	SGPRISM	WGECO	SGMAS	ASSESS	RIAS	BENCHMARK	ACOM
SGPRISM		Suggestions for analyses to explore	Suggestions for analyses to explore	Questions	Suggestions for analyses to explore	Questions	Direction or Guidance on Priorities
WGECO	Suggestions for analyses to explore		Suggestions for analyses to explore	Questions	Suggestions for analyses to explore	Questions	Direction or Guidance on Priorities
SGMAS	Suggestions for analyses to explore	Suggestions for analyses to explore		Questions	Suggestions for analyses to explore	Questions	Direction or Guidance on Priorities
ASSESS						Guidance on: “WHAT to consider”. Guidance on “HOW to consider it”	Direction or Guidance on Priorities
RIAS	Suggestions for analyses to explore	Suggestions for analyses to explore	Suggestions for analyses to explore	Questions		Suggestions for analyses to explore	Direction or Guidance on Priorities
BENCHMARK WORKSHOPS	New methods to include forcers and		Recommended strategies for use in		Recommended new analyses,		DIRECTION on Revised objectives

	species interactions in assessments		assessments		relationships & indicators to consider for the assessments.		for assessments, DIRECTION on preferred methods from EG recommendations
ACOM	Recommendations for new objectives; & for priorities to other types of EGs	Recommendations for new objectives; & for priorities to other types of EGs BASIS FOR ADVICE on Impacts of Pressures (usually generic. Case specific generally from Assessment-type Groups)	Recommendations for revised objectives; & for priorities to other types of EGs	BASIS FOR ADVICE of status relative to objectives		Questions to ACOM re expectations and needs	

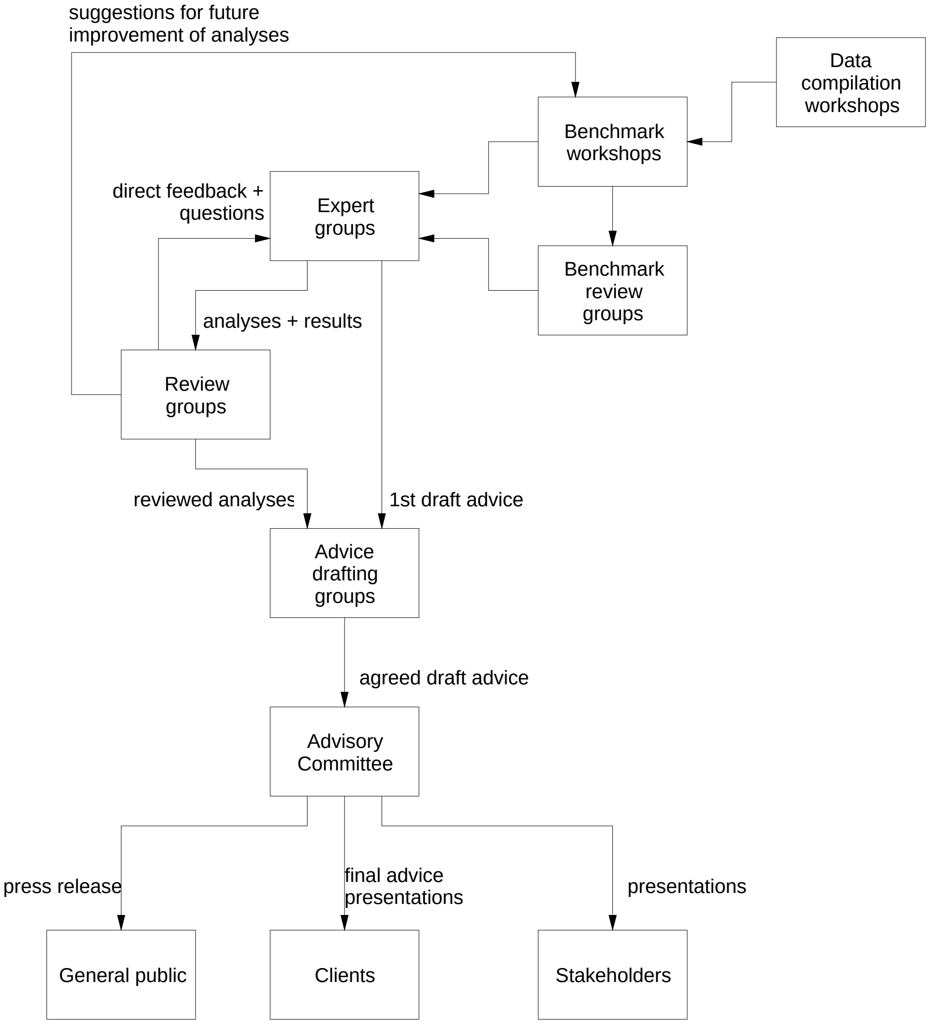

Figure 4.1. General flowchart of ICES advisory services: generation of advice, as provided from AMAWGC 2008.

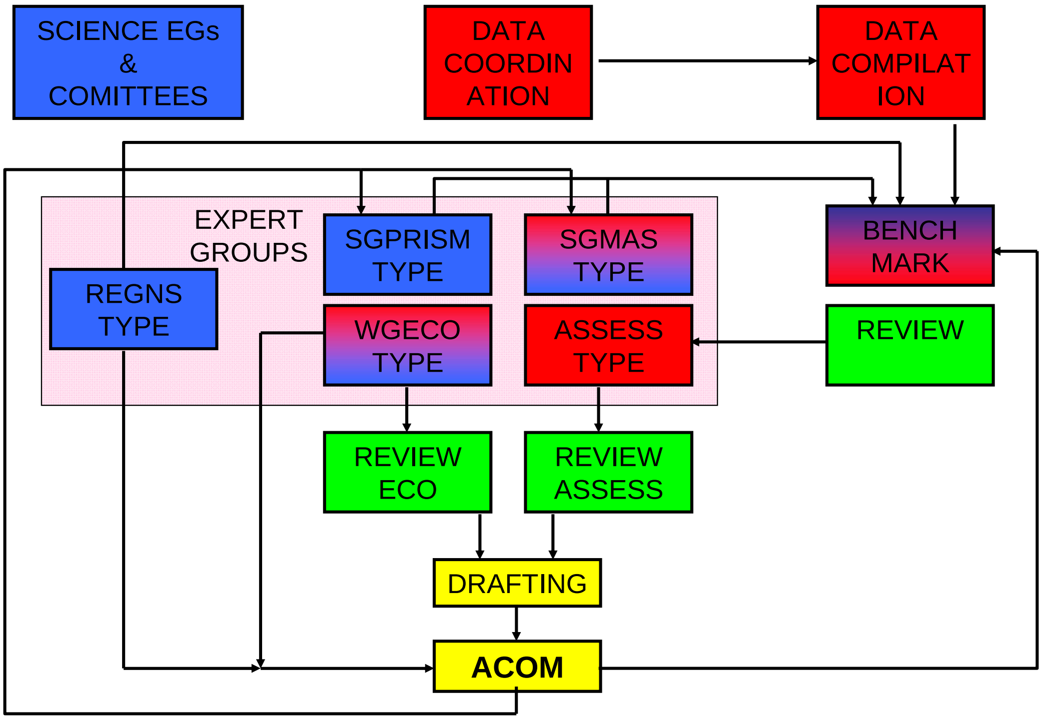

Figure 4.2. Diagram showing the different types of Groups in ICES, with colouring to reflect the nature of the various roles. Blue reflects the science nature of the group, red the advisory-working level nature. Green is the review level and yellow, the strategic.

5 Recent significant environmental events

As described in detail in last year's report, there has been no evidence that other ICES Expert Groups have done more than comment on any "significant environmental events" highlighted in previous reports, This year WGRED agreed with its past conclusion that past guidance to other Expert Groups for dealing with such events was neither effective nor particularly welcomed, and has discontinued providing it. The highlighting of these events is considered a valuable activity, but this year the events are incorporated directly into the appropriate regional overviews. These overviews get read much more widely than the Working Group Report, and thus the overviews are considered a much more effective vehicle for disseminating information about such events. WGRED presents ideas for achieving even better dissemination of the information in the Overviews in Section 5.

Discussion of specific "significant environmental events can be found in

- Section 3.10, Bay of Biscay and Western Iberian. Anomalously cold winter in Bay of Biscay in 2005 and subsequently strong modifications of summer 2006 upper water layers.
- Section 3.12, Norwegian Sea. There was observed a significant increase in western and northern distribution area of adult North East Atlantic Mackerel in the Norwegian Sea in summer 2007. Furthermore, juvenile mackerel from the 2006 year class where present for the first time in relatively large quantities up to 66ºN and constituted about 10% of the sampled specimen.

6 Additional matters for ICES consideration

6.1 The future of WGRED

WGRED has concluded that should ICES implement changes of the nature outlined in Section 4 of this report, in order to provide more integration of advice, then there would be no need to continue WGRED as a separate Working Group. In the past WGRED has served two main functions: preparing the regional overviews, and identifying significant environmental events for attention during the assessment Working Groups' activities. It was clear this year that the structure and content of the overviews is mature. Major revisions are not necessary; only the updating of time series and perhaps addition of an occasional sentence or paragraph to reflect new knowledge as it is acquired, and the addition of a paragraph should some significant environmental event be observed. Whatever changes are made to the work assignments of the Expert Groups supporting the advisory process, doing the updates and reviewing them does not require a special meeting of a special Expert Group. It can be done by correspondence, or as described below.

If the changes are made for integration, both of the past functions of WGRED will be better served by the more integrated assessment-type Expert Groups themselves. Such Expert Groups would have the right mix of expertise to update the Overview(s) corresponding to the region of interest to the EG as part of their basic integration of information. They would also have the right mix of expertise to identify significant environmental events, and the ideas for what to do about them in the integrated advice would be part of the core work of the Expert Group. Generating the ideas themselves, there might be a greater likelihood that the Expert Group would act on them. As a consequence, if the advisory process is adapted as needed to provide better integration of advice, then the functions currently served by WGRED would be assimilated into the basic assessment and advisory process of ICES, which is probably as it should be. In that case WGRED can conclude that it has succeeded completely in its mission, and either retire or be given some new and even more visionary mandate.

The future of the ecosystem overviews

The WGRED had a discussion on the future use of the Ecosystem overviews. As these were deemed informative for a broader audience one suggestion was to put it on the Wikipedia net-based free encyclopedia for popularization. A quick scroll through Wiki for articles of this kind showed a clear niche for this type of information. Some geographic areas are fairly well covered whilst other were hardly mentioned, at least not with regard to ecosystem considerations.

If such a use should be devised it is recommended that some degree of standardization is carried out prior to publication. The job could be done by the WGRED group by correspondence, after which the articles can be put into Wiki as they have been approved by a committee. Such a job could be carried out within some months to half a year.

6.2 The Value of Integrated Ecosystem Component Analysis

The primary value of such an approach is that it can be used to assess the status of ecosystem in terms of its energy cycling through the food web as well as the relative importance of multiple pressures acting on the ecosystem using all available data (monitoring programmes and models). There is no constraint on which components need to be included. It may provide evidence of how effective the management measures are in relation to environmental forcing of ecosystems with an instantaneous view of which pressures are dominating the structure & function of the system and therefore which may require management intervention.

Where do these Integrated Analyses fit into the new process?

The groups conducting the integrated ecosystem analyses have to work closely with the Data Groups, to allow such integrated analyses to be conducted efficiently. In fact, it is likely that if the linkages among the Data Groups, the groups conducting the integrated ecosystem assessments and ICES Secretariat were effective, then most data requirements for the other types of expert groups would also be met. Also, these integrated ecosystem assessments are a particularly appropriate avenues for progress by science-based Expert Groups to be brought for the first time into the stream of the advisory process. For both of these reasons, these integrated assessments would be a crucial node in the overall advisory process, even though their activities are very largely in the science realm of ICES.

The greatest value of these integrated ecosystem analysis would come if they were held prior to the benchmark workshops. That would make new insights into ecosystem relationships and interactions among pressures and between pressures and ecosystem components available for consideration during the benchmark assessments. They also have the potential to make quite concrete as well as conceptual contributions to the advisory process, through, for example, identifying new and informative indicators of ecosystem structural and functional properties, facilitating the inclusion of these properties in integrated advice.

What does it mean for the advice?

This approach would not replace the existing stock assessment advice but it would complement it by providing an assessment of the status of ecosystem in terms of its energy cycling through the food web including an overview of the importance of various pressures (environmental and human) on a wide range of ecosystem components and attributes. As such it would contribute to objectives pertaining to the "environmental status of the marine environment" as expressed in e.g. the Marine Strategy Directive.

Considering the amount of work involved and the rate at which these ecosystem level changes are expected to occur an approximately five-year cycle should be sufficient. Considering that these integrated ecosystem assessments have already been conducted for two major European waters (i.e. North Sea and Baltic Sea) while for some other regions national initiatives have occurred (i.e. Barentz sea) or shown scope for such assessments (e.g. Western waters) a way forward could be to alternate these regional ecosystem assessments for the selected major EU marine regions.

Annex 1: List of participants

Working Group for Regional Ecosystem Description

ICES Headquarters, Copenhagen, Denmark

25 February–29 February 2008

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Annex 2: Recommendations

Recommendation 1 – Act on our Section 4

Recommendation 2 – Make the Overviews into Wiki-contributions

Recommendation 3 – If there is action on Recommendation 1, assigned the updating over Overviews to the appropriate Expert Groups. WGRED can be adjourned or given some new role in commencing the annual work towards integrated advice.