## ICES WGRED REPORT 2005

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# Report of the Working Group for Regional Ecosystem Description (WGRED)

14–18 February 2005

ICES Headquarters

International Council for the Exploration of the Sea
Conseil International pour l'Exploration de la Mer

**International Council for the Exploration of the Sea**
**Conseil International pour l’Exploration de la Mer**
H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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# Contents

# 1 Meeting Opening and Working Protocols

The Working Group on Regional Ecosystem Descriptions (WGRED) met at ICES Headquarters, Copenhagen from 14-18 February 2005. Attendees at the meeting see Annex 1.

This was the first meeting of WGRED, which had been constituted to play a central role in facilitating the inclusion of more ecosystem and environmental information in the short term advisory tasks for ICES. The Terms of Reference for the meeting were:

a) review and revise as necessary a report template for the ecosystem description in the advisory reports. This template will be provided by the Secretariat. The template will propose a bioregion structure (ecosystems). The Secretariat will in developing this template *inter alia* consider RAC's and European Marine Strategy Bioregions;

b) review and propose any revisions to the proposed Table of Contents (ToC) for the ICES Advisory Report for 2005. This ToC proposal will be drafted by the Chairs of the advisory committees for consideration at the MCAP January 2005 meeting;

c) Using a) and b) on an ecosystem basis to:

    i) Identify sections in the ICES advisory report (ToC defined under b)) for which information on ecosystem characteristics and linkages - on basis of existing knowledge - can be incorporated in the ICES advisory report;

    ii) Review available information sources regarding ecosystem characteristics and major events, important environmental drivers for ecosystem productivity and important human impacts on the ecosystems;

    iii) Compile information identified above. This compilation is intended for inclusion in the ICES advisory report 2005 or be used by fisheries and relevant science expert groups to support their input to the ICES advisory process;

d) Consider ways to develop regional assessments based on an incremental approach taking on board existing knowledge and incorporating integrated assessments when such become available.

The Working Group will report by 31 March 2005 for the attention of ACE, ACFM and ACME. The report of this Group and information compiled will be made available to relevant fisheries and ecosystem assessment groups.

The meeting was timed to co-occur with the Annual Meeting of Assessment Working Goup Chairs, so that there could be significant interaction between WGRED and the Chairs of the Assessment Working Groups. The two groups met jointly on two occasions during the week. At the first joint meeting, the goals, objectives, and information requirements of both groups were discussed. At the second WGRED presented its preliminary of list of environmental and ecosystem considerations that were thought to warrant specific attention in the 2005 assessments, and proposals for what specific treatments of the information might be appropriate in the assessment process. This joint discussion highlighted the importance of differentiating the treatment of environmental issues in the assessment *process* from the inclusion of environmental variables in assessment *models.* The substance of that discussion is captured in Section 3 of this Report. Section 4 contained some ideas from the joint discussions which can only be addressed in the longer term, as well as a number of ideas from subsequent discussions in WGRED.

Term of Reference a) was discussed several times through the meeting, and resulted in a final template which is incorporated in all the draft Regional Ecosystem Overviews. The template is the topic headings which are used consistently in each of these drafts. Note that in a few cases further subheadings are also used, when the information on a topic was sufficiently extensive that subdividing a topic resulted in greater clarity and readability.

In the discussion of Term of Reference b) it was agreed to use the ecoregions which had been recommended to DG Environment by ACE in 2004. These regions comprise the major sub headings of Section 2 of this report. In preparing the draft Ecosystem Overviews, it quickly became clear that some of these units are sufficiently large that they are internally too heterogeneous for a single integrated overview to be meaningful. In those cases (for example East Greenland and Iceland, and the Bay of Biscay and the northern and central Iberian seas) the Overviews ended up *de facto* reporting on the different areas separately within each topic in the template, even though the major regional units were kept in the structure of the Report.

In summary, Section 2 contains the Regional ecosystem overviews. Its subsections reflect the decisions about ecoregions as per Term of Reference b) whereas the internal organisation of each subsection display the template which was adopted. Sections 3 and 4 go on to address Term of Reference d) in the short and the long term respectively.

**Acknowledgements**

The Working Group thanks the ICES Secretariat for the usual high level of support during the meeting, and Bodil Chemnitz for preparing the final report from quite diverse input files. The very receptive attitude of the Chair of ACFM and the members of AMAWGC to the ideas and proposals of WGRED provided the participants with substantial incentive to fulfill their tasks clearly and completely. The Chair thanks all the participants for creative and dedicated efforts during and after the meting, and the Chairs of Ace, ACFM, and REGNS for spending time with WGRED, to ensure all these initiatives were working together as constructively as possible.

# 2 Ecosystem Overviews

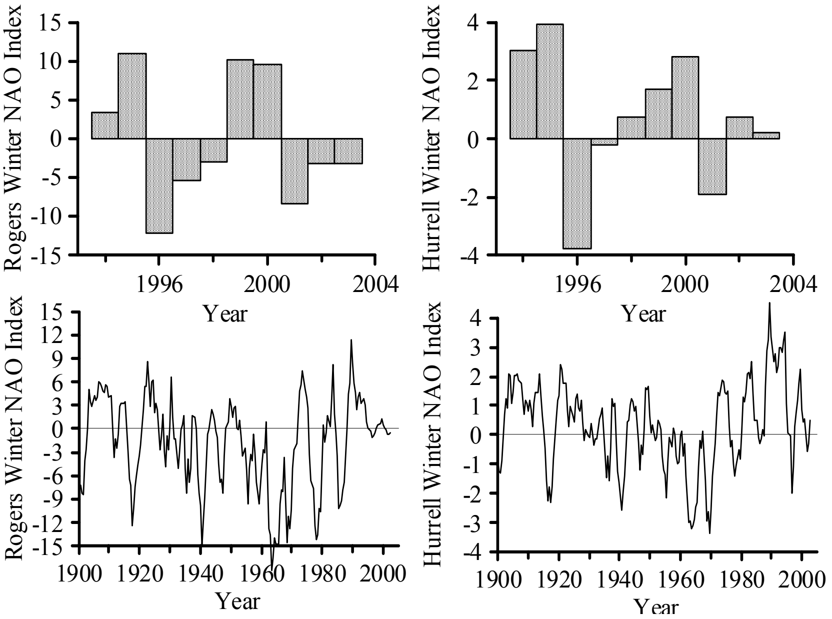
## 2.1 Northeast Atlantic (General Patterns)

Hydrography sets the context for the major ecosystems in the North East Atlantic. The upper water layers are characterized by two major current systems. See figure right. Warm and saline waters that originate from the subtropical gyre are transported polewards by the North Atlantic Current and southwards by the Canary Current; these relatively warm waters dominate the eastern and southern parts of the area. In addition, the European Shelf Edge Current transports warm water northwards along the continental slope. This current is found throughout the year north of Porcupine Bank, but often disappears in summer along the shelf break in southern European Atlantic waters. In this area upwelling events can occur seasonally and these are considered important in the recruitment of some small pelagic species. Norwegian Sea deep water, which is generally very cold (around 0°C), travels through the Faroe Bank Channel where it drops into the Iceland Basin while mixing with the warmer Atlantic waters. Relatively cold and fresh Arctic waters, on the other hand, are transported southwards by the current systems in the west, e.g., by the East Greenland Current. These relatively cold waters dominate in the northwestern parts of the North East Atlantic. Detailed information on the hydrography of this area is available from the Annual ICES Ocean Climate Status Summary (Hughes and Lavin, 2004).

The topography is highly complex, but is best defined by a number of key features. These are the shelf areas, which are narrow with a steep drop off in the Iberian Peninsula, but broader to the north and often with reduced slopes into deep water e.g. at Porcupine Bank, Faroe-Shetland Channel and Tampen Bank. The North Sea, and the Baltic are distinct and environmentally separate parts of this shelf system. The North Sea links to the wider NE Atlantic via major inflows in the north and less importantly through the English Channel. In turn, the Baltic Sea ecosystem is dependent on a variable inflow of saline oxygenated water from the North

Sea. To the west of the shelf break and north and west of Scotland across to Iceland there is a complex area of banks, ridges and plateaus e.g. Faroe, Rockall and Iceland itself, representing a boundary between the Norwegian Sea basin to the north and the NE Atlantic basin to the south.

**The winter NAO index for the last decade (top) and century (bottom). The Rogers Index (left) and the Hurrell Index (right).**



The overall circulation pattern outlined above is modulated by short- and long-term climatic variability. The most studied of these is the North Atlantic Oscillation (NAO). When the NAO is in the positive index phase there is a strengthening of the Icelandic low and Azores high. This strengthening results in colder and drier conditions over the western North Atlantic and warmer and wetter conditions in the eastern North Atlantic. During a negative NAO index phase, a weakening of the Icelandic low and Azores high tends to reverse these effects. A high NAO index is believed to lead to a weakening of the warm North Atlantic Current and a stronger poleward current along the European shelf break, as well as stronger cold Labrador Sea water inflow. A low NAO index suggests a stronger North Atlantic current penetrating further into the Norwegian Sea and a weaker slope current.

In most areas of the North Atlantic during 2003, temperature and salinity in the upper layers remained higher than the long-term average, with new records set in several regions. In Biscay, sea surface temperature in summer 2003 was the warmest in the time-series (1993–2003). Values were 1ºC above the mean from June to October and the thermocline was shallow. In the Rockall Trough there were high surface temperatures and salinities, continuing a rise which began in 1995. Salinity values over the top 800 m were the highest on record, and corresponding temperatures were more than 0.5°C above the long-term average. Surface waters in the Faroe Shetland Channel continued the general warming trend observed over the last 20 years. Modified Atlantic Waters in the Faroe Shetland Channel were warmer and saltier in 2003 than at any period during the last 50 years. The sea surface temperature in 2003 was higher than normal over most of the Norwegian Sea. The distribution area of Atlantic water has decreased since the beginning of the 1980s, while the temperature has shown a steady increase. Since 1978 the temperature of Atlantic water has increased by about 0.6°C.

The area contains a number of widely distributed migratory stocks (Mackerel, horse mackerel, blue whiting, Atlanto-Scandian herring, hake & European eel). These mostly reside in the relatively warm waters in the eastern part of the North East Atlantic. The geographic distribution and properties of these water masses must therefore be important for the dynamics of these stocks. Probably the best-known factor impacting on fish stocks is the abundance of zooplankton (particularly copepods). In broad terms the long-term Continuous Plankton Recorder database provides useful data. Long-term trends in the North East Atlantic show a general decline in zooplankton abundance and particularly of copepods (Heath *et al.* 2000; Edwards *et al.,* 2004). An important consideration is that all life history stages of copepods are important for both adult and larval/juvenile fish. CPR records show that primary productivity in the NE Atlantic was consistent and restricted to the period April to November in the northern NE Atlantic. From the late 1990s, the period extended to March to November and intensified. Further south the productivity in the 1990s was greater than in previous decades, but diminished to some extent in the late 1990s. Seasonality was similar to the northern NE Atlantic (SAHFOS 2003).

References can be found in section 2.7.6.

## 2.2 Area a – Iceland – Greenland

### 2.2.1 Ecosystem Components

#### 2.2.1.1 Bottom topography, substrates, and circulation

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

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

The Polar Front extends between Greenland and Iceland. It separates the cold and relatively less saline south-flowing East Greenland Current from the Irminger Current, the westernmost branch of the warmer and more saline North Atlantic Current (Figure 2.1). To the south and east of Iceland the North Atlantic Current flows towards the Norwegian Sea, dominating the water mass properties between Iceland and the Faroes and Norway. The Irminger Current flows northeasterly to the west of the Reykjanes Ridge, before splitting into an arm which flows eastward to the north of Iceland and an arm which flows southwestward parallel to the East Greenland Current. Further north of Iceland the cold East Icelandic Current (an arm of the East Greenland Current) forms a counter-clockwise gyre around the Iceland Sea.

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

#### 2.2.1.2 Physical and Chemical Oceanography (temperature, salinity, nutrients)

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

Hydrobiological conditions are quite stable in the domain of Atlantic water south and west of Iceland, whereas there may be large seasonal as well as inter-annual variations of hydrography in the mixed waters on the N- and E-Icelandic shelf. On longer timescales changes in the strength and position of major currents and water masses probably tied to NAO regime shifts combine to have a large influence on the marine ecosystem of the north Icelandic shelf (Figure 2.2) (Malmburg *et al.* 1999).

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

### Broad-scale climate & Oceanographic features & drivers

The NAO has a strong effect on ocean climate and water mass distributions in these waters, and environmental regimes are thought have altered several times over the past decades. These regimes are thought to have affected the productivity of many exploited fish stocks, as well as the fish and zooplankton on which they feed.

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

### 2.2.1.3 Phytoplankton – timing, biomass/abundance, and major taxonomic composition

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

The East Greenland Shelf is a low productivity (<150 gC/m$^2$-yr) ecosystem based on SeaWiFS global primary productivity estimates. The melting of the ice in the summer has significant effects on ecological conditions, causing large amounts of nutrients to be transported into the waters around East Greenland. Owing to these climatic factors and to the high latitude of the region, the seasonal phytoplankton production is of short duration and of limited extent. The plankton bloom is dominated by diatoms, but in some years the flagellate *Phaeocyctis* may also contribute. http://na.nefsc.noaa.gov/lme/text/lme19.htm

#### 2.2.1.4 Zooplankton

Collectively, the Iceland Sea water fosters such arctic types of zooplankton as *Calanus finmarchicus, C. hyperboreus* and *C. glacialis*, *Metridia longa,* amphipods and others, with *C. finmarchicus* commonly comprising 60-80% of the spring zooplankton bloom. Zooplankton productivity is highest along the frontal area to the south and East of Iceland, along the North Atlantic Current, and lowest to the west and north of Iceland. Zooplankton production has shown a trend interannually, although with different patterns in the Arctic, the Atlantic, and the mixed Arctic/Atlantic waters. Zooplankton production tended to increase in all three water masses throughout the 1990s (Astthorsson and Vilhalsson 2002). 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.

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

In the pelagic ecosystem off Greenland and Iceland the population dynamics of calanoid copepods and to some extent krill are considered to play a key role in the food web as a direct link to fish stocks, baleen whales (*Mysticeti*) and some important seabirds, such as little auk (*Alle alle*) and Brünnitch's guillemot (*Uria lomvia*).

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

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

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

**Biogenic habitat taxa**

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

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

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

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

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

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

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

### 2.2.1.6 Fish Community

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

Capelin is important in the diet of cod as well as a number of other fish stocks, marine mammals and seabirds. Unlike other commercial stocks, adult capelin undertake extensive feeding migrations north into the cold waters of the Denmark Strait and Iceland Sea during summer.

Capelin abundance has been oscillating on roughly a decadal period since the 1970s, producing a yield of >1600 Kt at the most recent peak. Herring were very abundant in the early 1960s, collapsed and then have increased only slowly since 1970. Abundance of demersal species has been trending downward irregularly since the 1950s, with aggregate catches dropping from over 800 Kt to under 500 Kt in the early 2000s.

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

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

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

Warm conditions returned since the mid 1990 and, in particular off East Greenland, some increase in the abundance of juvenile cod has been observed in the most recent years. However, recruitment has remained much below what have seen at comparable hydrographic conditions before. This indicates that other factors might have become more prominent, such as the age structure of the cod spawning stock at Iceland (reduced egg quality and changed location and timing of larval hatch) and the by-catch of small cod in the increased fishery for northern shrimp.

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

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

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

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

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

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

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

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

### 2.2.2 Environmental Forcing on Fish Stock Dynamics and Fisheries

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

The transport of cod larvae from Iceland to East Greenland has been a major ecological feature of this region. Its strong decadal signal, tied to climatic regimes, has significant impacts on stock sizes in both areas, but particularly in East Greenland. Because of the strong influence of cod eggs and larvae transported from Iceland on the dynamics of the East Greenland cod (and in some periods return migration of adult cod to Iceland has an impact of the cod fisheries in Iceland), management strategies designed for stocks whose dynamics are determined by local biomass and environmental conditions cannot be counted on to ensure sustainable use of at least the East Greenland cod. The scientific community should give priority to development of sustainable management strategies for fisheries on stocks whose dynamics are not primarily determined by stock sizes and environmental conditions in the local management area.

### 2.2.3 Ecosystem Effects of the Fisheries

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

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

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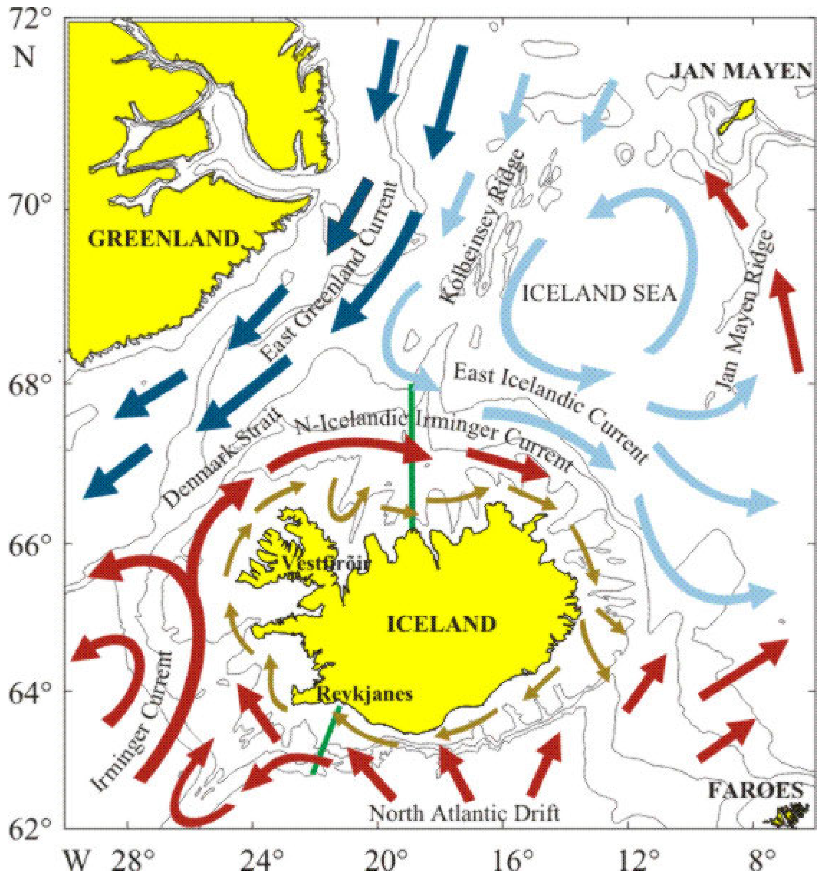

**Figure 2.1. The system of ocean currents around Iceland and in the Iceland Sea**

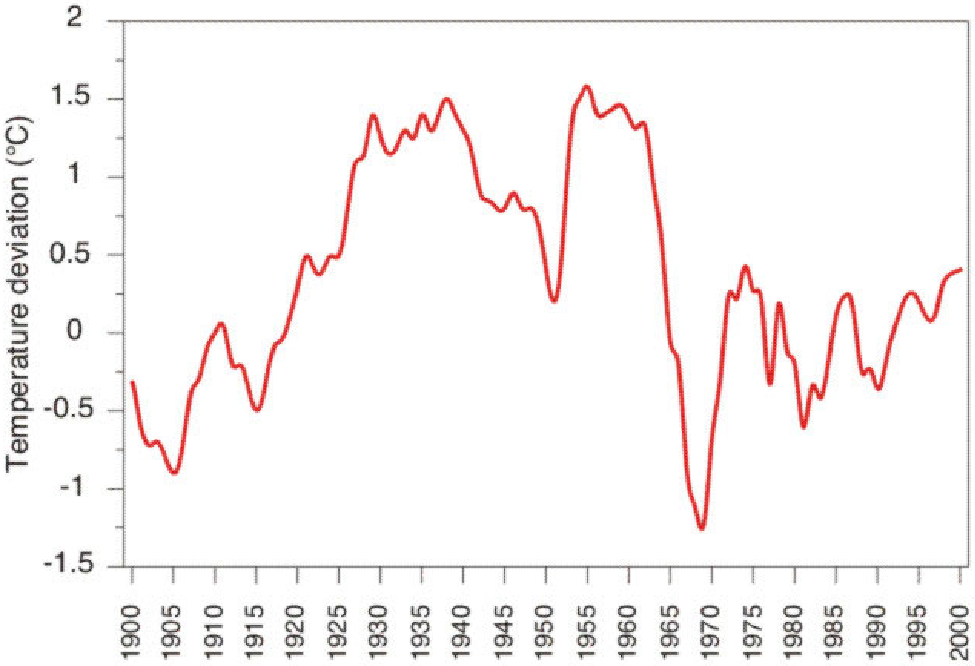

**Figure 2.2. Temperature deviations north of Iceland 1900-200, five year running averages.**

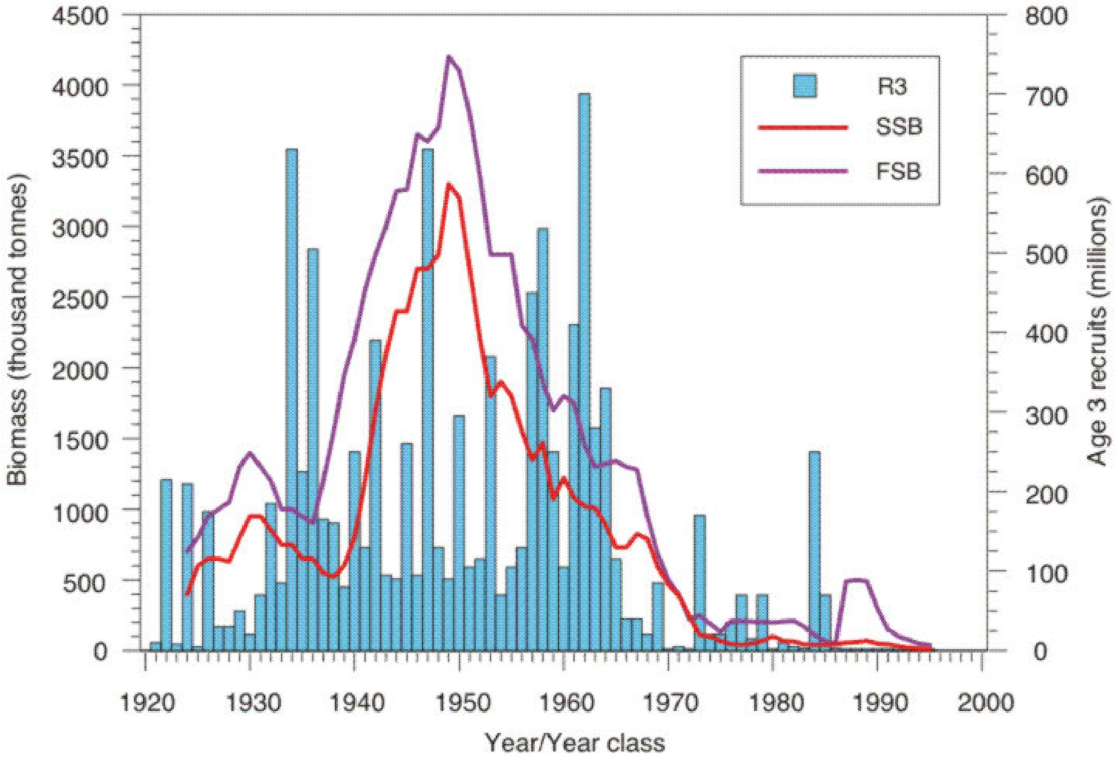

**Figure 2.3. Recruitment at age 3, spawning biomass and fishable biomass of cod off West Greenland.**

# 2.3 The Barents Sea

## 2.3.1 Ecosystem Components

### 2.3.1.1 Physical environment and plankton

The Barents Sea is a shelf area separated from the Norwegian Sea by the continental slope. It has an average depth of 230 m, although deeper channels and basins exist which strongly influence currents (Figure 2.4) (von Quillfeldt and Dommasnes, in prep.). North-flowing currents transport warm Atlantic water into the Barents Sea and north along the western coast of Svalbard (Figure 2.4). The branch flowing into the Barents Sea separates into a southern part and a northern part. Cold Arctic water flows into the Barents Sea from the northeast to the southwest. In the west there is a sharp, relatively stationary transition zone between Atlantic and Arctic water called the Polar Front following the bottom contours along approximately the 2˚C isotherm. In the east, the transition zone is less distinct and much wider. The Polar Front constitutes a natural, dynamic bio-geographical border for many ecosystem properties. The Barents Sea area is highly productive. However, many factors contribute to great differences between years in the ability of the primary and secondary production to support the larger organisms. Inflowing and outflowing water facilitates mixing of the water and nutrient supply and, therefore, primary production. Moreover, there is a substantial transport of organisms into the area (e.g. *Calanus finmarchicus* from the Norwegian Sea, and ice fauna from the Arctic Ocean. Advection results in the accumulation of many organisms (e.g. shrimp) in areas like the trenches on the Spitsbergen shelf. The areas around Bjørnøya and northeastward toward Hopen (Spitsbergenbanken) have depths of 20-100 m and mixing of the water reaches the bottom. The steady supply of new nutrients in these shallow areas makes them the most productive in the Barents Sea and, therefore, attractive to young fish feeding on zooplankton.

There are also variations in the spatial structure of the flux. This may partly explain the variation in advections in nutrients, phytoplankton and zooplankton from the Norwegian Sea to the Barents Sea, since the timing of strong inflow events have to co-occur with peaks in the phyto- and zooplankton biomass in the Norwegian Sea in order to have maximum effect on the Barents Sea ecosystem. The properties of inflowing Atlantic water fluctuates considerably interannually, particularly in heat content, which again influence winter ice conditions. The northern, central and eastern parts of the Barents Sea as well as most of the areas around Svalbard are covered with ice during winter, and the northern parts have ice also during summer in most years. This sea ice is mostly seasonal (i.e. one-yearly), with drift ice dominating. There is a relationship between sea temperature during winter and ice coverage, while meteorological conditions, especially increased radiation, are controlling factors during summer. During “cold” years ice also covers part of the Atlantic waters for some time.

As the ice melts a stable surface layer develops, uncovering winter concentrations of nutrient salts. The spring algae bloom starts 6-8 weeks earlier at the ice edge than in open sea further south. These favourable production conditions support large concentrations of crustaceans and other species of zooplankton and abundant fish, seabirds and marine mammals which feed on them. The blooms in Arctic water are, however, often short-lasting compared to those in Atlantic water, which are therefore more productive overall. Warm years with less ice result in higher production, generally shorter generation times for zooplankton and greater import of zooplankton from the south than in cold years. A critical phase for the ecosystem is the transition from a warm to a cold period, with reduced production of phytoplankton and zooplankton to support the populations of larger animals dependent on them.

In cold years, when the ice stretches into Atlantic water, the warm Atlantic water under the ice prompts melting to start 4-6 weeks earlier than if the ice only covers Arctic waters. This may create an early spring phytoplankton bloom, but at the same time the probability of a mismatch between the bloom and zooplankton grazers increases and a greater part of the primary production is likely to sink down to the sea floor.

Some microalgae, zooplankton, and ice amphipods, have life histories dependent on the sea ice. Ice algae are a particularly important food source early in spring before primary production starts, and it is evident that regional and seasonal variations in sea ice development influence the overwintering strategy of grazing organisms. The production of ice algae has been estimated to be about one fifth of the total primary production, depending on the extent of the ice-free areas.

The water temperatures in the Barents Sea have been relatively high during most of the 1990s, with a continuous warm period from 1989-1995. During 1996-1997, the temperature was just below the long-term average before it turned warm again at the end of the decade, and has remained warm until present. 2004 has been one of the warmest years recorded and with a record salinity (Fig. 2.5) (Føyn, in prep.).

The calanus species are the most abundant zooplankton in the Barents Sea and also the most important for pelagic fish like herring, capelin and polar cod. Its biomass fluctuates between years. Investigations on species compositions of plankton, however, are scarce. The warm and salient water are good conditions for several of the plankton species, but as the 0-group abundance of several fish stocks was recorded to be high in 2004 in the Barents Sea, grazing is expected to be a constraint on the abundance of zooplankton in 2005.

### 2.3.1.2 Bottom habitat and bottom fauna

Most of the area in the Barents Sea is covered by fine-grained sediment with coarser sediment prevailing on the relatively shallow shelf banks (<100m) or in the sub littoral zone around islands (Jørgensen and Hop, in prep.). Stones and boulders are only locally abundant. The most south-westerly parts of the Barents Sea are influenced by Atlantic fauna with the diverse warm-water fauna decreasing and cold-water species increasing to the east and north. In general, the fauna biomass, including the benthic, increases near the polar front and in the shallow regions and edges of the banks. A generally reduced biomass towards the west is likely due to reduced mixing of water and consequently a shortage of food. The richest infauna is found on the sandy silts and silty-sand floors. Low biomass occur at areas with impeded upwelling, in areas of low primary production (and reduced vertical flux), and areas of less suitable substrata with heavy sedimentation (e.g. inner parts of glacial fjords).

In the open parts of the Barents Sea, polychaets (bristle worms) are predominant at great depths and on soft sediment. Bivalves dominate lesser depths and harder bottoms. The main mass of echinoderms is found in western and central parts of the Sea, whereas the mass developments of bivalves are found in the southeastern parts of the Sea. The deeper western part of the Sea is rich in echinoderms and particularly poor in polecats. The bivalves are considerably reduced with depth, whereas the echinoderms increase in numbers and the polycheates remain essentially unchanged.

Red king crab (*Paralithodes camtschatica*) was introduced to the Barents Sea, the Murmansk fiord, in the 1960s (Jørgensen and Hop, in prep.). The stock is growing and expanding eastwards but more dominantly along the Norwegian coast westwards. Adult red king crabs are opportunistic omnivores. Epibenthic species such as the commercial Iceland scallop *Chlamys islandica* beds might be particularly exposed to risk of local extinction. Decapods are known predators of benthic bivalves, including scallops. Both the red king crab and the scallop have a sub-Arctic distribution. The Iceland scallop has a life span of 30 years, and matures after 3-6 years.

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, preferrably silt or fine-grained sand. Shrimp in the southern parts of the Barents Sea grow and mature faster than shrimp in the central or northern parts.

#### 2.3.1.3 Fish community

The Barents Sea is a relatively simple ecosystem with few fish species of potentially high abundance. These are Northeast Arctic cod, saithe and 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 abundance in 2004 was estimated to be 1.4 million tons (IMR, 2004). The composition and distribution of species in the Barents Sea depend 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 is a key species because it feeds on the zooplankton production near the ice edge and is usually the most important prey species in the Barents Sea, serving as a major transporter of biomass from the northern Barents Sea to the south (von Quillfeldt and Dommasnes, in prep.). During summer they migrate northwards as the ice retreats, and thus have continuous access to new zooplankton production in the productive zone recently uncovered by the ice. They often end up at 78-80°N by September-October, and then they start a southward migration to spawn on the northern coasts of Norway and Russia. Cod prefer capelin as a prey, and feed on them heavily as the capelin spawning migration brings them into the southern and central Barents Sea. Capelin also is important prey for several species of marine mammals and birds.

Fluctuations of the capelin stock have a strong effect on growth, maturation and fecundity of cod, as well as on cod recruitment because of cannibalism. The juveniles of the Norwegian spring-spawning herring stock are distributed in the southern parts of the Barents Sea. They stay in this area for about three years before they migrate west and southwards along the Norwegian coast and mix with the adult part of the stock. The presence of young herring in the area has a profound effect on the recruitment of capelin, and it has been shown that when rich year classes of herring enter the Barents Sea, the recruitment to the capelin stock is poor and in the following years the capelin stock collapses. This happened after the rich 1983 and 1992 yearclasses of herring entered the Barents Sea. Also, when medium sized year classes of herring are spread into the area there is a clear sign of reduction in recruitment to the capelin stock, as is currently the case. In this way, the herring impact both the capelin stock (directly) and the cod stock (indirectly).

Cod is the most important predator fish species in the Barents Sea, and feeds on a large range of prey, including the larger zooplankton species, most of the available fish species, amphipods and shrimp (ICES 2004). The cod migrates out of the Barents Sea and spawns in the Lofoten area in March. The average age at first maturation has been declining the last decades (ICES, 2004). Haddock is also a common species, and migrates partly out of the Barents Sea. It is a predator on smaller organisms including bottom fauna. The stock has large natural variations in stock size. Saithe is common in coastal water. The smaller individuals feed on zooplankton, but larger saithe is known to be a predator on fish.

In warm years there may be considerable quantities of blue whiting coming in with the Atlantic water in the southern Barents Sea. The blue whiting is a plankton feeder. Polar cod is a cold-water species found particularly in the eastern Barents Sea and in the north. It seems to be an important forage fish for several marine mammals, but to some extent also for cod. There is little fishing on this stock.

Deep-sea redfish and golden redfish used to be important elements in the fish fauna in the Barents Sea, but presently the stocks are severely reduced. Young redfish are plankton eaters, but larger individuals take larger prey, including fish. Fishing on these two species is severely restricted in order to rebuild the stock.

Greenland halibut is a large and voracious fish predator with the continental slope between the Barents Sea and the Norwegian Sea as its most important area, but it is also found in much of the Barents Sea.

#### 2.3.1.4 Marine mammals and seabirds

Some mammal species have temperate mating and calving areas and/or feeding areas in the Barents Sea (e.g. minke whale (*Balaenoptera acutorostrata* and harp seals (*Pagophilusa groenlandicus)*), others reside in the Barents Sea all year round (e.g. white-beaked dolphin (*Lagenorhynchus albirostris*) and harbour porpoise (*Phocoena phocoena*)) (Bjørge and Kovacs, in prep.). Some species are rare, either because this is natural (like white whale *(Delphinapterus leucas*)) or because of historic exploitation (like bowhead whale (*Balaena mysticetus*)). Other species are abundant (like harp seals and white-beaked dolphin). The diet of the marine mammals ranges from zooplankton to fish like capelin and cod. The total consumption of marine mammals in the Barents Sea is estimated to be some million tons of biomass, whereof the consumption of minke whales and harp seals on fish of commercial fish stocks, like capelin, cod and haddock, may amount to the same order as the total commercial catches of these stocks (Nilssen *et al.*, 2000 and Folkow *et al.*, 2000). There are annual quotas on minke whales and harp seals.

The Barents Sea area, including the Lofoten area, is an important Arctic area for seabirds, and a significant number of them reside in the Barents Sea also during the winter (Anker-Nilssen *et al.,* 2000). More than 30 species of seabirds have been registered in the region. The numbers of seabirds in the Barents Sea have been estimated to 20 million individuals (Barrett *et al.,* 2001). The most abundant species are Brünnich's guillemot *(Uria lomvia),* black-legged kittiwake *(Rissa tridactyla),* Atlantic puffin *(Fratercula arctica),* little auk *(Alle alle*) and northern fulmar (*Fulmarus glacialis)* of which the three first prefer fish as prey. Barett *et al.* Estimated the total consumption of seabirds in the Barents Sea area to be half a million tons of 0-group and 1-group fatty fish: capelin, herring and sandeel. Some species, like Brünnich's guillemot and Atlantic puffin, seems to be sensitive to weak yearclasses of fish stocks (Anker-Nilssen *et al.,* 2000). Brünnich's guillemot experienced a serious decline as a result of the collapse of the Norwegian Spring Spawning herring in the late 60s and declines also when the capelin stock collapses. Atlantic puffin is affected when yearclasses of herring are poor, although the relationship is not as clear as with the Røst colonies in the Lofoten area. While harvest of marine birds has a long tradition in the Barents Sea Region, it is now reduced and strongly regulated.

There is a close link between marine and terrestrial ecosystems, particularly in terms of energy transport from sea to land (Bjørge and Kovacs, in prep.). Bird colonies often support nutrient-demanding plant communities, upon which geese and reindeer can subsist. Terrestrial vegetation also serves as a habitat for many rare invertebrates. Arctic foxes can subsist on seabirds and their eggs; fox denning areas are often in the vicinity of bird cliffs. Nutrient supply from seabirds can also influence the production in some lakes (observed on Bjørnøya and elsewhere). Furthermore, land serves as haul-out places (for birthing, moulting) for some marine mammals, denning areas for polar bears and as nesting sites for many seabirds.

### 2.3.2 Impact of fishing activity on ecosystem

The most widespread gear used in the Barents Sea for demersal fish species is otter trawl. 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 has been studied to some degree. 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 clayey-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, in press). The impacts of experimental trawling have been studied on a high seas fishing ground in the Barents Sea (Kutti *et al., in press*.) 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.

The harbour porpoise is common in the Barents Sea region south of the polar front. The species is most abundant in coastal waters. The harbour porpoise is subject to severe bycatches in gill net fisheries (Bjørge and Kovacs, in prep). 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.

Estimates on unreported catches on cod in 2002 and 2003 indicate that this is a considerable problem. Unreported catches are estimated at 90 000 tons each of these years, i.e. 20% in addition to official catches (ICES, 2004).

Discarding of cod and haddock is thought to be significant in periods although discarding is illegal in Norway and Russia. Data on discarding is scarce.

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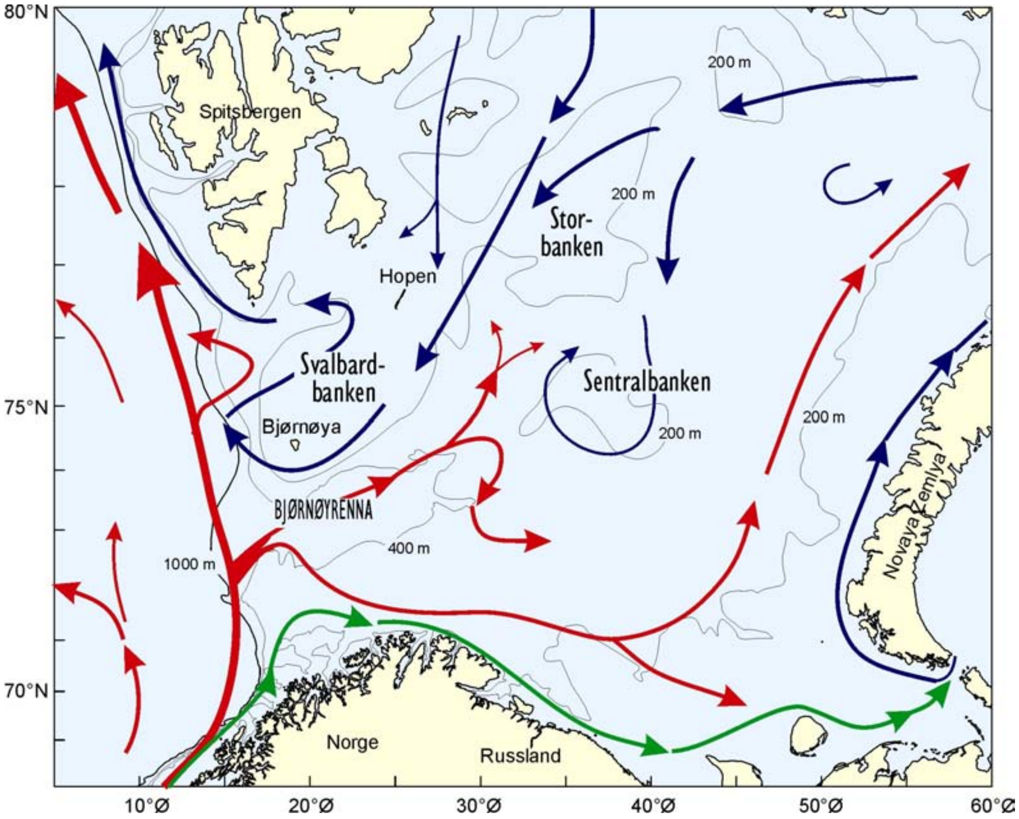

Figure 2.4. Main currents and depths in the Barents Sea. The red arrows show Atlantic water, the blue: arctic water and the green: coastal water

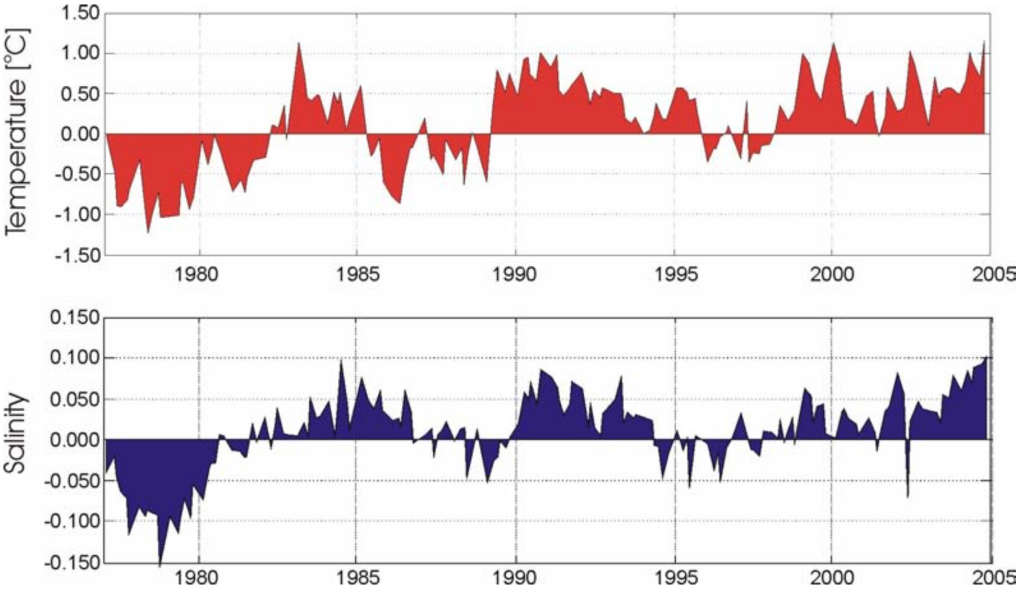

Figure 2.5. Average temperature and salinity of the Fugløya-Bjørnøya section

# 2.4 The Faroe Plateau Ecosystem

## 2.4.1 Ecosystem Components

### 2.4.1.1 Topography, water masses and circulation patterns

The Faroes are situated on a submarine ridge, which extends from Greenland, over Iceland, to Scotland (Figure 2.6, left panels). This ridge separates the Atlantic Ocean southwest of the ridge from the Norwegian Sea to the northeast. The sill of the ridge reaches different depths in different areas. Most of it is shallower than 500 m, but a small part is deeper with the Faroe Bank Channel being the deepest passage across the ridge.

- 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 2.6, upper left panel). This water is typically around 8°C and salinities around 35.25.
- Deeper than 500-600 m (Figure 2.6, lower left panel) the water in most areas is dominated by cold (T<0°C) with salinities close to 34.9.
- 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.
- 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. The ecosystem has distinct planktonic communities, benthic fauna and several fish stocks. Furthermore, about 1.7 million pairs of seabirds breed on the Faroe Islands and take most of their food from the shelf water.

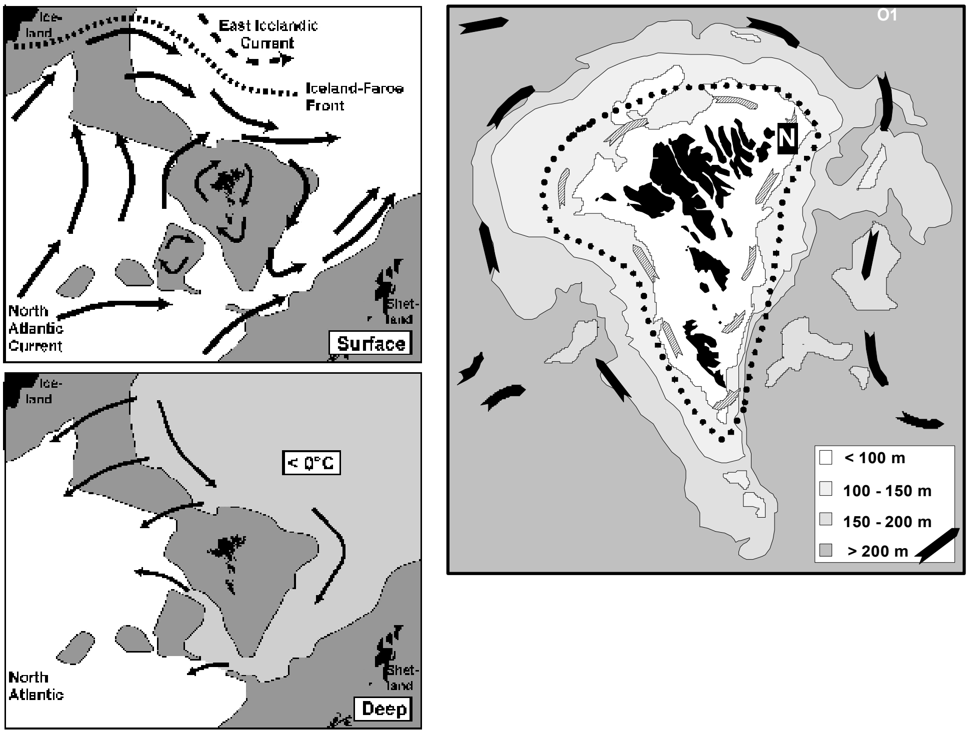

**Figure 2.6. Bottom topography, circulation and water masses at the surface (top left panel), at depth greater than about 500 m (bottom left panel) in the area around the Faroes and on the Faroe shelf (right panel). Dashed lines indicate fronts.**

#### 2.4.1.2 Phytoplankton

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

One distinguishing feature is a typical earlier establishment of the spring bloom on the shelf than offshelf, but observations (Gaard, 2003; Hansen *et al.,* 2005) have shown that the timing and intensity of this bloom can vary very much from one year to another.

In most years the phytoplankton community on the shelf is dominated by diatoms. However, in summers with low nutrient concentrations, smaller flagellates may take over (Gaard *et al.,* 1998).

Most of the new primary production on the shelf is between May and July. There has been observed high interannual variability in potential new primary production (Gaard, 2003). From 1990 to 2004 this new primary production (from spring to mid summer) has fluctuated by a factor ~5 (Figure 2.7).

A characteristic feature of this variability is a high correlation between the onset and intensity of new primary production. In years with an early spring bloom, the total new primary production from April to late June may be several times greater than in years with a late spring bloom development (Gaard, 2003; Hansen *et al.,* 2005). It has furthermore been observed that this high variability is transmitted quickly upwards through the food chain (See later sections in this document).

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

The index for 2004 is close to the 1990-2004 average (Figure 2.7).

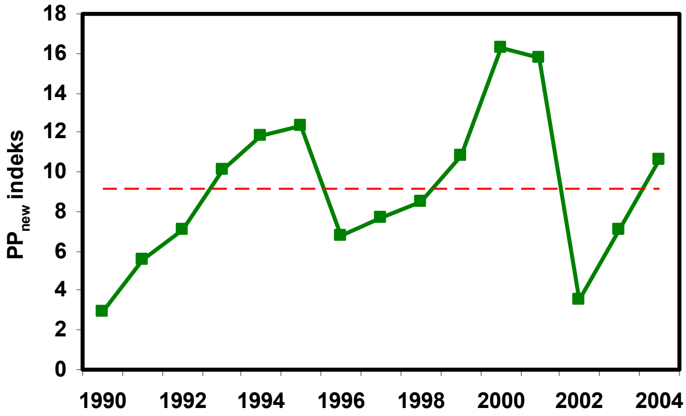

**Figure 2.7. Chlorophyll *a* concentration on the central Faroe shelf since 1997 (left panes) and index of new primary production from spring to mid summer on the Faroe shelf since 1990 (right panel). The vertical line represents average primary production value during the 1990-2004 period.**

### 2.4.1.3 Zooplankton

While the zooplankton community outside the shelf front is largely dominated by the copepod *Calanus finmarchicus*, the shelf zooplankton community is basically neritic (shelf related species). During spring and summer the zooplankton in the Shelf water is largely dominated by the copepods *Acartia longiremis* and *Temora longicornis*. *C. finmarchicus*, is advected from offshelf and occurs in interannually, highly variable abundance in the Shelf water. 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).

Reproduction rates of copepods depends largely on their feeding conditions and co-occurring fluctuations have been observed between phytoplankton abundance and copepod egg production rates, abundance and composition.

### 2.4.1.4 Fish community

A total of 170 fish species are found in Faroese waters. Many of these species occur, however, in low abundance and are not exploited. Of the demersal species, saithe, cod and haddock are the most abundant. Other common species are monkfish, Norway pout, ling, tusk, redfish, Greenland halibut, blue ling and other. 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. An overview of typical depth distribution of the main species in offshore and shelf areas (deeper then 65 m bottom depth) is shown in Figure 2.8.

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 ecoregion in May. They feed mainly on krill and other large zooplankton at depths between 300 and 500 meters and partly also on the smaller *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.

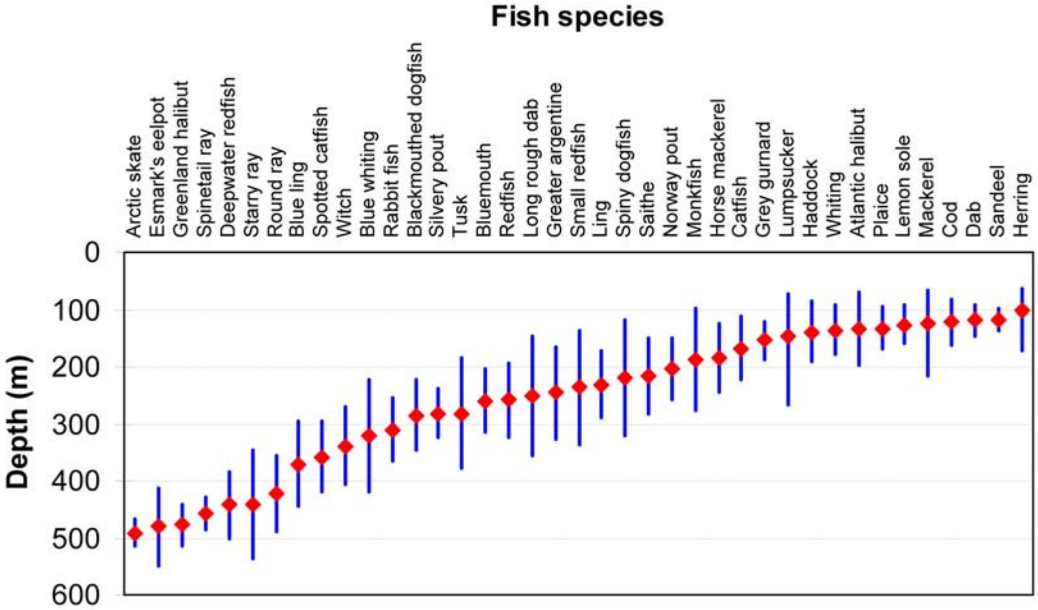

**Figure 2.8. Typical depth distribution of fish in areas deeper than ~65 m on the Faroe shelf and in the ocean around the Faroes.**

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 spawning grounds of the haddock are more disperse than those of cod and saithe. Their offspring is dispersed by the strong currents throughout the shelf area. As they grow they predate on progressively larger zooplankton prey items on the shelf (Gaard and Steingrund, 2001; Gaard and Reinert, 2002). In July, at lengths of about 4 cm, the cod juveniles migrate into the littoral zone of the fjords and sounds, while the haddock make the transition to a predominant demersal habit on the plateau and the banks at depths of 90-200 m. 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.

Detailed knowledge about variability in food consumption of cod and haddock in Faroese waters is not conclusive. Both cod and haddock show diversity in prey items, and predate on benthic fauna as well as fish, with fish being a somewhat more prevalent prey item for cod than for. Of the fish prey, sandeel seems to be a key species in the shallow areas and is a main link between zooplankton and higher trophic levels. When sandeels are abundant they are a preferred food item for cod on the shelf and hence affecting the feeding conditions for demersal cod on the shelf already during the first year after recruitment of the sandeel. At bottom depths less than 200 m sandeels and benthic crustaceans may also be important cod diet, but when sandeels are abundant, they form the principal food item for cod. Years with high cod production seem to be associated with a high abundance of sandeels.

In deeper areas other species (mainly Norway pout) have been observed to be more important as prey item for cod and haddock. On the slope other species e.g. blue whiting may be important.

Despite a marked increase in fishing effort on cod and haddock, the landings have not increased correspondingly. The long-term landings of the cod usually have fluctuated between 20,000 and 40,000 tonnes during the 20th century and of haddock between 15,000 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. Consequently, it is likely that the catches reflect interannual variability in production of these fish stocks.

There has been observed a very clear relationship, from primary production to the higher trophic levels (including fish and seabirds), in the Faroe Shelf ecosystem, and all trophic levels seem to respond quickly to variability in primary production in the ecosystem (Figure 4). The temperature on the shelf has increased about 1°C during the last ten years. However, interannual temperature variability does not correlate with variability in primary production or cod and haddock growth or recruitment.

In 2002 the primary production was on a very low level, and this affected cod hand haddock recruitment and weight-at-age shortly after. In 2004 the production again reached average levels.

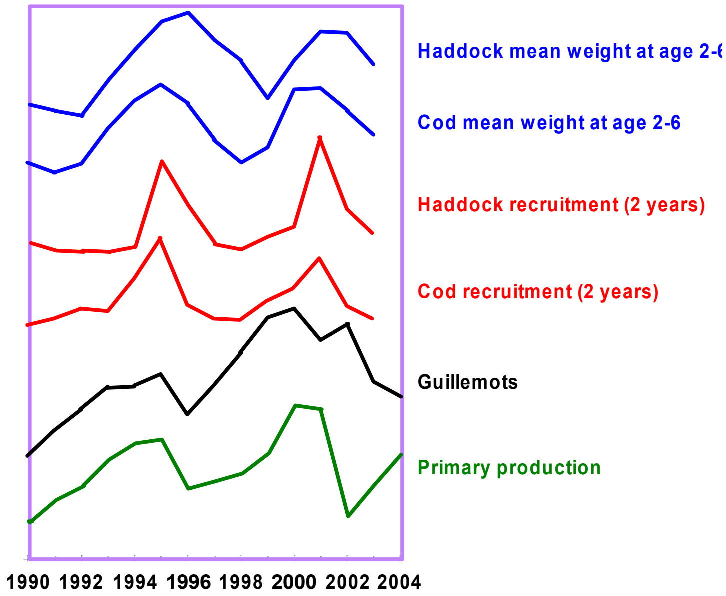

**Figure 2.9. Relative variability in calculated new primary production, number of attending guillemots, recruitment of 2 years old cod and haddock, and mean weight of 2-6 years old cod and haddock since 1990 (Updated from Gaard *et al.,* 2002).**

### 2.4.1.5 Benthos

Due to strong tidal currents on the shelf, the seabed 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. decapods and 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 recently have closed three areas for trawling. On the shelf there is local fishery (dredging) for scallops and in inshore areas there is lobster (*Nephrops*) fishery for pots.

## 2.4.2 Environmental impacts on the ecosystem dynamics

### 2.4.2.1 Cod and haddock recruitment

There is no clear relationship between fluctuations in cod and haddock spawning stock biomasses and recruitment on the Faroe plateau but 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 (Gaard *et al.,* 2002; 2005). Since 1990, when monitoring of environmental parameters in the Faroe shelf ecosystem started, clear co-occurring fluctuations can be observed in primary production and recruitment of cod and haddock (Figure 2.9).

The cod and haddock stocks have proven several times that when environmental conditions are favourable, they are, even with very small SSB, able to recover quickly. But it is when the environmental conditions are poor, that the importance of spawning stock size and age composition most likely is significant. Therefore, the lack of direct relationship between SSB and recruitment is no argument for decreasing the significance of SSB.

The year-class strength of cod seems to be determined rather late in live, i.e. during the second winter, with coincides with the migration towards deeper waters (Steingrund and Gaard, 2005). The bottleneck seems to be food availability in the area, which is determined by phytoplankton production (about 6 months before) and competition from older cod (Figure 2.10).

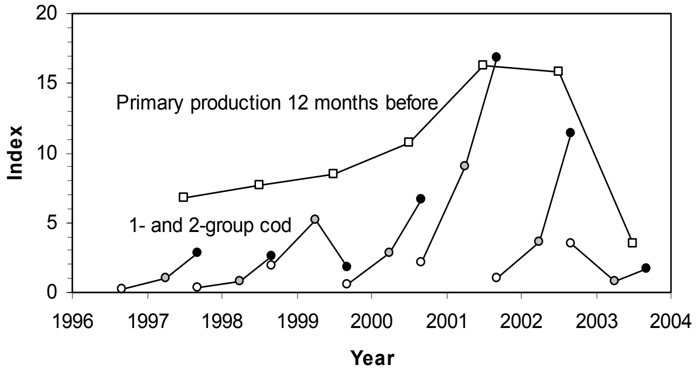

**Figure 2.10. Relationship between primary production (12 months before) and catch per unit effort (number per trawl hour) of 1-group cod in August and 2-group cod of the same year class in March and August the following year (Steingrund and Gaard, 2005).**

### 2.4.2.2 Cod and haddock growth

Growth rates on cod and haddock on the Faroe plateau are highly variable. Since 1990 the mean growth rates of 2-7 years old cod have fluctuated between 0.24 and 1.36 kg individual$^{-1}$ year$^{-1}$ and the mean growth rates of 2-7 years haddock between 0.13 and 0.46 kg individual$^{-1}$ year$^{-1}$. No correlation is between the growth rates and the *in situ* temperature, but good relationship is found between primary production and growth variability of both species (Figure 2.11). 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 (e.g. benthic crustaceans and especially sandeels).

Since primary production is rapidly transferred to cod and haddock, they obviously eat young prey items. Detail analysis of interannual variability in food items for cod and haddock are not available at the present, but the available information indicates that sandeel is the main food item during productive years. In low-productive years they seem to predate more on benthic fauna. Fish furthermore seems to be a somewhat more prevalent prey item for cod than for haddock. This may be the reason for why haddock growth variability often is lagging one year behind cod growth variability, especially during low productive periods (Figure 2.11). Possibly, the benthic fauna have higher ages than the fish pray (which mostly are 0-group sandeels in the shallow areas). Detail analysis of this are needed before final conclusions can be drawn.

The increased primary production during the last two years, just above average level, indicates that a minor increase of growth rates (mainly of cod) can be expected (Figure 6).

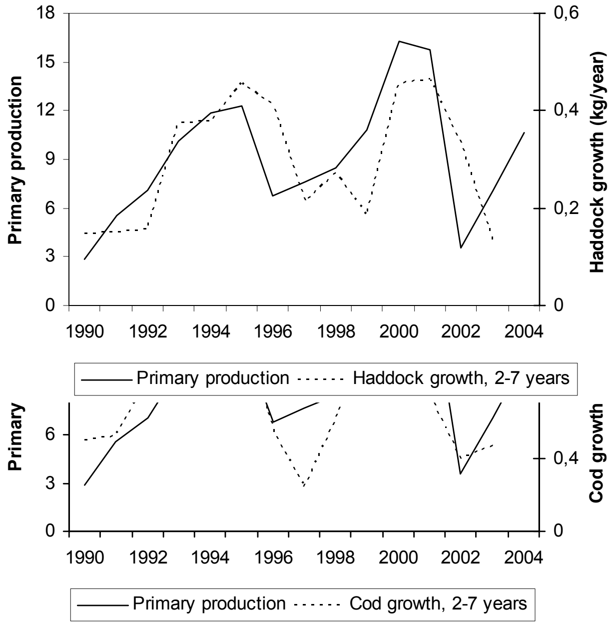

**Figure 2.10. Primary production and cod growth rates (upper panel) and haddock growth rates (lower panel) during the 1990-2004 period.**

### 2.4.2.3 Fish production

Fish production in the ecosystem is clearly food limited. Mainly cod production (numbers x individual growth summed up for all age groups) fluctuates well with primary production (Figure. 2.11). When comparing primary production with production of cod haddock and saithe combined, the correlation is even better.

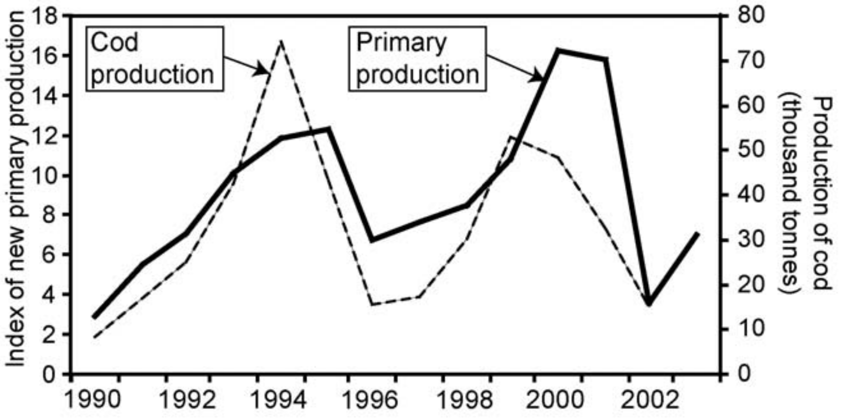

**Figure 2.11. Index of new primary production on the Faroe shelf and corresponding production of Faroe Plateau cod older than 1.5 years. Updated from Steingrund *et al.,* 2003.**

Since young age classes are the most numerous (mainly in the productive years) the observed variability in cod production in Figure 2.11 largely is due to variable abundances of recruits (Figure 2.12). The figure furthermore illustrates, that in the 1960 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.

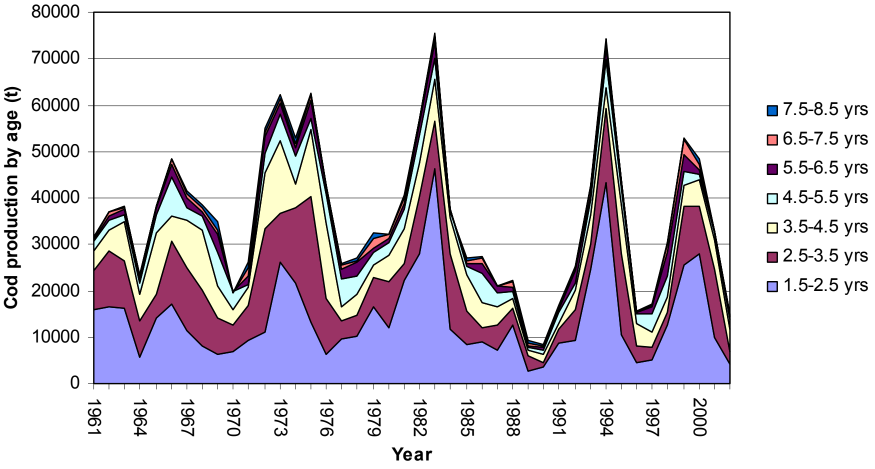

**Figure 2.12. Production of Faroe Plateau cod split into age groups**

As cod grow older, they tend to move into deeper areas, feeding on the slope outside the shelf front (Steingrund and Gaard, 2005). Since fish production in the system is food limited (even year by year), a higher proportion of individual that feed in deeper areas seems to be the only possibility for increased fish production. It is likely that a reduced fishing mortality, allowing a higher fraction of older individuals in the stock, would allow a higher total cod production, and would possible also have a smoothing affect on the stock production variability. There is, however, not sufficient available information at the moment to quantify this potential effect.

### 2.4.3 Fisheries effect on the ecosystem

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

Of other steps towards ecosystem based management can be mentioned.

Since fishery on the Faroe Plateau is effort regulated, discard of commercially fish most likely is small. By-catch of no-commercial species and of no-commercial size in unknown and may, however, be higher, especially during periods of high recruitment.

### 2.4.4 Concluding remarks

Since studies on environmental conditions on the Faroe shelf started in 1990, there has been observed a clear relationship between primary production and cod and haddock, recruitment and growth rates. Food production seems to be transferred quickly into higher trophic levels in the ecosystem.

The food production (based on primary production, as shown in Figure 2.7) reached average values in 2004, after having being well below average in recent years. There therefore can be expected an increase in growth rates of cod toward average value. Haddock growth rates may be somewhat smaller, since its fluctuations often lag somewhat behind the cod growth rates, especially during recovering periods. Feeding conditions for next coming year will, however, largely depend on food production in spring-summer 2005. These data will be available in July 2005.

There is no clear relationship between fluctuations in cod and haddock spawning stock biomasses and recruitment on the Faroe plateau but their recruitment success correlates well with variability in primary production, while the correlation to SSB is weak.

The cod and haddock stocks have proven several times that when environmental conditions are favourable, they are, even with very small SSB, able to recover quickly. But it is when the environmental conditions are poor, that the importance of spawning stock size and age composition most likely is significant. Therefore, the lack of direct relationship between SSB and recruitment is no argument for decreasing the significance of SSB.

Fish production in the ecosystem clearly is food-limited. Since cod tend to migrate into deeper feeding habitats as they grow older, this may be a way to increase the total cod production. There is, however, not sufficient available information at the moment to quantify this potential effect.

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## 2.5 Norwegian Sea

### 2.5.1 Ecosystem Components

#### 2.5.1.1 General geography

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

The Norwegian Sea has an area 1,1 million km2 and a volume of more than 2 million km3, i.e. an average depth of about 2000m. The Norwegian Sea is divided into two separate basins with 3000m to 4000m depth, with maximum depth 4020m. Along the Norwegian coast there is a relatively narrow continental shelf, between 40 and 200 km wide. and has a 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. Gravely and sandy bottoms are found near the shelf-break and on ridges where the currents are expected to be strong and the sedimentation rates low

#### 2.5.1.2 General Oceanography

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 NAC 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 Arctic water flows into the southern Norwegian Sea in the East Icelandic current, and the boundary between these waters and the warm Atlantic

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 blanket the entire Norwegian Sea and thus preclude 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 are topographically influenced and clockwise in the two basins. The cold deep water flows out of the Norwegians Sea through the Faroe Bank channel, the deepest connection to the North Atlantic.

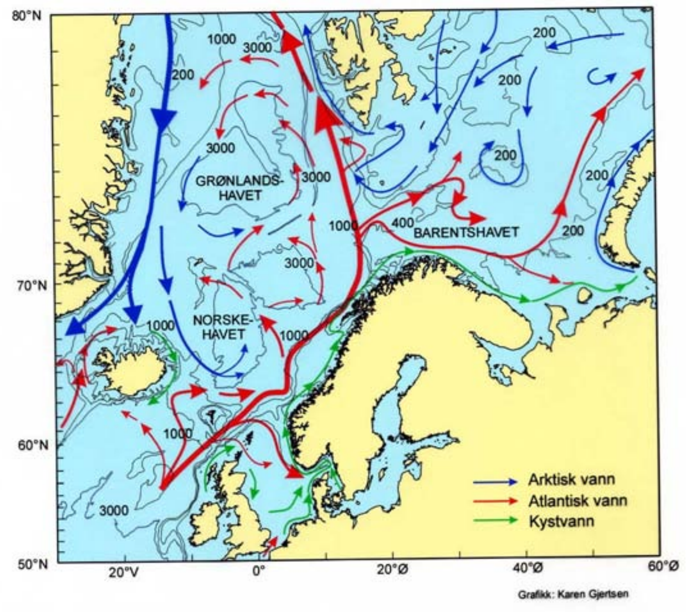

**Figure 2.13. Norwegian Sea main circulation pattern.**

### 2.5.1.3 Climate variability

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

### 2.5.1.4 Phytoplankton

The annual rate of primary production in the Atlantic Water has been estimated to be about 80gCm-2year-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 gCm-2year-1.

### 2.5.1.5 Zooplankton

The zooplankton community of the Norwegian Sea is dominated by copepods and euphausids. The main copepod is *Calanus finmarchicus* in the Atlantic water while *Calanus hyperboreus* is the dominant species in the artic 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/m2 dryweight in 1997 to 28 g/m2 dryweight in 1995. The highly variable availability of zooplankton is an important factor for fish stocks productivity.

### 2.5.1.6 Benthic habitats in the Norwegian Sea

Coral reefs formed by the cold-water coral *Lophelia pertusa* are quite common in the eatern 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 off Lofoten. *Lophelia* reefs offers habitats (microhabitats) for a great diversity of other species. Redfish (*Sebastes* spp.) are common on the reefs. The great abundances of this fish has been known by local fishers for a long time. More recent fishery practice employing rock hopper trawl gear close to or directly on these reefs has led to severe damages. Other corals such as gorgonians also form habitats utilised by fish and other organisms. These habitats are often called “gorgonian forests”, and are common in some fjords and along the shelf break.

### 2.5.1.7 Fish community of the Norwegian Sea

The Norwegian Sea fish community is characterised by a number of large stocks of medium sized highly migratory pelagic species exploiting the pelagic zone of the waste 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 while those visiting the more marginal north eastern shelf area for spawning is expected to be of less significance.

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 their entire lifecycle within the Norwegian Sea ecosystem. The blue whiting spawns west of the British Isles and perform a northerly and westerly feeding migration into the Faroese ecosystem and the Norwegian Sea ecosystem. The Mackerel spawn west of the British Isles and in the North Sea and perform 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 areas 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 has only been carried out to a limited degree and what exists are mainly of descriptive character. For instance was the highest catches of salmon ever (1970'ies) taken during a period when the herring stock was at a record low level. This has been suggested to be a potential effect of reduced competition beneficial for salmon stock productivity (Hansen et al., 2000).

The NE Artic 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 Artic saithe also spawn 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 western areas 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 radiate* and *Bathyraja spinicauda* (Bergstad et al., 1999).

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

### 2.5.1.8 Seabirds

No information was provided

### 2.5.1.9 Seals in the Norwegian Sea

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

### 2.5.1.10 Whales in the Norwegian Sea

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

The minke whale *Balaenotera 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 feeding with special preference for herring in the Norwegian Sea ecosystem.

The killer whales *Orcinus orca* in the area are 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 kiler whales.

### 2.5.2 Fisheries effects on the ecosystem

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

Work is carried out within the frames 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 artic seals large mortality of seals has been observed in net fisheries. This mortality has not been regarded problematic for seal stocks due to healthy state of these stocks and a general low harvesting level.

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

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

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

### 2.5.3 Major significant ecological events and trends in the Norwegian Sea in 2004

Generally warming climate during the last 20 years with the last three years as outstanding at about 1ºC above mean for period 1978-2004 in Svinøy section. Otherwise no major hydrographic events in 2004.

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

Large stocks of all major pelagic stocks.
Herring: 6.5 million tonnes SSB + 3.5 million tonnes young herring from May 2005.
Blue whiting: 10 million tonnes including young fish.
Mackerel: 2 million tonnes spawning stock, unknown young fish.
The total stock of highly migratory plankton feeders is high at ~20-25 million tonnes.

Herring growth deficiencies from 2001. Continued low growth conditions could be expected unless major migration or productivity changes occur.

### 2.5.4 Knowledge Gaps

#### 2.5.4.1 Important knowledge gaps

Knowledge on ecological processes is low. This could be exemplified with a total lack of understanding the strong increase in blue whiting productivity since about 1995, lack of understanding the of role of large pelagic stocks to relatively low stocks of zooplankton and lack of understanding the low herring stock productivity during 4 last years.

#### 2.5.4.2 How to fill knowledge gaps

Present research effort is too focused on monitoring. A better balancing between monitoring and process studies must be sought to increase ecologic understanding of major ecologic interactions.

#### 2.5.4.3 In what ways will the advice will be improved if the knowledge gap is filled

Better understanding of basic ecosystem functioning will allow for more strategic management.

## 2.6 Celtic Sea

### 2.6.1 Ecosystem Components

#### 2.6.1.1 Bottom topography substrate and circulation

In the Celtic seas (ICES sub-areas VI and VII) the continental shelf is of variable width. The Celtic sea, south of Ireland is an extended shelf which most of the area is shallower than 100m. It is limited to the west by the slope of the Porcupine seabight and the Goban Spur. In these area the slope is rather gentle and sedimentary. To the west of Ireland the Porcupine bank forms a large extension of the shelf limited to the west by the Rockall Trough, the transition between the Porcupine bank and the trough is a steep and rocky slope along which reefs of deepwater corals occur. Further North, to West of Scotland the slope of the Rockall Trough is closer to the coast line, particularly off NW Ireland, and the Hebrides. West of the shelf break and the Rockall Trough is the Rockall Plateau with depths of less than 200m. The shelf area itself contains mixed substrates, generally with soft sediments (sand and mud) in the west and tending to more rocky, pinnacle areas to the east. At these latitudes (55° to 58°N) the continental slope is mainly sedimentary and a trawl fishery for mid slope fish such as roundnose grenadier, Blackscabbard fish, deep sea squalids, blue ling and Orange roughy have been operating since the late 80s. The eco-region also contains several important seamounts; Anton Dohrn, Hebrides and Rosemary Bank, which have soft sediments on top and rocky slopes. The Irish Sea is distinct from the rest of the eco-region as a semi-enclosed sea area, with mostly soft subtrates and an indigenous fish population.

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

Summer frontal systems are formed at the Ushant Front , in the English Channel, the Celtic Sea front at the southern entrance to the Irish Sea, and the Irish shelf front west of Galway. These represent changes from stratified inshore and mixed offshore waters. The other major feature is the very high amplitude tides in the Celtic Sea area and the Bristol channel in particular.

### 2.6.1.2 Physical and chemical oceanography

### 2.6.1.3 Temperature/salinity

The slope current introduces warm saline water from further south into the whole area. The ICES Annual Ocean Climate Status Summary (IAOCSS) does not deal with this eco-region as a bloc, but data are available for the Rockall Trough area in detail. More extensive and synoptic data are undoubtedly available but could not be collated in the context of the WGRED meeting. The report suggests that the Rockall trough has been warming steadily over recent years and is presently at an all time high. Similar trends appear for salinity (see figure 2.14 below).

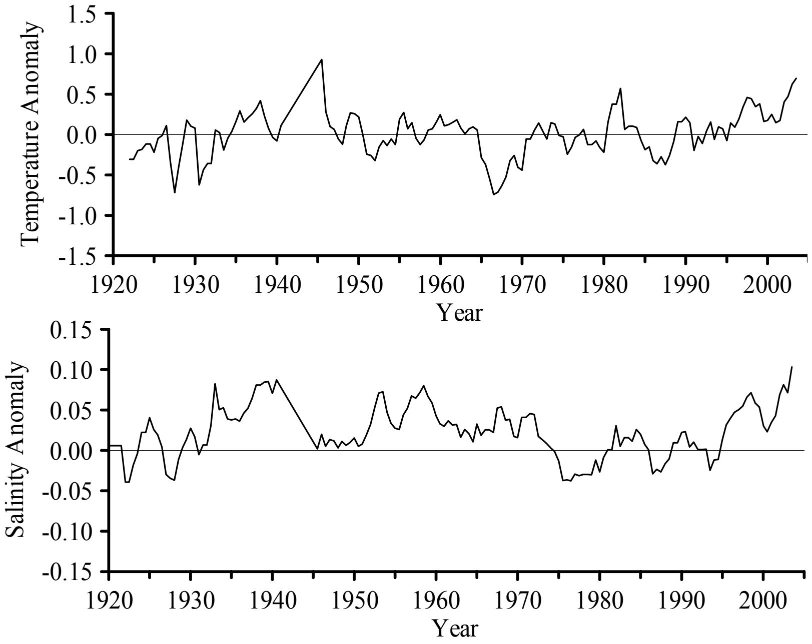

**Figure 2.14. Rockall Trough temperature and salinity anomalies for the upper ocean (0–800 m) of the northern Rockall Trough. Average across section, seasonal cycle removed.**

### 2.6.1.4 Input of Freshwater

The major river inputs are into the Bristol channel, Irish Sea and The Malin Sea north of Ireland. These are locally important in reducing salinity in these areas.

### 2.6.1.5 Broad-scale climate & Oceanographic features

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

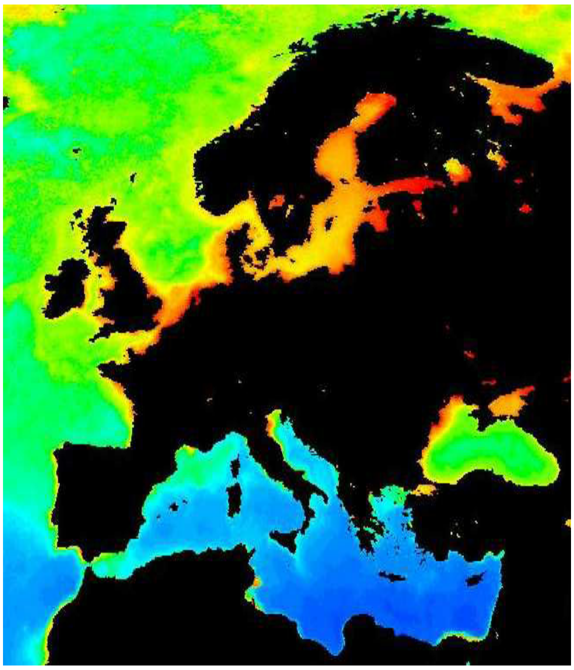

**Figure 2.15. Spring chlorophyll (1998-2003).**

### 2.6.1.6 Phytoplankton

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

### 2.6.1.7 Zooplankton

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

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

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

Major fisheries dredging for scallops and some smaller bivalves exist in the western Channel, Irish Sea and west of Scotland. Pot fisheries exploit the lobster *Homarus gamarus* and brown crab *Cancer pagurus* in the water around the Channel Islands, off France (French landing about 150 t/year), and the west of Scotland. Estimated landings of whelk (*Buccinum ondatum*) may be as high as 20 000 t/year . Cuttlefish are also targeted by pot fishery but trawl catch are much higher and target juvenile in coastal water in some areas.

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

The benthos of the Celtic seas is largely influenced by shelf sea dynamic processes that generate areas with high levels of seabed stress and erosion. Coastal faunas are dominated by relatively small sized bivalve and polychaete infauna with a highly mobile epifauna. Further offshore larger body-sized bivalves, suspension and filter-feeders dominate the assemblage. Benthic habitat diversity is high in the Celtic Seas, varying from sand, through mud to bedrock in some places. Biogenic reefs of horse mussels *Modiolus modiolus*, maerl and Serpulid worms occur in specific locations (Irish Sea, West coast of Scotland). The latter can support benthos of conservation interest such as sea fans and structurally complex bryozoans. Offshore areas on the shelf slope support reefs of deep water corals such as *Lophelia pertusa*.

### 2.6.1.9 Fish Community

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

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

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

**Table 2.1. The indicators for the demersal fish community of the Celtic Sea (From Bretrand, 2004)**

| CATEGORY OF INDICATOR | INDICATOR | DIRECTION OF CHANGE |
|---|---|---|
| Population | Abundance of populations | 1 in 43 decreasing, 9 in 43 Increasing |
| | Mean size in the population | 9 in 43 decreasing, 1 in 43 Increasing |
| Community | Total abundance | Stable |
| | Total biomass | Stable |
| | Mean weight in the community | Decreasing |
| | Mean size in the community | Stable |
| | Multispecies size spectra<br>Slope<br>Intercept | decreasing<br>Stable |

### 2.6.1.10 Trophic web

Feeding of commercial and forage species were investigated by Dubuit. The trophic relationships of four main commercial demersal predators (cod, hake, megrim and whiting) and three forage species (blue whiting, pouts (*Trisopterus* spp.) and mackerel were analysed by Trenkel et al. (in press). This study concluded that the main predator species in the Celtic Sea are generalist feeders which exhibit size-dependent, temporal and spatial prey-switching behaviour. Consequently, utilisation of a conventional multispecies assessment model such as MSVPA in such a system would be unlikely to yield useful insights. These results from the Celtic sea sensus stricto (the southern part of region E, limited to the North by Ireland, and between longitudes of 4°E and 12°W) even for the same in other areas. The studied forage species as present seasonally in the Celtic resulting in prey shifting behaviour by predators

No major studies of forage fish have been conducted in the north of the eco-region. Sand eel, sprat and norway pout are known to be present, however their role and importance in the ecosystem is unclear. The WG is not aware of any major industrial fisheries currently exploiting these species.

A major component of the ecosystem is the migration into the area in spring of a large abundance of migratory small pelagic fish, principally blue whiting and mackerel, but including horse mackerel. All three species spawn and feed extensively in the area, prior to migrating north out of the eco-region in the summer.

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

The blackspot (=red) seabream (Pagellus bogaraveo) used to be an important target species of English fishery is the 30s (Desbrosses, 1932), catches in the Celtic seas declined well before the collapse of the fishery in region G (see this chapter for a longer account on this species). The species can be considered as eradicated from the Celtic seas.

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

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

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

#### 2.6.1.12 Birds & Mammals:

Dominant species composition, productivity (esp seabirds), spatial distribution (esp. mammals)

### 2.6.2 Fishery effects on benthos and fish communities

This eco-region is characterized by the presence of a number of important benthic features which are considered important and vulnerable to fishing activity. These include cold water corals, and particularly the Darwin mounds, other biogenic reefs and natural reefs. Cold water corals structures have been identified in many areas including Porcupine Bank, Rockall, the slope areas west of Scotland & Ireland and on the seamounts. The Darwin mounds are found in about 1000m of water NW of Cape Wrath, Scotland. These structures are all vulnerable to trawling, but particularly deep water trawling, which uses larger and heavier gears. One caveat in considering these features and their impact on the reefs is the possibility that most such structures have actually been identified by fishing activity. The possibility of other such structures in unfished areas needs to be considered.

The impact of fishing activities on the shelf fish communities is unclear, although there are numbers of severely depleted stocks e.g. cod, whiting and plaice and hake. It can be assumed that similar size spectra and community changes occur in this area as have been reported for the North Sea. Trawling in the deep waters have almost certainly caused substantial changes in the community structures of the deeper waters west of the shelf break. Initial studies of catch rates from surveys west of Scotland in the 1980s compared to the last 5-10 years suggest substantial reductions in large, slow growing species and a switch to smaller faster growing fish.

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

Cetacean bycatch in fisheries has been acknowledged to be a threat to the conservation of cetaceans in this eco-region (CEC 2003a, Ross & Isaacs 2004). As in other areas this mainly affects small cetaceans – i.e. dolphins, porpoises and the smaller toothed whales. Species caught in the region are primarily the harbour porpoise, common dolphin, striped dolphin, Atlantic white-sided dolphin, white-beaked dolphin, bottlenose dolphin and long-finned pilot whale (CEC 2002a). However, other larger cetaceans, such as the minke whale, can also be affected.

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

- Bass fishing in the western channel

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

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

#### 2.6.2.1 Major environmental signals and implications

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

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

### 2.6.3 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 in the context of eco-regions. For example, the ICES Annual Ocean Climate Status Summary does not address this area as a whole. The WG would recommend that ICES develops an inclusive approach to the use of eco-regions so that all output data can be matched up easily. The CPR programme samples within the area, but detailed breakdown of these data has not been carried out. As noted above, the primary, and hence presumably secondary production change substantially from the shelf, to the shelf break to the open ocean. Therefore, data aggregated over all these systems is likely to difficult to interpret. There is also no single assessment working group responsible for the fisheries in the area. These are covered by both northern and southern shelf demersal WGs, WGMHSA, HAWG, WGNEPH, WGDEEP and even WGNPBW and WGNEW. This also makes the integration of data by eco-region more complex.

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## 2.7 North Sea

### 2.7.1 Ecosystem Components

#### 2.7.1.1 Sea bed topography and substrates

The topography of the North Sea can broadly be described as a gradual slope from shallow (<50m) in the south to deeper (100-150m) in the north. The other main feature is the Norwegian Trench in the northeastern North Sea along the Norwegian coast into the Skagerrak with depths greater than 200m. The shallow area is found south of a line drawn from 53oN on the UK coast to 57oN on the Danish coast. The 100m contour runs approximately east to west at around 58oN. The remainder, up to 62oN, is between 100 and 200m deep in the west and up to 500m deep in the Norwegian Trench area in the east. Further to the southeast, the Kattegat east of Denmark is also a marked shallow watershed. The substrates are dominated by fine muds and sands in the main part of the North Sea. This generally trends to coarse sands and gravels in patches to the east and west. 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 mostly fine muds, however, some of the slopes have rocky bottoms and several underwater canyons extend further towards the coasts of Norway and Sweden. There are a number of sand banks across the North Sea which qualify for protection under the EU habitats directive, mainly along the UK coast, eastern Channel and the approaches to the Skagerrak. Extensive biogenic reefs of Lophelia have recently been mapped in the Norwegian part of the eastern Skagerrak.

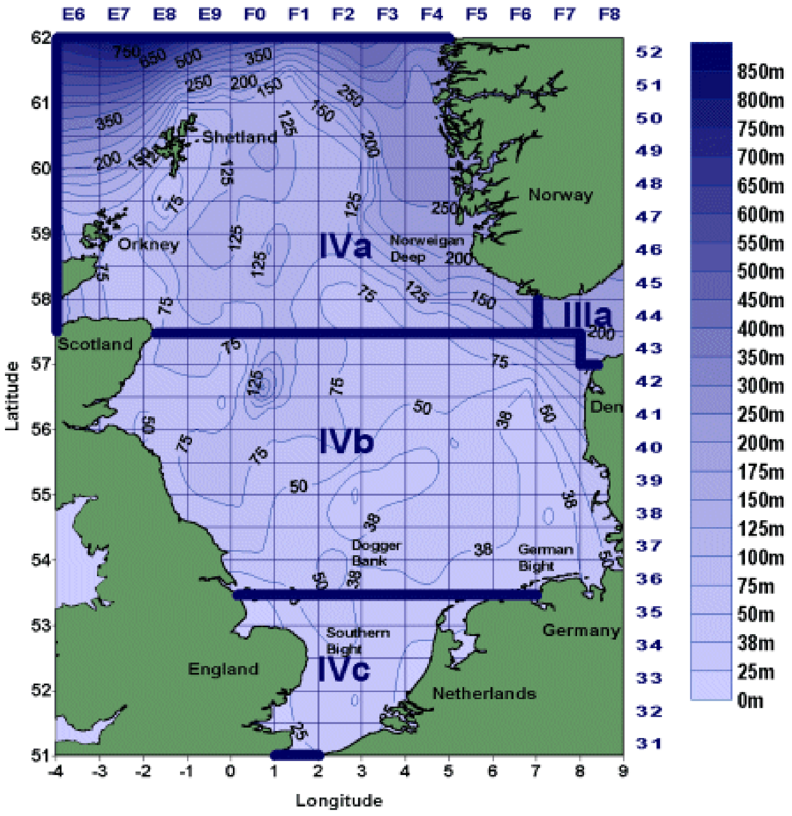


**Figure 2.16 Bathymetry (left) of the North Sea (source – CEFAS, Lowestoft).**

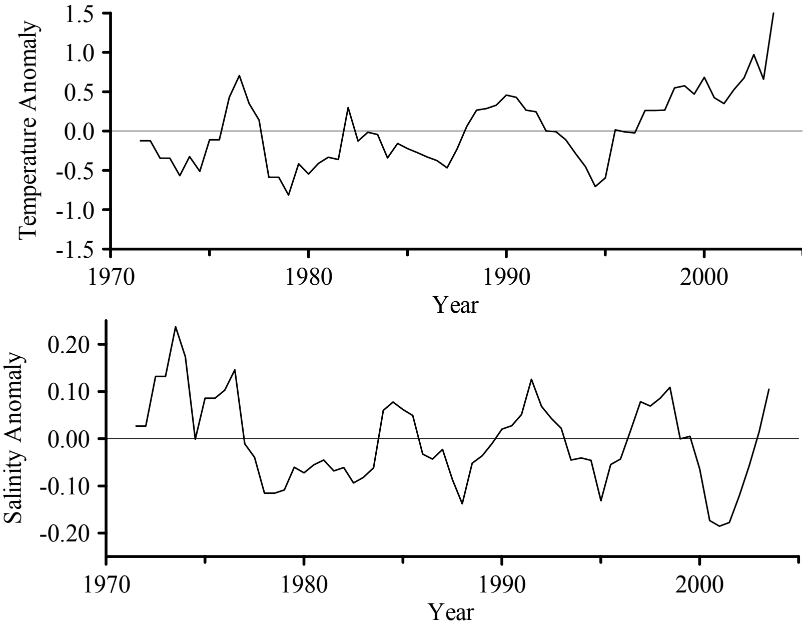
### 2.7.1.2 Circulation patterns

Circulation in the North Sea is classically presented as an anticlockwise gyre driven mainly by wind forcing. However modelling and some empirical observations suggest that this may be reversed some of the time as a result of wind forcing, and may also split into two gyres in the north and south. Circulation may even cease for limited times (Kauker & von Storch 2000). Empirically, it seems likely that these changes and their timings may be important for fish stocks e.g. the transport of larval herring to nursery areas in the southeastern North Sea. However, no precise data on these changes have been located.. The main inflows are of warm and more saline North Atlantic water along the shelf break into the Norwegian Trench and also around the Shetland Islands. The strength of these inflows has been linked to zooplankton and fish distributions. Atlantic water also enters into the southern North Sea, via the Channel. (Hughes & Lavin, 2004). The eastern Skagerrak and the Kattegatt are strongly influenced by the brackish surface water entering from the Baltic that follows the Swedish coast and turns west along southern Norway. However the bottom water layer, which runs below the brackish water layer in the opposite direction, is of oceanic origin, (giving rise to similar bottom fauna components as commonly found in the North Sea proper)There are a number of known frontal systems in the North Sea (e.g. Fair Isle, Flamborough and Skagerrak). Changes in these frontal systems would be expected to be important for several fish species and would merit monitoring.

### 2.7.1.3 Physical and chemical oceanography

North Sea oceanographic conditions are mainly determined by the inflow of saline Atlantic water through the northern entrances and to a lesser degree through the Channel. This mixes with river runoff and lower-salinity Baltic outflow along the Norwegian coast. The temperature of the North Sea is largely controlled by local solar heating and atmospheric heat exchange. The salinity and the temperature of the North Sea 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 North Sea circulation depending on the state of the NAO. A balance of tidal mixing and local heating force the development of a seasonal stratification from April/May to September in most parts of the North Sea. This stratification is absent in the southern part of the North Sea (up to 100km from the Dutch/German coast) throughout the summer. The extent and duration of this mixed area is probably an important environmental factor for fish in this area. Recently, the NAO index (Hurrell winter index) was weak after a strong negative in 2001. The ICES Annual Ocean Climate Status Summary (IAOCSS) for 2003/04 suggests that it may have been negative in the winter of 2003/04. A negative NAO would suggest colder drier weather conditions in the North Sea (Hughes and Lavin, 2004).

**Figure 2.17 Temperature and salinity anomalies in the Fair Isle Current (FIC) entering the North Sea from the North Atlantic**



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

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

### 2.7.1.4 Major climatic and oceanographic features

See general text on this topic in separate section on the NE Atlantic (section2.1).

### 2.7.1.5 Phytoplankton

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

Zooplankton

Zooplankton production in the North Sea is dominated by copepods and euphausids, both important food items for many key commercial stocks. Zooplankton change in the North Sea has been linked to Atlantic inflow patterns across the twentieth century (Reid et al 2003). CPR and other data sources show that the abundance of copepods (particular Calanus finmarchicus) has declined dramatically in the last 10 years. (Heath et al 1999 and www.marlab.ac.uk/FRS.web/Uploads/Documents/Zooplankton.pdf). This decline shows a strong link to the NAO and can be linked to spring wind patterns and the volume of cold bottom water in the Faroe-Shetland Channel rather than to conditions in the North Sea per se. At the same time the relative proportions of Calanus finmarchicus to C. helgolandicus have changed markedly. Up to the 1970s C. finmarchicus was dominant, representing around 70% of the zooplankton biomass. In recent years (since 1995) the copepod abundance has been dominated by C. helgolandicus. Additionally, C. helgolandicus is generally a smaller and less profitable prey than C. finmarchicus. C. finmarchicus is seen as a cold water species while C. helgolandicus is generally considered a more warm water species. The CPR data also show a reduction in euphausid availability. This trend appears to be continuing and links have been made with cod and flatfish recruitment (Beaugrand et al 2003, Beaugrand 2004)) and herring growth and migration patterns. It seems likely that if both cod and herring life histories are linked to zooplankton availability, there may be implications for other demersal and pelagic species.

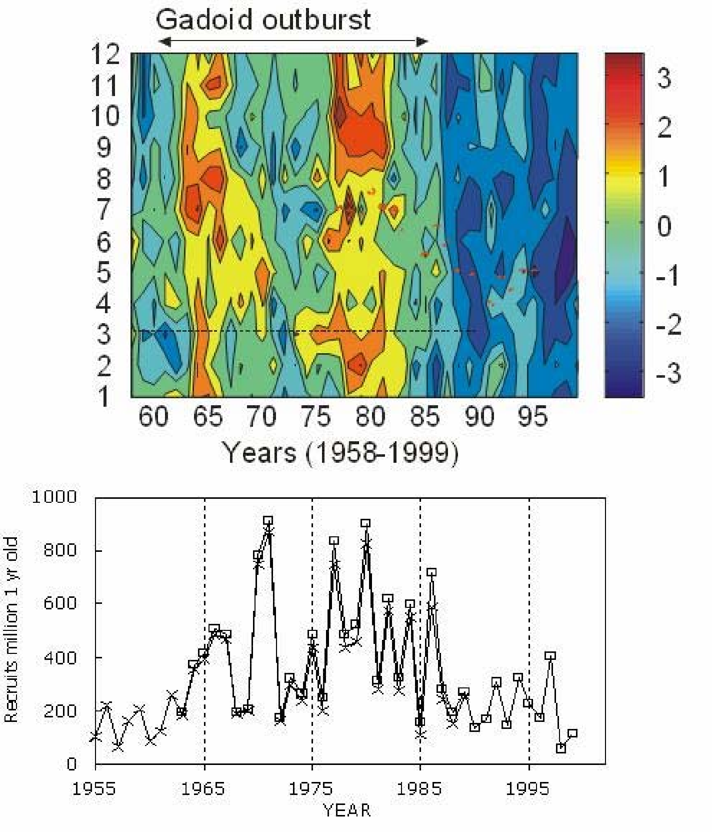


**Figure 2.18 Top; long-term monthly changes (1958-1999) in the Beaugrand et al. (2003) plankton index. A negative anomaly in the index indicates a low value for Calanus finmarchicus, euphausiids, mean size of calanoid copepods with the exception of C. helgolandicus (opposite pattern) and Pseudocalanus spp. (no relationship). A positive anomaly indicates a high abundance of prey (and prey of suitable size). The lower plot shows cod recruitment (in decimal logarithm) in the North Sea. The period of the Gadoid Outburst is also indicated. Source; SAHFOS 2003 - modified, from Beaugrand et al. (2003).**

### 2.7.1.6 Benthos and larger invertebrates

The 50m, 100m and 200m depth contours broadly define the boundaries between the main benthic communities in the North Sea, with local community structure further modified by sediment type (Künitzer et al., 1992; Callaway et al., 2001). Descriptions of the spatial distribution of infaunal and epifaunal invertebrates show that the diversity of infauna and epifauna is lower in the southern North Sea than in central and northern North Sea. However, large spatial scale gradients in biomass are not so pronounced. Bottom temperature, sediment type and beam trawling intensity have been identified as the main environmental variables affecting community structure, but the relationships are not necessarily causal. Epifaunal communities are dominated by free living species in the south and sessile species in the North.

In areas with periodical oxygen deficiency e.g. in the Kattegatt, benthic fauna are affected by mortality and reduced growth (Diaz and Rosenberg 1995). This may in turn cause shortage of food for demersal fish.

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

### 2.7.1.7 Fish community

#### 2.7.1.7.1 Dominant species

The pelagic component of the North Sea fish community is throughout the year dominated by herring. Mackerel and horse mackerel are mainly present in the summer half year when they enter the North Sea from the south and from the northwest. Dominating gadoid species are cod, haddock, whiting and saithe, whereas the main flatfish species are dab, long rough dab, plaice, sole and lemon sole. The major forage fish species in the North Sea are sandeels, herring, sprat and Norway pout. The total biomass of North Sea fish is in the order of 10 million tonnes.

The late 1960s and early 1970s were characterised by a sudden and yet unexplained increase in the abundance of a number of gadoid species, the 'gadoid outburst'. In this period the gadoids cod, haddock, whiting and saithe, all produced a series of strong year classes. Since the early 1980s however, the stocks of these species have been decreasing and especially cod is at the lowest level observed over the last century. North Sea herring was heavily overfished in the 1960s and 1970s. After a closure of the fishery in the late 1970s the stock has increased again and is now above precautionary levels.

Over the last decade a number of so-called 'southern' species have increased which is probably a response to the raise in water temperatures (Beare et al, 2004).

#### 2.7.1.7.2 Size spectrum

On the basis of three trawl surveys Daan et al. (2005) have shown that abundance of small fish (all species) as well as abundance of species with a low maximum length (demersal species only) have steadily and significantly increased in absolute numbers over large parts of the North Sea during the last 30 years (For comparison along the Swedish Skagerrak coast see Svedäng 2003). At the same time the abundance of the larger fish species decreased.

#### 2.7.1.7.3 Biomass/abundance of crucial species in the food chain

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

#### 2.7.1.7.4 Status of vulnerable species

Certain species that have been fairly common in the North Sea have disappeared completely (e.g. tuna) or have become very rare (e.g. halibut). Recently species like hake and pollack in the Skagerrak and Kattegat are decreasing.

The stocks of most elasmobranchs are at low levels. The spurdog (Squalus acanthias) was the most common shark species but is now considered to be depleted to approximately 5% of its virgin biomass in the whole Northeast Atlantic (Hammond & Ellis 2005). Species as porbeagle and tope have become rare. Most ray species are at low levels and have disappeared from large parts of the North Sea (Walker & Heessen, 1996).

#### 2.7.1.7.5 Fish population structure

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

Notwithstanding uncertainties concerning the cod meta-population structure in the North Sea region, historic spawning aggregations are well known from various parts of the area, and it may be argued that such aggregations are important aspects of the cod meta-population structure. Remaining cod spawning aggregations may thus not necessarily give a reassurance of a readily recovery of the stock biomass in the Kattegat or in the North Sea, even if the fishing intensity is substantially reduced.

### 2.7.1.8 Birds

About 2.5 million pairs of seabirds breed around the coasts of the North Sea. The seasonal distributions, current and historical, of these populations are quite well known. Some progress was made in tabulating the current status (i.e., size) and trends of seabird populations in some parts of the North Sea. The seabird fauna is dominated by seagulls (black-headed gull, mew gull, lesser black–backed gull, herring gull) kittiwakes, fulmars, and by terns, common guillemots and puffins. There is an observed increase in the number of cormorants in coastal areas in the southern North Sea and in the Kattegat. Certain fisheries activities disturb various species such as marine birds and mammals. Recent restrictions to the North Sea sandeel fishery in order to safeguard predation by birds and mammals and the driftnet ban to protect sea mammals are examples where environmental problems were the origin of fisheries management actions. Seal population trends have been by ICES recommended as useful EcoQ elements as well as trends in individual colonies of kittiwakes might serve as an index of seabird community health.

### 2.7.1.9 Mammals

Seven marine mammal species occur regularly and frequently in the North Sea, others occur in low numbers or in small parts of the area (e.g., killer whale, Risso's dolphin, sperm whale). The cetacean species that occur regularly are: harbour porpoise (Phocoena phocoena), white-beaked dolphin (Lagenorhynchus albirostris), Atlantic white-sided dolphin (Lagenorhynchus acutus), bottlenose dolphin (Tursiops truncates), and minke whale (Balaenoptera acutorostrata). The seal species are the harbour seal (Phoca vitulina) and the grey seal (Halichoerus grypus). The only abundance estimate in the North Sea for harbour porpoises is 262,540 individuals. This estimate was made in 1994 (Hammond et al. 2002) and included the whole North Sea and the Channel. The Kattegat and part of the Skagerrak had an additional estimate of 36,046 harbour porpoises.

### 2.7.2 Major environmental influences on ecosystem dynamics

No specific environmental signals were identified specifically to be considered in assessment or management in this area in 2005.

### 2.7.3 Fishery effects on benthos and fish communities

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

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

Many management actions could result in effort redistribution that could increase fishery impacts on benthic communities and habitats. Fisheries advice should consider this factor, and seek to provide advice which does not encourage managers to implement measures which merely provide incentives for the industry to relocate effort to new areas.

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

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

### 2.7.4 Important topics for further research

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, a nd the focused scientific effort historically and currently through, for example REGNS, it may be appropriate to highlight the research needs for this area. Progress in this aera should be viewed with regard to implications for other areas, however, and opportunities for collaborative and integrative work should be sought.

- Community ecology: what are the ecological effects of a diminishing size spectrum and a dominance of prey species like herring. Can these changes be readily reversed through management.

- Temperature preferences i.e. what are the effects of climate change on reproduction, egg mortality, growth, and the implications for changes stock population dynamics and distributions
- What are the consequences of the loss of meta-population structure and erosion of spawning aggregations in depleted populations.
- There should be better estimations of population fecundity, i.e. better understanding of reproduction biology including better estimates of maturity ogives, variation in maturation rates, the linkage between maturation and growth, temperature, for a more realistic view of stock productivity

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

### 2.7.5 Synthesis

The observed low abundance of species that play an important role in the North Sea food web (Calanus, sandeels, and Norway pout) is 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 are presently seriously depleted (e.g. cod and plaice). Recruitment of commercially important gadoids is at a low level and the ecosystem may be changing in an irreversible direction.Another phenomenon worth mentioning is the increase in a number of southern species. In the case of red mullet Mullus surmulletus the increase is so significant that a new fishery is developing.

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## 2.8 Bay of Biscay and Iberian Seas

### 2.8.1 Ecosystem Components

#### 2.8.1.1 General description

Four different areas can be distinguished in the eco-region G, (i) the eastern Bay of Biscay, (ii) the Cantabrian Sea, with a diminishing Atlantic influence towards the interior of the Bay of Biscay, (iii) the west coast of the Iberian Peninsula with seasonal coastal upwelling in summer and constituting the northern limit of the Eastern North Atlantic Upwelling Region and (iv) the Gulf of Cadiz area with strong influence of the Mediterranean Sea. Within these zones the topographic diversity and the wide range of substrates result in many different types of coastal habitat (OSPAR, 2000).

#### 2.8.1.2 Bottom topography, substrates, and circulation

**Bottom:** The continental shelf in the northern Bay of Biscay has more than 140 km wide and gentle slopes, and becomes narrower to the south. From coast to offshore, the depth increases almost regularly down to 200 m, the shelf is mainly flat. One major sedimentary area off South West Brittany is known as Grande Vasière (large muddy area).

On the southern border of the Bay of Biscay, the continental shelf of the Cantabrian sea is as narrow as 12 km. Off western Iberia the only relatively wide shelf section is between the river Miño and the Nazaré Canyon, whereas the continental shelf in the Gulf of Cadiz is of the order of 50 km wide, particularly to the east (OSPAR, 2000). The shelf-break occurs at depths of around 200 m to the north of the eco-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.

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

**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$^{-1}$).

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

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

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

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

Upwelling events are a common feature in Portugal, Galicia and western Cantabrian Sea, especially in summer (Fiuza *et al.,* 1982, Blanton *et al.,* 1984). The appearance of upwelling pulses during the summer is important in fuelling nutrients in the surface layer. Under conditions of moderate upwelling, the innermost coastal 25 km are about 10 times higher productive than offshore waters and the upwelling centres about 20 times. However upwelling events in the Northern Iberian Shelf are generally restricted to a narrow band near the coast in the western Cantabrian Sea (Botas *et al.,* 1990; OSPAR, 2000). In Northeast Bay of Biscay, mainly in summer, weak upwelling events occur off South Brittany and the Landes coastline (Fig 2.19).

Mean wind speed in the Bay of Biscay decreased in the first half of the 20th century then increased thereafter to speeds comparable to the 1840-70s. The windspeed 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 interannual 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).

Rivers represent the principal sources of freshwater. On yearly average, the French region received 27000 $m^3$ $s^{-1}$ of run-off from the major rivers. The major indicators show that flows for 2002 and 2003 are slightly below the long-term average from 1952-2003 and the last 10 years average and preliminary data indicate that in 2004 is close to the long term average (Figure2.20. In the Northern Spanish coast, rivers flowing into the Cantabrian Sea are of short length and with smaller importance compared with those of the French coast, as Garone or Loira. On the other hand, in North West Spanish Coast the "*rias*" constitute an important sediment and fresh water source, although river plumes have smaller importance than in France.

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, 1998 ; Planque *et al.* 2003). The increase in heat content stored in the water column appears to be greater in the 200-300 m layer (González-Pola and Lavín, 2003); in this layer ENACW responds quickly to climatological forcing.

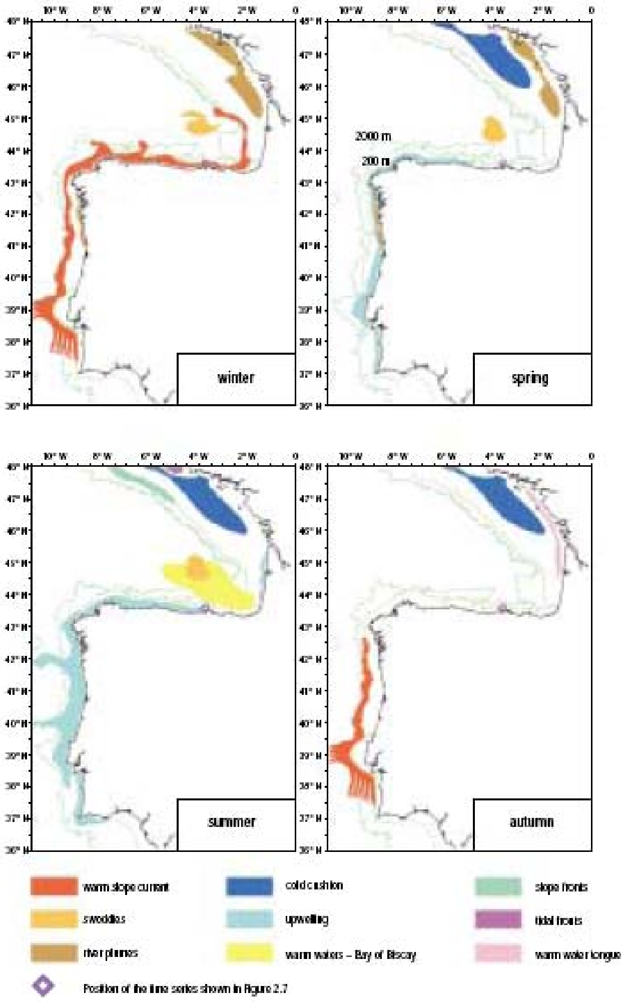

**Figure 2.19. Seasonal variation in the main hydrographic features. Source: Koutsikopoulos and Le Cann (1996).**

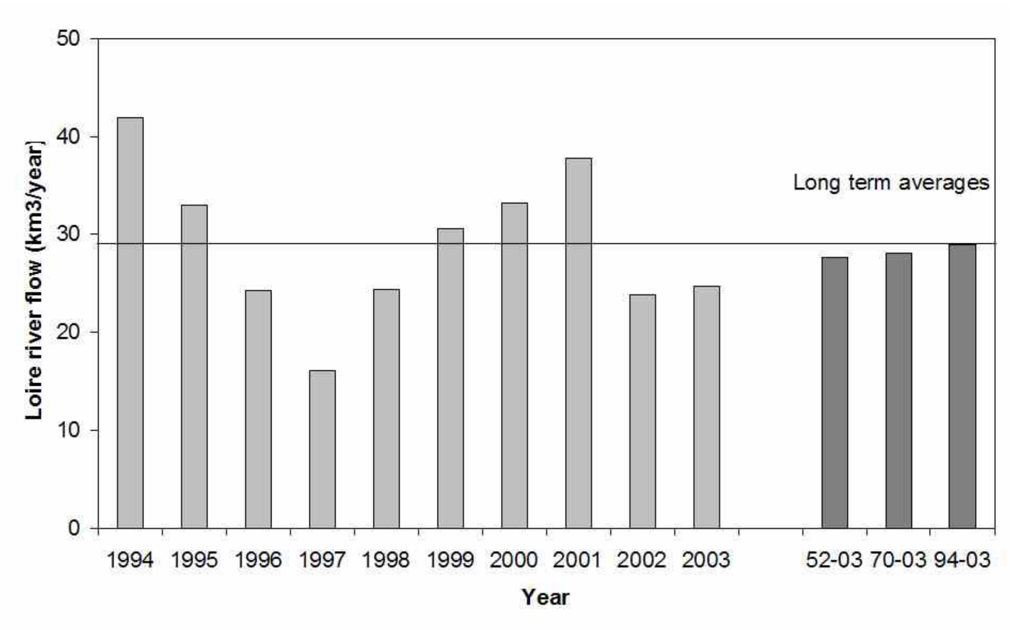

**Figure 2.20. Time series of the river Loire outflow. Data from the French data bank on hydrology and hydrometry, available at [http://hydro.rnde.tm.fr/](http://hydro.rnde.tm.fr/)**

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

Large positive values of the NAO index are associated with higher dominance of the middle-latitude easterly wind flow during winter that can lead to increased winter upwelling episodes. Dickson *et al.* (1988) related the decline in zooplankton and phytoplankton in the North Atlantic and in the catch of sardines off Portugal with the increase in northerly winds during the 1970s.

### 2.8.1.4 Phytoplankton

In the Bay of Bisacy the onset of the spring bloom occurrs with remarkable regularity in March, by March-early April the spring bloom covers the entire region. From May onwards, chlorophyll drops sharply, and the lowest values are observed in summer. The autumn bloom is variable in timing and intensity, and restricted to coastal areas. During winter months and in the coastal areas inwards the 100 m isobath chlorophyll estimates persist relatively high.

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

In the Northern and Central Iberia the main patterns of phytoplankton biomass are related to water column stratification, nutrient availability and the intensity and persistence of upwelling conditions. Maximum values of chlorophyll usually occur in spring (can occur since February) and summer (Nogueira *et al.,* 1997; Moita, 2001), although high chlorophyll values may also be recorded in autumn, particularly in zones with elevated retention characteristics: 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). In summer, a recurrent band of high chlorophyll concentration is found near the coast and associated with upwelled waters and strong cross-shelf gradients that separate upwelled and oceanic waters (Figure 2.22). Maximum values of chlorophyll near the coast occur in surface waters, while offshore these extend in a subsurface maximum which coincides with the nutricline (Moita, 2001; Tilstone *et al.,* 2003). Pulses of weak to moderate upwelling disrupt stratification and bring nutrients into the photic zone allowing phytoplankton growth on the inshore side of a well-developed thermal front, at the same time that stratified oceanic waters are poor in phytoplankton due to nutrient depletion (Moita, 2001). During strong upwelling events and weak thermal stratification, features typical of early spring, phytoplankton blooms are advected from the coast and occur on the oceanic side of a poorly developed upwelling front (Figure 8). Under these conditions, chlorophyll maxima are often found in an area of convergence or retention formed by poleward-flowing slope water which serves as a barrier to the offshore flow of surface upwelled waters (Moita, 2001; Santos *et al.,* 2004).

### 2.8.1.5 Zooplankton

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

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

In relation to the summer upwelling, the regional zooplankton biomass production is highest off Galicia where in several months it surpasses 30 mg DW m$^{-3}$ (60 mg DW m$^{-3}$ peak are frequent) (Bode *et al.,* 1998). Along the Cantabrian Sea the biomass decreases towards the east (Figure 2.22) (Llope et all.,2002).

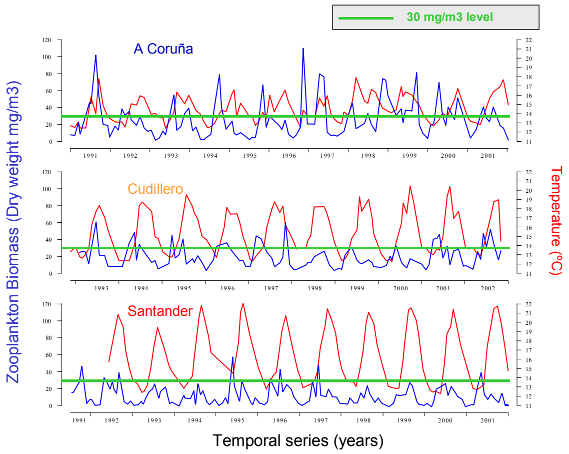

**Figure 2.22 ( Llope et al ; 2002, modified by Valdés)**

Regarding the whole Bay of Biscay, since 1992, temporal and spatial biomass distribution of mesozooplankton (200-2000 µm) shows 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. Oceanic and oligotrophic waters of the Bay of Biscay basin remain in very low abundances most of the time.

### 2.8.1.6 Benthos

The bathymetric differences in species distribution show a progressive decrease in mean fish species richness with depth in the Cantabrian Sea (Sanchez, 1993). In contrast the inverse phenomena appears in invertebrates (Olaso, 1990), which prefer deeper water and muddy substrates due to their predominantly detritivorous feeding habits.

In the North Spanish Coast, the distribution of both epibenthic an endobenthic communities is determined by depth as main driving factor, followed by sediment characteristics (grain size and organic contents). In the Cantabrian Sea, as for the rest of the communities there is an increase of the presence of Mediterranean species westwards which is more evident in the littoral and not so clear on the shelf communities.

The eco region is locally suitable for aquaculture, e.g. >200.000 tons per year of mussels from raft aquaculture in Iberia area. and fishery exploited invertebrates are: red shrimp (Aristeus antennantus) rose shrimp (Parapeneus longirostris), Nephrops and Cephalopods (Octopus vulgaris, Sepia officinalis, Loligo spp., and others).

### 2.8.1.7 Fish community

#### 2.8.1.7.1 Species composition and diversity

The main pelagic species are sardine, anchovy, mackerel, horse mackerel and blue whitting. To the south, chub mackerel (*Scomber japonicus*), Mediterranean horse mackerel (*Trachurus. mediterraneus*) and blue jack mackerel (*T. picturatus*) are common too. Seasonally, albacore

(Thunnus alalunga) occur along the shelf break. The main commercial demersal species caught by the trawl fleets are hake, blue whiting, megrims (*Lepidorhombus boscii* and *L. whiffiagonis*), anglerfishes and sole, being also horse mackerel an important target for these fleets. Most of these demersal species are distributed all through the eco-region, although not evenly.

In the demersal habitats major elasmobranchs species are the rays, *R. clavata* and *R. montagui,* and the catsharks, *S. canicula* and *G. melastomus* at the coast and on the inner and outer shelf respectively (Rodríguez-Cabello *et al.* 2004). Deeper, several deepwater sharks and chimaeroids are found (Sánchez and Serrano, 2003; Lorance *et al.* 2000), and among the pelagic species only blue shark (*Prionace glauca*) is a target species for longliners operating in the area during the summer.

Fish diversity is quite high in relation to the co-occurrence of sub-tropical, temperate and boreal species which relative abundances follow latitudinal gradients. More than 200 species occur in demersal survey in the North East 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). The fish community is organised according to depth, bottom and latitude and is stable over time despite species abundance variations and trends (Souissi *et al.,* 2001, Poulard *et al.,* 2003). Species richness is highest in coastal shallow water, down to 50 m (Blanchard, 2001).

Strong environmental gradients in their distribution are found in this area, especially in the Cantabrian Sea; where, due to its narrow and steep shelf, depth is the most influential factor determining the assemblages observed. Regarding species richness and diversity both have remained quite stable during the 1990s, with changes in diversity due to blooms of some species. The only exception is the coastal stratum (70-120 m depth) were there was a decrease in richness from 1990 to 1994, but in the rest of the decade this index increased again (Sánchez & Serrano, 2003).

Off west Iberia, species richness seemed to have increased slightly in the 90s, but no clear pattern of diversity was detected over time (Bianchi et al 2000, Sousa et al 2004b). Recently, rare species from North Africa were reported in the Algarve (Brander *et al.* 2003).

### 2.8.1.7.2 Tropic web

In the northern Iberian shelf ecosystem, most of the biomass and production are contained within the pelagic domain. Phytoplankton grazing is low, consequently, detritivorous species are important. Suspension and deposit feeders constitute a high percentage of the biomass to the detriment of pelagic plankton (Sanchez and Olaso, 2004). Abundant suprabenthic zooplankton is available to pelagic and small demersal fish species (mackerel, horse mackerel, blue whiting, *Gadiculus argenteus*, *Capros aper*).

Sardine, anchovy, mackerel and horse mackerel have all been found in the diet of cetacean and fish species (e.g. hake, tuna, John Dory, etc. with sardine and anchovy being taken also by mackerel and horse mackerel). Also blue whiting is one of the main preys of many demersal ichtiophagous fishes (Velasco and Olaso, 1998a and 1998b; Preciado *et al.* Submited). Decapod crustaceans also play an important role as preys of other benthic fish species as megrims, gurnards, skates and *Trisopterus* sp. (Rodríguez-Marín, 2002), whereas cephalopods are minor preys for most of the demersal fish predators found in this area (Velasco *et al.* 2001).

Sardine and anchovy are the main preys of common dolphins (*Delphinus delphis*) (Silva, 1999a; Santos *et al.,* 2004, Meynier, 2004). There is a degree of cannibalism by adults on juveniles and/or eggs when food is scarce (e.g. Silva, 1999b; Cabral & Murta, 2002).

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

There are evidences of an important utilization of discards by demersal fishes in Galicia and the Cantabrian Sea (Olaso *et al.* 1998) indicating that discards probably play an important role as food source on the trophic web in north Spanish shelf.

## 2.8.1.8 Mammals and birds

No information was provided for this meeting.

### 2.8.1.8.1 Mammals

Seven species of mysticeti, twenty-three species of odontocet and seven species of pinnipeds have been reported in the eco-region. The main habitat and status of these species is summarised in Table 2.2. Detailed information on distribution and migratory patterns is restricted to the most common species.

**Table 2.2 Main marine mammals species**

| SPECIES | FREQUENCY AND TRENDS | HABITAT, OR TEMPORAL OCCURENCE |
|---|---|---|
| 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 eco-region |
| Fin Whale (*Balaenoptera Physalus*) | Fairly Common | Oceanic waters only |
| Sperm whale (*Physeter macrocephalus*) | | Summer aggregation feeding on cephalopods over continental slope |
| Cuvier's beaked whale (Ziphius cavirostris) | Small permanent numbers | Slope and canyons |
| Common dolphin (*Delphinus delphis*) | Most common (>50% of strandings) | Continental shelf, slope and oceanic waters |
| Bottlenose dolphin (*Tursiops truncatus*) | Common | All eco-region (mainly coastal) |
| Striped dolphin (*Stenella coerulaeoalba*) | Most common | Oceanic waters |
| Long-finned pilot whale (*Globicephala melas*) | Common | Mostly slope waters, visits into coastal waters in the summer |

### 2.8.1.8.2 Birds

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

#### 2.8.1.8.3 Impact of the "Prestige" oil spill

Between November 2002-August 2003 23000 birds (6000 alive and 17000 dead) were collected in French, Spanish and Portuguese coasts, as a consequence of the "Prestige" oil spill. 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 less affected species. In general, more than 60 % of the oily birds were females (http://www.seo.org/2002/prestige).

### 2.8.2 The major environmental effects on ecosystem dynamics

Upwelling intensity, and in a lesser extent other factors 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; Carrera and Porteiro 2003; Allain *et al.* 2001; Villamor *et al.,* 2004).

As stated above, demersal and benthic species distribution is determined mainly bathymetrically and by sediment types, being these also related with the mesoscale features mentioned in the previous paragraph, but also with bottom topography and rivers outlets.

Global warming has been related with changes on the distribution of several species (Quéro *et al.* 1998) that are progressively increasing their northernmost distribution limits. Recently, rare species from North Africa were reported in the Algarve (Brander *et al.* 2003).

### 2.8.3 The major effects of the ecosystem on fisheries

Northerly winds and its intensity seems to be related with anchovy recruitment. When upwelling is particularly intense, surface signals can be observed and studied by remote sensing, which reveals that upwelled waters are advected offshore forming filaments that extent westward following the 200 m isobaths and transporting biological material towards oceanic waters.

Borges *et al.,* (2003) showed that a NAO positive phase corresponded to a low catch period of sardine, whereas a NAO negative phase coincided with high catches. 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). Also in relation with the strength of the upwellings and the Navidad current optimal environmental windows have been defined for some demersal species as hake and megrims (Sánchez *et al.* 2003a & 2003b).

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

### 2.8.4 The major effects of fishing on the ecosystem

Fishing is the major disturbance to the megafaunal communities of the offshore shelf of the Bay of Biscay. On the grande vasière, a sedimentary area trawled for nephrops, species diversity was lesser and large invertebrates were less abundant in the most exploited areas. In less exploited areas, the dominant species were commercial species and a benthic species sensitive to the physical effects of the fishing gears. In the heavily exploited areas, the dominant species were opportunistic carnivorous species of minor or no commercial interest and there were no fragile invertebrates (Blanchard *et al.,* 2004).

No significant changes in the community of the Bay of Biscay were seen from indicators based on cruises over the period 1987 to 2002 (Table 2.3) (Bertrand, 2004). Further on-going analysis of the effects of fishing and warming observed during the last 3 decades in the Bay of Biscay indicate that the mean trophic level decreased and the biomass ratio of pelagic/demersal increased, consistently with fishing effects. (Blanchard *et al.,* 2004b).

In the Cantabrian Sea, the fisheries have a major effect on the structure and dynamics of the ecosystem (Sánchez and Olaso, 2004). They have become more industrialised over the past 50 years, with the catch reaching about 200 000 tons per year. Trawlers fish on the muddy bottoms of the shelf, whereas longliners operate mainly on the shelf-break bottoms and gillnets are used on rocky grounds near the coast and shelf-break, a pattern similar to what occurs on the Galician shelf.

**Table 2.3. The indicators for the demersal fish community of the Bay of Biscay**

| CATEGORY OF INDICATOR | INDICATOR | DIRECTION OF CHANGE |
|---|---|---|
| Population | Abundance of populations | 1 in 51 decrease ; 20 in 51 increase |
| | Mean size in the population | 3 in 51 decrease ; 0 increase |
| Community | Total abundance | Stable |
| | Total biomass | Increase |
| | Mean weight in the community | Stable |
| | Mean size in the community | Stable |
| | Multispecies size spectra<br>Slope<br>Intercept | <br>Stable<br>Increase |

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*) and teleosts *Trigla lyra* 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 and rays seem more subject to adverse impact.

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, which might be regarded as a major change in the fish community as is used to be one of the dominant large fish species, taxonomically different from other main species.

The common spiny losbter, *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.

**Incidental catch of cetaceans**

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

### 2.8.5 Other effects of human use of the ecosystem

Concerning other anthropogenic impacts on the ecosystem it is important to mention the "Prestige" oil spill in front of Galicia's coast in November 2002. This catastrophe affected most of the northern Spanish coast and especially the northern part of Galicia. Nevertheless and up to know the Prestige oil spill has not had an evident direct impact on the demersal stocks in the area, although possible long term impacts through the food chain or fecundity reductions will require further research. However, there was an indirect and immediate impact on the demersal exploited species due to the reduction of the fishing effort in the Galician area, due to the closures after the oil spill. It is difficult to assess the effect of this reduction in the fishing activity of the fleets.

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## 2.9 The Baltic Sea

### 2.9.1 Ecosystem Components

#### 2.9.1.1 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 bottom topography features a series of basins separated by sills. The Gulf of Bothnia and the Gulf of Riga are internal fjords, while the Baltic Proper and the Gulf of Finland consists of several deep basins with more open connections. The western and northern parts of the Baltic have rocky bottoms and extended archipelagos, while the bottom in the central, southern and eastern parts consists mostly of sandy or muddy sediment.

#### 2.9.1.2 Physical and Chemical Oceanography

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

A strong inflow of new saline and oxygen rich water from the North Sea can lead to a renewal of the oxygen depleted bottom water. Strong inflows can occur when a high air pressure over the Baltic is followed by a steep air pressure gradient across the transition area between the North Sea and the Baltic. Such situations typically occur in winter. Strong inflows were frequent prior to mid-1970's, but have since become rarer and as a result salinity has decreased over the last 25 years. Major inflows occurred, however, in 1976, 1983, and 1993. In 2003 an inflow of medium size (200 $km^3$, ICES 2004) introduced salty, cold and well-oxygenated water into all main basins of the Baltic Sea, including the Gotland Deep. In 2005 an inflow of approximately 140 $km^3$ of water occurred between January 1 and 14 (http://www.smhi.se/oceanografi/oce_info_data/waterlevel/follow_up/waterlevel_uppfoljning.html).

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

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

### Contaminants:

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

### Broad scale climate and oceanographic features and drivers:

The oceanographic conditions in the Baltic are very much driven by meteorological forcing influencing inflow from the North Sea. Hydrographic characteristics and significant correlations have been demonstrated between NAO and total freshwater runoff, westerly winds and salinity (Häninnen *et al.* 2000), ice conditions (Koslowski & Loewe 1994) as well as local circulation and upwelling (Lehmann *et al.* 2002). Climate variability has been shown to affect the dynamics of many of the components of the Baltic ecosystem. The consequences of a recent severe winter (2002/2003, ICES 2004) for commercial fish stocks remain to be quantified.

### 2.9.1.3 Phytoplankton

The species composition of the phytoplankton depends on local nutrients and salinity with gradual change in the species composition going from the southwest to the northeast. 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. Primary production exhibits large seasonal and interannual variability (Helcom 2002, p. 182), but 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, increased in the Baltic proper (Wasmund and Uhlig 2003). Observed changes in trends during the two decades are discussed to indicate a shift in the ecosystem.

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

Red tides (dinoflagellate blooms) are regularly observed, including blooms of the toxic Gymnodinium mikimotoi. (Helcom 2002, 2003).

### 2.9.1.4 Zooplankton

The species composition of the zooplankton reflects the salinity with more marine species (e.g. *Pseudocalanus* sp.) in the southern part and brackish species (e.g. *Eurytemora affinis* and *Bosmina longispina maritima*) in the northern areas.

As a result of the declining salinity, the relative abundance of small plankton species has increased in some parts of the Baltic (Viitasalo *et al.* 1995). The abundance of Pseudocalanus sp. has declined since the 1980s in the central Baltic, whereas the abundance in spring of Temora longicornis and Arcartia spp. increased (Möllmann *et al.* 2000, 2003 a). This change is unfavourable for cod recruitment (Hinrichsen *et al.* 2002) and herring growth (Möllmann *et al.* 2003a, Rönkkonen *et al.* 2004), whereas it favours sprat, the fish species presently dominant in the Baltic.

Gelatinous zooplankton is being monitored, but its impact is not thought to be important for recruitment of the principal commercial fish species in the central Baltic because the bulk biomass only develops in mid-summer in the upper water layer, whereas spawning of pelagic takes place in spring, and spawning of cod in summer, but in the deep water.

### 2.9.1.5 Benthos

The composition of the benthos depends both on the sediment type and salinity, with suspension feeding mussels being important on hard substrate while deposit feeders and burrowing forms dominating on soft bottoms. The major parts of the hard bottoms are inhabited by communities of Fucus vesiculosus and Mytilus edulis while the main parts of the Baltic soft bottom have been classified as a Macoma community after the dominating marine mussel Macoma balthica (Voipio, 1981). In shallow areas seaweed and seagrass form important habitats (including nursery grounds) for many animals. The distribution of seaweed and seagrass has changed over time, in some cases in response to eutrophication (Helcom 2003, p. 114).

In the Bothnian Bay and the central part of the Bothnian Sea the isopod Saduria entomon and the amphipod Pontoporeia spp. dominate the zoobenthos. The species richness of the zoobenthos is generally poor, and declines from the southwest towards the north due to the drop in salinity, but species poor areas and low 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 some of these areas can, however, be seen.

### 2.9.1.6 Fish community

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 biomass and numbers. Commercially important marine species are sprat, herring, cod, various flatfish, and salmon. Sea trout and eel, once abundant, are of very low population sizes. Sturgeons, once common in the Baltic Sea and its large rivers are now extinct from the area. Recruitment failures of coastal fish, e.g. perch (*Perca fluviatilis*) and pike (*Esox lucius*) in Sweden have been observed along the Swedish Baltic coast (Nilsson *et al.* 2004, Sandström and Karås 2002).

Cod is the main predator on herring and sprat, and there is also some cannibalism on small cod (Köster *et al.* 2003a). Herring and sprat prey on cod eggs, and sprat are cannibalistic on their eggs, although there is seasonal and inter-annual variation in these effects (Köster and Möllmann 2000a).

The trophic interactions between cod, herring and sprat may periodically exert a strong influence on the state of the fish stocks in the Baltic, depending on the abundance of cod as the main predator. To accommodate predator-prey effects, information (e. g., predation rates by cod on herring and sprat) multispecies assessments are used in the assessment of pelagic stocks. However, interactions with other potential top predators such as seals, which are potentially important in the northern Baltic Sea, have not yet been quantified and are therefore not directly included in the present ICES fisheries advice.

### 2.9.1.7 Birds and mammals

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

The seabirds in the Baltic Sea comprise pelagic species like divers, gulls and auks, as well as benthic feeding species like dabbling ducks, seaducks, 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 seaducks. The common eider exploits marine waters throughout the annual cycle, but ranges from being highly migratory (e.g., in Finland) to being more sedentary (e.g., in Denmark).

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

### 2.9.2 The major environmental influences on ecosystem dynamics

Variations in the abiotic environment of the Baltic Sea are strong and depend on climate forcing. Populations of fish are affected by this variability both with respect to growth and recruitment. The growth rate of herring and sprat diminish with reduced salinity in the eastern and northern part of the Baltic (Flinkman *et al.,* 1998; Cardinale *et al.* 2002, Möllmann *et al.* 2003a, Cardinale and Arrhenius, 2000; Rönkkonen *et al.,* 2004). The recruitment of herring in the Gulf of Riga and sprat in the entire Baltic are positively related to spring temperatures and the North Atlantic Oscillation index (MacKenzie and Köster 2004).

The recruitment of the eastern cod stock depends primarily on the volume of water with sufficient oxygen content and salinity available in the deeper basins (Sparholt 1996, Jarre-Teichmann *et al.* 2000, Hinrichsen *et al.* 2002, Köster *et al.* 2003a and see below). The present hydrographic situation in the Central basins of the southern Baltic suggests that during the spawning season in 2005, the most favourable conditions for cod egg survival are expected still to be restricted to the Bornholm Basin and the Slupsk Furrow, but not in the more eastern basins.

### 2.9.3 The major effects of the ecosystem on fisheries

#### 2.9.3.1 Central Baltic cod

The spawning areas for Central Baltic cod have in the past been the Bornholm, Gdansk, and Gotland Deeps (Figure 2.23). The Bornholm Deep has been important in all years while the Gdansk and Gotland Deeps have been important only in years where the salinity and oxygen conditions have allowed successful spawning, egg fertilisation and egg development and when the spatial distribution of the cod stock has included these areas.

The volume of water suitable for cod spawning and egg survival ("reproductive volume", RV) has been very low or zero since the mid-1980s in the Gotland Deep (Fig. 2.24) except 1994 (as a result of the 1993 inflow, MacKenzie *et al.* 2000). The same is true for the Gdansk Deep except that for 1995-1999 there have been several positive RV values. Prior to the mid-1980s there were many periods where the RV was high in both areas and cod reproduction took place.

The Baltic Sea is characterised by a series of deep basins separated by shallow sills, and an inflow will usually fill up the first basin (the Bornholm Deep) only, with little or no transport in an eastern direction. Under exceptional circumstances will the eastern Baltic basins benefit from the water exchange. Thus, hydrographic monitoring and the unique topography make predictions of RV in each area possible in a given year, when conducted after the inflow period in January to March. The additional effects of eutrophication on the fisheries are complex and difficult to resolve, but any process leading to a reduction in oxygen concentration in the deep layers during cod spawning periods will affect cod egg survival, as well as the survival of benthic animals that are prey for demersal fish species.

Central Baltic cod peak spawning time was in July-August during the first half of the 20th Century, but changed to May until the mid-1980s when it slowly moved backwards in time year by year to June and July by around 1995 (Wieland *et al.* 2000). It is likely that for 2004 the main spawning time was June-July-August. The distribution of spawning effort, egg mortality (Wieland *et al.* 1994, Wieland and Jarre-Teichmann 1997, Köster and Möllmann 2000), larval and early juvenile mortality and atmospheric forcing conditions post spawning

(Hinrichsen *et al.* 2002 a, b) all contribute to uncertain recruitment predictions (Köster *et al.* 2001, 2003a,b). The dynamics of maturation influence the estimation of reference points, and values of SSB relative to these reference points (Köster *et al.* 2003b).

### 2.9.3.2 Clupeids

Sprat and herring are the dominant zooplankton predators in the ecosystem. However, it is not easy to differentiate the effects of changes in zooplankton predator abundance and consumption (Möllmann and Köster 2002) from the effects on zooplankton of changing nutrient availability and hydrographic conditions (Möllmann *et al.* 2003b).

The growth and condition of herring deteriorated along with the decline in the abundance of their main food, Pseudocalanus sp. (Möllmann *et al.* 2003a, Rönkkonen *et al.* 2004), and earlier than the sprat stock increased in abundance, The reason for the decrease in Pseudocalanus sp. have primarily been related to lower salinity and low oxygen conditions (Möllmann *et al.* 2003a, Schmidt *et al.* 2003), and subsequent increased predation by sprat may have amplified its decline (Möllmann and Köster 2002, Möllmann *et al.* 2004).

For Baltic sprat a strong coupling between the NAO index, ice/temperature conditions and recruitment has been demonstrated by MacKenzie and Köster (2004). Köster *et al.* (2003b) were able to improve the S/R relationship presently used in the ICES assessment by almost 50% by incorporating SSB, temperature and growth anomalies. However, the understanding of the underlying processes is still limited (ICES 2004).

## 2.9.4 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 10-15 years have led to a shift in the fish community from cod to clupeids (herring, sprat) by first weakening cod recruitment (Jarre-Teichmann *et al.* 2000) and subsequently generating favorable recruitment conditions for sprat and thus increasing clupeid predation on early life stages of cod (Köster and Möllmann, 2000, Köster *et al.,* 2003; MacKenzie and Köster, 2004). Thus, the shift from a cod to a sprat-dominated system may be explained by differences in the reproductive requirements of both fish species in a changing marine environment. Additionally, the dominance shift was supported by high fishing pressure on cod, a top-down effect which also was maintained after the severe reduction in biomass (see also Jarre-Teichmann 1995). Possible factors leading to future destabilization of the sprat dominance include unfavourable hydrographical conditions for sprat reproduction, e.g. low water temperatures in spring following severe winter, or high fishing mortalities caused by the developing industrial fishery, with concurrent low fishing pressure on cod and inflow of oxygenated water from the North Sea.

Coastal fishery by anglers and commercial fishermen has probably 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 sedentary.

### 2.9.4.1 Bycatch of fish

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

It is currently impossible to come up with quantitative accounts of the by-catch of cod in the small-meshed sprat and herring fishery in the cod spawning areas (ICES 2004/Advice on IBSFC request on closed areas).

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

#### 2.9.4.2 Bycatch of seabirds and mammals

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

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

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

#### 2.9.4.3 Other effects of fishing on seabirds and mammals

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

### 2.9.5 Other effects of human use of the ecosystem

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

### 2.9.6 Conclusions

#### 2.9.6.1 Short term:

Ad a) The 2003 year class of cod will recruit to the fishery this year. The effect of the 2003 inflow on cod recruitment should be estimated by the Assessment WG, using different available recruitment models (i.e., comparison of effects) and spatial information.

Further, winter temperatures have been shown to affect sprat recruitment. The Assessment WG should consider ways in which the consequences of severe winters on sprat recruitment can be implemented in stock projections, both in the short and medium term.

Ad b) e.g., Interactions with other potential top predators such as seals, which are potentially important in the northern Baltic Sea, are not yet quantified and are therefore not directly included in the present ICES fisheries advice.

### 2.9.6.2 Medium-term:

Depletion of cod in the Baltic has contributed to a shift in the trophic structure from a gadoid dominated system to a clupeoid dominated system. This has been accompanied by shift in zooplankton and phytoplankton, for which there is increasing evidence, and which may also be partially a consequence of eutrophication. The change in species dominance has far-reaching consequences for people living in coastal areas, and may be very difficult to reverse through management. Methodology needs to be developed for management advice to take regime changes into account.

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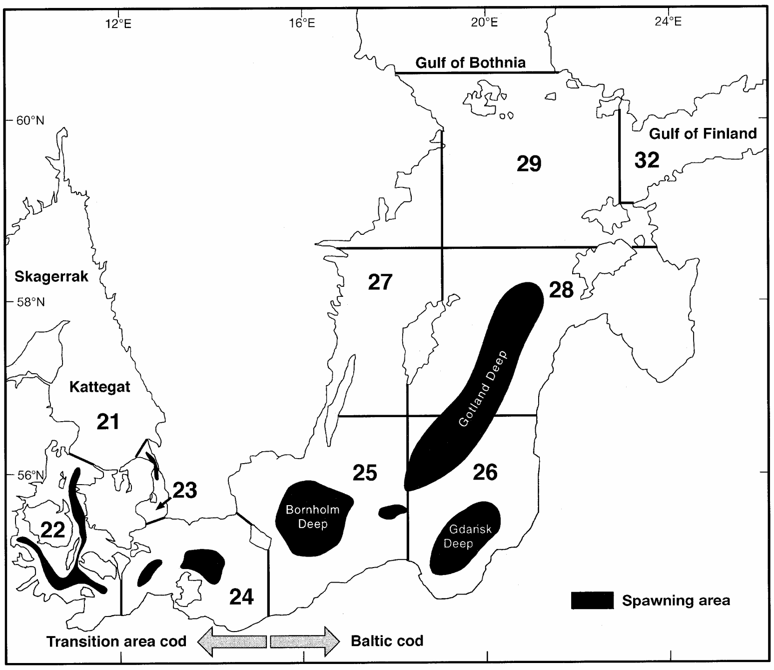

**Figure 2.23 Historical spawning areas for cod in the Baltic Sea. From Bagge, O., Thurow, F., Steffensen, E., Bay, J. 1994. The Baltic Cod. Dana Vol. 10:1-28, modified by Aro, E. 2000. The spatial and temporal distribution patterns of cod (*Gadus morhua callarias*) in the Baltic Sea and their dependence on environmental variability – implications for fishery management. Academic dissertation. University of Helsinki and Finnish Game and Fisheries Research Institute, Helsinki 2000, ISBN-951-776-271-2, 75 pp.**

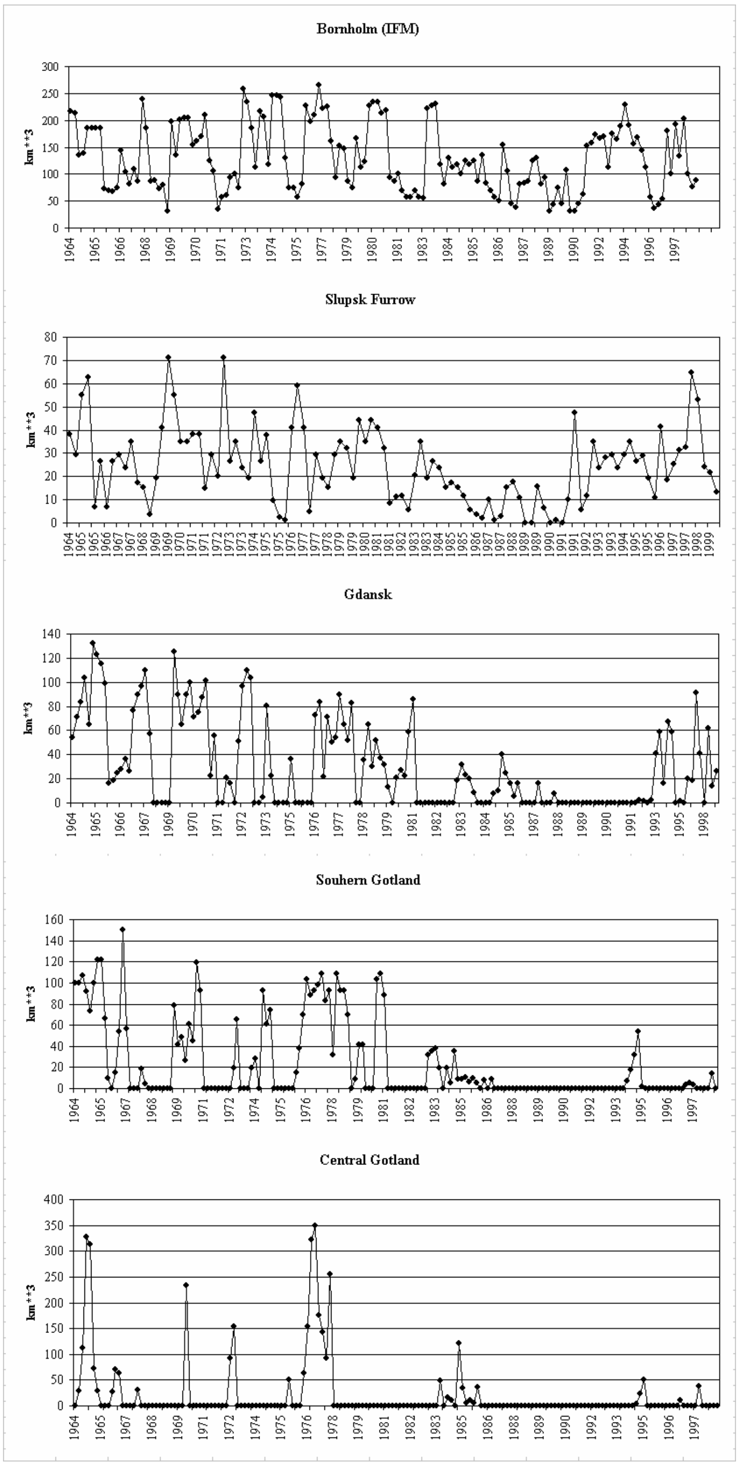

**Figure 2.24 Time-series of reproductive volume for each spawning site. From MacKenzie, B. R., Hinrichsen, H.-H., Plikshs, M., Wieland, K., Zezera, A. 2000. Quantifying environmental heterogeneity: estimating the size of habitat for successful cod *Gadus morhua* egg development in the Baltic Sea. Marine Ecology Progress Series 193: 143-156. With updates by Maris Plikshs (Pers. Comm.).**

# 3 Short term considerations for 2005 assessments and advice

## 3.1 Introduction

In the process of preparing the ecosystem overviews, the Working Group identified several specific environmental factors which were suspected of being in anomalous conditions in the recent past (roughly, but not precisely the past one or two years), relative to the long-term more usual conditions. In each case the anomalous state of the environmental feature was thought to pose a higher than usual risk that applying routine assessment practices might lead to assumptions about stock status or dynamics that were incorrect. The incorrect assumptions in the assessment could, in turn, lead to advice that would not guide managers to management actions appropriate for the special environmental conditions.

From these anomalous environmental factors, the Working Group further selected a subset of them for which we could recommend some practical steps to take in the 2005 assessment and advisory process, which would allow the additional risk posed by the environmental conditions to be addressed. These were discussed with AMAWGC, to allow the Assessment Working Group chairs to consider how to implement the recommended steps. In the rest of this section, for each of the ecosystems, we describe the environmental feature(s), stocks possibly affected, and potential steps in the assessment process to address the risks.

## 3.2 Iceland – East Greenland

### 3.2.1 Environmental Anomalies:

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

### 3.2.2 Opportunity to Address in Assessment Process:

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

## 3.3 Barents Sea

### 3.3.1 Environmental Anomalies

It is first noted that assessment models for several Barents Sea stocks already have a great deal of biology in them, so the main predator-prey and hydrography-recruitment effects are considered in the assessment.

In 2004 over 1200 Kt of blue whiting have moved into this area. This is greatly more blue whiting than has been previously recorded in that area. There is insufficient knowledge to predict the specific impacts of such a change in the fish community, but there is some chance that they could be quite large, particularly as a competitor for the other species in the area.

It has been documented that the predation pressure inflicted by large abundances of juvenile herring in Barents Sea cause a major reduction in capelin eggs and larvae, and the subsequent lack of capelin leads to reduced growth on predatory sizes of cod. The 2002 and 2004 year-classes of herring were both very strong so the abundance of juvenile herring is exceptionally strong right now.

### 3.3.2 Opportunity to Address in Assessment Process

There is no easy change in the assessment process to accommodate the potential ecological impact of the large amount of blue whiting in Barents Sea. However, this large increase in uncertainty about the energy that is available to flow to cod in the short term indicates that a particularly precautionary harvesting approach would be appropriate, until the uncertainty about the impacts of the blue whiting can be reduced.

With regard to the juvenile herring, it is expected that the capelin assessment will conclude biomass is very low, affecting both the advice on capelin directly, and the advice on cod through the impact of low capelin on the estimated yield of cod. The cod-capelin relationship is built into the basis for advice on Barents Sea cod, but the results need to be examined even more carefully than usual because of the large biomass of juvenile herring.

## 3.4 Faroes Plateau & Area

### 3.4.1 Environmental Anomalies

The relationships between fluctuations of lower trophic levels and productivity of major demersal species including cod and haddock are well documented in this area. In 2004, in general oceanographic conditions and lower trophic level productivity were not greatly different from longer term average conditions, so no particularly atypical effects of environmental drivers on demersal stocks are expected.

### 3.4.2 Opportunity to Address in Assessment Process

None considered necessary.

## 3.5 Norwegian Sea

### 3.5.1 Environmental Anomalies

There has been a generally warming climate during the last 20 years with the last three years as outstanding at about 1ºC above mean for period 1978-2004 in Svinøy section. However there was no major unique hydrographic events in 2004.

Similarly, there has been a generally low zooplankton in the central Norwegian Sea for several years, and very large stocks of all major pelagic stocks.

### 3.5.2 Opportunity to Address in Assessment Process

Both the hydrographic and food web changes have been accumulating gradually over several years. Although they need to be considered in the long-term management of resources in the area, there are no special accommodations which are required in the 2005 assessment process.

## 3.6 Celtic Seas

### 3.6.1 Environmental Anomalies

Although no experts attended the meeting from this area, it was noted that there has been a overall warming in areas to the west of Scotland and Ireland, particularly in the last two years. Similar changes have been documents to have had substantial effects on distribution (and therefore catchability) and productivity of demersal and some pelagic stocks in other areas, but the effects on stocks in the Celtic Seas are not known.

### 3.6.2 Opportunity to Address in Assessment Process

The WG had insufficient expertise to know what to recommend as appropriate actions for the assessment process in 2005. However, extra care should be taken in the examination of all tuning indices, because of the possible effects on q, and any effects on stock productivity due to the very warm waters would affect the success of recovery plans for stocks in these seas.

## 3.7 North Sea

### 3.7.1 Environmental Anomalies

Three of the major forage species in the North Sea, sand eel, Norway pout, and *Calanus* are all exceptionally low. This makes feeding conditions much poorer than usual for many stocks, although the magnitude of the combined effect of all three forage stocks being low at once is unknown.

The herring biomass is very high, which, combined with the poor feeding conditions, could have particularly detrimental effects on many of the life history parameters for North Sea Herring.

Over the past several years there has been an increase in the representation of species with more southerly distributions historically, in at least the Southern and Western North Sea. Although not a single-year anomaly this change could have major implications of sustainable management of North Sea stocks and fisheries.

### 3.7.2 Opportunity to Address in Assessment Process

For most of the demersal stocks, pessimistic assumptions of weights at age are justified due to the poor feeding conditions.

For herring very pessimistic assumptions of weight at and age and the maturation vector are both justified.

In the longer term, experts developing management strategies and recovery planning for North Sea stocks need to consider the evidence for and implications of a permanent change in the fish community species composition of the North Sea.

### 3.7.3 Recent redistributions of effort that may change/increase the ecosystem effect of the *Pandalus* fishery

Fisheries for *Nephrops norvegicus* and *Pandalus borealis* are of increasing importance in the Kattegatt-Skagerrak. Both these fisheries have high discards and by-catches including threatened and declining species such as skates and rays. The new effort regulations (EU 27, 22.12.2005) for the *Nephrops* fishery and the mixed demersal fisheries will most likely redistribute parts of the trawling-fleet to both *Pandalus* and unregulated species such as witch that is taken as by-catch in this fishery. The potential redistribution of effort to this fishery may thus increase the pressure on threatened and unregulated species. This problem should be addressed with mandatory use of sorting grid/excluding device of in the *Pandalus* fishery (Isaksen *et al.* 1992).

## 3.8 Baltic Sea

### 3.8.1 Environmental Anomalies

There was a period of inflow from the North Sea to the Baltic Sea in January 2005, but preliminary estimates suggest that it was unlikely to have been more than one half the size of the moderate 2003 inflow event. This means that the volume of oxygen-deficient water in the Baltic may have been reduced somewhat, increasing the quality and quantity of spawning habitat for Baltic cod, but probably not by a great amount.

Much work has been done on changes to the maturity at age rates of cod in the Baltic. The changes have been large enough to affect assessment results substantially.

The very high abundance of sprat and herring in the Baltic Sea and low abundance of cod has built up over several years. It had changed patterns of energy flow in the ecosystem, and increased predation on early life stages cod reproductive products in ways that may be hard to reverse, even under favourable environmental conditions.

### 3.8.2 Opportunity to Address in Assessment Process

Even though there has been a recent inflow event to the Baltic, optimistic assumptions regarding cod recruitment are not justified. The most favoured areas for cod egg survival are expected to still be restricted to the Bornholm Basin and Slupsk Furrow. The 2003 year class of cod will recruit to the fishery in 2005. The effect of the 2003 inflow on cod recruitment should be estimated by the assessment WG, using different suitable recruitment models and spatial information.

The work done on changes in cod maturity at age should be included in the 2005 assessments. In the longer term more investigation is needed of the role that the high biomasses of sprat may be playing in the continued poor state of cod. However, until more is known about the relationships among cod, herring, sprat, and environmental conditions, no immediate measures can be recommended to address this relationship in the assessment or management processes. However the assessment WG should consider ways that the consequences of cold winters on sprat recruitment can be implemented in stock projections.

## 3.9 Bay of Biscay – Iberian waters

### 3.9.1 Environmental Anomalies

The freshwater river runoff into the Bay of Biscay has been below average for the past three years. This has been shown to be associated with poor recruitment to flatfish.

There is good evidence that the intensity of northerly winds is related with anchovy recruitment, through the effect of the winds on upwelling. The 2004 upwelling was not greatly different from average.

### 3.9.2 Opportunity to Address in Assessment Process

Assessment of flatfish stocks in the Bay of Biscay should include pessimistic assumptions about recruitment since 2003.

The assessment of anchovy does not need to make a special accommodation for the effect of upwelling on recruitment.

# 4 Longer term considerations for management strategies and scientific advice

In the process of preparing the ecosystem overviews, the Working Group identified a number of environmental factors and ecosystem effects of fishing which were considered to be important for the management approaches which should be followed. These were not readily dealt with by short term changes to the practices of ICES Assessment Working Groups or Advisory Committees. Rather, they required investments of time and expertise by ICES scientists and Expert Groups, to build sound scientific foundations for management approached taken ecosystem considerations into account, and to develop the advisory and strategic tools for implementation of the approaches.

From these ecosystem and environmental aspects of strategic management approaches, WGRED selected a subset which were considered to be both of high priority, and for which ICES is in a uniquely strong position to draw the necessary mix of experts to attack these issues. We present each of these topics, with a statement of the ecological issue and a clear prescription of what we think ICES and its Expert Groups should do to make progress. Although together the list represents a significant workload challenge to ICES, many of the different initiatives below would engage different groups of experts already associated with the ICES community. Hence it is possible to make progress simultaneously on all these issues, although some are inherently longer term than others. Moreover, unless progress is made on all of these issues, ICES and the management agencies it advises will not be able to make substantial progress on implementing an ecosystem approach to management of fisheries and other human activities in the sea.

## 4.1 Rebuilding strategies

Many of the stocks assessed by ICES are outside safe biological limits and for some rebuilding plans have been adopted. These plans have been designed using conventional stock assessment models with added random noise. This may be problematic for at least two reasons:

1. In a number of cases strong correlations have been identified between environmental variables and fish distribution, recruitment and growth. Changes in environmental parameters often show a fair amount of autocorrelation and assuming residual noise to be random in medium predictions of recruitment or growth may therefore lead to biased predictions.
2. In many ecoregions the fish community has changed considerably in recent years. In the North Sea the relative abundance of small individuals and species has increased in trawl survey catches at the same time as traditional forage fish such as sandeel and Norway pout have declined. In the Baltic the change in the clupeoids is likely to have altered cod growth, maturity and larval survival. In northern regions changes in the abundance of herring and capelin has affected cod growth and maturity.

Some of the priority issues to investigate are the influence of changes in environmental and tropic drivers on rebuilding strategies. Major points include:

- What is the typical pattern of auto- and cross correlation of the major environmental drivers influencing growth and recruitment and how will this autocorrelation impact on medium term single species predictions?
- How will medium term predictions be influenced by changes in trophic interactions?
- Will the generally observed change in the proportion of small fish in heavily fished systems increase or decrease the likelihood of stock recovery following reductions in fishing mortality?

- What is the joint effect of changes in trophic interactions and environmental drivers on medium term predictions? E.g. How will medium term predictions for North Sea gadoids be influenced by changes in the North Sea ecosystem such as the reduction in forage fish, the general increase in small sized species, and changes in environmental parameters?

## 4.2 Reference points and regime shifts

Since the mid 1990s ICES has based its fisheries management advice on precautionary reference points for Spawning Stock Biomass (SSB) and Fishing Mortality (F). These reference points usually were estimated using all the historic data available on SSB and productivity (recruitment), to estimate a single limit and associated precautionary Reference Point for each of SSB and F. Although ICES is currently developing the advisory framework to address management strategies and control rules which are more complete than just remaining inside precautionary reference point boundaries, it generally has retained the approach of developing management rules for a stock as if productivity dynamics were the result of a noisy but homogeneous process.

There is now strong evidence that meteorological and ocean climate variation on longer term (decadal or near-decadal) scales affects the productivity of many exploited fish stocks. These longer-term productivity changes are often referred to as regime shifts, (although some debate remains about exactly what comprises a “regime shift”, see overview in Table 4.1).

For stocks where the productivity per spawner is affected by oceanographic conditions or the status of dominant predators or prey, and those conditions have regime-like variation, then there are a number of implications for biologically sound reference points, control rules, and management strategies. For example:

- Sustainable exploitation rates of a stock will differ in high and low productivity regimes.
- Biomasses necessary to ensure full stock productivity will differ by regime.
- Control rules and strategies providing a low risk of unsustainable harvesting in one regime may pose very different risks of unsustainable harvesting in another regime.
- Reference points estimated, or control rules and management strategies evaluated using long time series as if they reflected homogenous but variable dynamics of stock productivity may be unreliable in any of the actual productivity regimes.

ICES has started to give increased attention to this problem in a theme session at the 2004 ASC in Vigo. To take the work further, a group of ICES scientists containing both experts in fish population dynamics and management strategies, and experts in ecosystem dynamics and environment-fish interactions needs to investigate these issues as a high priority. Their results should be incorporated fully in reference points, control rules and management strategies used in the provision of advice by ICES.

**Table 4.1 Definitions of regime, regime shift, and species replacement/alternation (adapted from Jarre *et al.* (submitted)**

| REFERENCE | DEFINITION |
|---|---|
| | *Regime* |
| Mantua (2004) | A period of quasi-stable biotic or abiotic system behaviour where temporal variations in key state variables are concentrated near distinct dynamical attractors, or stability wells, within phase space. |
| Lluch-Belda *et al.* (1989,1992) | Prolonged periods of high or low abundance of species. |
| Isaacs (1976) | Distinct climatic and/or ecosystem states and is multifarious, involving biology or climate, or oceanography, or migrations, temperature, or weather, or combinations of these. |
| | *Regime shift* |
| Bakun (2004) | Persistent radical shift in typical levels of abundance or productivity of multiple important components of marine biological community structure, occurring at multiple trophic levels and on a geographical scale that is at least regional in extent. |
| Cury and Shannon (2004) | Sudden shift in structure and functioning, which affect several living components and which result in an alternate state. |
| Wooster and Zhang (2004) | Abrupt change in a marine ecosystem and its abiotic environment from one stationary state to another. |
| Polovina (2004) | High-amplitude changes in community composition, species abundance and trophic structure, thought to be a response to shifts in the oceanic and atmospheric climate, and therefore relatively coherent with climate changes. |
| de Young *et al.* (2004) | Changes in marine system structure and functioning that are relatively abrupt, persistent, occurring at large spatial scales, observed at different trophic levels, and related to climate forcing. |
| Mantua (2004) | Relatively brief time period in which key state variables of a system are transitioning between different quasi-stable attractors in phase space. |
| Mantua and Hare (2002) | Abrupt change in relation to the duration of a regime, from one characteristic behaviour to another. |
| Reid *et al.* (2001) | Large decadal-scale switches in the abundance and composition of plankton and fish. |
| Miller and Schneider (2000) | Change from a persistent and relatively stable period of biological productivity after a similarly stable period in physical oceanographic variables. |
| Caddy and Garibaldi (2000) | "Punctuated equilibria" involving fundamental changes in ecosystems and reflecting ecological change. |
| Beamish and Mahnken (1999) | The process whereby a large marine ecosystem that is climate-linked, undergoes a shift in state over a 10-30 year period, and to which fish and other marine biota respond by changes in their dynamics; |
| Steele (1996, 1998) | Concurrent change in several stocks at longer time scales, and causally connected<br>Implies a coherent response, at the community level, to external stresses. |
| Lluch-Belda *et al.* (1989,1992) | Dramatic and long-lasting switches between periods of sardine and anchovy-dominated states in upwelling systems of eastern boundary current systems. |
| *Species replacement or alternation* | |
| Cury and Shannon (2004) | Species composition of an ecosystem changes, but ecosystem is not necessarily altered in terms of its structure (e.g., food-web, size composition) and functioning. |
| Lluch-Belda *et al.* (1992) | Negative correlation observed between similar species (e.g. sardine and anchovy) in the same ecosystem |

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## 4.3 Fish population structure:

To facilitate management advice, marine fishes are often assessed by fixed fishing areas, which suppose the existence of isolated stocks. This introduces an obvious risk of neglecting structuring elements within the unit stock area such as the existence of more or less isolated subpopulations, migratory behaviour, spawning site fidelity and dispersal patterns. Concepts and information on population structure is of pivotal importance for the accuracy of stock assessments, and consequently, for fisheries management. Without such knowledge of structuring elements, conclusions drawn from assessment work, and fishery biology studies in general, might simply be irrelevant and misleading.

Notwithstanding uncertainties concerning fish population structure in many regions, a multitude of historic spawning sites are well known from various parts of the North Atlantic (Hutchings *et al.* 1993; Lawson and Rose 2000). Recent studies on the cod stock complex off Newfoundland and Labrador have pointed out important structuring elements as well as in European waters (e.g. Knutsen *et al.* 2003). Ruzzante *et al.* (1996, 2001) and Green and Wroblewski (2000) provide evidence of discrete cod (sub-)populations in the coastal waters relative to offshore populations. It may be argued that such population elements are important aspects of the metapopulation structure of many commercial marine fishes. Consequently, remaining fish spawning aggregations may thus not necessarily give a reassurance of a readily recovery of the stock biomass, even if the fishing intensity would be substantially reduced (Smedbol and Stephanson 2001; Smedbol and Wroblewski 2002). This put an urge on the need for a rather specific knowledge in population structure of many marine fish stocks. Following action points should be considered:

- Compile on-going stock identification projects
- Review and give recommendations on stock identification methodology
- Investigate research needs both concerning stock identification methodology and metapopulation processes, such as re-colonisation rates
- Put together an inventory on species/stocks whose population structure possibly need to be studied/ revised
- Give recommendations on short term actions, such as documentation of spawning sites either by historic records (e.g. fishermen's knowledge) or by research activities
- Develop management strategies for marine fish stocks in relation to complex population structure

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## 4.4 Development of management in response to an environmental signal; example Biscay anchovy and sardine

One subset of the ecosystem approach to fisheries management (EAFM) would be the use of an environmental signal directly as a component in the advice offered to management on a particular fishery. For this to be operational there should be a proven strong link between the signal and some key component of the assessment/prediction process. Ideally, the link should NOT be based on correlation but on an *a priori* and validated hypothesis.

A candidate for such an approach is the link between anchovy recruitment and upwelling and stratification in the Bay of Biscay. The original work on this subject by Borja et al (1998) suggested that the strength of upwelling could be used as a predictor of recruitment level. The derived index had some utility, but was not sufficiently accurate. The hypothesis was elaborated by Allain et al (2001) and a stratification breakdown index included. In the latest report of this model to WGMHSA (Anon. 2005), it was concluded that the model was robust at predicting poor recruitment, although performed less well for medium levels. The WG agreed with this potential use for the model.

The challenge for the advisory system is how to incorporate such an understanding into the prediction and advice process. One possibility is to use the model to decide on the recruitment levels used in the projection. When the model suggests poor recruitment, projections could be made using an average of the lowest historical recruitments e.g. the bottom 25 percentile or some similar measure. Alternatively, the projection could be run with a historic mean recruitment, or a survey derived estimate, and the advice conditioned on the perception from the environmental index. In either case it should be recognized that the model predictions cannot be guaranteed, but do have a good probability of being correct. It is arguable that landings and survey data should be considered in the same way. The managers should be aware that either strategy (using or not using this model) carries risk, and that the management process should recognize this. A similar use of environmental indicators for anchovy has been proposed in South Africa along with a operational approaches (Korrûbel et al 1999, Miller & Field 2002).

If they are serious about the EAFM, ICES, ACFM and the managers should agree on a method to operationalise this use of an environmental indicator, and to deal with the possibility of inaccuracy in the projection. The retrospective performance of the model and the method of operationalisation should be evaluated by external referees before implementation.

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## 4.5 Bycatch of low productivity species in trawl fisheries

Many large and vulnerable species e.g. elasmobranchs like sharks and rays, may be subject to unsustainable mortality rates even when taken as bycatch in mixed fisheries. Management plans should evolve to take account of the status of these species when providing management advice for target stocks. Methods exist to quantify fishing mortality on these species and to estimate their vulnerability to that mortality (e.g. Pope *et al.,* 2000).

Possible measures to be taken to prevent bycatches includes:

- Regulation of quotas and effort with regard to vulnerable species
- Avoiding areas where bycatches of vulnerable species are high
- Develop bycatch and mortality reduction measures

Managers should also carefully consider the consequences of management measures for vulnerable species, with regard to redistribution of effort to other fishing grounds or fisheries following e.g. closures and effort regulations.

With few exceptions, the spatial distribution of catches of vulnerable species are not known. In addition, since these species are now threatened and therefore rare, gathering this information is difficult. In the north Atlantic, the problem with bycatches of vulnerable species is largest in mixed demersal trawl fisheries and also in e.g. deep sea long-line fisheries.

Recommendations for further research to improve the assessment of elasmobranches have mainly been developed by the DELASS project (Heessen 2003). The recommendations are:

- Gather spatial distribution for vulnerable species.
- High priority should be given to establishing market sampling and observer programs to provide information on species compositions of catches and landings, where such information is missing.
- Detailed species-specific data on length, weight, sex, age, maturity, fecundity etc. should be collected.
- There is a need to improve knowledge of species- and age-specific data on natural mortality, reproduction, gestation period, spawning areas, nurseries, etc.
- Data collection for pelagic and deep-water sharks caught in international waters should be improved and standardised in accordance with other organisations (e.g. ICCAT) involved in fisheries management, including a consideration of the distribution of different life-history stages that inhabit international waters.
- Species identification skills should be improved.
- There is an urgent need for a user-friendly identification guide for elasmobranchs in European waters.
- Archived survey data should be further explored to construct time series of abundance and for use in biodiversity analyses.
- Data from existing surveys and observer programmes should be analysed to provide information on vulnerability and stock status of less common elasmobranch species.
- Biodiversity conservation and the status of rare, threatened and declining species is an area of growing concern. More work focusing on these aspects is needed to allow an evaluation of the ecosystem effects of fishing on these vulnerable species.

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## 4.6 Enhanced ecosystem process understanding in management

The present basis for ecosystem function understanding is biased towards relatively easily measurable physical (eg. temperature, salinity) and biological (eg. standing stock biomasses, species and size distribution) parameters, and derivates of these. Temperature and other physical parameters sets important limits to biological distribution and productivity but give little insight into and understanding of important ecologic processes governing major marine biological fluxes and productivity.

For a future success of ecosystem management a systematic shift towards more process oriented research strategies is strongly recommended. The ultimate aim for such a shift will be to qualitatively and quantitatively describe an increasing number of major driving ecologic processes and their inclusion in various management models. A rare example of such process understanding and inclusion in management models is the capelin larvae - young herring relationship in the Barents Sea. Candidate potent processes are numerous within and between the ecosystems described.

A shift in the proposed direction will be costly and often conflicting with optimal measurement strategies for different parameters. A conceptual discussion with the aim of developing an appropriate balance between process-based investigations and systematic measurement investigations is recommended as an important starter.

## 4.7 Deep water Fisheries

### 4.7.1 Effect of Deep water fisheries on the ecosystems

Deep water species are typically; slow growing, long lived, late maturing and of low fecundity, essentially they represent a low productivity. As a result the standing biomass is high compared to the sustainable yield and for most species sustainable catches are as low as a few percent of the biomass (Koslow *et al.* 2000). Moreover, some species are aggregative and modern fishing fleets have proved to be efficient at detecting and fishing down such concentrations. However, more dispersed species such as roundnose grenadier can also be overexploited. The low productivity of the target species requires very low exploitation rate to achieve sustainability.

Discards in these fisheries are a compound of a large biomass of unpalatable smoothheads and numerous small species so that the whole deep sea fish biomass tends to be depleted. It is suspected that the discarding of these fish encourages small scavenging eel like species *vs* other foraging strategies, thus potentially altering the species as well as functional diversity of the community. Lastly, the main commercial target species in the ICES area (Roundnose grenadier) is subject to discards of juveniles that will lower the potential future yield.

Benthic fauna in deep waters is also understood to be diverse and of low productivity. The obvious example is deep water corals, which is also very sensitive to trawling. However, fishing vessels risk gear damage on such areas, so their choosing to continue fishing on deep water corals should be considered as a clue to the depletion of deep water fish over adjacent soft bottoms. Exploiting deep sea fish at their MSY should not then require fishing on these coral grounds. On the contrary, banning fishing on coral should prevent depletion of some deepwater stock below safe biological limits.

Gillnets can easily come fast on corals reefs and are highly prone to generating ghost fishing thereafter. Some, but not all, deepwater stocks can be exploited from longline. A deepwater trawling fishery for Patagonian toothfish (*Dissostichus elegenoides*) was successfully switched to longline around the Kerguelen Island (south Pacific Ocean). Such a switch could be considered for fisheries in the ICES area. However, neither orange roughy or roundnose grenadier are susceptible to longlines so a properly managed trawl fishery may be acceptable for these species. Such a fishery should be restricted to particular soft seabed areas (e.g. the west of Scotland slope) and trawlers licensed for deepwater fishing should not be allowed to fish elsewhere in the deepwater.

Current TACs will not be sustainable. Regarding the fleets the commissioning of new vessels to replace those built before the start of the fishery clearly corresponds to an increase in fishing capacity, making management more difficult. Allocation of an access right to deepwater fisheries is probably the best way to reconcile capacity and sustainable yields.

Required management actions

- Reduce TACs
- Allocate individual fishing rights
- Restrict trawling to a few predominantly soft bottom areas
- Turn half or more of the fishing capacity into longlining fleet
- Set coral areas as MPAs

Further research to be done include:

- Inventory of fragile deep water habitat in order to provide suitable advice for area management (including accurate location of desirable MPAs)
- Sustainable harvesting strategies for low productive and high catchability (aggregative) target species
- Analysis of discards data in particular those from on-board observations collected in compliance with EU regulation no 2347/2002 from council of 16 december 2002.

### 4.7.2 References

Koslow J.A., Boehlert G., Gordon J.D.M., Haedrich R.L., Lorance P., Parin N., 2000. Continental slope and deep-sea fisheries: implications for a fragile ecosystem. ICES J. Mar. Sci., 57, 3, 548-557.

# 6 Recommendations

Management strategies should take account of ecosystem considerations, but currently few or none do. ICES needs to focus its diverse expertise on development of such strategies.

**Recommendation 1:**

A provision has to be made within ICES so that members of Expert Groups which are working on management strategies and Expert Groups which are working on ecosystem issues will collaborate on methods to include for each ecoregion, environmental and ecosystem considerations in the management strategies and advisory frameworks to be used by ICES. A start could be made by having the relevant Expert Groups meet jointly, and there would be value to a Theme Session on the topic at an ASC. In the medium term making progress on this work is likely to require redistribution of responsibilities among some of the current Expert Groups and possibly creation of one or more new groups. The existing focus on management science in SGMS should take account of ecosystem considerations. This could be facilitated by having SGMS and WGECO meet concurrently in 2006, with a ToR to collaborate on this topic.

One of the key tasks of WGRED was to identify emerging major environmental changes that need to be considered by assessment WGs in carrying out their work. For this to be done effectively, these environmental changes should be identifiable in the same time scale as the most recent fisheries data used by these WGs, and be available before the assessment season begins. Hence we would seek to use environmental data from the preceding year when providing suggestions and guidance to the assessment WGs scheduled to meet following our meeting each year. WGRED recognises that it may not be possible to obtain synthesised environmental data this quickly, and that existing Expert Groups and Science Committees are likely most knowledgeable of what is possible to provide on these time-scales.

**Recommendation 2:**

Key environmental WGs, particularly those under the Oceanography Committee and ACE, should provide WGRED with a guide to key diagnostic indicators that could be consulted at the time of the WGRED meeting in February. Ideally these indicators should be specific to eco-region and substantiated by previous research. They would be made available to WGRED when it meets annually, and augmented by any additional ecosystem or environmental signals which the Expert Groups thought were of particular importance that year. As an extension of this WGRED recommends that key environmental WGs, particularly those under the Oceanography Committee and ACE be invited to provide eco-region specific descriptions of their expert area, acknowledging the overall size limit expected for these Ecosystem Overviews in the ICES Advisory Documents.

**Recommendation 3:**

To support 2) WGRED recommends that ICES develops a global approach to the use of eco-regions or RACs to provide coherent data provision across activities. Non exclusive examples would be the use of eco-regions in the preparation of the ICES Annual Ocean Climate Status Summary, and commercial catch distributions.

In addition to the role of WGRED in facilitating the inclusion of environmental and ecosystem considerations in the annual work of Assessment working groups and their tactical advice, there is longer term need to include these considerations in management strategies and strategic advice. These tasks are likely to require use of more synthetic indicators of the state of ecosystem components, and indicators specific to the management approached being applied.

**Recommendation 4:**

One or more Expert Groups within ICES, including WGRED, WGECO [others] should review the results of the Symposium on Quantitative Ecosystem Indicators in Fisheries Management, and other relevant sources, with the objective of selecting a tractably small but ecologically meaningful set of ecosystem indicators whose values could be prepared routinely for each ecosystem, for inclusion by WGRED in the annual updates of the Ecosystem Overviews. They would also consider from time to time progress on process-based studies of stock and ecosystem dynamics, and ensure that indicators appropriate for inclusion in management strategies and/or assessment approaches were being made available on appropriate time scales.

# Annex 1: PARTICIPANTS LIST

## WORKING GROUP FOR REGIONAL ECOSYSTEM DESCRIPTION

## ICES Headquarters

## 14 – 18 February 2005

| NAME | ADDRESS | TELEPHONE | FAX | E-MAIL |
|---|---|---|---|---|
| Jake C. Rice | Canadian Stock Ass. Secretariat<br>200 Kent Street, Stn 12036<br>Ottawa, ONT K1A 0E6<br>Canada | +1 613 990 0288 | +1 613 954 08 07 | icej@dfo-mpo.gc.ca |
| Manuel Barange | Plymouth Marine Laboratory<br>Prospect Place<br>Plymouth PL1 3DH<br>United Kingdom | | | m.barange@pml.ac.uk |
| Maria .F. Borges | IPIMAR<br>Avenida de Brasilia<br>P-1449-006 Lisbon<br>Portugal | +351 21 302 7098 | +351 21 301 5948 | mfborges@ipimar.pt |
| Massimiliano Cardinale | National Board of Fisheries<br>Institute of Marine Research<br>Box 4<br>SE-453 21 Lysekil<br>Sweden | +46 523 187 501 | +46 523 13977 | massimiliano.cardinale@fiskeriverket.se |
| E. Gaard | Faroese Fisheries Laboratory<br>Nóatún<br>P.O. Box 3051<br>FO-110 Tórshavn<br>Faroe Islands<br>Denmark | | | eilifg@frs.fo |
| Henrik Gislason | Danish Institute for<br>Fishery Research<br>Charlottenlund Slot<br>DK-2920 Charlottenlund<br>Denmark | | | hg@dfu.min.dk |
| Henk Heessen | Netherlands Institute for<br>Fisheries Research<br>Haringkade 1<br>P.O. Box 68<br>NL-1970 AB IJmuiden<br>Netherlands | +31 255 564 692 | +31 255 564 644 | henk.heessen@wur.nl |
| Kjellrun Hiis-Hauge | Institute of Marine Research<br>P.O. Box 1870 Nordnes<br>N-5817 Bergen<br>Norway | | | kjellrun.hiis.hauge@imr.no |
| Joakim Hjelm | National Board of Fisheries<br>Institute of Marine Research<br>Box 4<br>SE-453 21 Lysekil<br>Sweden | | | joakim.hjelm@fiskeriverket.se |

| NAME | ADDRESS | TELEPHONE | FAX | E-MAIL |
|---|---|---|---|---|
| Jens Christian Holst | Institute of Marine Research<br>P.O. Box 1870 Nordnes<br>N-5817 Bergen<br>Norway | +47 55 238500 | +47 55 238531 | jens.christian.holst@imr.no$ |
| Astrid Jarre | Danish Institute for Fisheries Research<br>P.O. Box 101<br>9850 Hirtshals<br>Denmark | +45 3396 3255 | +45 3396 3260 | ajt@dfu.min.dk |
| Simon Jennings | CEFAS<br>Lowestoft Laboratory<br>Lowestoft<br>Suffolk NR33 0HT<br>United Kingdom<br>$ $  $ | +44 1502 562244 | +44 1502 513865 | s.jennings@cefas.co.uk |
| Andrew Kenny | CEFAS<br>Burham-on-Crouch Laboratory<br>Remembrance Avenue<br>Burnham-on-Crouch<br>Essex CM0 8HA<br>United Kingdom | | | a.j.kenny@cefas.co.uk |
| Santiago Lens | Inst. Español de Oceanografía<br>Centro Oceanográfico de Vigo<br>Cabo Estay - Canido<br>Apdo 1552<br>E-36200 Vigo<br>Spain | | | santiago.lens@vi.ieo.es |
| Pascal Lorance | IFREMER<br>150, Quai Gambetta<br>F-62200 Boulogne-sur-Mer<br>France | +33 298224040 | | pascal.lorance@ifremer.fr |
| Carmela Porteiro | Inst. Español de Oceanografía<br>Centro Oceanográfico de Vigo<br>Cabo Estay - Canido<br>Apdo 1552<br>E-36200 Vigo<br>Spain | +34 986 492111 | +34 986 492351 | carmela.porteiro@vi.ieo.es |
| Dave G. Reid | Fisheries Research Services<br>Marine Laboratory<br>P.O. Box 101<br>375 Victoria Road<br>Aberdeen AB11 9DB<br>United Kingdom | +44 1224 295 363 | +44 1224 295 511 | reiddg@marlab.ac.uk |

| NAME | ADDRESS | TELEPHONE | FAX | E-MAIL |
|---|---|---|---|---|
| Mattias Sköld | National Board of Fisheries<br>Institute of Marine Research<br>Box 4<br>SE-453 21 Lysekil<br>Sweden | | | mattias.skold@fiskeriverket.se |
| Henrik Søiland | Institute of Marine Research<br>P.O. Box 1870 Nordnes<br>N-5817 Bergen<br>Norway | | | henrik.soiland@imr.no |
| Henrik Svedäng | National Board of Fisheries<br>Institute of Marine Research<br>Box 4<br>SE-453 21 Lysekil<br>Sweden | | | henrik.svedang@fiskeriverket.se |
| Mark Tasker | JNCC<br>Dunnet House<br>7, Thistle Place<br>Aberdeen AB10 1UZ<br>United Kingdom | + 44 1 224 655 701 | + 44 1 224 621 488 | mark.tasker@jncc.gov.uk |
| Bill Turrell | Fisheries Research Services<br>Marine Laboratory<br>P.O. Box 101<br>375 Victoria Road<br>Aberdeen AB11 9DB<br>United Kingdom | +44 1224 876544 | +44 1224 295511 | B.Turrell@marlab.ac.uk |