



Bottom Trawling and Scallop Dredging in the Arctic

Impacts of fishing on non-target species, vulnerable
habitats and cultural heritage

Authors:

*Elena Guijarro Garcia (ed.), Stefán A. Ragnarsson,
Sigmar A. Steingrímsson, Dag Nævestad, Haukur Þ. Haraldsson,
Jan H. Fosså, Ole S. Tendal, Hrafnkell Eiríksson*

Collaborators:

Unnur Skúladóttir, Rikke Frandsen, Helle Siegstad

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Nordic Council of Ministers

Store Strandstræde 18
DK-1255 Copenhagen K
Phone (+45) 3396 0200
Fax (+45) 3396 0202

Nordic Council

Store Strandstræde 18
DK-1255 Copenhagen K
Phone (+45) 3396 0400
Fax (+45) 3311 1870

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Summary

The project *Bottom trawling and dredging in the Arctic* has been carried out within the frame of the Nordic Action Plan 2000–2004, with the aim of improving basic knowledge and strengthening environmental monitoring in the Arctic.

The scallop and shrimp fisheries constitute an important part of the report because the impact on non-target species, geological features and cultural heritage of these fisheries is not well-known despite the large fishing effort they have sustained since the early 1970s. However, the impact of other fishing gear in vulnerable habitats is also acknowledged. The report also includes information on the presence and conservation status of cultural heritage within the study area, which constitutes one of the priorities of the Nordic Action Plan 2000–2004. Finally, protection and conservation strategies implemented in the study area are reviewed, with a mention to cultural heritage and the need for implementation of more marine protected areas.

Recommendations (Chapter 1)

Findings from this report form the basis of our recommendations, which can be divided into three main categories:

- Recommendations that highlight the need to map the distribution of vulnerable habitats and species and cultural heritage.
- Recommendations to increase research effort.
- Recommendations to implement management measures aimed to protect areas with known occurrences of vulnerable habitats and species, or that need to be closed to fishing to avoid depletion of target stocks. Other management measures suggest a wider implementation of sorting grids in the Arctic to protect non-target species and closures to protect archaeological remains.

In addition, the working group highlighted a number of other issues that are relevant for future work and could serve as guidelines. These issues were not formulated as recommendations because the working group felt they were not directly related to the scope of this project. They concerned, for example, the need to implement networks of marine protected areas, the need to protect areas that are still not affected by fishing gears and the implementation of mandatory environmental assessment prior to the use of new fishing grounds.

The scallop fisheries in the Northeast Atlantic (Chapter 2)

This review is mostly based on grey literature written in Icelandic, Danish or Norwegian, some of which is difficult to access.

The start of the Iceland scallop fishery in Iceland, Greenland and Norway (Svalbard, Bjørnøya and Jan Mayen) followed the discovery of virgin scallop beds made up of old, large specimens in very high densities.

The Icelandic fishery dates from 1969. Catches and fleet size increased steadily in spite of the implementation of management measures in 1973 and low market prices during the years 1973–1977. Landings in Breiðafjörður reached a maximum of over 12,000 tonnes in 1985 and 1986. Catches decreased subsequently and by 2003 the stock had declined to 35% of its size during the years 1993–2000. As a precautionary measure the fishery has been closed since the fishing season 2003–2004. Causes for this decline are being investigated but are still unclear. It is most likely that some of the factors contributing are too high fishing effort, increased sea bottom temperature in summer and the presence of cyst-forming protozoan parasites (*Coccidia*) in adult scallops. However, the great variability in the increase of natural mortality in different scallop banks within Breiðafjörður suggests that there might be other still unknown reasons to explain the observed mortality.

Scallop dredging commenced in West Greenland in 1983. The stock is not very large, but fishing was driven by social issues. Nuuk is the only locality where the scallop fishery has been operating since 1984 and where catches are higher. Annual catches ranged from 400–1,900 tonnes during the period 1988–1992 and from 1,200–2,600 tonnes since 1995. The main problem of this fishery has been the impossibility to estimate accurately the stock size and the appropriate fishing mortality due to lack of background data and resources to implement a monitoring program. There have been no surveys since 1994 and the total allowable catch (TAC) is fixed at 2,000 tonnes and based on catches from previous years.

The Norwegian fishery started in 1984 in Jan Mayen. The stock was reduced from 30,000 to 8,000 tonnes in 1986, and the fleet turned to Svalbard. Annual catches amounted to 44,100 and 19,000 tonnes in 1987 and 1988 respectively, and declined afterwards to 3,000–7,000 tonnes. The archipelago was closed to dredging in 1995.

The failure of the Iceland and Norway fisheries might have been prevented by taking into account the recruitment processes, which are largely unknown within the study area but essential in management of stocks that are self-recruiting, as scallop beds seem to be, and where the fishery depends on year-class strength.

Effects of dredging on the benthic community in Breiðafjörður, West Iceland

By-catch data from scallop stock assessment surveys and fishing effort data from the commercial scallop fishery were used in this study. By-catch represented 28% of the total catch, with eight benthic macrofaunal taxa alone making up nearly 98% of the by-catch. The macrofaunal benthic community in Breiðafjörður consisted mostly of hard-shelled molluscs, holothurians, crabs and starfish that are characteristic of disturbed communities. Emerging epifauna was absent in all the samples taken since 1993.

The data used in this study do not show evidence of major impact of scallop dredging on distribution and abundance of by-catch taxa. However, scallop dredging started in 1970, whereas by-catch data have been available only since 1993. Previous studies in other countries concluded that effects of fishing are more severe in the early phase of the fishery, which involves the loss of epibenthic biogenic structures and their associated fauna. It is therefore most likely that scallop dredging had already altered the benthic community by removing effectively the sensitive species before by-catch data started to be collected. Thus the current macrofaunal assemblage might be very resilient towards physical disturbance, hence the apparently small effect of fishing effort on the benthic community in Breiðafjörður.

The offshore shrimp fisheries in the Northeast Atlantic (Chapter 3)

Most of the information for this review has been obtained from NAFO SCR Documents in the case of Greenland, ICES CM papers and annual reports from the research institutes involved in stock assessment of the shrimp stocks under study.

The Icelandic offshore shrimp fishery started in 1975. Landings rose from 1,000 to 66,000 tonnes between 1977 and 1997, and they have constituted between 68 and 94% of the annual catch since 1984. The first signs of overfishing were detected in 1987, when the first TAC was set, and catches decreased during a few years despite the discovery of new fishing grounds. Good recruitment allowed catches to rise steadily from 1990 to 1996. However, catches and stock index have decreased markedly since then, with a minimum catch for the period 1998–2003 of 21,500 tonnes in 2000. It has been suggested that predation by cod is an important factor affecting shrimp stock size, but mortality due to predation seems to be similar to fishing mortality.

The Greenlandic offshore shrimp fishery is the largest by far in the Northeast Atlantic. It started in 1970 in West Greenland with landings of 1,200 tonnes and it has contributed with 59 to 89% of the annual catch

since 1974. Offshore catches have reached a maximum of 113,000 tonnes and a stock estimation of around 300,000 tonnes in 2004. This spectacular growth has been possible because of the spatial expansion of the fishery and the fleet improvement over the past three decades. Other fishing grounds on the East coast, between 65°N–67°N, have been fished since 1978. The discovery of more fishing grounds in 1993 extended the East fishery south to Cape Farewell. However, catches in the East have oscillated between 5,000 and 15,000 tonnes during the period 1980–2004, and unlike the fishery on the West coast, most of the catch is taken by foreign countries.

The main problem of the shrimp fishery in Greenland is its overlapping with nursery areas of redfish, Greenland halibut, cod and other groundfish species, some of which show declining trends of biomass and abundance. By-catch has been reduced with sorting grids and closures since 2000, but it is likely that ecological processes only partially understood, such as the trophic web and hydrography of the area also influence largely the stock abundance of the demersal community.

The offshore Norwegian shrimp fishery started in 1973 and the main fishing grounds are in the Svalbard area and Barents Sea. Catches and stock size fluctuate largely. Shrimp stock size seems to be largely dependent on abundance of predator species (mostly cod), the annual hydrographic variability in the presence of different water masses in the area, and consequently on the location of the Polar front. Shrimp mortality in the Barents Sea due to predation is similar to fishing mortality, and therefore fishing effort probably accounts for part of the observed variability in stock size.

There is a large population of juvenile cod, haddock, redfish and Greenland halibut found within the shrimp fishing grounds. The implementation of sorting grids in 1991 was not enough to solve the by-catch problem, and a bioeconomical model has been applied since 1993 to estimate the allowable maximum catches of the commercial by-catch species mentioned above. However, this strategy has not produced the expected results, and all the commercial fish species found in the shrimp grounds are currently below safe biological limits.

By-catch in the offshore shrimp fishery in North Iceland

By-catch data from shrimp stock assessment surveys, groundfish surveys and by-catch and fishing effort data from the logbooks supplied by the shrimp fleet were analysed for this study. During the period 1988–1994, prior to the introduction of sorting grids in 1995, reported by-catch represented between 2.7 and 7.3% of the shrimp catch, cod and Greenland halibut being the most abundant by-catch species landed.

Abundance of demersal fish, considering the 71 species recorded in shrimp and groundfish surveys, has been decreasing since 1997 despite

the marked reduction of by-catch in the commercial fleet and fishing effort. However, this study did not find a clear relationship between fish abundance and fishing effort, but the results could be influenced by lack of by-catch data since the beginning of the fishery.

Vulnerable habitats (Chapter 4)

Deep-water corals

Habitat-forming deep-water corals include soft corals, such as Alcyonacea, Pennatulacea and Gorgonacea; and stony, reef-building corals. The main reef-building species is *Lophelia pertusa*. Deep-water corals are patchily distributed in the Nordic waters.

Lophelia reefs, including reef complexes up to 40km long, are found along the Norwegian shelf break and in many fjords from the Swedish border to Finnmark.

L. pertusa in Icelandic waters is mainly confined to the Reykjanes Ridge and near the shelf break off the South coast of Iceland (commonly at 500 to 600m depth). Coral areas (possibly including *L. pertusa*) were known to exist close to the shelf break off NW and SE Iceland in the 1970s and 1980s. Other known coral areas are small. There are no records of *L. pertusa* off Greenland.

The distribution of soft corals (Gorgonacea and Pennatulacea) off Norway is not well-known, but several of the gorgonian species, e.g. *Paragorgia arborea* and *Primnoa resedaeformis*, are widely distributed and many of them are associated with the *Lophelia* reefs. Gorgonians are relatively uncommon on the shelf (< 500m depth) around Iceland, but they are found in relatively high numbers in deeper waters (> 500m) off South, West and North Iceland. Similarly, the pennatulaceans are more common in deeper waters, especially off South Iceland.

Several studies have shown that the deep-water stony corals provide a habitat for invertebrates and ground fish. More than 600 species associated with the *Lophelia* reefs off the coasts of Norway have been recorded, but this figure increases to 1,300 if we consider the whole Northeast Atlantic. Coral reefs are therefore important both from a general biodiversity perspective and as a habitat for commercial fish species. If coral reefs disappear, populations of associated species may have difficulty in sustaining themselves and significant changes in species distribution and diversity along the continental shelf and slope in the Nordic Seas may take place.

Similarly, deep-water gorgonian corals provide various microhabitats for other organisms but little is known about their ecological significance.

Deep-water corals are fragile, slow-growing and long-living. *L. pertusa* may grow 0.5–25mm a year and live for hundreds of years. Corals are, therefore, sensitive to fishing impacts and their recovery may take

centuries. Bottom trawling is the main threat to *Lophelia* reefs and soft corals. Severe damage to coral reefs has been documented on fishing banks and along the shelf break off Norway and Iceland. Longline and gill net fishing also causes corals to break but such disturbance is assumed to be limited compared to the effects of bottom trawling.

Norway was the first country in Europe to implement, in 1999, measures for protecting cold-water corals from fishing activities by prohibiting intentional destruction of coral reefs and protecting specific reefs from bottom-tending fishing gear. So far, five reefs off Norway have been protected. Protection measures for corals do not exist in Iceland or Greenland.

Sponges

Sponges (Porifera) are found under very diverse ecological conditions. Sponge-dominated biotopes have been found in a number of places in the Nordic Seas. In this report, such mass occurrences of sponges receive two different names; ostur, which is a restricted area where large sponges constitute more than 90% of the benthic biomass, and sponge ground, an area dominated by large sponges and their skeletons.

Ostur has not been reported from West Greenland. The available literature suggests mass occurrences of sponges off East Greenland in several locations. Ostur is also known to exist in a number of localities in the Denmark Strait and off North Iceland, some of which can be classified as sponge grounds. Comprehensive ostur and some sponge grounds are also present around the Reykjanes Ridge, off SW Iceland. Mass occurrences of sponges, mainly ostur, have been reported from waters off northern Norway, in the western Barents Sea and south and west off Svalbard.

Large sponges add a low three-dimensional structure to the bottom, thus increasing habitat complexity and attracting a large number of other species. No study has been conducted on the fauna associated with large sponges off Greenland, Iceland and Norway, but it has been estimated that fauna inside sponge grounds is at least twice as rich in species as the surrounding areas and faunal abundance is higher.

No investigation has been conducted on the impact of trawling on sponge communities in the Arctic. However, studies from other areas indicate that lumpy, non-flexible sponges – such as ostur – are most easily affected. Trawling causes physical damage to sponges, turns over their substrate (stones and boulders) and the resuspension of sediment affects sponge feeding.

Sponges are slow-growing species. Therefore, it will take a long time for a sponge-dominated area to recover even after partial destruction, and repeated disturbance may lead to permanent extirpation of the species in the area. No management efforts have so far been made in Norway, Iceland or Greenland regarding mass occurrences of sponges.

Maerl

Maerl consists of loose-lying coralline red algae and it is composed of living (upper sediment layers) and dead algae that accumulate in beds or banks. Maerl species have been reported from Norway and Iceland but no published accounts exist from waters off Greenland and Svalbard.

The three-dimensional structure of maerl provides a wide range of niches for infaunal and epifaunal invertebrates. Studies on maerl carried out outside the Arctic have shown that their biotic diversity can be high.

Scallop dredging and suction dredging have a severe negative impact on maerl beds and associated fauna. Despite this, scallop fishing has taken place on some maerl beds and there are initiatives to harvest maerl in Icelandic waters.

Hydrothermal vents and cold seeps

Hydrothermal vents occur in areas of deep tectonic activity. Cold seeps are another geographical feature involving emission of gases from the ground. Benthic communities around such phenomena are unique and many species are endemic.

Several hydrothermal vents have been found in Icelandic waters but their biota is not known. Trawling in areas where hydrothermal vents and cold seeps occur can cause long-lasting or irreversible damage to these geological features and their associated fauna. Due to lack of data on hydrothermal vent distribution in the Nordic Seas, it is difficult to assess whether they are under threat from trawling activities in these waters.

A type of cold seep (“mud volcano”) has been found south of Svalbard ($\approx 1250\text{m}$ depth) with a more diverse fauna than the adjacent non-seep areas. Areas with pockmarks have also been found north of Norway.

The impact of the fisheries on cultural remains on the seabed (Chapter 5)

The environmental conditions in Arctic waters favour the survival of cultural heritage. Wrecks have been found in excellent condition after 150 years on the seabed. There is a high potential of finding more well-preserved wrecks in open water and in deep fjords in inshore waters, where the conditions for preservation are exceptionally good, due to the low temperature and abundant fine sediments. A well-preserved vessel represents a time capsule where little is added or destroyed by later actions, as is often the case with archaeological remains on land.

In addition, areas like the coastlines of Troms (Norway) and Greenland have also the potential for finding Stone Age habitats and more recent remains, which have become submerged due to transgressions (elevations of the sea level).

Trawling and dredging have a great negative impact on wooden wrecks and artefacts on the sea bottom as fishing gear crushes, displaces and depletes the wreck sites on each passage.

Assessment of cultural heritage on the seabed

A limited study has been carried out to highlight the areas with the largest probability of accumulation of wrecks, and other cultural heritage in the Barents Sea, Spitsbergen, Iceland and Greenland waters. Systematic recording of submerged cultural remains in these areas is nonexistent, but there are available sources of knowledge on shipwrecking and past activities that suggest the existence of abundant unknown cultural material on the sea bottom. In the case of the Barents Sea, these potential archaeological sites overlap with the most heavily trawled areas.

Mapping and registering of cultural heritage on the seabed

It is important to map the cultural heritage in Arctic waters and to enforce the legislation available in all the Nordic countries that states that it is mandatory to report wrecks. According to the research carried out for this project, fishing fleets have never, or rarely, complied with these regulations, nor have survey vessels or other marine research expeditions. The Norwegian MAREANO project (Marine spatial database for Norwegian coast and sea areas) aims to establish a detailed topographical mapping of the seabed, incorporating seabed morphology, geological resources, contamination, biological diversity, natural environment, cultural heritage and marine resources.

Protection of natural and cultural heritage in the Arctic (Chapter 6)

Marine protected areas are used to conserve nature or cultural remains of high value and to protect target stocks in order to maintain sustainable fisheries. There are international and Nordic agreements on nature conservation, some of which have to do directly with marine conservation. The conservation management schemes are decided by national governments and can differ between countries. These are, however, based to some extent on the international guidelines (the IUCN categories) and legislation.

According to the IUCN definition, Iceland has two offshore MPAs, which include the islands Surtsey and Eldey, a smaller inshore MPA in Eyjafjörður to protect the hydrothermal vents found there and 13 coastal protected areas, one of them included in the Ramsar Convention. In addition, there are several offshore areas where fishing is restricted.

Greenland has four MPAs, of which only one is offshore and three are included in the Ramsar Convention. However, neither Iceland nor Greenland has applied a systematic approach to conservation. The location and size of the protected areas is not necessarily correlated with their value or importance and at the present stage these areas do not represent adequately their marine habitats. In contrast, the protection of nature in Svalbard is carried out systematically in order to conserve representative habitats.

There are currently six MPAs in Svalbard, three of them being national parks, one of them a nature reserve and two Ramsar sites. In addition, within the national parks there are three other Ramsar sites. There are also six areas with known occurrences of the cold-water coral *Lophelia pertusa* off the Norwegian coast that have been protected against fishing with bottom trawl.

National legislation in the Nordic countries and international legislation concerning cultural heritage on the seabed

In general, the national legislation of the Nordic countries offers adequate legal protection to cultural heritage on the seabed. The laws are, however, not always enforced. As for the protection of archaeological sites, only the Environment Act of Svalbard offers protection from trawling and dredging, although this is restricted to a 100m radius from the archaeological finds. However, this Act is currently not enforced.

The national legislation of the countries fishing in Arctic waters should comply with the international conventions, United Nations Convention Law of the Sea (UNCLOS) and the UNESCO proposal for a "Convention on the protection of the underwater cultural heritage" (not ratified). Such acts would make it possible to prosecute illegal activities. In 2003 Denmark added a paragraph on international waters to their legislation on cultural heritage, concerning Danish vessels and subjects. According to this, it is forbidden to inflict changes in the state of the cultural heritage objects under water. In considering bringing the national legislation of the other Nordic countries into compliance, this wording should be noted, as it protects the cultural heritage and its environment.

Some measures to improve the effectiveness of juridical measures at international, regional and national levels are suggested.

Marine protected areas as a fishery management tool in Arctic waters

Temporary and permanent closures are used as a fishery management tool in Arctic waters to protect spawning and nursery grounds. In Icelandic waters there are real-time closures that aim to reduce discarding of undersized fish and permanent closures that ban one or more gear types,

mainly otter trawl and longline. The size and boundaries of these areas have been subjected to considerable revision over time.

The main purpose of the closures in Norwegian waters is to protect spawning and nursery grounds and to minimize conflict between vessels using different gear types. The Norwegian management system includes permanent closures and real-time closures in areas open to fishing only part of the year or areas where fishing is limited to certain gear.

In Greenland, there are several areas off the West coast where the shrimp fishery is restricted with closures. Similarly, there is a closed area (the redfish box) off the East coast to minimize discarding of juvenile redfish.

We conclude that the establishment of marine protected areas could contribute to the sustainable use of fish stocks and conservation of vulnerable habitats, biological diversity, natural heritage and historical remains.

Sammendrag

Prosjektet *Bunntråling og dregging i Arktis* er blitt gjennomført innenfor rammene av Den nordiske handlingsplanen for 2000–2004 og med formål å forbedre de grunnleggende kunnskapene om emnet samt styrke miljøovervåkingen i Arktis.

Kamskjell- og rekefisket utgjør en viktig del av rapporten ettersom virkningen på andre arter, på geologiske strukturer og kulturarven fra disse fiskeriene ikke er spesielt godt kjent på tross av det store fisket på disse artene siden begynnelsen av 1970-årene. Men virkningen av andre fiskeredskaper på sårbare habitater er også erkjent. Rapporten inneholder informasjon om tilstedeværelsen og konserveringsstatus når det gjelder kulturminner i området, noe som er en av prioritettene i Den nordiske handlingsplanen for 2000–2004. Til sist blir verne- og konserveringsstrategier som brukes i det studerte området gjennomgått, med henvisning til kulturminner og til behovet for å opprette flere marine verneområder.

Anbefalinger (Kapittel 1)

Funnene i denne rapporten utgjør grunnlaget for våre anbefalinger. De kan deles inn i tre hovedkategorier:

1. Anbefalinger som setter søkelyset på behovet for å kartlegge distribusjonen av sårbare habitater, arter og av kulturminner.
2. Anbefalinger om å øke forskningsaktiviteten.
3. Anbefalinger om å implementere forvaltningstiltak som er rettet mot å verne områder der man vet at det finnes sårbare habitater og arter eller som må stenges for fiske for å unngå utarming av målbestander. Andre forvaltningstiltak foreslår en bredere implementering av sorteringsnett (selektive nett) i Arktis for å verne ikke-målarter og stenging for å verne arkeologiske funn.

I tillegg har arbeidsgruppen satt søkelyset på en rekke andre spørsmål som er relevante for det videre arbeidet og som kan tjene som retningslinjer. Disse spørsmålene ble ikke formulert som anbefalinger fordi arbeidsgruppen mente at de ikke var direkte relatert til prosjektets innhold. De omfatter f.eks. slike ting som nødvendigheten av å implementere et nettverk at marine verneområder, nødvendigheten av å verne områder som fremdeles ikke er påvirket av ulike typer for fiskeutstyr og implementering av frivillige miljøanalyser før man tar i bruk nye fiskefelter.

Kamskjellfisket i Nordvestatlanteren (Kapittel 2)

Denne analysen er først og fremst basert på «grå» litteratur skrevet på islandsk, dansk eller norsk. Noe av den er vanskelig tilgjengelig.

Oppstarten av det islandske kamskjellfisket i Island, Grønland og Norge (Svalbard, Bjørnøya og Jan Mayen) kom etter oppdagelsen av jomfruelige kamskjellbanker med høy tetthet av store, gamle eksemplarer.

The islandske fisket begynte i 1969. Fangstmengde og antallet båter økte stadig på tross av implementeringen av forvaltningstiltak i 1973 og lave markedspriser i perioden 1973–1977. Landingen i Breiðafjörður var på sitt høyeste i 1985 og 1986 med 12 000 tonn. Etter dette gikk fangstmengdene ned, og i 2003 var de nede på 35 % av den gjennomsnittlige mengden for perioden 1993–2000. Som et vernetiltak har fisket vært forbudt siden 2003–2004-sesongen. Grunnene til nedgangen blir nå undersøkt, men det er fremdeles uklart hva som ligger bak. Det er sannsynlig at medvirkende faktorer er et for høyt fiske, økt temperatur på havbunnen om sommeren og tilstedeværelsen av cystedannende protozoan-parasitter (*Coccidia*) i voksne kamskjell. Men de store forskjellene i økningen av naturlig død på ulike kamskjellbanker i Breiðafjörður antyder at det kan være andre og fremdeles ukjente faktorer for å forklare den observerte dødeligheten.

Kamskjelldregging ble påbegynt i Vest-Grønland i 1983. Bestanden er ikke spesielt stor, men fisket ble drevet av sosiale hensyn. Nuuk er den eneste byen der man har drevet kamskjellfiske siden 1984 og der fangstene er høyere. Årlige fangstmengder varierte fra 400 til 1 900 tonn i perioden 1988–1992 og fra 1 200 til 2 600 tonn etter 1995. Hovedproblemet i dette fisket har vært vanskelighetene i å bestemme bestandsstørrelsen og dødeligheten siden man verken har bakgrunnsdata nok eller ressurser til å iverksette et overvåkingsprogram. Det er ikke blitt foretatt noen undersøkelser siden 1994, og den totale tillatte fangstmengden (TAC) er satt til 2000 tonn og er basert på tidligere års fangst.

Det norske fisket begynte i 1984 ved Jan Mayen. Bestanden ble redusert fra 30 000 til 8 000 tonn i 1986. Flåten gikk derfor mot Svalbard isteden. Årlig fangst lå på 44 100 og 19 000 tonn i 1987 og 1988 henholdsvis. Deretter gikk fanget mengde ned til mellom 3 000 og 7 000 tonn. I 1995 ble området stengt for dregging.

Det at fisket slo feil i Island og Norge kunne ha bli avverget dersom man hadde tatt rekrutteringen i betraktning. Dette er noe som i stor grad er ukjent i det studerte området, men som er svært viktig i en forvaltningssprosess av bestander som er selv-rekrutterende, noe kamskjellbanker ser ut til å være, og der fisket avhenger av årsklassenes størrelse.

Effekter av dreggng på bentos-samfunnene i Breiðafjörður, Vest-Island

Bifangstdata fra undersøkelser av kamskjellbestandene og data fra det kommersielle kamskjellfisket ble brukt i denne studien. Bifangst representerte 28 % av den totale fangsten, og åtte bentiske makrofauna-taxoner alene utgjorde 98 % av bifangsten. Makrofauna bentossamfunnet i Breiðafjörður bestod for det meste av bløtdyr med hardt skall, sjøpølser, krabber og sjøstjerner, noe som er karakteristisk for samfunn med forstyrrelser. Fremvoksende epifauna var fraværende i alle prøvene som er blitt tatt fra 1993 av.

Dataene i denne studien viser ingen større påvirkninger på distribusjonen og mengden av bifangst-taxoner fra kamskjelldregging. Men kamskjelldregging begynte i 1970 og bifangstdata foreligger bare fra perioden etter 1993. Tidligere studier i andre land kom til den konklusjon at effektene av fisket er større i den tidlige perioden av fisket der man ser tap av epibentiske biogene strukturer og faunaen assosiert med dem. Det er derfor sannsynlig at kamskjelldregging allerede hadde endret bentossamfunnet ved effektivt å fjerne de sårbare artene før man begynte å samle inn data om bifangst. Slik kan dagens makrofauna være robust overfor fysiske endringer og derfor har effektene på bentossamfunnet i Breiðafjörður fra fisket åpenbart vært ganske små.

Rekefisket på kontinentalsokkelen i Nordvestatlanten (Kapittel 3)

Det meste av informasjon i denne studien er hentet fra NAFO SCRs dokumenter når det gjelder Grønland samt ICES CM-dokumenter og årsrapporter fra forskningsinstituttene som er involvert i bestandsvurderinger av de rekebestandene som er studert.

Det islandske rekefisket på kontinentalsokkelen ble påbegynt i 1975. Fangstmengdene økte fra 1 000 tonn til 66 000 tonn i perioden 1977–1997, og de har ligget på mellom 68 og 94 % av den totale årlige fangsten siden 1984. De første tegnene på overfiske ble oppdaget i 1987 da de første totale tillatte fangstmengdene (TAC) ble fastsatt og fanget mengde i noen år gikk ned selv om man oppdaget nye fiskefelter. God rekruttering gjorde at fanget mengde økte jevnt fra 1990 til 1996. Men siden den gang har fanget mengde og bestandsindeksen gått markert ned med minimumfangst for perioden 1998–2003 på 21 500 tonn i år 2000. Det er blitt hevdet at det at torsken spiser reker er en viktig faktor som påvirker rekebestanden, men dødeligheten som en følge av dette er like stor som fiskedødeligheten.

Det grønlandske rekefisket på kontinentalsokkelen er det største i Nordvestatlanten. Det begynte i 1970 i Vest-Grønland med en fangst på 1200 tonn og har utgjort mellom 59 og 89 % av det totale fisket siden 1974. Fangsten kom opp på 113 000 tonn og bestandsvurderingen lå på

ca. 300 000 tonn i 2004. Denne store veksten har vært mulig ettersom fisket har kommet til å omfatte et større område og flåten er blitt forbedret de siste 30 årene. Andre fiskefelter på østkysten, mellom 65°N og 67°N, er blitt fisket på siden 1978. Oppdagelsen av flere fiskefelter i 1993 gjorde at fisket på østkysten ble utvidet sørover til Kapp Farvel. Fangstene på østkysten har variert med mellom 5000 og 15 000 tonn i perioden 1980–2004, og til forskjell fra fisket på vestkysten blir det meste her fisket opp av andre lands fiskere.

Hovedproblemet for rekefisket på Grønland er at det til dels foregår i oppvekstområdene til uer, blåkveite, torsk og annen bunnfisk. Noen av disse artene har vist en nedadgående tendens når det gjelder biomasse og antall. Bifangst er, siden år 2000, blitt redusert gjennom å bruke forskjellig sorteringsnett (selektive nett), men det er sannsynlig at de økologiske prosessene bare delvis er forstått, som f.eks. at det trofiske næringsnett og hydrografen i området i stor grad påvirker bestandsstørrelsen hos bunnfisk.

Det norske rekefisket på kontinentalsokkelen begynte i 1973, og de viktigste fiskebankene er rundt Svalbard og i Barentshavet. Fangst og bestandsstørrelse er i stadig endring. Størrelsen på rekebestanden synes for en stor del å være avhengig av antallet predatorer (først og fremst torsk), de årlige hydrografiske variasjonene mellom ulike vannmasser i området og, som en følge derav, Polarfrontens plassering. Reke-dødeligheten i Barentshavet som en følge av predatorer er lik fiskedødeligheten, og derfor er selve fisket sannsynligvis delvis skyld i at bestanden varierer.

Det fins store bestander av ungtorsk, hyse, uer og blåkveite på rekebankene. Innføringen av sorteringsnett i 1991 var ikke nok til å løse problemet med bifangst, og en bioøkonomisk modell er blitt brukt siden 1993 for å vurdere den tillatte maksimale fangsten av de kommersielle bifangstartene som er nevnt ovenfor. Denne strategien har ikke gitt de forventede resultater, og alle de kommersielle artene som i dag fins på rekebankene, befinner seg under de sikre biologiske grenseverdiene.

Bifangst i rekefisket på kontinentalsokkelen i Nord-Island

Bifangstdata fra undersøkelser av rekebestandene, bunnfiskundersøkelser og bifangst- og fiske-data fra loggbøkene fra rekeflåten ble analysert i denne studien. I perioden 1988–1994, før man introduserte sorteringsnett i 1995, utgjorde rapportert bifangst mellom 2,7 og 7,3 % av rekefangsten. Torsk og blåkveite var de artene som dominerte i bifangsten.

Antallet bunnfisk, og det tenkes her på de 71 ulike artene som er inntatt i studiene av reker og bunnfisk, har gått ned siden 1997 på tross av en markert nedgang i bifangst tatt av den kommersielle flåten. Denne studien fant dog intet klart forhold mellom antallet fisk og selve fisket,

men resultatene kan være påvirket av mangelen på data om bifangst siden fisket startet opp.

Sårbare habitater (Kapittel 4)

Dypvannskoraller

Habitatsdannende dypvannskoraller inkluderer bløte koraller som Alcyonacea, Pennatulacea og Gorgonacea og steinete revdannende koraller. Den viktigste revdannende arten er *Lophelia pertusa*. Dypvannskoraller finnes på spredte steder i havområdene i nord.

Lophelia-rev, inkludert rev som er opp til 40 km lange, fins langs Norskerenna og i mange fjorder fra svenskegrensen til Finnmark.

L. pertusa i islandske farvann fins først og fremst på Reykjanesryggen og nær kontinentalsokkel-riften utenfor sørkysten av Island (vanligst på 500–600 m dybde). Korallområder (muligens også med *L. Pertusa*) ikke langt fra sokkelriften utenfor Nordvest- og Sørøst-Island var kjent i 1970- og 1980-årene. Andre kjente korallområder er små. Det fins ingen opplysninger om *L. Pertusa* utenfor Grønland.

Distribusjonen av bløte koraller (Gorgonacea og Pennatulacea) utenfor norskekysten er ikke spesielt godt kjent, men flere av de gorgoniske artene, som *Paragorgia arborea* og *Primnoa resedaeformis*, er vidt utbredt, og mange av dem er ved *L. Pertusa*-revene. Gorgoniske arter er ganske uvanlige på sokkelen (< 500 m dybde) rundt Island, men de fins i ganske store mengder i dypere vann (> 500 m) utenfor Sør- Vest- og Nord-Island. På liknende måte er pennatulaceaner vanligere i dypere vann, spesielt utenfor Sør-Island.

Flere studier har vist at dypvanns-steinkorallene er habitat for virvelløse dyr og bunnfisk. Mer enn 600 arter er blitt knyttet til *Lophelia*-rev utenfor norskekysten, og dette tallet stiger til 1 300 dersom vi ser på hele Nordøstatlanteren. Korallrev er derfor viktige både fra et generelt biomangfoldssynspunkt og som habitat for kommersielle fiskeslag. Dersom korallrevene forsvinner, kan bestander av arter som er knyttet til dem få problemer med å opprettholde sin eksistens, og det kan føre til store endringer i artsdistribusjonen og -mangfoldet på kontinentalsokkelen i de nordlige områdene.

Dypvanns-gorgonkoraller utgjør flere ulike mikrohabitater for andre organismer, men det er lite man vet om deres økologiske betydning.

Dypvannskoraller er skjøre, de vokser sakte og lever lenge. *L. Pertusa* kan vokse 0,5–25 mm per år og leve i flere hundre år. Koraller er derfor følsomme overfor virkningene av fisket, og det kan ta århundrer før de blir gjenoppbygd. Bunntråling er den største trusselen mot *Lophelia*-rev og bløte koraller. Store skader på korallrev er blitt dokumentert på fiskebanker, langs Norskerenna og langs sokkelriften utenfor Island. Langline-

og garnfiske fører også til at koraller brekker, men slike skader anses som begrensede sammenliknet med effektene av bunntråling.

Norge var det første landet i Europa som, i 1999, innførte tiltak for å verne kaldtvannskoraller mot følgene av fisket ved å forby tilsiktet ødeleggelse av korallrev samt verne spesielle rev mot bruk av bunnskrapende fiskeutstyr. Hittil har fem rev utenfor norskekysten blitt vernet. I Island og Grønland er det ikke iverksatt vernetiltak for koraller.

Svamper

Svamper (Porifera) lever under svært ulike økologiske forhold. Svampdominerte biotoper er blitt funnet flere steder i de nordlige havområdene. I denne rapporten har slike store forekomster av svamper fått to navn: ostur, som er et begrenset område der store svamper utgjør mer enn 90 % av den bentiske biomassen, og svampgrunn, et område som er dominert av store svamper og deres rammeverk.

Ostur er ikke rapportert ved Vest-Grønland. Den tilgjengelige litteraturen antyder store forekomster av svamper flere steder utenfor Øst-Grønland. Ostur fins også flere steder i Danskestredet og utenfor Nord-Island. Enkelte av disse stedene kan klassifiseres som svampgrunn. Omfattende ostur og noe svampgrunn fins også rundt Reykjanes-ryggen utenfor Sørvest-Island. Store forekomster av svamper, først og fremst ostur, er blitt innrapportert fra områder utenfor Nord-Norge, i den vestlige delen av Barentshavet og sør og vest for Svalbard.

Store svamper føyer en lav tredimensjonal struktur til bunnen, noe som øker kompleksiteten i habitatene og tiltrekker seg en rekke andre arter. Det er ikke blitt gjennomført noen studier angående faunaen på store svamper utenfor Grønland, Island eller Norge, men det er blitt anslått at faunaen på svampgrunnene er minst dobbelt så rik på arter som i de omkringliggende områdene, og at antallet individer i faunaen er høyere.

Det er ikke blitt undersøkt hvilken effekt tråling har på svampsamfunnene i Arktis. Studier fra andre områder indikerer dog at klumpformede, ikke-fleksible svamper, som ostur, blir lettest påvirket. Tråling fører til fysiske skader på svampene, snur opp ned på deres substrat (steiner og rullesteiner), og resuspensjonen av sedimenter påvirker svampenes inntak av næring.

Svamper vokser sakte. Det vil derfor ta lang tid for et svampdominert område å bygge seg opp igjen etter en delvis ødeleggelse, og gjentatte forstyrrelser kan føre til permanent utryddelse av artene i området. Det er hittil ikke fattet noen forvaltningsbeslutninger i Norge, Island eller Grønland når det gjelder store forekomster av svamp.

Maërl

Maërl er løstliggende koralliske rødalger og består av levende (i de øverste sedimentlagene) og døde alger som akkumuleres i leier eller banker.

Maërl-arter er blitt innrapportert fra Norge og Island, men det fins ikke opplysninger om at de eksisterer ved Grønland eller Svalbard.

Den tredimensjonale maërl-strukturen gir en rekke nisjer for infauna og epifauna virvelløse dyr. Studier av maërl som er utført utenfor Arktis har vist at deres biotiske mangfold kan være stort. Kamskjelldregging og suging har en svært stor negativ effekt på maërl-banker og assosiert fauna. På tross av dette har kamskjellfiske blitt foretatt på flere maërl-banker, og det foreligger et initiativ til å høste maërl i islandsk farvann.

Hydrotermiske utstrømningsåpninger og kald utsiving

Hydrotermiske utstrømningsåpninger forekommer i områder med dyp tektonisk aktivitet. Kald utsiving er et annet geografisk trekk som omfatter utslipp av gasser fra grunnen. Bentiske samfunn rundt slike fenomen er unike, og mange arter er endemiske.

Det er blitt funnet flere hydrotermiske utstrømningsåpninger i islandsk farvann, men deres biota er ikke kjent. Tråling i områder med hydrotermiske utstrømningsåpninger og kald utsiving kan føre til langvarige eller uomstøtelige skader på disse geologiske fenomenene og deres assosierte fauna. På grunn av mangel på data om distribusjonen av hydrotermiske utstrømningsåpninger i de nordlige havområdene, er det vanskelig å vurdere om de er truet av trålvirksomhet eller ikke.

En type kald utsiving («mudder-vulkan») er blitt funnet sør for Svalbard ($\approx 1\,250$ m dybde) med en mer ulikartet fauna enn de nærliggende områdene som ikke har kald utsiving. Områder med «kopparr» er også blitt funnet nord for Norge.

Virkningene av fisket på kulturminnene på havbunnen (Kapittel 5)

Miljøforholdene i arktiske farvann gjør det enklere for kulturminner å overleve. Vrak er blitt funnet i svært god behold 150 år etter at de sank. Det er et stort potensial for å finne flere godt bevarte vrak i åpen sjø og i dype fjorder langs kysten der forholdene for bevaring er spesielt gode pga. lave temperaturer og store mengder finkornede sedimenter. Et godt bevart skip er et tidsbilde der lite er lagt til eller ødelagt ved senere inngripen, noe som ofte er tilfelle ved arkeologiske funn på land.

I tillegg er områder som kysten av Troms og Grønland steder hvor man potensielt kan finne steinalderboplasser og andre, og senere, minner som har havnet under havoverflaten ettersom sjøen har hevet seg.

Tråling og dregging har stor negativ innflytelse på vrak av tre og gjenstander som ligger på bunnen siden fiskeredskapene knuser, flytter og tømmer vrakstedene hver gang de passerer.

Vurdering av kulturminner på havbunnen

En begrenset studie er blitt gjennomført for å sette fokus på områdene der det er størst sannsynlighet for å finne vrak og andre kulturminner i havområdene ved Barentshavet, Spitsbergen, Island og Grønland. Det fins ingen systematisk registrering av kulturminner i disse områdene, men det fins kilder til kunnskap om skip som har gått ned og annen aktivitet som anslår at det fins store mengder ukjent kulturmateriale på havbunnen. Når det gjelder Barentshavet, befinner disse potensielle arkeologiske områdene seg i de områdene der tråling er mest utbredt.

Kartlegging og registrering av kulturminner på havbunnen

Det er viktig å kartlegge kulturminnene i arktiske farvann og benytte de lovene som eksisterer i alle de nordiske landene og som sier at det er obligatorisk å innrapportere vrak. Ifølge den forskningen som ble gjort innenfor rammene av dette prosjektet, har fiskeflåten aldri, eller bare svært sjelden, overholdt disse lovene. Det samme gjelder for oppsynsskip og andre marine forskningsekspedisjoner. Det norske MAREANO-prosjektet (Marin arealdatabase for norske kyst- og havområder) har som mål å foreta en detaljert topografisk kartlegging av havbunnen, inkludert havbunnsmorfologi, geologiske ressurser, forurensning, biologisk mangfold, naturmiljø, kulturminner og marine ressurser.

Vern av natur- og kulturarv i Arktis (Kapittel 6)

Marine verneområder brukes til å verne natur- og kulturarv av høy verdi og beskytte målarter for å kunne opprettholde et bærekraftig fiske. Det fins internasjonale og nordiske avtaler om naturvern, og noen av dem angår vern av det marine miljø. Forvaltningen av vernetiltakene avgjøres av de nasjonale myndigheter og er ulike i de ulike landene. Disse er i en viss grad basert på internasjonale retningslinjer (IUCN-kategoriene) og på lovgivning.

I følge IUCNs definisjon har Island to offshore MPA (marine verne-soner) som inkluderer øyene Surtsey og Eldey en mindre kystnær MPA i Eyjafjörður for å verne de hydrotermiske utstrømningsåpningene som fins der samt 13 kystvernesoner hvorav en er inntatt i Ramsar-konvensjonen. I tillegg fins det flere områder på sokkelen med begrensninger på fisket. Grønland har fire MPA hvorav en er på sokkelen og tre er inntatt i Ramsar-konvensjonen. Men verken Island eller Grønland har hatt en systematisk tilnærmingssåte til vern. Beliggenheten til og størrelsen på verne-sonene er ikke nødvendigvis i overensstemmelse med deres verdi eller viktighet, og per i dag representerer ikke disse områdene de marine habitatene på en adekvat måte. Som kontrast blir vernet av naturen på Sval-

bard utført på en systematisk måte slik at representative habitater blir tatt vare på.

Per i dag er det seks MPA på Svalbard. Tre av dem er nasjonalparker, en av dem et naturreservat og to er Ramsar-områder. I tillegg er det andre Ramsar-områder i nasjonalparkene. Det er også seks områder der man vet at det fins kaldevannskoraller av arten *Lophelia pertusa* utenfor norskekysten som er blitt vernet mot fiske med bunntål.

Nasjonal lovgivning i de nordiske landene og internasjonale lover om vern av kulturminner på havbunnen

Generelt kan man si at de nasjonale lovene i de nordiske landene gir god nok juridisk beskyttelse av kulturminner på havbunnen. Men lovene blir ikke alltid håndhevd. Når det gjelder vern av arkeologiske funnsteder er det bare Miljøloven for Svalbard som gir beskyttelse mot tråling og dredging selv om dette er begrenset til en sone med en radius på 100 m fra det arkeologiske funnstedet. Men denne loven blir for øyeblikket ikke håndhevd.

Den nasjonale lovgivningen i landene som fisker i Arktis må være i overensstemmelse med internasjonale konvensjoner, UNCLOS (United Nations Convention Law of the Seas) og UNESCOs forslag om en «Convention on the protection of the underwater cultural heritage» – «Konvensjonen for vern av undervannskulturminner» (ikke ratifisert). Slike lover gjør det mulig å rettsforfølge ulovlig aktivitet. I 2003 føyde Danmark til et avsnitt om internasjonale farvann i sin lov om kulturminner. Dette avsnittet angår danske skip og danske statsborgere. I følge avsnittet er det forbudt å foreta endringer av statusen til kulturarvobjekter under vann. Når det gjelder å bringe de nasjonale lovene i andre nordiske land i overensstemmelse med dette, er det viktig å ta seg denne formuleringen ad notam siden den verner kulturarven og dens miljø.

Noen tiltak for å forbedre effektiviteten av juridiske tiltak på internasjonalt, regionalt og nasjonalt nivå blir foreslått.

Marine vernesoner som et fiskeriforvaltningsinstrument i arktiske farvann

Midlertidig og permanent stengning blir brukt som et fiskeriforvaltningsinstrument i arktiske farvann for å beskytte gyte- og oppvekstområder. I islandsk farvann blir det foretatt midlertidige stengninger som har som formål å redusere kassering av for små fisk og permanent stengning som forbyr en eller flere utstyrstyper, først og fremst oter og langline. Størrelsen på og grensene for disse områdene er blitt gjennomgått og endret kraftig over tid.

Hovedformålet med stengningene i norske farvann er å verne gyte- og oppvekstområder samt minimalisere konflikten mellom båter som bruker

ulike former for fiskeutstyr. Det norske forvaltningsregimet inkluderer permanente og tidsbegrensede stengninger i områder som er åpne for fiske bare i deler av året eller områder der fiske er begrenset til bruk av spesielt utstyr.

I Grønland er det flere områder utenfor vestkysten der rekefisket er begrenset gjennom stengninger. Det fins også et stengt område («uer-området») utenfor østkysten som har som formål å minske kasseringen av ungfisk.

Vi konkluderer med at opprettelsen av marine vernesoner kan bidra til en bærekraftig bruk av fiskebestandene samt vern av sårbare habitater, biologisk mangfold, naturarven og historiske minner.

1. Introduction

*E. Guijarro Garcia, S.Á. Ragnarsson, S.A. Steingrímsson,
H. Eiríksson and D. Nævestad*

1.1 The project mandate

1.1.1 Mandate

The Nordic Council of Ministers implemented in 1996 the “Nordic Environmental Strategy for 1996–2000”. This cooperation program ensured a larger investment and better coordination of research efforts on environmental problems in the Arctic. From this program arose the “Nordisk handlingsplan for nature- og kulturmiljøbeskyttelse i Arktis- Grønland, Island og Svalbard”, called Nordic Action Plan hereafter (Anonymous 1999). The primary goals of this Action Plan were:

- To coordinate monitoring and data handling of nature and the environment in the Nordic countries, ensuring collaboration with other nations in this area.
- To ensure a Nordic effort to preserve the arctic flora and fauna and the marine environment with a sustainable perspective and to fulfil the biodiversity conventions and the Arctic Environmental Strategy.

The mandate of the Nordic Action Plan has a very wide scope, and identifies five key actions. The project “Bottom trawling and scallop dredging in the Arctic” is relevant to four of them:

- 1. Biological diversity, including biotope protection, species protection, hunting, trapping and fishing*

The mandate of the Nordic Action Plan specifically states the need to investigate the effects of trawling and scallop dredging. In response, this project has examined thoroughly the effects of scallop dredging and the shrimp fishery on target species and on those species lacking commercial interest, which are either caught incidentally or killed or damaged as a result of the fishing operations. The project has also considered the impact of fishing on cold-water coral reefs, sponge communities and other vulnerable habitats. These represent very diverse and highly specialized benthic communities of very high conservation value that may take centuries to recover after fishing disturbance.

2. *Landscape protection, including protection of geological sites and the follow-up of World Heritage Sites*

There are outstanding submarine features of geological origin within the study area of this project, such as the ikaite towers in Ikka Fjord, Greenland, and the hydrothermal vents in Eyjafjörður, Iceland. These represent the only protected submarine geological features in the Arctic. In addition, the United Nations Educational, Scientific and Cultural Organization (UNESCO) elected the Ilulissat Icefjord as a World Heritage Site in 2005. Icefjord was elected because of its outstanding geology, but the World Conservation Union (IUCN) Technical Evaluation indicated the need to monitor closely the living resources, many of which have been over-harvested. This project has reviewed the status of protection of vulnerable habitats and geological features.

3. *Cultural environment, including preserving the cultural landscape and buildings*

The Nordic Action Plan considers the conservation of cultural heritage as a priority. This project contributes with a review of the status and threats of submerged archaeological remains in Arctic waters that are susceptible to severe damage, destruction or removal by bottom-tending gear.

4. *Environmental data and monitoring*

The work carried out in this report has focussed on long-term effects of fishing activities where data covering long periods of time are prerequisite.

1.1.2 *Project group*

This project has been carried out by a multidisciplinary group including scientists from the fisheries, marine biology, environmental management and the cultural heritage sectors.

Elena Guijarro Garcia, marine biologist ⁽¹⁾
 Stefán A. Ragnarsson, marine ecologist ⁽¹⁾
 Sigmar A. Steingrímsson, marine ecologist ⁽¹⁾
 Hrafnkell Eiríksson, fisheries biologist ⁽¹⁾
 Dag Nævestad, marine archaeologist ⁽²⁾
 Jan H. Fosså, marine ecologist ⁽³⁾
 Ole S. Tendal, marine ecologist ⁽⁴⁾
 Haukur Þ. Haraldsson, biologist ⁽⁵⁾
 Rikke Frandsen, marine biologist ⁽⁶⁾
 Helle Siegstad, fisheries biologist ⁽⁶⁾

- (1) Marine Research Institute, Iceland
- (2) Norwegian Maritime Museum, Norway
- (3) Institute of Marine Research, Norway
- (4) Zoological Museum University of Copenhagen, Denmark
- (5) Environment and Food Agency, Iceland
- (6) Greenland Institute of Natural Resources

1.1.3 Workframe

Geographical scope of the project

The Nordic Action Plan confines the study area to Greenland, Iceland, Svalbard and Jan Mayen and the intervening oceanic area. However, the working group decided to extend the geographical boundaries to include the marine region along the Norwegian coast south to 67°N and the Norwegian territorial waters in the Barents Sea. The inclusion of these two areas is important and relevant to the goals of the Nordic Action Plan. The discovery and recent protection of coral reefs off West Norway could not be ignored as they could serve as a cornerstone for further initiatives in protection of marine habitats and establishment of marine reserves, whereas the Barents Sea is an important ecosystem under great pressure from the fishing industry.

Main description of the status of the trawling and bottom dredging fisheries

Two of the most commonly used demersal fishing gear in the Arctic are the otter trawl and the scallop dredge. The scallop dredge is a heavy gear of variable size and weight. The width of most scallop dredges used within the study area ranged from 1.5 to 6m, and the smallest dredges weigh roughly 700 kg. While dredging, the entire bottom surface of the dredge is in contact with the seabed. The otter trawl is of variable size and predominantly used to target fish and shrimp. During towing, the net is held open vertically by the force of water moving against two otter boards. The components of the trawl that are in direct contact with the seabed are the ground rope (generally fitted with “rock hoppers”) and the boards.

Fishing effort has decreased in many Arctic fisheries in response to declining stocks, such as the collapse of the scallop stocks in Svalbard and Jan Mayen waters between 1987 and 1995. In the Icelandic scallop fishery, catches have decreased from 2000 onwards until the fishery was suspended in 2003. The scallop fishery in West Greenland is the only one persisting within the study area, with annual catches of about 2,000 tonnes.

In Icelandic waters, both the number of vessels using otter trawls and the total engine power has decreased over the last decade, resulting in an overall decrease in effort. As an example, fishing effort estimated as fish-

ing hours in the shrimp and *Nephrops* fishery has decreased by 50 and 60% respectively. Trends of fishing effort in Greenland refer mostly to the shrimp fishery, which occupies the largest fleet. Number of fishing hours peaked in 1992 but has subsequently decreased. The Svalbard fisheries target mainly shrimp and cod. Shrimp catches peaked at 45,000 tonnes in 1985 but they have decreased since that time. The Norwegian cod fishery in the Barents Sea has averaged an annual catch of roughly 250,000 tonnes over the past ten years.

Main impacts of fishing gear on habitat features, benthic communities and archaeological remains

Several scallop stocks have collapsed in Arctic waters due to overfishing, and their recovery is very slow. Some of the stocks have not attained population levels as those prior to fishing in spite of being protected for decades. In addition, several studies have shown that intensive scallop dredging can have serious consequences for benthic communities, especially in areas dominated by habitat-forming organisms, whose local extinction would lead to decreased diversity.

In all fisheries where towed-bottom gear is used, a large variety of non-target fish and invertebrate species are caught incidentally. This part of the catch (by-catch) is generally returned to sea (discarded). Mortality rates of discards vary between animal groups but are generally high. In the shrimp fishery, demersal and some pelagic fish species are caught, most of which are discarded because they are not marketable species or because they are undersized. In the scallop fishery, the by-catch consists primarily of benthic invertebrates.

Detrimental effects of bottom gear towed over the seabed include habitat alteration and direct mortality of a wide range of organisms. Any three-dimensional fragile structures rising above the seabed, such as cold-water corals, sponges, geological formations and archaeological remains are easily destroyed by towed-bottom gear. The surface area of the seabed that trawls sweep during a single tow is generally between one and two square kilometres. This implies that only a few tows are needed to disturb benthic communities in a relatively large area. Scallop dredges, due to their heavy weight, have been shown to affect a large variety of organisms, especially those consisting of fragile forms.

New areas are continuously under threat from fishing activities. Advances in gear technology and development of larger and better-equipped vessels enable fishing activities in previously inaccessible areas that are often populated by fragile organisms, such as zones where boulders occur, steep slopes or deep waters.

Archaeological remains occur widely on the seabed in the Arctic. They are often very well-preserved and therefore have a very high conservation value. These remains consist mainly of shipwrecks but there are also Stone Age settlements that have become submerged. The damage

and dispersal effected by bottom-tending gear on archaeological remains can be substantial. Archaeological remains can be exposed and subsequently subjected to faster rates of decay in areas where sediment disturbance due to intensive fishing is frequent.

1.1.4 Work description

The work carried out by this project can be broadly divided into two categories: review of existing information and case studies involving data analysis. The reviews on the scallop and the shrimp fisheries include comparison of stock trends, management strategies and research within the study area, whereas the review on vulnerable habitats such as coral reefs and sponge communities includes information on their distribution, ecology and susceptibility to fishing activities. The review on archaeological remains focuses on the distribution of wrecks, their preservation state and main threats; it also includes an overview of the current legislation relevant to the cultural heritage in Scandinavia and Greenland. Finally, conservation measures and the role of protected areas in the Arctic are reviewed.

As stated in the Nordic Action Plan, one of the main goals of this project is to investigate the impact of scallop dredging and shrimp trawling. The effects of these fisheries on the non-target species in the Arctic are little known. To fill that gap in knowledge, two case studies consisting of extensive analysis of data from the scallop and shrimp stocks and fisheries collected by the Marine Research Institute of Iceland were carried out to investigate specifically the impact of these types of gear.

One of the strong points of this project is the multidisciplinary character of the working group, which included scientists with backgrounds in marine biology, marine archaeology and nature conservation. Such cooperation has enabled us to focus on the threats that fishing activities pose on the environment from a wider perspective. Today, management of natural resources is carried out separately by various sectors. While the main goal of closures in fisheries management is to ensure sustainability of fish stocks, nature conservation bodies are more concerned with protecting natural heritage, and protection of marine archaeological remains is based on legislation. However, the goals in fishery management, nature conservation and protection of archaeological remains can go hand in hand. As an example, protecting an area for fishery management will also benefit both cultural and natural heritage. More cooperation among partners from different disciplines is clearly the way forward that will facilitate the development of better management strategies.

1.1.5 Summaries of the different chapters

1.1.5.1 The scallop fisheries in the Northeast Atlantic

This review focuses on the history and management of the Iceland scallop fishery in Iceland, Greenland and Norway (Svalbard, Bjørnøya and Jan Mayen), with information on research into each stock. The start of the fishery in all these regions followed the discovery of virgin scallop beds made up of old, large specimens in very high densities. Despite the apparent similarity of original conditions, the fishery has followed very different trends in each region, with drastic results in Iceland and Norway.

The Icelandic fishery dates from 1969. Catches and fleet size increased steadily in spite of the implementation of management measures in 1973 and a period of low market prices during the years 1973–1977. Landings in Breiðafjörður reached a maximum of over 12,000 tonnes in 1985 and 1986 harvested by a fleet of 25 ships. Catches decreased to between 9,000 and 11,000 tonnes during 1987–1993 and to 7,500–9,000 tonnes during 1994–2000, and the fleet was reduced to ten ships. By 2003 the stock had declined to 35% of its size during the years 1993–2000 and as a precautionary measure the fishery has been closed since the fishing season 2003–2004. Causes for this decline are being investigated but are still unclear. It is most likely that several factors have contributed to the current situation:

- a) the fishing effort may have been too high considering the trend of the stock index and annual variability of environmental factors,
- b) bottom sea temperature in summer has increased by 2–3°C during the past few years,
- c) cyst-forming protozoan parasites (Coccidia) have been detected in adult scallops.

However, the increase of natural mortality has shown great variability among the different scallop banks within Breiðafjörður, suggesting that there might be other still unknown reasons to explain the observed mortality.

Scallop dredging commenced in West Greenland in 1983. The stock is not very large, but fishing was driven by social issues. Nuuk is the only locality where the scallop fishery has been operating since 1984. Several areas were surveyed between 1984 and 1989 and many small scallop beds were mapped, but they could not sustain a fishery. Other localities where scallops have been discovered and dredging has taken place in most years since 1991 are Tugtulik / Attu, Mudderbugten and Saqqaq / Sisimiut. Annual catches ranged from 400–1,900 tonnes during the period 1988–1992 and from 1,200–2,600 tonnes since 1995, and they have always been higher in Nuuk, where the average annual catch for the period 1984–2002 is 580 tonnes. Average annual landings from the other

localities mentioned above range from 100 to 235 tonnes. The main problem of this fishery has been the impossibility to estimate accurately the stock size and the appropriate fishing mortality due to lack of background data and resources to implement a monitoring program to collect biological data prior to exploitation of the stock. There have been no surveys since 1994 and the total allowable catch (TAC) is fixed at 2,000 tonnes. This figure is based on catches from previous years. There are indications that each scallop bed is extensively dredged before the fleet moves on to new areas, but the TAC seems to be appropriate.

Offshore scallop fishing started in Norwegian waters as an alternative to declining traditional fisheries. An unregulated scallop fishery started in 1984 following the discovery of large scallop beds in Jan Mayen, and by 1986 the fleet consisted of 26 trawlers. The first survey took place in 1986 and estimated the stock at 31,000 tonnes. Later in the year the Jan Mayen stock had been reduced to 8,000 tonnes and the fleet turned to Svalbard. The stock in Svalbard and Bjørnøya was estimated in 1987 at roughly 420,000 tonnes, but several banks were entirely or partially within national parks and were therefore closed to fishing. Annual catches amounted to 44,100 and 19,000 tonnes in 1987 and 1988 respectively, and declined afterwards to 3,000–7,000 tonnes until 1995, when the archipelago was closed to dredging. The available data showed declining populations more than ten years after dredging ceased but some signs of recovery have been detected lately.

The failure of the Iceland and Norway fisheries might have been prevented by taking into account the recruitment processes, which are largely unknown within the study area. According to a model developed by Smith and Rago (2004), unexploited scallop populations in equilibrium have a large biomass and very low recruitment. When a fishery is introduced into the model, recruitment shows increased variability as the population oscillates towards a new equilibrium point with much smaller biomass. If fishing effort is too high, recruitment can be jeopardized due to depletion of the spawning stock (recruitment overfishing). These results suggest that understanding of recruitment processes is essential in management of stocks that are self-recruiting, as scallop beds seem to be, and where the fishery depends on year-class strength.

Effects of dredging on the benthic community in Breiðafjörður

Scallop dredging can have a direct and indirect impact on benthic fauna and habitats, including enhanced mortality on animals that are killed or injured following direct contact with the gear and subsequently become more prone to predation. Long-lived, slow-growing epizoa often have a fragile body structure and are especially sensitive to encounters with the gear, whereas taxa protected by exoskeletons or thick shells are more resilient.

Scallop dredges can also increase the sediment load, relocate boulders and destroy topographical features. Differential mortality among taxa and habitat destruction may cause important short- and long-term changes in faunal assemblages that are regularly disturbed by fishing gear.

The largest scallop beds in Iceland are located in Breiðafjörður, West Iceland, and catches in this area have amounted from 80 to 100% of the total annual landings since the beginning of the fishery.

The effects of scallop dredging on benthic communities in Breiðafjörður were investigated by analysing existing by-catch data from scallop stock assessment surveys and fishing effort data from the commercial scallop fishery. By-catch represented 28% of the total catch, with eight benthic macrofaunal taxa alone making up nearly 98% of the by-catch.

There are three distinct areas that have been subjected to very different fishing effort since the fishery started. Area 1 never supported more than 30% of the total effort and has been scarcely dredged since 1981. Fishing effort oscillated between 10 to 80% of the total in area 2 between 1973 and 1987, decreased greatly during the period 1988–1995 and it has been negligible ever since. Area 3 also supported highly variable fishing effort (15 to 90%) until 1987, when it started to increase steadily. From 1991 onwards, 80 to 100% of the fishing effort concentrated in area 3 except during 1998.

The faunal assemblages in the three areas were found to be significantly different, and signs of disturbance were detected in areas 1 and 3. The diversity indices evenness (J) and Shannon's diversity (H') showed slightly decreasing trends in these areas, whereas the number of species increased somewhat. The indices varied greatly in area 2 without showing any trend. There was a positive significant relationship between production of *Buccinum undatum*, *Eupagurus bernhardus* and *Hyas araneus* versus fishing pressure, in agreement with previous studies showing that biomass of scavenger species may increase with disturbance. However, no other significant relationships were found among production of other by-catch species or diversity indices and fishing effort.

Modiolus modiolus and *Cucumaria frondosa* dominated in terms of abundance and biomass in most of the study area regardless of intensity of fishing effort, although both have been identified as sensitive to fishing in other studies. The macrofaunal benthic community in Breiðafjörður consisted mostly of hard-shelled molluscs, holothurians, crabs and starfish that are characteristic of disturbed communities. Emerging epifauna was absent in all the samples taken since 1993.

The data used in this study do not show evidence of major impact of scallop dredging on distribution and abundance of by-catch taxa. However, scallop dredging started in 1970, whereas by-catch data have been available only since 1993 and the existing information from non-dredged areas is very limited. This is a major drawback in this study, as we cannot

compare the dredged areas with other locations that are rarely or not dredged at all. Previous studies in other countries concluded that effects of fishing are more severe in the early phase of the fishery, which involves the loss of epibenthic biogenic structures and their associated fauna. It is therefore most likely that scallop dredging had already altered the benthic community by removing effectively the sensitive species before by-catch data started to be collected. Thus the current macrofaunal assemblage might be very resilient towards physical disturbance, hence the apparently small effect of fishing effort on the benthic community in Breiðafjörður.

1.1.5.2 The shrimp fisheries in the Northeast Atlantic

The shrimp fisheries within the study area

The Icelandic offshore shrimp fishery started in 1975. Landings rose from 1,000 to 66,000 tonnes between 1977 and 1997, and they have constituted between 68 and 94% of the annual catch since 1984. The offshore fleet increased from 40 to 180 ships during the years 1983 to 1987, and catch per unit of effort (CPUE) rose by 50%. This could be due to the quota regulations applied to many fish stocks in 1984, that did not concern the shrimp fishery until 1988 and encouraged many skippers to engage in the shrimp fishery at that time. Between 1987 and 1990 the CPUE decreased to 1980 levels, but it doubled between 1989 and 1996 despite that the number of ships in the fishery had nearly halved. The first signs of overfishing were detected in 1987, when the first TAC was set, and catches decreased during a few years despite the discovery of new fishing grounds. Good recruitment allowed catches to rise steadily from 1990 to 1996 although the stock index oscillated until it also reached a maximum in 1996. However, catches and stock index have decreased markedly since then, with a minimum catch for the period 1998–2003 of 21,500 tonnes in 2000. Similarly, inshore catches have declined from 12,000 tonnes in 1987 to 1,500 tonnes by 2003. CPUE reached a minimum below 1980 levels in 1999 but has increased somewhat since. The fleet consists currently of about 50 ships. The total allowable catch (TAC) decided by the Ministry of Fisheries has usually been the same or very similar to the quota recommended by the MRI of Iceland, except for the fishing season 1995–96, in which it was exceeded by 57%. It has been suggested that predation by cod is an important factor affecting shrimp stock size, but since mortality due to predation has been estimated to be similar to fishing mortality, the impact of fishing cannot be diminished. The fishery is managed with licenses, minimum size of capture, minimum mesh size, use of sorting grids and TAC.

The Greenlandic offshore shrimp fishery is the largest by far in the Northeast Atlantic and shrimp is the main export product of Greenland after the collapse of the cod fishery, representing 90% of its export value. The Greenlandic offshore fishery started in 1970 in West Greenland with

landings of 1,200 tonnes and it has contributed with 59–89% of the annual catch since 1974. Offshore catches have increased at rather regular time intervals since the beginning of the fishery, until reaching a maximum of 113,000 tonnes in 2004 and a stock estimation of around 300,000 tonnes in 2004. This spectacular growth has been possible because of the spatial expansion of the fishery from the original fishing grounds in the Disko Island area to all the West coast south of 75°N and the fleet improvement over the past three decades. Inshore catches have increased mostly after 1989 and reached their maximum in 2000 with 23,000 tonnes. Other fishing grounds on the East coast, between 65°N–67°N, have been fished since 1978. The discovery of more fishing grounds in 1993 extended the East fishery south to Cape Farewell. However, catches in the East have oscillated between 5,000 and 15,000 tonnes during the period 1980–2004, and unlike the fishery on the West coast, most of the catch is taken by foreign countries. The catch of the Greenlandic fleet off the East coast reached 9,000 tonnes in 1988 and decreased steadily from then onwards. The discovery in 1993 of the shrimp grounds south of Dorhn Bank elevated the catches to 5,500 tonnes in 1999. After that, catches south of 65°N (Dorhn Bank) have declined but they increased markedly in the Dorhn Bank, from 300 tonnes in 2003 to 2,300 tonnes in 2004. Off the West coast, annual catches and fishing effort are on average higher in Subarea 1B, being 53,000 tonnes and 65,000 fishing hours respectively. However, mean CPUE is higher in Subarea 1C at 630 kg of shrimp per fishing hour. CPUE has increased rather fast since the mid-nineties in all but Subarea 1A. The main problem of the shrimp fishery in Greenland is its overlapping with nursery areas of redfish, Greenland halibut, cod and other groundfish species, some of which show declining trends of biomass and abundance. This led to the implementation in 2000 of sorting grids and laws that forbid fishing when by-catch exceeds legal limits, but it is likely that ecological processes only partially understood, such as the trophic web and hydrography of the area also influence largely the stock abundance of the demersal community. The fishery is managed with licenses, minimum size of capture, minimum mesh size, maximum by-catch limits, use of sorting grids and TAC.

The offshore Norwegian shrimp fishery is unique within the study area because it is the only one not regulated with a TAC system, but which does employ licenses, minimum size of capture of shrimp and maximum by-catch limits. The fishery started in 1973 and the main fishing grounds are in the Svalbard area and Barents Sea. Some fishing takes place in Jan Mayen but catches there never exceeded 2,200 tonnes or represented more than 5% of the total annual catch. The largest catches were mostly from Svalbard and the Barents Sea (S and SE of Bjørnøya), but the Hopen area has supplied 15 to 75% of the annual catch since 1992. Large fluctuations in catches and stock size are the main characteristic of this fishery. Shrimp stock size seems to be largely dependent on

the annual hydrographic variability in the presence of different water masses in the area, and consequently on the location of the Polar front, but it also seems to be related to the size of the cod stock and other predator species. As was the case for the Icelandic fishery, shrimp mortality in the Barents Sea due to predation has been estimated to be similar to fishing mortality, and therefore fishing effort probably accounts for part of the observed variability in stock size. Another drawback in this fishery is the large population of juvenile cod, haddock, redfish and Greenland halibut found within the shrimp fishing grounds. The implementation of sorting grids in 1991 was not enough to solve the by-catch problem, and a bioeconomical model has been applied since 1993 to estimate the allowable maximum catches of the commercial by-catch species mentioned above. Areas with more by-catch than allowed by law were closed to the fishery. The model is based on the estimation of market price of the shrimp that could be fished now versus the price of the by-catch fish individuals after their recruiting to the fishery, and the decision to open or close an area is taken according to what would generate the largest profit. Sampling and decision making are carried out in real time. This strategy has not produced the expected results, and all the commercial fish species found in the shrimp grounds are currently below safe biological limits. The bioeconomical model lacks variables like multispecies interactions, cannibalism and the so-called non-use values, which included factors such as the importance of conserving the resource and its future availability. While the model is improved it seems advisable to put aside economic considerations and enforce biological management of by-catch, consisting of setting the maximum allowable by-catch according to year-class strength to avoid weakening the year-classes before they recruit to the fishery.

By-catch in the offshore shrimp fishery in North Iceland

The effect of shrimp trawling on the benthic fish assemblage in North Iceland was investigated by analysing by-catch data from shrimp stock assessment surveys, groundfish surveys and by-catch and fishing effort data from the logbooks supplied by the shrimp fleet. During the period 1988–1994, prior to the introduction of sorting grids in 1995, reported by-catch represented between 2.7 and 7.3% of the shrimp catch, cod and Greenland halibut being the most abundant by-catch species landed.

Abundance of demersal fish, considering the 71 species recorded in shrimp and groundfish surveys, has been decreasing since 1997 despite the marked reduction of by-catch in the commercial fleet and fishing effort.

This study did not find a clear relationship between fish abundance and fishing effort, but the results could be influenced by lack of by-catch data since the beginning of the fishery.

1.1.5.3 Vulnerable habitats

Deep-water corals

In the Nordic waters habitat-forming deep-water corals include soft corals, such as Alcyonacea, Pennatulacea and Gorgonacea; and stony, reef-building corals (Scleractinia). The main reef-building species is the stony coral *Lophelia pertusa*. Corals are often a dominant taxon in deep-water hard substrate communities. The deep-water corals are patchily distributed in the Nordic waters, predominantly along the shelf margin, on the slope and continental rise and on submarine ridges, e.g. the Reykjanes Ridge.

Lophelia reefs are found along the whole coast of Norway, from the Swedish border to Finnmark, including reef complexes up to 40 km long. Their distribution is largely concentrated along the Norwegian shelf break. Coral reefs are also found in many of the fjords. It is neither known whether *L. pertusa* is distributed further east into the Russian waters nor if the species is growing along the entrance to the Barents Sea, between the Norwegian mainland and Bjørnøya.

Limited information is available on the distribution of *L. pertusa* in Icelandic waters. Its distribution was mainly confined to the Reykjanes Ridge and near the shelf break off the South coast of Iceland (commonly at 500 to 600m depth). Coral areas (possibly including *L. pertusa*) were known to exist close to the shelf break off NW and SE Iceland at around 1970. More coral areas were found in the 1970s and 1980s, reflecting the development of the bottom-trawling fisheries extending into deeper waters. At present considerably large coral areas exist on the Reykjanes Ridge and off SE Iceland. Other known coral areas are small. There are no records of *L. pertusa* off Greenland.

The distribution of soft corals (Gorgonacea and Pennatulacea) off Norway is not well known. However, several of the gorgonian species, e.g. *Paragorgia arborea* and *Primnoa resedaeformis*, are widely distributed and many of them are associated with the *Lophelia* reefs. Gorgonians are relatively uncommon on the shelf (< 500m depth) around Iceland, but they are found in relatively high numbers in deeper waters (> 500m) off South, West and North Iceland. Similarly, the pennatulaceans are relatively rare in water shallower than 500m, but they are more common in deeper waters, especially off South Iceland.

Several studies have shown that the deep-water stony corals provide a habitat for diverse invertebrate and ground fish species. Corals may provide habitats for shelter-seeking fish and enhance food availability for suspension feeders that are attached to the coral. However, the actual magnitude of their importance for fish populations has not been demonstrated yet. More than 600 species associated with the *Lophelia* reefs off the coasts of Norway have been recorded, but this figure increases to 1,300, including ground fish, if we consider the whole Northeast Atlantic.

Coral reefs are therefore important both from a general biodiversity perspective and as a habitat for commercial fish species.

Similarly, deep-water gorgonian corals provide various microhabitats for other organisms to utilize. Information on the distribution and abundance of deep-water gorgonians is scarce as well as knowledge about their biology and ecology. Consequently, little is known about the significance of gorgonian corals as habitat for other species in deep-water ecosystems, and how they may be linked to ecosystems in shallower waters.

Deep-water corals are fragile and typically slow-growing and long-living. *L. pertusa* may grow 0.5–25mm a year and live for hundreds of years. Corals are, therefore, sensitive to fishing impacts and the recovery of impacted coral is believed to be very slow, maybe taking centuries. Bottom trawling is the main threat to *Lophelia* reefs and coral forests (soft corals). Severe damage to coral reefs has been documented on fishing banks and along the shelf break off Norway and Iceland. Longline and gill net fishing also causes corals to break but with a relatively low frequency of disturbance. Because of their longevity, such disturbances may accumulate over time and have a clear impact on corals, although it is assumed to be limited compared to the effects of bottom trawling.

Recent studies in Norway have shown aggregations of gravid redfish (*Sebastes* spp.), tusk (*Brosme brosme*) and ling (*Molva molva*) on coral reefs. The reef habitat also plays an important role for many invertebrate species and studies in Norway indicate that species diversity is about three times higher on *Lophelia* reefs compared to the surrounding soft-bottoms. This implies that the reefs represent patches of high diversity in an environment of otherwise low diversity. If coral reefs disappear, populations of associated species may have difficulty in sustaining themselves and significant changes in species distribution and diversity along the continental shelf and slope in the Nordic Seas may take place.

Norway was the first country in Europe to implement, in 1999, measures for protecting cold-water corals from fishing activities by prohibiting intentional destruction of coral reefs and protecting specific reefs from bottom-tending fishing gear. So far, five reefs off Norway have been protected. Protection measures for corals do not exist in Iceland or Greenland.

Sponges

Sponges (Porifera) are found on all types of substrata, in all marine geographic and bathymetric regions and under very diverse ecological conditions. Sponge-dominated biotopes have been found in a number of places in the Nordic Seas. In this report, such mass occurrences of sponges receive two different names:

Ostur: A restricted area where large sponges are strikingly common and constitute more than 90% of the benthic biomass (“ostur” means “cheese” in Faroese and Icelandic).

Sponge ground: An area dominated by large sponges and their skeletons. All large sponges have a skeleton of silicious needles (spicules) or horny fibres (spongine) or a combination of both. In practice, sponge grounds occur where a heavy load of spicules of dead sponges and large-sized sponge species constitute more than 90% of the volume of the catch.

Ostur has not been reported from West Greenland. The available literature suggests mass occurrences of sponges off East Greenland in several locations between approximately 73°–78°N and 130 (seamount) – 1000m depth. Ostur is known to exist in a number of localities in the Denmark Strait, generally between 200 and 500m depth and also off North Iceland (300–750m depth), some of which can be classified as sponge grounds. The available information indicates the presence of comprehensive ostur and also some sponge grounds around the Reykjanes Ridge, off SW Iceland. Mass occurrences of sponges, mainly ostur, have been reported from waters off northern Norway, in the western Barents Sea and South and West off Svalbard.

The presence of large sponges adds a low three-dimensional structure to the bottom, thus increasing habitat complexity and attracting a large number of other species. No study has been conducted on the fauna associated with large sponges off Greenland, Iceland and Norway, but ostur off the Faroe Islands is known to house about 250 species of invertebrates. It has been estimated that fauna inside sponge grounds is at least twice as rich in species as the surrounding areas and faunal abundance is higher. Very few species utilize the sponges as a food source; therefore, it is suggested that sponges provide associated species with a habitat, refuge from predation or physical strain and enhanced food supply from the surrounding water. Juvenile redfish (*Sebastes* spp.) and other groundfish have been regularly observed in association with large sponges, suggesting that ostur is a suitable feeding ground for particular life history stages of some fish species.

No investigation has been conducted on the impact of trawling on sponge communities in the Arctic. However, studies from other areas indicate that lumpy, non-flexible sponges – such as ostur – are most easily affected. Trawling causes physical damage to sponges and turns over the stones and boulders to which they are attached. In addition, the resuspension of sediment affects sponge feeding by clogging their filtering mechanism.

Sponges are slow-growing species. Therefore, it will take a long time for a sponge-dominated area to recover even after partial destruction, and repeated disturbance may lead to permanent extirpation of the species in the area. No management efforts have so far been made in Norway, Ice-

land or Greenland regarding the conservation of mass occurrences of sponges.

Maerl

Maerl consists of loose-lying coralline red algae and it is composed of living (upper sediment layers) and dead algae that accumulate in beds or banks. Maerl species have been reported from Norway and Iceland but no published accounts exist from waters off Greenland and Svalbard. Previous investigations indicate that the geographical distribution of coralline algae is driven by water temperature.

The three-dimensional structure of maerl forms an interlocking lattice that provides a wide range of niches for infaunal and epifaunal invertebrates. Studies on maerl carried out outside the Arctic have shown that their biotic diversity can be high, and the species composition was similar to that of maerl beds off West Ireland.

Previous studies on the effects of scallop dredging on maerl beds have shown that this activity has a severe negative impact on the associated fauna. However, scallop fishing has taken place on some maerl beds in Icelandic waters. Anecdotal information indicates the detrimental effects of the fishery on the maerl beds involved. Although suction dredging is another threat to maerl beds, there are now several initiatives to harvest maerl at two locations in Icelandic waters by using this technique.

Hydrothermal vents and cold seeps

Hydrothermal vents occur in areas of deep tectonic activity. “Cold seeps” are another kind of geographical feature also involving emission of gases from the ground. Benthic communities around such phenomena are unique. Many species found in these habitats are endemic and dependent upon the energy derived from sulphur-containing inorganic compounds (hydrothermal vents) or methane (cold seeps).

Several hydrothermal vents have been found in Icelandic waters but their biota is not known. Trawling in areas where hydrothermal vents and cold seeps occur can cause long-lasting or irreversible damage to these geological features and their associated fauna. Due to lack of data on hydrothermal vent distribution in the Nordic Seas, it is difficult to assess whether they are under threat from trawling activities in these waters.

A type of cold seep (“mud volcano”) has been found south of Svalbard (≈1250m depth) with a more diverse fauna than the adjacent non-seep areas. Areas with pockmarks have also been found north of Norway.

1.1.5.4 The impact of the fisheries on cultural remains on the seabed

The special conditions in Arctic waters favour the survival of shipwrecks

The environmental conditions in Arctic waters favour the survival of cultural heritage. Wrecks have been found in excellent condition, with masts, hull and superstructure intact after 150 years on the seabed. The

process of wrecking by ice pressure in Arctic waters deposits the ships more or less in one piece on the seabed. Therefore, there is a high potential of finding well-preserved wrecks in open water along the ice edge, and also in waters with drift ice. They may also be found in deep fjords in inshore waters, where the conditions for preservation are exceptionally good, due to the low temperature and abundant fine sediments. A well-preserved vessel represents a time capsule where little is added or destroyed by later actions, as is often the case with archaeological remains on land.

Apart from wrecks, some Arctic areas, such as the coastlines of Troms (Norway) and Greenland have the potential for finding Stone Age habitats and more recent remains, which have become submerged due to transgressions (elevations of the sea level).

The impact of trawling and bottom dredging on cultural heritage

Trawling and dredging have a great negative impact on the seabed, coral reefs, sponge beds and wrecks alike. The impact on wooden wrecks and artefacts on the sea bottom will be substantial as fishing gear crushes, displaces and depletes the wreck sites on each passage. Trawler skippers have reported that wooden wrecks do represent a resource because going through such locations may yield an extra catch of up to 18–20 boxes of cod.

Scallop dredgers fishing in waters off Spitsbergen in the 1980s came up with large quantities of black oak from the wrecks of a whaling fleet from the 15th century, anchors and ceramic vessels. Apart from one anchor, such findings have not been reported or delivered to the appropriate authorities. The dredges used measured 6m by 1.5m. The areas were fished out quite fast, and the scallop stock has not recovered. Neither has the cultural heritage of the wrecks – a non-renewable resource.

Assessment of cultural heritage on the seabed

A limited study has been carried out to highlight the areas with the largest probability of accumulation of wrecks, and other cultural heritage in the Barents Sea, Spitsbergen, Iceland and Greenland waters. Systematic recording of submerged cultural remains in these areas is nonexistent. Overall, there are not many registered or positioned finds, but there are available sources of knowledge on shipwrecking and past activities that suggest the existence of abundant unknown cultural material in and on the sea bottom. The study describes the known navigational routes in each region, their history of navigation and display sketch maps of the areas most liable to wrecking, due to traffic, ice conditions, etc. In the case of the Barents Sea, it appears that these potential archaeological sites overlap with the most heavily trawled areas.

Mapping and registering of cultural heritage on the seabed

The previous assessment of areas of wrecking and submerged cultural heritage in the Arctic is, as stated, based on a large-scale evaluation. A protection plan should be founded on knowledge based on precise information. However, as the written sources on wrecks and wrecking in Arctic waters greatly vary in exactness and reliability, the information at hand is inconsistent. The reports on actual finds may also be approximate as far as positioning is concerned, but they are usually more precise. It is therefore important to enforce the legislation available in all the Nordic countries that states that it is mandatory to report wrecks. According to the research carried out for this project, fishing fleets have never, or rarely, complied with these regulations, nor have survey vessels or other marine research expeditions. There are, however, several records and compiled data available from a number of different sources. These records, a policy of informing on found wreckages, and enforcement of the legislation at hand may provide managers with an accumulating base of knowledge. The Norwegian MAREANO project (Marine spatial database for Norwegian coast and sea areas) aims to establish a detailed topographical mapping of the seabed, incorporating seabed morphology, geological resources, contamination, biological diversity, natural environment, cultural heritage and marine resources. The Barents Sea and the sea areas close to the Lofoten Islands have been given priority, and work will be in progress from 2005 onwards. The non-renewable cultural heritage sites on the seabed are one of the parameters to be mapped and considered in this holistic concept.

1.1.5.5 Protection of natural and cultural heritage in the Arctic

Nature conservation in the Arctic

There are two main reasons for the establishment of marine protected areas. Firstly, to conserve nature or cultural remains of high value and secondly, to protect target stocks in order to maintain sustainable fisheries. This chapter reviews nature and cultural conservation and fisheries management in waters around Iceland, Greenland and Svalbard.

There are international and Nordic agreements on nature conservation, some of which have to do directly with marine conservation. The conservation management schemes are decided by national governments and can differ between countries. These are, however, based to some extent on the international guidelines (the IUCN categories) and legislation. The law on nature conservation and on conservation measures and actions in Iceland, Greenland and Svalbard is reviewed. Conservation plans exist for both Svalbard and Iceland but not for Greenland.

Marine protected areas in Greenland, Iceland and Svalbard are reviewed. The World Conservation Union (IUCN) defines MPAs as: "Any area of intertidal or subtidal terrain together with its overlying water and

associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment” (Kelleher and Kenchington 1991).

According to the IUCN definition, Iceland has two offshore MPAs, which include the islands Surtsey and Eldey, a smaller MPA in Eyja-fjörður to protect the hydrothermal vents found there and 13 coastal protected areas, one of them included in the Ramsar Convention. In addition, there are several offshore areas where fishing is restricted.

Greenland has four MPAs, of which only one is offshore and three are included in the Ramsar Convention. However, neither Iceland nor Greenland has applied a systematic approach to conservation. The location and size of the protected areas is not necessarily correlated with their value or importance and at the present stage these areas do not represent adequately their marine habitats. In contrast, the protection of nature in Svalbard is carried out systematically in order to conserve representative habitats.

With this approach, Norway leads the conservation of marine habitats and fauna within the study area.

There are currently six MPAs in Svalbard, three of them being national parks, one of them a nature reserve and two Ramsar sites. In addition, within the national parks there are three other Ramsar sites, and six areas with known occurrences of the cold-water coral *Lophelia pertusa* off the Norwegian coast that have been protected against fishing with bottom trawl.

National legislation in the Nordic countries and international legislation concerning cultural heritage on the seabed

In general, the national legislation of the Nordic countries offers adequate legal protection to cultural heritage on the seabed. The laws are, however, not always enforced. The practice of the legislation concerning the fisheries generally lacks enforcement of the obligation to report finds. Likewise, preliminary investigations of the seabed prior to exploitation are nonexistent. These practices should be assessed with the aim of changing this situation. As for the protection of archaeological sites, only the Environment Act of Svalbard offers protection from trawling and dredging, although this is restricted to a 100m radius from the archaeological finds. However, this Act is currently not enforced.

The conclusion on the part of international waters is that the national legislation of the countries involved in trawling and bottom dredging in Arctic waters should be compelled to comply with the international conventions, United Nations Convention Law of the Sea (UNCLOS) and the UNESCO proposal for a “Convention on the protection of the underwater cultural heritage” (not ratified). Such acts would make it possible to prosecute illegal activities. In 2003 Denmark added a paragraph on international waters to their legislation on cultural heritage, concerning Dan-

ish vessels and subjects. According to this, it is forbidden to inflict changes on the state of the cultural heritage objects under water. In considering bringing the national legislation of the other Nordic countries into compliance, this wording should be noted, as it protects the cultural heritage and its environment.

The following measures should be taken to improve the effectiveness of juridical measures at international, regional and national levels:

- a) Bringing national legislation into compliance with international agreements,
- b) Initiating a change in the attitude towards the implementation of existing legislation,
- c) Informing managers and politicians of the consequences of non-implementation of the law,
- d) Informing the fishing fleet of their actual responsibilities,
- e) Looking into the possibilities of Nordic cross-field cooperation on the subjects mentioned,
- f) Allocating resources to the management to ensure adequate level of information, fisheries monitoring and enforcement of the legislation.

Marine protected areas as a fishery management tool in Arctic waters

Temporary and permanent closures are used as a fishery management tool in Arctic waters to protect spawning and nursery grounds. Several types of closures have been established in Icelandic waters. A real-time closure is a short-term management measure that aims to reduce discarding of undersized fish. Permanent closures are those that are located off North Iceland, have been permanently closed to one or more gear types, mainly otter trawl and long line. The size and boundaries of these areas have been subjected to considerable revision over time.

The main purpose of the closures in Norwegian waters is to protect spawning and nursery grounds and to minimize conflict between vessels using different gear types. The Norwegian management system includes permanent closures and real-time closures in areas open to fishing only part of the year or areas where fishing is limited to certain gears.

In Greenland, there are several areas off the West coast where the shrimp fishery is restricted with closures. Similarly, there is a closed area (the redfish box) off the East coast to minimize discarding of juvenile redfish.

We conclude that the establishment of marine protected areas could contribute to the sustainable use of fish stocks and conservation of vulnerable habitats, biological diversity, natural heritage and historical remains.

1.1.6 Recommendations

The report focuses on several of the threats caused by fisheries in the Arctic ecosystems, with emphasis on scallop dredging and shrimp trawling, and their impact on vulnerable habitats, submarine landscapes and cultural heritage.

Findings from this work form the basis of our recommendations, which can be divided into three main categories (see also table 1.1):

1. Recommendations that highlight the need to map the distribution of vulnerable habitats and species and cultural heritage.
2. Recommendations to increase research effort.
3. Recommendations to implement management measures aimed to protect areas with known occurrences of vulnerable habitats and species, or that need to be closed to fishing to avoid depletion of target stocks. Other management measures suggest a wider implementation of sorting grids in the Arctic to protect non-target species and closures to protect archaeological remains.

In addition, the working group highlighted a number of other issues that are relevant for future work and could serve as guidelines. These issues were not formulated as recommendations because the working group felt they were not directly related to the scope of this project. They concerned, for example, the need to implement networks of marine protected areas, the need to protect areas that are still not affected by fishing gears and the implementation of mandatory environmental assessment prior to the use of new fishing grounds.

1.1.6.1 Habitat Mapping

One of the obstacles to protecting many of the habitats sensitive to impact due to fishing is the lack of information on their distribution. Mapping the distribution of these habitats requires highly specialized equipment, e.g. multibeam sonar, which produces a topographical map of the seabed and may actually discern some habitat types, and Remotely Operated Vehicles (ROVs) to photograph the seabed. Mapping of large areas of the seabed is extremely expensive and time consuming, but it is of paramount importance. Advances in gear technology coinciding with larger and more powerful fishing vessels mean that fishing can take place in areas that were not accessible in the past. Therefore, there is an urgent need to locate those areas with undisturbed vulnerable habitats and to protect them before any damage may be inflicted by fishing gear in the future. Priority could be given to areas that have become ice-free over the past few years due to climate change (ACIA 2004).

RECOMMENDATION 1: Increase the effort in mapping the sea bottom

Why: Mapping the seabed with a detail close to that achieved for land maps has been possible only recently. Acoustic technology produces accurate images of the seafloor with the technique called multibeam mapping.

Multibeam systems not only provide images of the seabed topography, but the strength of the return signal, or “backscatter”, can be used to determine the sediment type or seabed hardness. Sediment type is one of the main factors influencing the distribution of benthic animals. Standard multibeam bathymetry maps combined with information on sediment type, interpreted from multibeam signal data, can be used to identify and locate potential areas of concern, e.g. coral reefs and other types of vulnerable habitats. Therefore, detailed maps are ideal tools for designing efficient seabed surveys, as they minimize the amount of sampling required for habitat mapping. Also, detailed maps can increase fishing efficiency and reduce damage to benthic habitats by the fishing gear. Multibeam mapping provides a sound basic knowledge to develop a sustainable fishery collectively managed by the government (spatial planning) and the industry.

Implementation: Create detailed bathymetric maps of the shelf areas, shelf slopes and ocean ridges in the Arctic waters, using the multibeam technique.

RECOMMENDATION 2: Complete detailed mapping of vulnerable habitats¹

Why: Mapping of the deep-water coral *Lophelia pertusa* in the study area and research on their status has given evidence of substantial damage to coral reefs by bottom trawling. Also, there is anecdotal information that old (1,000 years) and large individuals of gorgonians are disappearing due to the impact of fishing activities. This is probably an irreversible process for the corals and the associated fauna. Furthermore, there is a growing understanding that sponge aggregations are ecologically important habitats and that damage of sponge areas may lead to a depletion of high-diversity patches in otherwise low-diversity environments. Previous studies indicate that this can also be applied to maerl beds and hydrothermal vents.

Detailed information on the distribution of vulnerable habitats is lacking. Although new knowledge on the distribution of the deep-water coral *Lophelia pertusa* has been obtained in the last years, there are large areas that have not been mapped yet. Systematic mapping of other types of vulnerable habitats has still not been carried out in the Arctic waters.

Information on the distribution, abundance, biology and ecology of deep-water gorgonians and mass occurrences of large sponges is scarce.

¹ Vulnerable species and habitats: *Lophelia pertusa* coral reefs, gorgonian aggregations, sponge aggregations, maerl beds, hydrothermal vents and cold seeps.

This also applies to hydrothermal vents and cold seeps. Consequently, little is known about the significance of these habitats in deep-water ecosystems, and how they may be linked to ecosystems in shallower waters. Detailed maps on the occurrence of vulnerable habitats are important for future studies on the ecological function of these habitats.

Implementation: Conduct research to identify and locate vulnerable habitats.

RECOMMENDATION 3: Map cultural heritage in Arctic waters.

Why: The information on positions of cultural heritage in Arctic waters is scarce and lacks reliability. In order to protect non-renewable cultural heritage sites on the seabed, it will be necessary to establish baseline knowledge of their distribution. Mapping and registering cultural heritage should be done on a holistic basis, integrated with other vulnerable habitats and other ecological features, to generate a cross-field synergetic effect.

Implementation: Collate and map information on cultural heritage from systematic mapping programs, general surveys and fishermen, as well as from written sources and reports. Establish a management register, and routines to upgrade and evaluate the information.

1.1.6.2 Research

RECOMMENDATION 4: Further research on the ecological function of vulnerable habitats

Why: Previous studies have demonstrated that deep-water coral and sponge ecosystems are biodiversity hotspots. Corals and sponges serve as habitats for a large number of associated benthic species and there are also strong indications that coral reefs and sponge areas are preferred habitats for certain demersal fish species.

Hydrothermal vents and “cold seeps” support unique benthic communities and many species found in such habitats are endemic and dependent upon such geological features.

All these vulnerable habitats are, therefore, important from both a general biodiversity perspective and as fish habitats. However, our understanding of these ecosystems is still fragmented and incomplete. Vulnerable habitat-forming species may provide habitats for shelter-seeking fish and serve as a basis for the distribution of benthic invertebrates. However, the actual level of their importance for fish populations and their role in the distribution of benthic invertebrates in Arctic waters has not been demonstrated yet. The same applies to other kinds of vulnerable geological habitats.

Implementation: Promote research on the biology and ecology of deep-water corals (reefs and forests), sponge aggregations, maerl beds, hydrothermal vents and “cold seeps”.

RECOMMENDATION 5: Increase research on the impact of trawling and dredging in Arctic waters

Why: Knowledge of the effects of demersal fishing gears on benthic communities and habitats has in general increased over the last decade. However, very few studies have investigated the effects of fishing gear in Arctic waters, which may differ from those recorded in other parts of the world due to dissimilar structure of benthic communities and habitats.

Two types of demersal gear are mainly used in the Arctic: dredges and trawls. Dredges are heavy gear that have been shown to have considerable impacts on benthic communities. The impact of trawls and dredges are, however, dependent upon the habitat type, being greater on bottoms dominated by three-dimensional structures.

This project examined the effects of scallop dredging on by-catch species. The analysis was constrained by the fact that there were no data on by-catch for a 20-year period after the start of the fishery. In addition, the sampling effort was limited to fishing grounds, as the main goal of the surveys was to estimate scallop stock size. It is likely that the main effects of scallop dredging occurred in the early phase of the fishery with the removal of sensitive species, leaving those that are resilient to fishing to dominate. There is, therefore, a clear need to investigate the effects of scallop dredging in undisturbed areas. Regarding otter trawling, most studies on the impact of fishing have been carried out in shallow waters (< 100m). Benthic communities in shallow waters are generally more resilient towards physical disturbances compared to deep-water fauna. Therefore, it is important to investigate the impacts of otter trawling at greater depths.

Implementation: Two main approaches are proposed to investigate the effects of scallop dredges and otter trawls:

- Trawl impact experiments. Areas within a site that have not been fished (or have not been fished for a long time) are trawled or dredged. Samples are taken from fished and unfished plots to assess the impacts on fauna and habitats. Experiments on the effects of otter trawling should be carried out in deeper waters.
- Establish a network of closed areas within heavily fished areas. This would allow investigation on the recovery patterns following the closures.

RECOMMENDATION 6: Modify scallop stock assessment surveys

Why: The data collection needs to incorporate more parameters. Iceland, Norway and Greenland use the swept area method for scallop stock assessment. This is a widely used method based on random sampling theory, and it assumes that scallop density is randomly distributed over the study area. However, this assumption does not apply to sedentary species such as scallops, with aggregated distribution patterns that are persistent

in time and space and depend largely on environmental conditions. For these reasons, geostatistical sampling techniques may constitute a better approach. These techniques take into account the spatial organization of the resource and their location on regular grids or fixed stations.

The surveys should also include and monitor:

- Indicators of fishing pressure, such as the ratio catch:maximum sustainable yield (to investigate the correlation between number of eggs and recruits to the fishery), the ratio predator:stock abundance (to investigate pressure from the ecosystem), status of the environment (to assess the effect of dredging on the fauna).
- Biological reference points for biomass, stock-recruitment relationship and fishing mortality, as indicated in the FAO Code of Conduct for Responsible Fisheries.
- Identification of larval sources and larval sinks: the scallop beds within a given location constitute a metapopulation. Some scallop beds may act as larval sources, producing large amounts of larvae that disperse and settle elsewhere, and other scallop beds act as larval sinks, because they receive more larvae than they disperse. For management purposes it is very important to identify what beds act like sources and what beds act like sinks because overfishing of source beds could lead to a collapse of the stock.

Implementation:

- Review the existing literature on application of geostatistical techniques on shellfish stocks and design new surveys incorporating these techniques.
- Select those indicators of fishing pressure and biological reference points that can be estimated with the available information and describe best the state of the stock and the impact of the fishery.
- Analysis of length distribution of scallops in the different beds to identify larval sources and sinks. All year-classes are present in source areas, whereas in sink areas recruitment does not occur regularly and only a few year-classes will be present.

1.1.6.3 Management Measures

Habitat-forming species tend to be especially vulnerable to direct impact of fishing gear in the Arctic. These species provide an important habitat for a wide range of organisms that are heavily dependent on them and have therefore been termed “diversity hotspots”. The report details the importance of habitat-forming species. Their societal importance increases as the general public becomes aware of them. In addition fishermen and stakeholders have shown a greater acceptance of measures aimed to protect vulnerable habitats, as they may be important spawning grounds for fish.

This report provides evidence that the scallop stocks in the Arctic are very sensitive to fishing. They are characterized by slow growth and high age at maturity, and knowledge on scallop recruitment processes within the study area is very scarce. The discovery in Greenland of empty scallop shells several thousand years old suggests that some scallop populations within the study area may be relic populations. There is an urgent need to identify those stocks that are under threat from high fishing effort and to implement area closures. Even a relatively short closure period can be an effective management measure in order to enhance local scallop stocks. For example, closures have successfully been applied to scallop stocks in the Georges Bank, and scallop biomass increased 14-fold following only four years of closure.

RECOMMENDATION 7: Vulnerable habitats should be protected

Why: Vulnerable habitats are by definition easily impacted and have a low recovery rate. Also, they often serve an important ecological role as habitats for a large number of associated species, including demersal fish. Evidence shows that corals in Arctic waters have been damaged substantially by fishing activities and they are under serious threat from increased resource exploitation in the deep areas. Although no investigation has been conducted on trawl impact on sponges and maerl beds in the Arctic, anecdotal information from the Faroe Islands (sponges) and Iceland (maerl) indicate detrimental effects of trawling / dredging on such habitats.

To avoid local extinction of these ecosystems, urgent actions and measures are needed. Area closure is the only effective management measure to protect vulnerable habitats from negative effects of fishing activities. Norway has taken a very important step towards protection of vulnerable habitats by closing a number of deep-water coral reefs off the coasts of Norway. Similarly, the Ikka Fjord in Greenland and its vulnerable submarine rock formations (ikaite tufa) became protected by law in 2000. In Iceland, the hydrothermal vents in Eyjafjörður became protected as a natural monument in 2001. However, no comprehensive measures have been developed for the protection of vulnerable habitats in the Arctic, although they also occur in the international waters of the Arctic high seas that are beyond national jurisdiction.

Any management regulations and measures should be precautionary and designed to prevent deliberate or accidental damage to vulnerable habitats because their restoration, if possible at all, will take generations and require considerably more expenditure, resources and effort than the implementation of precautionary preventive measures.

Implementation:

- Support at global and regional levels the establishment of urgent and precautionary measures designed to sustainably conserve, protect and

manage vulnerable marine habitats in the Arctic, both within national jurisdictions and in international waters.

- Develop and adopt precautionary regulations and measures to protect, conserve and manage in a sustainable manner the vulnerable habitats in the Arctic to prevent their deliberate or accidental damage caused by human activities. This should include consideration of interim prohibitions to reduce or eliminate human activities that adversely impact vulnerable habitats within and beyond the limits of national jurisdiction.

RECOMMENDATION 8: Measures to protect scallop stocks

Why: The scallop stocks within the study area have proven to be very sensitive to overfishing and have declined greatly over the past 20 years. Besides, the protection of the scallop stocks will also benefit other benthic species.

Implementation:

- Permanent closure of a large part of the areas containing scallop beds that act as larval sources to ensure larval supply and to protect other benthic species that are vulnerable to dredging and are very important for scallop settlement, such as bryozoans. Closures have shown to be effective to increase yield-per-recruit, and what is more important, they reduce the risk of recruitment and growth overfishing (fishing individuals that have not reached the maximum yield per recruit).
- Design a rotational closure system for the areas open to the fishery. For areas that are larval sinks, the rotation should be planned in a way that each area is fished when scallop biomass is higher.
- Decrease fishing effort. Closures are most successful when their implementation is combined with a significant decrease of fishing pressure. This can be achieved by decreasing quotas, number of licenses and / or limiting the number of fishing days, for example.
- Increase minimum landing size to prevent recruitment overfishing (overfishing of sexually mature individuals to the point of jeopardizing spawning processes due to low density of spawners) and regulate the fishing mortality at all ages. This measure would ensure that all year-classes are present in the population and increase the probability that each individual has the chance to reproduce in several years. Note that in 1998 it was recommended to *decrease* the minimal landing size for the scallop stock in Svalbard and Bjørnøya to increase the fishable stock during the following fishing season.

RECOMMENDATION 9: Measures to protect spawning/nursery areas found in shrimp fishing grounds

Why: The shrimp fisheries seem to have a detrimental effect on by-catch species and benthic sessile species that are injured or die following con-

tact with the fishing gear or as a result of habitat modification. Shrimp fishing grounds overlap in certain locations within the study area with spawning and nursery grounds of commercial fish species, leading to high mortality of juvenile fish. Temporal closures and the use of sorting grids have been implemented for a long time within the study area but abundance of by-catch species has nevertheless decreased significantly. Furthermore, the commercial fish stocks in the Barents Sea are below safe biological levels.

Implementation:

- Long-term closures of areas that are known to be spawning/nursery grounds.
- Decrease fishing effort by decreasing quotas, number of licenses and/or limiting the number of fishing days, to cite a few examples.

RECOMMENDATION 10: Measures to protect cultural heritage

Why: The cultural heritage on the seabed is a non-renewable resource, often depleted and damaged by human activities. The environment in Arctic waters favours the preservation of shipwrecks and other organic matter, thus representing a valuable but fragile resource of knowledge of our common past. The protection of cultural heritage on the seabed should be strengthened, with the aim to preserve such cultural remains *in situ*.

Implementation: Improve the effectiveness of juridical and management measures at international, regional and national levels:

- Bringing national legislation in accordance with international agreements, so that violations of the legislation may be legally prosecuted.
- Informing and educating the management on the implementation problems of national legislation and international agreements concerning the damage of archaeological remains by fishing activities.
- Assessing, evaluating and signalling the consequences of non-implementation of the legislation and informing politicians.
- Informing the fishing fleet of their legal responsibilities, such as the duty to report wrecks, and establish a map and register of such finds.
- Looking into the possibilities of Nordic cross-field cooperation on the subjects mentioned above in order to establish a common level of awareness.
- Allocating resources to ensure an adequate level of information, fisheries monitoring and enforcement of the legislation.

1.1.7 Food for thought

Human impact on the marine ecosystem is wide ranging. In this project, the work focused primarily on the effects of trawling and dredging on vulnerable seabed habitats, non-target species and cultural heritage. However, a number of important issues emerged during the meetings of the working group that could not be formulated into recommendations because they were out of the scope of this project:

- The need to integrate environmental impact assessment into fisheries management to protect vulnerable habitats and cultural remains
- The establishment of a network of protected areas
- The need for more research on development of towed bottom gear with less impact on the seabed
- The need for more collaboration and communication between scientists and stakeholders
- The need to inform the public about the impact of fishing gear on the marine ecosystem and its consequences.

Integrating environmental impact assessment in fishery management

During the last few decades great developments have taken place in the trawling fisheries in Arctic waters. Modern trawlers have become much larger and more powerful than the trawlers operating prior to the 1970s. Consequently they use heavier fishing gear that have significantly more impact on the seabed. Also, the relatively recent introduction of rock hoppers made possible the use of bottom trawls on rough stony bottoms and in coral areas. With larger and more powerful vessels, bottom-trawl fishing in the Arctic progressed into deeper waters and incidents of encountering coral areas became more common.

The onset of scallop fisheries in different areas of the Arctic followed the discovery of virgin scallop beds. The scallop stocks in Svalbard, Bjørnøya and Jan Mayen were depleted in three fishing seasons during which landings reached 45,000 tonnes without a previous stock assessment. The Icelandic fishery was closed in 2003 but catches had been decreasing since 1988. Scallop dredging is still carried out in West Greenland, with annual catches of roughly 2,000 tonnes.

On land, an environmental impact assessment (EIA) is generally required before any development takes place. In the marine environment, EIA is often required prior to any development in coastal areas and in shallow waters, such as gravel extraction and aquaculture. We are, however, not aware of any examples where EIA is integrated in fisheries management. It should be possible to implement EIA by law as a prerequisite prior to licensing fisheries in pristine areas. For this purpose, the availability of very detailed data on distribution of fishing effort is extremely important. The first step to implement EIA on the fishing industry would be to quantify and map the present distribution of bottom trawling and

dredging in the Arctic waters, preferably by using satellite tracking of fishing vessels. With this information, the areas exposed to low or no trawling effort can be delineated and closed to all fishing activities until an EIA has been carried out, and the occurrence of vulnerable habitats and species and cultural remains is known. In a way, this is a precautionary approach to deter unnecessary damage to natural and cultural heritage. Measures to protect these areas against human activity would be taken if the results of EIA indicate that natural and cultural heritage of high importance occur within the investigated area. Otherwise the investigated area would be open to fishing and / or other activities.

Establishing a network of protected areas

It is considered of vital importance to protect those habitats consisting of fragile three-dimensional forms. However, many other habitat types can be important for ecosystem functioning. As an example, muddy bottoms contain a large variety of organisms that are relevant in food-web dynamics of commercial fish species. Intensive anthropogenic disturbance in such habitats may result in a complex cascade of effects that are often difficult to discern.

In the Arctic, area closures take place as a fisheries management strategy or to protect vulnerable features of biological or geological origin, but despite these actions there is a clear need to protect a range of marine habitats. Recent work by OSPAR and IUCN has culminated in guidelines that are used to evaluate the importance of habitat types on the basis of a wide range of criteria. For example, in the OSPAR framework, the selection of sites for protection is a two-stage process. The first stage involves identification of possible sites; in the second stage, the sites are prioritized. At both stages, several criteria are taken into consideration. The criteria in the first stage include the presence of threatened or declining species and habitats / biotopes, ecological significance, representativity and sensitivity. Some of the criteria used in the second stage are “potential for restoration”, “degree of acceptance” and “scientific value”.

Modification of towed bottom gear in order to decrease their impact on the seabed

Demersal fishing gear targets animals that are highly associated with the seabed, and for that reason they always exert some impacts that are difficult to avoid. Several studies have been carried out to develop towed bottom gear with little or no impact on the seabed, or to make them more selective. These studies include the development of trawls where the contact of the otter boards or the footrope with the seabed is minimized. This is for example achieved by using flexible kites that enhance the horizontal lift and therefore make the trawl doors lighter. One problem that may hinder the use of such modified gear is that these are often unpopular with fishermen due to increased costs and / or reduction of catches.

Another problem of towed fishing gear is the large incidental catch of non-targeted species (by-catch) that are very often returned to the sea (discarded). In many fisheries, the rate of discarding is unacceptably high and measures to decrease such practices are therefore of extreme importance. The use of sorting grids is used widely in shrimp fisheries in the Arctic and it has proved to be useful to decrease by-catch of fish > 20 cm. However, these are not effective to sort out small-sized and juvenile fish. Research on the development of fishing gears with little or no contact with the seabed should be strengthened. Similarly, more research is needed to develop very selective gear and to decrease the by-catch.

Communication and cooperation between scientists and stakeholders

It is important to strengthen the cooperation between scientists and stakeholders (e.g. fishers, fishing industry, nature conservation bodies and the public) on conservation issues and sustainable use of marine resources. Consultation and collaboration with stakeholders is important as they can help managers and scientists by supplying local knowledge. As an example, the knowledge accumulated by fishermen can be taken into account alongside fisheries science. Similarly, conservation schemes can be designed by nature conservation bodies, fisheries managers and other stakeholders. Such integration is a step forward to the development of more effective integrated management measures. This cooperation can take place in form of workshops, seminars and more discussion on fishery and conservation issues in newspapers and periodicals.

Educating the public

Awareness of the public regarding environmental issues, such as the illegal commerce of threatened species, the need to preserve the biodiversity or the by-catch of dolphins in the tuna fisheries has increased greatly over the past few decades. However, people are often ignorant of the need for conservation of the marine natural and cultural heritage. It is necessary and very important to educate and inform people about the environmental threats of fishing to their natural and cultural heritage. The opinion of a well-informed public can be relevant to policy makers and can improve management decisions. As an example, the public in Australia had their say in the recent modification of the management plan for the Great Barrier Reef. Information related to marine environmental issues can be divulged in websites, explaining scientific work with comprehensible text for laymen, articles in newspapers and popular periodicals, seminars, television documentaries and frequent discussion about fishing and marine environment issues in the media.

Table 1.1. Overview of the recommendations based on the work carried out for this project.
Recommendations are grouped into three main categories: mapping, research and management measures.

Recommendations WHAT	Actions HOW	Reasons WHY
MAPPING		
<i>Recommendation 1</i> Allocate more resources to map the sea bottom.	Creating detailed bathymetric maps of the shelf areas, shelf slopes and ocean ridges in Arctic waters, using the multibeam technique.	Mapping is a base for spatial management. For example, a detailed bathymetric map is an essential tool to identify and locate potential areas of concern, such as vulnerable habitats².
<i>Recommendation 2</i> Intensify detailed mapping of vulnerable species and habitats².	Conducting research to identify and locate vulnerable habitats.	Knowledge on the distribution of <i>Lophelia pertusa</i> has increased in recent years but large areas remain unmapped. Detailed information on the distribution of vulnerable habitats is still lacking. Presently, management effort is limited to a number of coral reefs and one hydrothermal vent area.
Map important occurrences of gorgonians.	Collating available information from systematic mapping programs, general benthic surveys and fishermen.	Old (1,000 years) and large individuals of gorgonians are disappearing due to the impact of fishing activities and this is probably a non-reversible process. No management efforts have so far been made for gorgonians.
Map sponge aggregations.	Collating available information from systematic mapping programs, general benthic surveys and fishermen.	There is a growing understanding that sponge aggregations are ecologically important habitats. Damage of sponge areas may lead to a depletion of high diversity patches in otherwise low diversity environments. No management efforts have so far been made for sponges.
<i>Recommendation 3</i> Map and register cultural remains / natural heritage in Arctic waters.	Collating information from systematic mapping programs, general surveys and fishermen.	Baseline knowledge on the distribution of cultural remains and natural heritage is needed. This will be the platform for further decision making in order to prioritize protection of cultural remains and natural heritage.

² Vulnerable species and habitats: *Lophelia pertusa*, coral reefs, gorgonian aggregations, sponge aggregations, maerl beds, hydrothermal vents and cold seeps.

Table 1.1. (Cont.)

Recommendations WHAT	Actions HOW	Reasons WHY
RESEARCH		
<i>Recommendation 4</i> Increase research on the biology of coral reefs, coral forests and other habitat-forming organisms and their functional role in deep-sea ecosystems.	Establishing the variations in species diversity and community structure of habitat-forming organisms in Arctic waters. Confirming the ecological requirements of habitat-forming organisms in Arctic waters. Determining the reproduction, development modes and the dispersal capabilities of habitat-forming species in Arctic waters. Establishing the role habitat-forming species play in mediating the distribution and abundance of mobile species, and in providing sites for fish to spawn, feed and shelter from predators.	Organisms that provide three-dimensional structure (i.e. deep-sea corals and sponge beds) are important fish habitats used for shelter, feeding, spawning and as nursery areas for post-settlement individuals. Previous studies have documented diverse faunal associations in such habitats. These habitats are therefore important both from a general biodiversity perspective and as habitats for commercial fish species. However, current knowledge is limited to the biology and functional role of habitat forming organisms in deep-sea ecosystems.
<i>Recommendation 5</i> Increase research on impact of trawling and dredging in Arctic waters.	Investigating the impact of towed bottom gear with field experiments and by establishing networks of closed areas. Investigating the effects of bottom gear in deeper waters.	The impact of towed-bottom gear, such as dredges and trawls on benthic communities and habitats in Arctic waters is not well known. Dredges are heavy gear known to have considerable impact on benthic communities. It is expected that both trawls and dredges can exert a large impact, especially in deep waters, where the fauna tends to be more vulnerable to physical impacts than in shallow waters.
<i>Recommendation 6</i> Modify the scallop stock assessment surveys.	Use of geostatistical techniques in survey design. The surveys should include and monitor: • Indicators of fishing pressure. • Biological reference points for biomass, stock-recruitment relationship and fishing mortality, as indicated in the FAO Code of Conduct for Responsible Fisheries. • Identification of larval sources and larval sinks.	The swept area method currently used is not the best to study sessile species with aggregated distribution patterns. To know the egg:recruit ratio. To monitor the state of the stock and ensure a sustainable use of the resource. To avoid overfishing of source beds that could lead to the collapse of the stock.

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1.2 Introduction to the Arctic environment

1.2.1 Hydrography and ecology

1.2.1.1 Definition of the region / study area

The major part of the study area is collectively called ‘the Nordic Seas’, which is a common name for the seas north of the Greenland–Scotland Ridge and south of Spitsbergen, i.e. the Greenland, Iceland, Norwegian and Barents Seas (Figure 1.1). The study area also covers the Irminger Sea and waters off the West coasts of Greenland. In relation to vulnerable marine habitats, the recent discoveries of coral reefs around Norway and their protection by Norwegian authorities are an important issue in the present study. Therefore, the group decided to extend the geographical boundaries of the study area to include maritime areas off Norway south to 67°N.

1.2.1.2 Bottom topography

The most distinctive topographic feature of the study area is the submarine Greenland–Scotland Ridge – from which Iceland and the Faroe Islands rise above the sea surface (Figure 1.1). The ridge has a sill depth of 480 to 840m and forms a barrier between the deep-water masses of the ocean areas to the north of the ridge and the rest of the Atlantic Ocean (OSPAR 2000).

The Greenland, Iceland and Norwegian Seas north of the ridge are also defined by the bottom topography. The Iceland Sea extends between Iceland, Greenland and a line along 71°N between Jan Mayen and Greenland, with depths around 1500m. The ocean ridge that crosses Iceland and continues across Jan Mayen north-eastwards into the Arctic Ocean, forms the boundary between the Greenland and Norwegian seas, which have almost 4000m deep basins (Figure 1.1). These basins have a relatively open connection to the Arctic Ocean through the Fram Strait. The Barents Sea, one of the widest shelf areas in the World Ocean (OSPAR 2000), is linked to the Nordic Seas through the gap between Norway and Svalbard and to the Arctic Ocean in the North and Northeast. Its mean depth is 230m and there are wide areas shallower than 300m.

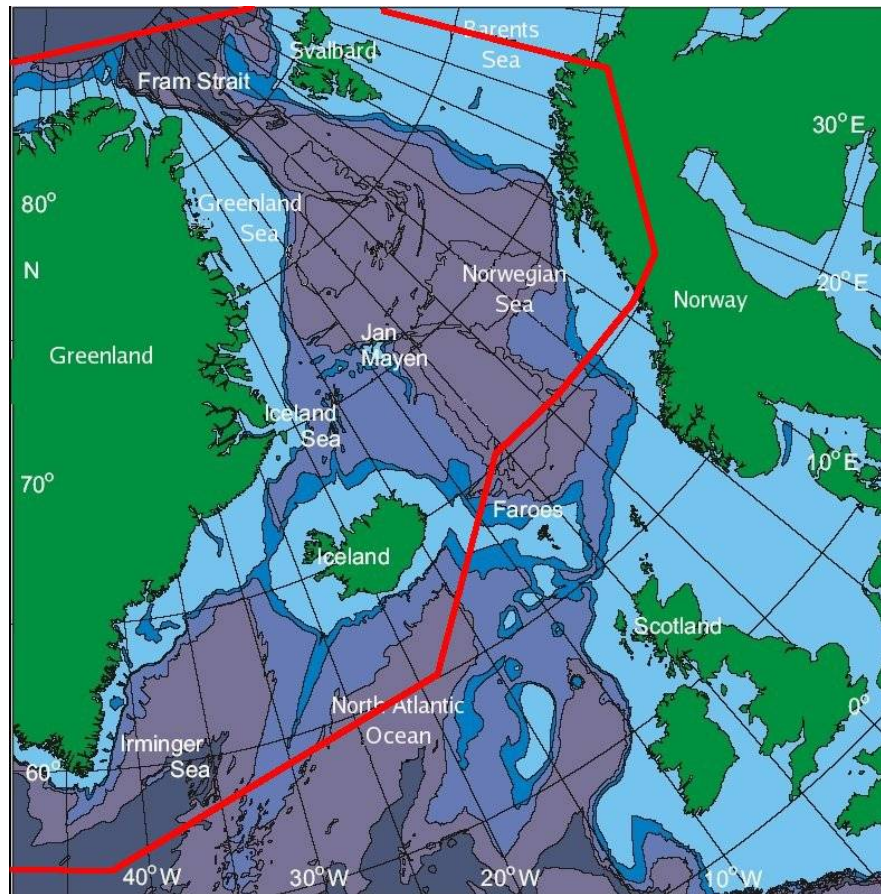


Figure 1.1 Main bathymetric features in the Nordic Seas. Boundaries of the study area are indicated with red.

1.2.1.3 Geology and sediments

During the last 1.6 million years (the Quaternary ice ages), the land areas around the Nordic Seas have been severely denuded and the eroded material was mainly deposited in the ocean (OSPAR 2000). Thick, coarse-grained deposits occur along the continental margins but finer grained sediments (silt and clay) were deposited in the deeper ocean basins. During late and post-glacial times, redeposition and transport of glacial sediments into the deep ocean basins has taken place by movements of ocean water masses.

The areas along the spreading ridges in the Atlantic and the Nordic Seas have a high input of volcanic sediments but are otherwise covered by a relatively thin coat of sediments. At present, deposition in the deep ocean basins is generally ruled by the major ocean currents and is dominated by pelagic sedimentation (OSPAR 2000). The coastal areas are dominated by sediments of terrestrial origin that are either trapped in deep fjords and do not reach the open ocean, or are transported into the ocean by glacier rivers.

1.2.1.4 Water masses

Bodies of water (“water masses”) are principally identified on the basis of their temperature and salinity. The major water masses are grouped according to the depths at which they are typically found (upper, intermediate and deep water masses). A large number of intermediate water masses have been defined in the Nordic Seas but will not be reviewed here, as they are not relevant in the context of this report. The following description of upper and deep water masses in the Nordic Seas is based on the OSPAR Quality Status Report (OSPAR 2000) and Buch (2000).

Upper layer water masses

Several water masses represent the surface and upper layer water of the Nordic Seas. The North Atlantic Water (NAW) (Figure 1.2) is flowing along the continental slope of Norway up to Svalbard and to some extent also into the Barents Sea. It is the warmest water mass in the Nordic Seas (9–10°C) and has also the highest salinity (35.3–35.4‰).

Modified North Atlantic Water (MNAW) derives from the open North Atlantic. It mainly enters the Nordic Seas between Iceland and the Faroe Islands, with temperature ranging from 7 to 10°C and salinity mainly between 35.1 and 35.4‰. As it progresses further north the water mass becomes cooler and more diluted.

The Norwegian Coastal Water (NCW) originates in the Baltic and its salinity is usually > 30‰ when it enters the Nordic Seas off the South coast of Norway. Due to further mixing with oceanic waters, its salinity increases on its journey further north, reaching a maximum around the Lofoten Islands. The NCW shows great seasonal variation in temperature (between –1.8 and 14°C).

The Polar Water (PW) is formed in the Arctic Ocean and enters the Nordic Seas between Greenland and Svalbard. It is found along the coast of East Greenland all the way down to the area of Cape Farewell. The water mass occupies the top 30–50m of the surface layer and is supplied with large quantities of river runoff that varies seasonally depending on the freezing and melting of sea ice. The Polar Water has low salinity (30.0–34.0‰) and it is cold (between –1.8 and 3°C).

South of Iceland a minor part of the NAW splits off to flow north along the West coast of Iceland. At the Iceland-Greenland Ridge the current splits in two branches, the smaller flows eastwards around NW Iceland and continues along the North coast of Iceland. The larger branch turns west and forms a cyclonic eddy off the East Greenland coast, eventually joining the southward flowing East Greenland Current (Vilhjálmsen 1994).

The Irminger Sea lies roughly between the East Greenland coast and the West coast of Iceland. The Irminger Sea Water (ISW) is mainly formed by winter convection that reaches 500m depth (Buch 2000). Off-shore it flows around Cape Farewell into the West Greenland waters,

together with the East Greenland Polar Water (closer to the shore). The ISW is relatively warm ($3.5\text{--}5^{\circ}\text{C}$) compared with the East Greenland Polar Water ($-0.5\text{--}4^{\circ}\text{C}$) and it also has higher salinity ($34.75\text{--}34.0\text{‰}$ and $31.5\text{--}33.78\text{‰}$, respectively). Both are predominant in the upper layer water masses off the coasts of West Greenland.



Figure 1.2 Illustration of the main surface water masses and currents in the Nordic Seas. MNAW= Modified North Atlantic Water, NAW = North Atlantic Water, NCW = Norwegian Coastal Water, PW = Polar Water (Hansen and Østerhus 2000).

Deep sea water masses

The Greenland Sea Deep Water (GSDW, temperature $< -0.5^{\circ}\text{C}$, salinity $34.88\text{--}34.89\text{‰}$) is formed through cooling during winter, mainly in the centre of the Greenland Sea Gyre, which circulates cyclonically (anti-clockwise) around the deep Greenland Basin (Figure 1.3). The density increases in the surface layer due to the winter cooling, which may be sufficient for surface waters to sink to great depths (“deep convection”) and in extreme cases to the basin floor (deep winter convection).

Development of the Eurasian Basin Deep Water involves the formation of bottom water on the adjacent shelves (“shelf convection”). For example, in the Barents Sea such water (temperature $< -1.7^{\circ}\text{C}$, salinity $> 35.0\text{‰}$) is formed over shallow banks by winter cooling and brine rejection during ice formation. This water will eventually leave the shelf area,

through the Bjørnøya Trough or from the Storfjord Deep, and sink into the Norwegian Sea.

The relatively shallow sill depth of the Greenland–Scotland Ridge prevents deep water from entering or leaving the Nordic Seas. Thus all deep waters north of the ridge have been formed in the Nordic Seas or the Arctic Ocean and flow into the North Atlantic as overflow water, over the Greenland–Scotland Ridge or through deep channels. The formation of deep waters in the Nordic Seas and the Arctic Ocean is recognized as one of the most important features in the global ocean circulation.

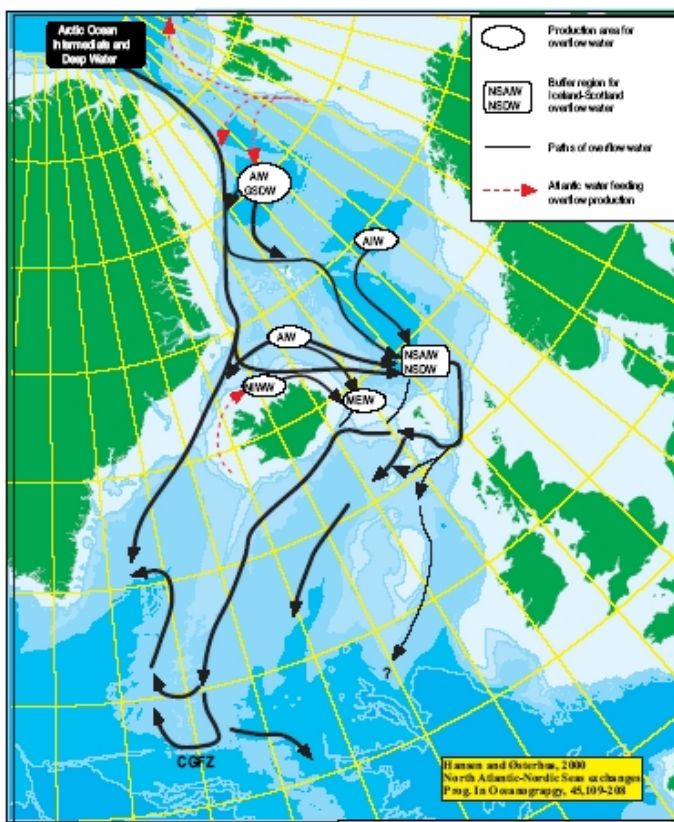


Figure 1.3 Illustration of the main deep-water masses and currents in the Nordic Seas. GSDW= Greenland Sea Deep Water, NAW = North Atlantic Water, NCW = Norwegian Coastal Water, PW = Polar Water (Hansen and Østerhus 2000).

Estuarine and coastal waters

In addition to the open ocean water masses, a number of different water masses are found in fjords and estuaries, depending on the estuary type, freshwater input, mixing conditions, etc. Generally, the salinity of these water masses is lower than in the open ocean due to the larger freshwater input from land. As the estuarine waters propagate offshore, they mix with the more saline ocean waters, and a fairly well-defined coastal water mass of intermediate salinity is often formed in the shelf region.

Ocean circulation

In contrast to most other oceanic areas, the circulation in the Nordic Seas is truly three-dimensional. Both the upper and deeper layers have complicated systems of horizontal currents, but in addition the deep-water formation induces a vertical exchange. The areas north of the Greenland–Scotland Ridge therefore have a net inflow from the Atlantic in the upper layers and a net outflow to the Atlantic in the deeper layers.

1.2.1.5 Overview of the marine ecosystems

The high latitude ecosystems of the Nordic Seas and the Arctic are characterized by large natural fluctuations. This is due to the high variability in recruitment to fish stocks combined with strong biological interactions in relatively simple food webs (OSPAR 2000). The area comprises the transition zone between the boreal and true Arctic biogeographic regions. In Polar Front areas this transition zone can be very sharp but is more gradual in areas where the mixing of water masses occurs.

The primary production is conveyed to higher trophic levels, often through short food chains within simple food webs. This allows for efficient transfer of energy and supports large stocks of fish, mammals and seabirds. Climatic variability causes large interannual variability in ice cover and hydrographic conditions, which again affects plankton production and fish stocks (OSPAR 2000).

A substantial fraction of the primary production is lost from the pelagic food web by sedimentation before it is grazed by the zooplankton. The amount grazed depends on the coupling between the time of the phytoplankton bloom and the zooplankton grazing. The volume of phytoplankton (primary producers) removed from the pelagic system by sedimentation governs the level of mesopelagic and benthic production.

The nature of the interactions between the zooplankton and the other trophic levels varies for the different water masses and biogeographical regions. The Nordic Seas are the feeding area for several large pelagic fish stocks, including herring, blue whiting and mackerel. In the northern areas, capelin and herring are the key pelagic fish species, while blue whiting, herring and mackerel are the most important zooplankton predators in the central and southern regions. Demersal fish, such as cod, feed to a large extent on other fish. However, during their pelagic larval and juvenile stages, they depend mainly on copepods as their food source. In addition, marine mammals and seabirds are major zooplankton predators.

The benthos, constituted by organisms living in and on soft sediments and hard bottoms, is an integral part of marine ecosystems and it represents a major link between the pelagic production and sedimentary deposition (Gage and Tyler 1991; Graf 1992). Benthos also re-mineralizes deposited organic matter, re-circulates nutrients necessary for primary production and is a food source for fish.

The underlying features that seem to determine the structures of benthic communities are temperature and substrate types. Accordingly, the distribution of benthic communities is closely related to water masses and types of bottom substrate and topography. The Greenland–Scotland Ridge represents a biogeographical boundary between boreal, arctic-boreal and true Arctic species. There is also a faunal gradient across the continental shelf and slope to the continental rise and abyssal plane (e.g. Svavarsson 1997). This transition zone in the slope region is rich in fish, hyperbenthos and micronekton.

Generally, there is limited knowledge on the benthic species composition and biomass in the Nordic Seas. Studies on hard-bottom benthos in fjords and on the shelf of Svalbard using underwater photography showed good correlation between faunal assemblages and bottom type, water temperature and ice conditions. Studies based on long-term data from the Svalbard shelf have shown that significant changes have taken place in the distribution of some macrofauna during several decades. This has been attributed to changes in bottom temperature (Blacker 1957; Christiansen and Christiansen 1962). In recent years the BIOFAR and the BIOICE research programs have collected data on the distribution of benthic fauna within the territorial waters of the Faroe Islands and Iceland, respectively. Major faunistic changes around Iceland and the Faroes are mainly associated with the Greenland–Scotland Ridge, possibly due to rapid changes in water temperature across the ridge. Studies based on the BIOICE material indicate that in the Iceland Sea and the western part of the Norwegian Sea, the benthic diversity increases with depth to about 320 to 1,100m (shelf slope), below which the diversity decreased (e.g. Svavarsson 1997). It has also been shown that large differences occur in species composition around the Kolbeinsey Ridge in the Iceland Sea. Abundance and diversity of benthos are higher on the western slope of the ridge in comparison with the east slope (Brandt and Piepenburg 1994). This indicates that benthos abundance and diversity is determined by differences in water temperature, bottom topography and food supply (largely pelagic primary production).

In the study area, there are several fish species that support major fisheries in the Nordic and Barents Seas: cod, saithe, haddock, redfish, blue whiting, herring and capelin. The continental shelves are the spawning areas for many commercially important fish species. From the spawning grounds the larvae are spread into the open ocean. Herring and capelin perform long annual migrations between the feeding and wintering areas. Four species are particularly important for commercial bottom-trawling fisheries in the study area: cod, haddock, saithe and redfish.

Cod is very important economically in the Nordic Seas. Historically, the main stocks are the Northeast Arctic cod in the Barents Sea and the Icelandic cod. Besides which, there are cod stocks in the North Sea around the Faroe Islands and off West Greenland. The Northeast Arctic

cod is potentially the largest cod stock in the world, with annual catches historically reaching around one million tonnes. The stock biomass has fluctuated considerably over the last 50 years; from three to four million tonnes in the 1950s a minimum was reached in the 1980s (OSPAR 2000).

Haddock is present in most parts of the Nordic Seas. It is a bottom-living (demersal) species that may become 110 cm long and weigh up to 20 kg. Spawning occurs mainly from April to May in deep water along the continental slope west of Tromsøflaket to Røst, Norway, and off the South and West coasts of Iceland. The eggs spread over vast areas. In 1997, the total stock of Northeast Arctic haddock was 430,000 tonnes, of which 145,000 tonnes were caught (OSPAR 2000).

Saithe is a true Atlantic species that can be up to 120 cm long and 20 kg in weight. In the eastern Atlantic the saithe is found over the continental shelf from the Bay of Biscay to Svalbard and Novaya Zemlya, as well as around Iceland. Within this distribution area several stocks are found. The largest stock (the Northeast Arctic saithe stock) is found in Norwegian waters, around Iceland and around the Faroes. Common to most of the stocks is that spawning takes place between February to April at about 200m depth. Juvenile saithe spend the first two to three years along the coastlines where they often occur in considerable concentration. At ages two to three the saithe move to somewhat deeper water at the coastal and offshore banks. Saithe reaches maturity at five to seven years. In 1997, 143,000 tonnes of Northeast Arctic saithe were caught from a total population of around 500,000 tonnes. (OSPAR 2000).

The redfish stock in the Nordic Seas consists of four closely related species, of which two are commercially exploited – *Sebastes marinus* and *S. mentella*. The redfish has internal fertilization, and the eggs hatch before they are released from the female. Copulation takes place in autumn but the females carry the sperm and delay fertilization until winter. The larvae are released in April and May (OSPAR 2000).

Redfish grow slowly and can become very old. *S. marinus* may reach age 60 and up to 100 cm in length. It is common at depths between 100–300m. The main spawning areas for *S. marinus* in the Northeast Atlantic are Southwest Iceland and along the Norwegian shelf.

S. mentella concentrate along continental slopes, but it is also an oceanic (pelagic) species in the Irminger and Norwegian Seas. The oceanic *S. mentella* in the Irminger Sea is considered as a separate stock from the *S. mentella* (the ‘Deep Sea Mentella’) found along the continental slope of the Faroe Islands, Iceland and Greenland. The oceanic *S. mentella* in the Irminger Sea constitutes the largest of the redfish stocks in the area (about two million tonnes). The catches from this stock in 1997 summed 122,000 tonnes, compared to 43,000 tonnes of the Deep Sea Mentella.

Two benthic invertebrate species are important for commercial bottom fisheries in the Nordic Seas, the deep-water shrimp *Pandalus borealis*

and the scallop *Chlamys islandica*. These fisheries are introduced in chapters 2 and 3 of the report.

1.3. Trawling in the study area

1.3.1 Iceland

Bottom-trawling trials were most likely initiated in Icelandic waters by English steam vessels in 1889, operating off the East coast with beam trawls (Þór 1982). Typical beam trawls were 50 feet wide and 4 feet high. From 1895 onwards beam trawls were replaced by otter trawls using 7 (max. 12) x 4 (max. 6) foot otter boards to open the trawl up to 70–80 feet width and 8–10 feet height. A 7x4 foot otter board weighed some 200 kg. Otter trawling enabled fishing to be carried out down to twice the depths previously reached as well as in worse weather and more uneven bottom substrates. Therefore, the introduction of the otter trawl greatly extended fishing activities spatially and led to an overall increase in fishing effort (Sæmundsson 1896).

By the beginning of World War I in 1914, trawling effort had doubled in respect to effort in 1905, mostly due to the increasing number of foreign trawlers primarily targeting cod and to a lesser extent haddock and plaice (Þór 1982). Total effort dropped during the war, but increased steadily in post-war years with catches of cod rising from 100,000 tonnes in 1918 to some 500,000 tonnes in the early 1930s. Haddock catches also rose fivefold, to around 50,000 tonnes by the end of the 1920s, mainly due to increased effort by foreign trawlers. Redfish catches increased sixfold or from 10,000 to 60,000 tonnes during the mid- to late-1930s, while the catches of cod and haddock dropped to 200,000 and 20,000 tonnes respectively (Anonymous 1905–1940).

Foreign trawlers were totally absent from Icelandic grounds during World War II, but still the Icelandic catch of cod increased from 150,000 to 200,000 tonnes by the year 1945 and the catch of saithe from 10,000 to 30,000 tonnes. Haddock catches, however, remained at 10,000 to 20,000 tonnes. In post-war years fishing intensity increased rapidly again with catches of cod surpassing 500,000 tonnes in 1953–1955, of which some 350,000 tonnes were taken by Icelandic and foreign trawlers (Eiríksson 1988). The haddock catches also rose steadily after the war from around 15,000 tonnes in 1945 to a historical high of around 100,000 tonnes in the early 1960s. Moreover, the catch of saithe reached a historical maximum of 130,000 tonnes in 1971. Approximately half of these gadoid catches were taken by foreign trawlers. A large market for redfish opened in the USSR around 1950, so a multinational trawler fleet increased their effort very rapidly, catching 120,000–160,000 tonnes in 1950–1954 (Anonymous 1941–1971).

During the period 1950–1970, total fishing effort had become more intense than ever before, covering fishing grounds more or less all around the country. Also, total catch of demersal fish (cod, haddock, saithe and redfish) reached a historical high of 700,000–800,000 tonnes during the period 1950–1970 (Anonymous 1950–1970). At this time the typical Icelandic, British or German side trawler towed a trawl with a headline length of roughly 120 feet, a footrope with steel bobbins and trawl doors weighing up to about 800kg. This gear, however, cannot easily be compared with the early 20th-century trawler employing a 80-foot headline trawl with a manila footrope and doors weighing only some 200kg, not to mention the late 20th-century stern trawler using a trawl with a high vertical opening and 150 feet wide, a rock-hopper footrope for fishing on rougher bottom substrates, and trawl doors of three tonnes or more.

Trawling effort increased rapidly in the early 20th century, with 20 Icelandic trawlers in 1915 and over 40 in the 1950s (Óskarsson 1991; Figure 1.4). However, since around 1990 the number of demersal trawlers has decreased by approximately 50%, from about 110 to 60, while their total demersal catch has dropped from roughly 350,000 tonnes to 200,000 tonnes. Also, even though the gross tonnage of the trawler fleet has remained rather stable in the last decade at around 100,000 tonnes, their main engine power has decreased by 25% or from 200,000 to 150,000 kW (Anonymous 2004b).

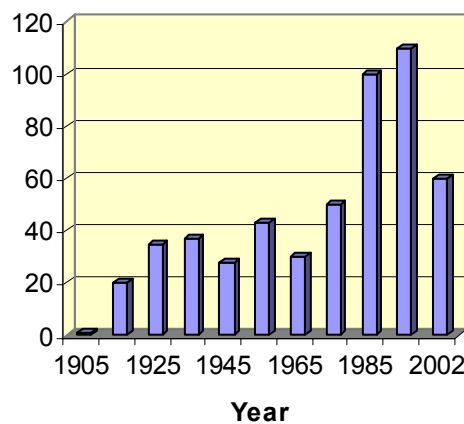


Figure 1.4 Number of Icelandic trawlers during the period 1905–2002.

The extension of the EEZ to 50 and later 200 nautical miles in the 1970s led to the disappearance of almost all foreign trawlers from Icelandic waters and a temporary decrease of fishing effort. However, the rapid renovation of the Icelandic trawler fleet with a modern fleet of stern trawlers soon reinstated the former effort. In addition, a relatively new fishery for Greenland halibut expanded rapidly in the 1980s in previously unfished grounds off Northwest Iceland, with catches increasing from 5,000 to 50,000 tonnes from the mid-1970s to the late-1980s (Figure 1.5a). All the stocks mentioned in the above section have shown a decline in the last

two decades, except for haddock, which has remained relatively stable at 40,000–60,000 tonnes in the last two decades and increased to 85,000 tonnes in 2004 (Anonymous 2005). In addition, all these stocks have been managed with a national total allowable catch (TAC) since 1984. Thus, their combined catches have amounted to 400,000 tonnes in recent years compared to 700,000–800,000 tonnes in the period 1950–1970.

In addition to the bottom-trawl fishery, an offshore shrimp-trawl fishery developed rapidly in the 1980s with catches surpassing 70,000 tonnes by the mid-1990s. Due to decreasing stocks, partly related to the cod-shrimp predator-prey relationship with cod off N Iceland, catches have decreased again to around 25,000 tonnes or less in recent years (Skúladóttir and Sigurjónsson 2004; Anonymous 2005). The initiation of the offshore shrimp fishery led to a great increase in trawling effort targeting cod and Greenland halibut on the continental slopes and in deeper muddy areas off the northern part of the country where bottom trawling had been relatively sporadic until then (Figure 1.5b). However, trawling effort measured in standardized trawling hours has decreased by some 50% in the last decade (Anonymous 2003). Although the shrimp trawlers often use a double-rigged gear with a minimum codend square-mesh of only 36mm, the impact of the fishery on undersized or juvenile fish is alleviated by the compulsory use of a Nordmøre grid since the mid-1990s, as well as a shrimp sorting grid and 40mm square-mesh codend in areas of juvenile shrimp.

The *Nephrops* fishery developed rapidly in the early 1960s in the muddy deeps and banks off South Iceland. Catches reached a historical maximum of 6,000 tonnes in 1963, but they decreased quickly thereafter and have only amounted to some 1,500 tonnes a year in the last decade. Although this is a relatively small fishery, it exerts localized and severe impact due to the use of 80mm codend mesh on grounds inhabited partly by juvenile haddock, whiting and witch (Figure 1.5c). However, fishing effort measured in number of trawling hours has decreased by some 60–70% in the last decade compared to the early 1970s (Eiríksson 1992; Anonymous 2003).

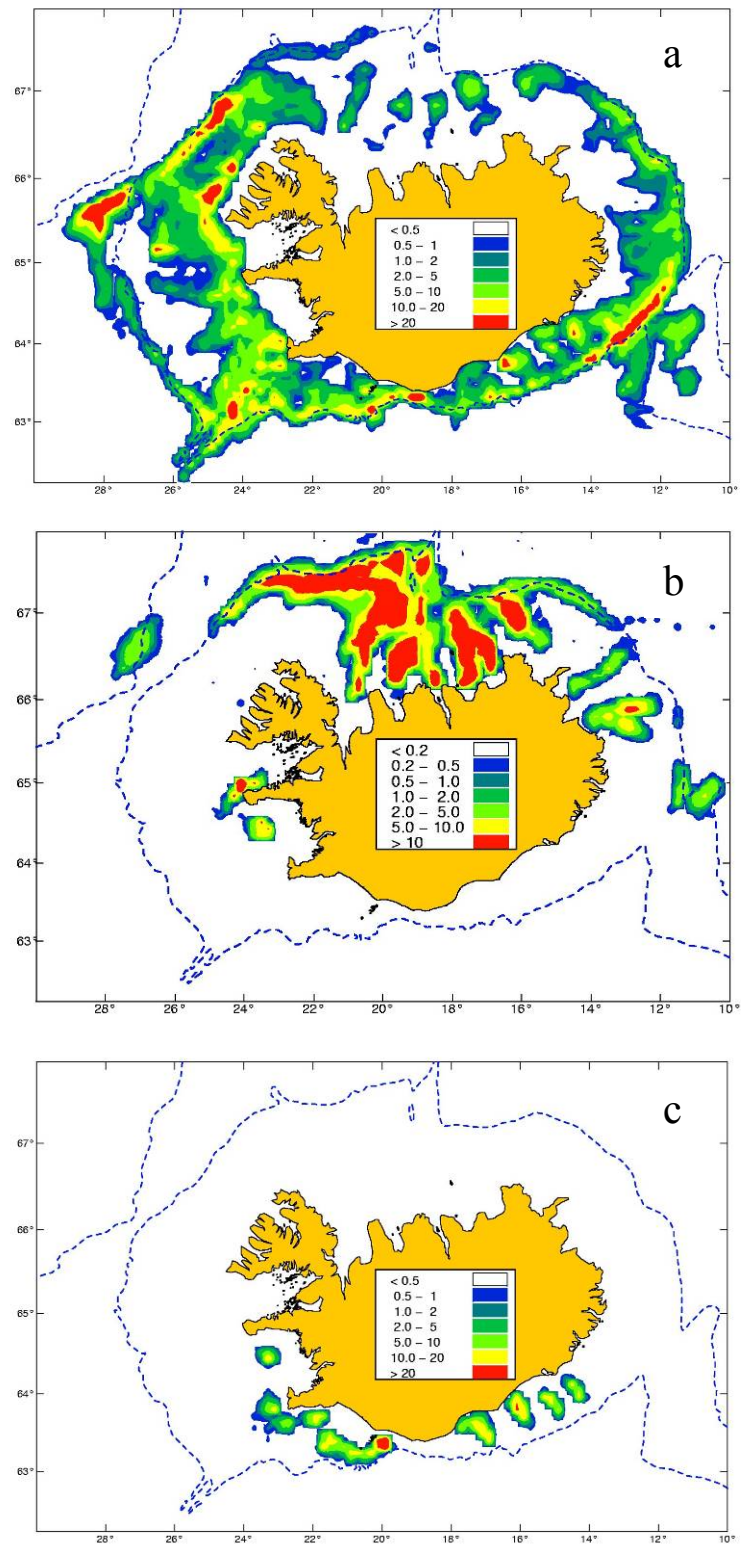


Figure 1.5 Distribution of total otter trawling effort (tow duration) in Icelandic waters targeting (a) demersal fish (b) shrimp and (c) *Nephrops* between 2000 and 2004. The 500m depth contour is shown.

The fishery for Iceland scallop dates back to the year 1969. Catches increased rapidly from roughly 3,000 tonnes in the mid-1970s to 16,000 tonnes in the mid-1980s. Following relatively stable catches, averaging about 10,000 tonnes in 1990–2000, most local stocks have been largely depleted, partly due to high natural mortality and low recruitment. The impact of the fishery is difficult to estimate but it cannot be ruled out. Thus, all local fisheries had been suspended by the year 2003. In Breiðafjörður, West Iceland, which has been the most important fishery with catches of over 12,000 tonnes in the mid-1980s and ranging from 8,000–9,000 tonnes or more for most of the 1990s, the stock is at present estimated at less than 30% of its average size between 1993–2000 and at only some 20% of its estimated historical high in the early 1980s (Anonymous 2003). Due to the heavy weight of the scallop dredges and a relatively high towing speed of up to four knots or more, the impact on benthic life is thought to be considerable (ref.: this report). These areas had been mostly undisturbed by other towed-bottom gear prior to 1970.

From a historical perspective, total trawling and dredging effort measured in fishing hours have decreased considerably over recent years, especially since early 1990 as a result of technological advances and the significant decreases in stock sizes of commercial fish species. Although the impact of fishing activities in the Arctic has not been investigated in detail, except for cold-water coral reefs (*Lophelia* spp., ref.: this report), it is likely that fishing has had a considerable negative impact on benthic habitats and species since the early 20th century.

1.3.2 Greenland

Due to somewhat unstable environmental conditions, individual marine resources in Greenland are often characterized by extreme stock variability, even more so than in Iceland and the Barents Sea. The most important marine species has traditionally been cod, and more recently shrimp. For most of the 20th century, Greenland's fishing industry was comparatively backward and its rich fishing grounds were primarily exploited by foreign fleets, mostly trawlers. During the past few decades, however, Greenland has developed a modern fishing industry including a fleet of stern trawlers, mainly targeting shrimp off the West coast in recent years (Árnason and Friis 1995).

In historical terms there were large US and British line-cod fisheries in the first half of the 18th and 19th centuries but a large and mainly foreign trawl fishery developed after 1920. During the 1950s and 1960s the annual cod harvest was between 250,000 and 400,000 tonnes, but it decreased drastically from around 1970 onwards, being only about 10,000 tonnes or less in recent years (Schopka 1987; Anonymous 1994; Árnason and Friis 1995). While environmental conditions have become unfavoura-

ble for cod since 1960, it is equally clear that overfishing has also played an important part in the extreme decline of the Greenlandic cod stock.

In conjunction with the decline of the cod stock there was a relatively rapid expansion of a shrimp fishery off West Greenland with catches increasing from around 10,000 tonnes in 1970 to some 50,000 tonnes by the mid-1970s, exceeding 80,000 tonnes in the early 1990s and 120,000 tonnes in 2002 (Anonymous 2004). The inshore and ocean-going shrimp-fishing fleet amounted to some 170 trawlers by the early 1970s, ranging in size between 20 and 150 GRT. The expansion of the offshore fishery led to an increase in the ocean-going fleet, which counted about 75 vessels in 1990 (Árnason and Friis 1995). Currently, however, the ocean-going fleet is made up of only 20–25 large trawlers between 1500–3000 GRT, largely equipped with multi-rigged shrimp trawls (Hvingel 2002).

1.3.3 Barents Sea and Svalbard

The Northeast Arctic cod fishery is by far the most important fishery in the Barents Sea and Svalbard area in terms of value. Landings of cod reached 1.2 million tonnes in the mid-1950s and late 1960s but dropped to just some 300,000 tonnes in the 1980s. However, in recent years, the total landings have amounted to 400,000–600,000 tonnes, mostly caught by Norway and Russia. It is estimated that 30 to 40% of the Norwegian and most of the Russian catch are taken by bottom trawls (Bogstad 2002).

Catches of saithe peaked in the early 1970s at 200,000–250,000 tonnes but decreased to about 150,000 tonnes during the last decade. Over 90% of the annual saithe catch is taken by Norwegian vessels, although their share of demersal trawlers has diminished from over 50% to 35% since the early 1990s (Mehl 2002). Landings of the third most important demersal species, Northeast Arctic haddock, reached over 250,000 tonnes in the early 1970s, but have stabilized at 100,000 tonnes or less in recent years. The proportion of haddock caught by Norway and Russia has ranged between 55 to 65% and 35 to 40%, respectively. Over 50% of the Norwegian haddock catch was taken with bottom trawls in the mid-1990s, although the trawl proportion had decreased to less than 40% after 1998 (Fotland 2002). Greenland halibut catches increased rapidly to about 90,000 tonnes in 1970 but have remained below 20,000 tonnes since the early 1990s. During the latest years roughly 50% of the total catch has been taken by Norwegian and Russian demersal and shrimp trawlers (Høines 2002).

Landings of shrimp increased rapidly from less than 10,000 tonnes in 1970–1975 to around 130,000 tonnes in 1984–1985 but they have fluctuated since then between 30,000 and 80,000 tonnes. In recent years, catches have declined from over 80,000 tonnes in the year 2000 to 35,000 tonnes in 2003, of which 65 to 85% were caught by Norwegian trawlers,

many of them being multi-rigged towing two or even three trawls at a time (Aschan 2004).

Partly due to the decline of traditional demersal and shrimp fisheries, trawlers turned to an offshore scallop fishery in the Jan Mayen, Svalbard and Bjørnøya areas around 1985, catching up to 45,000 tonnes in 1987. However, catches dropped below 6,000 tonnes in 1989 due to overfishing (Anonymous 1988, 1995). In the peak years some 20–25 scallop trawlers, many with onboard freezing facilities, took part in the fishery towing up to three large dredges simultaneously. The Jan Mayen area was closed to dredging in 1987 (Aschan 1991), although a small-scale fishery between 2,000 and 7,000 tonnes continued in other areas, mostly around Bjørnøya (Anonymous 1990).

Thus, total trawling and dredging effort has decreased in the Barents Sea and Svalbard areas in recent years compared to previous decades, as it happened in Iceland and Greenland.

1.4 The effect of trawling and dredging on benthic communities and the sea bottom

Trawling and dredging are known to effect a large and diverse impact on benthic communities and the sea bottom, mostly by increasing mortality of target and non-target species and altering the abiotic environment. Unfortunately, research on impact of fishing activities within the study area is very limited and therefore most knowledge on these issues draws from studies performed elsewhere.

Fishing activities pursue particular fish or invertebrate species, which are the target species. However, non-target species represent a variable percentage of the catch in many fisheries (Jørgensen and Carlsson 1998; Kingsley et al. 1999; Bergman and Santbrink 2000). Non-target species constitute the by-catch that can be split into two groups: the incidental catch, made up of marketable yet non-target species, and the discards, which are returned to the sea because they include non-marketable species and undersized individuals of marketable species. This can be expressed as follows:

Total catch= target catch + by-catch

By-catch= incidental catch + discards

By-catch is mostly a problem of the fisheries using towed-bottom gear. Contrary to pelagic, schooling species, most demersal fish and invertebrate species are found in mixed assemblages of both target and non-target species. The bottom trawls and dredges used to capture them are not very selective since they are designed to sweep and create a disturbance on the seabed that will lead the animals into the net. Consequently,

animals in the path of the gear are at risk of being captured, displaced, killed or seriously injured (Figures 1.6 and 1.7).



Figure 1.6 By-catch in a haul from a shrimp stock assessment survey, taken with a shrimp trawl without sorting grid. Catches of commercial shrimp fishing vessels differ from the catch shown in this picture, as the use of sorting grids decreases greatly the by-catch of fish of marketable size.



Figure 1.7 Crabs and sea urchins are among the most common by-catch taxa in the scallop fishery in Breiðafjörður, Iceland.

The main by-catch problem within the study area, according to the available literature, has been the capture of juvenile fish in the shrimp fishery, especially gadoids and redfish (Pálsson and Thorsteinsson 1985; Hylan

and Jacobsen 1987; Carlsson and Kannevorff 1998; Rätz 1998; Reithe and Aschan 2004; Storr-Paulsen 2004). By-catch in the scallop fishery is mostly constituted by non-marketable invertebrates, but the differential mortality between taxa has nevertheless an important negative impact on the sea bottom and associated fauna (see Chapter 3).

Alverson et al. (1994) estimated that, on a global scale, by-catch constituted 27 million tonnes of the annual 100 million tonnes of landings, most of which were associated with shrimp trawls, followed by bottom trawls, other undefined trawls, longline and pot fisheries. The same report shows that whiting and groundfish trawls used in the Northeast Atlantic have some of the lowest discard ratios, 0.043 and 0.083 kg of discards per kg landed. However, discard weight in the NE Atlantic was estimated at nearly 3.7 million tonnes and was second to the NW Pacific, with over 9 million tonnes of discards. The estimated by-catch for shrimp fisheries in the NE Atlantic (included in the above figure) was 210,000 tonnes, ranking ninth in a list of 15 areas where by-catch ranged from 19,000 to 4.3 million tonnes (Alverson et al. 1994).

Despite the serious damage that fishing inflicts on marine habitats, research on fishing impact on the ecosystem has been gaining increasing attention only over the past 20 years as a result of the growing interest in environmental issues and the development of the ecosystem approach in fisheries management.

1.4.1 Effects on populations of demersal species

The main impact of trawling and dredging is the increased mortality imposed on a wide range of species. Those that reach a large size, have a slow growth rate and reach maturity at a large size and high age are the most sensitive to fishing activities (Greenstreet and Rogers 2000). The mortality induced by fishing mortality can be categorized in two groups:

a) Direct mortality

Is caused by encounter with the fishing gear when the captured animals die inside the gear, during handling, or as a result of the damage inflicted during these processes.

Mortality caused by fishing operations is highly variable between different phyla and even between higher taxonomic groups (Lindeboom and De Groot 1998; Bergman and Santbrink 2000; Hill and Wassenberg 2000; Jenkins et al. 2001; Pranovi et al. 2001). For most fish species, mortality is close or equal to 100% due to distension of air bladders, although usually it is less among flatfish and elasmobranchs (Millner et al. 1993; Russell 1993; De Silva et al. 2001). In general, invertebrates have higher survival rates than fish, although their vulnerability is highly variable depending largely on the robustness of the species. Taxa protected with exoskeletons or shells, or that can regenerate missing limbs, such as

starfish, have higher survival rates, whereas sessile epizoans such as corals, sponges and bryozoans are much more sensitive to physical disturbance (Kaiser and Spencer 1995; Bergman and Santbrink 2000; Jenkins et al. 2001; Pranovi et al. 2001).

b) Indirect mortality

Animals that are not caught by the fishing gear can be killed following contact with the gear or as a result of habitat alterations caused by fishing activities.

Benthic macrofauna suffers substantial mortality or damage that increases their vulnerability to predation as a result of encounters with the fishing gear despite not being caught (Eleftheriou and Robertson 1992; Jennings and Kaiser 1998; Lindeboom and De Groot 1998; Prena et al. 1999; Jenkins and Brand 2001). Scavenging species have been shown to arrive quickly to recently trawled areas, and densities of many invertebrate scavengers increase greatly as they gather to predate on the wake of dead and injured animals left behind by fishing gear (Caddy 1973; Kaiser and Spencer 1994; Kaiser and Ramsay 1997; Veale et al. 2000a).

It has been suggested that most of the damage inflicted to benthic macrofauna during fishing activities takes place on the seabed rather than among the non-target species hauled on board (Lindeboom and De Groot 1998; Jenkins and Brand 2001). The killing or injuring of animals at the surface and uppermost layers of the sediment is the most drastic impact in soft bottoms (Gislason 1994). The removal of fragile and long-lived sessile habitat-forming epifaunal species is the longer lasting and most important impact in hard bottoms, as loss of three-dimensional biogenic structures can cause severe habitat degradation and renders it unsuitable for its associated fauna (Collie et al. 2000; Hall-Spencer and Moore 2000; Kaiser et al. 2000; Hall-Spencer et al. 2002).

Demersal fishing gear induce a range of diverse physical disturbances on the sediment, such as increase of the suspension load, relocation and overturning of boulders, change of topographical features, alterations in microbial communities and increase in the exchange of nutrients and pollutants between the sediment and the water column (Caddy 1973; Eleftheriou and Robertson 1992; Gislason 1994). The damage inflicted on the sea floor and the time necessary for recovery depends largely on the habitat type and the fishing gear used (Hall 1998; Collie et al. 2000).

1.4.2 Ecosystem effects

Long-lasting alterations in benthic communities may take place shortly after fishing. It is suspected that in hard-bottom habitats, the major impact of towed fishing gear takes place the first time an area is fished (Jennings and Kaiser 1998). This is especially true in the case of habitats formed by

animals consisting of fragile structures, such as corals, sponges and hydrozoans (Figure 1.8; Currie and Parry 1999; Prena et al. 1999).



Figure 1.8 Sponge community in the Denmark Strait at 337m depth.

As explained above, the impact of fishing on the sea floor depends among other factors on bottom type and the fishing gear. Dredges have been shown to have large impact on benthic habitats and fauna because they are very heavy and their whole surface comes into contact with the seabed or penetrates it while being towed (Figure 1.9). In high energy environments, such as mobile sands, recovery can be fast because the fauna is adapted to frequent physical disturbance (Riemann and Hoffmann 1991; Eleftheriou and Robertson 1992), but effects of dredging can be particularly severe in high diversity areas, such as maerl beds and communities of emergent epifauna (Hall-Spencer et al. 2002).

In any case, the enhanced mortality of certain taxa has been shown to lead to decrease of species richness and diversity (Currie and Parry 1996; Collie et al. 1997; Tuck et al. 1998; Veale et al. 2000b), marked changes in faunal composition of benthic communities (Hill et al. 1999; Kaiser et al. 2000), alterations of predator-prey relationships (Pauly et al. 1998), species replacement (Jennings and Kaiser 1998) and changes in the dynamics of populations.



Figure 1.9 Roller scallop dredge used in Iceland.

Discarding of non-target species, and especially the indirect mortality caused by encounters with the fishing gear, coupled with the physical impact of the gear on the sea bottom are thought to contribute to important changes in the ecosystem (Lindeboom and De Groot 1998). Consequently, even though long-term alterations in macrofaunal species assemblages have been described in several studies and are certainly due to fishing activities, it is difficult to assess to what degree these changes are related to the increased mortality inflicted on the fauna or to the habitat alterations caused by fishing gear (Currie and Parry 1994; Thrush et al. 1995; Collie et al. 1996; Currie and Parry 1996; Kaiser et al. 1996; Collie et al. 1997; Kaiser et al. 1998; Tuck et al. 1998; Hill et al. 1999; Prena et al. 1999; Bradshaw et al. 2000; Craeymeersch et al. 2000; Frid and Clark 2000; Jenkins et al. 2001; Jenkins and Brand 2001; Kenchington et al. 2001; Jennings et al. 2001).

Excessive bottom fishing is believed to lead to a decrease in species richness and species diversity (Greenstreet et al. 1999) as a result of low selectivity of the gear and the increased mortality imposed on many species. Predator-prey relationships may thus be altered if mortality is greatly increased on the predator but not the prey. Consequently, species that are resilient to fishing activities and with a high survival rate after

being discarded, may replace the target species and take over their ecological niches. A good example was the significant increase of skates and dogfish on the Georges Bank during a few decades of intensive fishing of gadoids (Greenstreet and Rogers 2000).

When discussing ecosystem effects of fishing it should nevertheless be considered that discards constitute in many cases a very small percentage of the population, and mortality derived from discarding practices endangers only those species with a very low reproduction rate (Woodley and Read 1991; Tasker et al. 2000). On the other hand, discards represent an important food resource for seabirds. It is thought that the significant increase during the past decades of several sea bird populations, such as fulmars and kittiwakes in the North Atlantic and the North Sea may be largely supported by this additional food supply (Camphuysen et al. 1995; Lilliendahl and Solmundsson 1997; Phillips et al. 1999). Benthic scavengers (Kaiser and Spencer 1994; Veale et al. 2000a) and, to some extent, pelagic species (Hall 1998) also benefit from the carrion left in the wake of fishing gear.

1.4.3 Effects of fishing on archaeological remains and submarine geological features of interest

1.4.3.1 Archaeological remains

The Arctic regions and waters can exhibit exceptional conditions for the preservation of organic material. Thus these areas can contain cultural material of exceptional quality. There is one example of a ship sitting upright on the sea bottom, masts still standing, 150 years after it was sunk in the ice. The navigational instruments are still on the shelf on the deck housing behind the wheel. The wreck is at 100m depth, and the impact of a trawl going through it would be devastating. This is an extreme example, but there are reasons to believe that vulnerable wrecks and other cultural remains under water have been, and will be, heavily affected by trawling and dredging activities.

At Spitsbergen, the scallop dredgers operating on the North coast (the area in which the great whaling fisheries took place in the 17th and 18th centuries) have often ploughed through wrecks, bringing the black oak planking, ceramics and even anchors of several hundred kilos up with the dredging gear.

In the Barents Sea region, on the coastline from the Lofoten Islands to the island of Senja, the coastline suffered a transgression that has placed underwater the former coastline and the Stone Age settlements that were located there. Knives made of slate and other Stone Age tools have been recovered with fishing gear in these areas. Dredging operations at 10m depth in the harbour of Andenes revealed peat and a former marsh preserved underwater.

In areas like the North Sea, which was dry land 10,000 years ago, large areas of the seabed are made up of sunken marshes. Large amounts of peat, up to 2m thick, are cut loose from the seabed by beam trawlers and caught in the trawl. Chainsaws are used to cut the peat out of the trawl on deck. In many cases, large mammoth bones and teeth, both tusks and molars, and skeleton parts of wool-haired rhinoceros, reindeer and other species that inhabited the now-sunken land are caught in trawls, occasionally with cultural remains from the hunters that lived in this former Arctic tundra. Also in the North Sea, trawler skippers have reported that with the available fishing equipment, wooden wrecks are not a hindrance to fishing activities but the opposite, as catches are better at wreck sites. However, steel wrecks are avoided.

Some heavily trawled areas in the Barents Sea are historical shipping lanes used from 1550 onwards between Western Europe and the Russian ports of Kildin and Arkhangelsk. The use of bottom-towed gear in these lanes can break, expose and disperse over large areas parts of the vessels or the objects contained in them, greatly jeopardizing later research. In fact wrecks are often found scattered and covered in nets, even in remote waters.

An approach to the management of these maritime cultural resources should be along the lines of joint ventures with other marine management surveys. This could also have a synergetic effect.

1.4.3.2 Geological features

Fishermen occasionally report accidental trawling on hydrothermal vent fields and other geological features, but these events have not been recorded. Impact of fishing on such habitats has not been investigated, but it could be assumed that fishing gear affects the hydrothermal vents, geological structures and their associated communities.

1.4.4 Solutions to the impact of trawling and dredging

Efforts to minimize the impact of fishing activities on the sea bottom and associated fauna are mainly based on modifications to fishing gear and regulations.

1.4.4.1 Modifications to fishing gear

Modifications to fishing gear are mostly oriented to make it more selective, excluding undersized individuals and non-target species when possible. Designing selective fishing gear requires a good knowledge of the behaviour of the different fish species when encountering the gear. In addition, the modifications have to be made without jeopardizing catches of the target species. Much research effort has been invested into measures to decrease by-catch, especially in the shrimp fisheries (see Chapter 3). Among the simplest measures to reduce by-catch are the adoption of a

minimal mesh size, depending on the target species, and the use of net panels of square mesh instead of diamond mesh, as the first one remains open during towing, allowing the escape of undersized individuals (van Marlen 2000).

Fish exclusion devices have also become widely used in many fisheries. They are based on the behaviour of the by-catch species, and they consist of grids of vertical bars that allow undersized or non-target fish to swim through and escape (van Marlen 2000). These have been successfully used in many shrimp fisheries, including those in the study area, where large by-catches of gadoids were common. The most widely used sorting device in the North Atlantic shrimp fisheries is the so-called Nordmøre grid (see Figure 3.9 in Chapter 3). It has a short interbar distance of 22mm that allows the shrimp to pass through the codend. The larger sized fish by-catch is directed upwards through a triangular opening on the upper panel in front of the grid.

However, there is very little that can be done to prevent damage of epifaunal species in areas open to trawling. The use of rock hoppers to keep the ground rope away from the sea floor has greatly decreased by-catch of invertebrates, but the bobbins and otter boards can easily damage epifauna. The possibility to pump water in the sediment as a substitute for tickler chains has been researched, but it seems that this option lowers considerably the catches of target species (van Marlen 2000).

1.4.4.2 Regulations

Regulating the access to fisheries is another way to reduce the impact of fishing. Effort reduction is an effective measure, but it is also the most difficult to carry out due to social, economical and political reasons (Alverson et al. 1994). A better alternative is the creation of Marine Protected Areas (MPAs) or areas closed to fisheries. This option has been often strongly recommended, both for monitoring of fished areas and protection of marine habitats, but they are equally difficult to implement (Ramos Esplá 1985; Lindeboom 1995; Gell and Roberts 2003).

Capture of juveniles of target species is regulated within the study area, among other places, with a by-catch quota, whereby an area is closed to fishing if capture of juvenile by-catch belonging to target species is above pre-determined thresholds (Alverson et al. 1994; Reithe and Aschan 2004).

Another straightforward method to decrease discards is encouraging fishermen and consumers to market all edible fish species captured as by-catch. This solution has been applied with success in some artisanal fisheries, but seems to be harder to use in fisheries of larger scale (Alverson et al. 1994).

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2. The scallop fisheries

2.1 The fishery for Iceland scallop (*Chlamys islandica*, (O.F. Müller, 1776)) in the Northeast Atlantic

E. Guijarro Garcia

2.1.1 Abstract

This review focuses on the history and management of the Iceland scallop fishery in Iceland, Greenland and Norway (Svalbard, Bjørnøya and Jan Mayen), with information on research into each stock. The start of the fishery in all these regions followed the discovery of virgin scallop beds made up of old, large specimens in very high densities. Despite the apparent similarity of original conditions, the fishery has followed very different trends in each region, with drastic results in Iceland, Svalbard and Jan Mayen.

The Icelandic fishery dates from 1969. There was a steady decrease in catch from 1985, when over 16,000 tonnes were caught. By 2004 the stock had declined to 35% of its former size and a zero quota was advised. This decline is thought to have resulted from overexploitation combined with a protozoan infestation and increasing sea bottom temperature.

Scallop dredging commenced in West Greenland in 1983. The stock is not very large, but fishing was driven by social factors. Catches ranged from 400–1,900 tonnes during the period 1988–1992 and from 1,200–2,600 tonnes since 1995. There are indications that each scallop bed is extensively dredged before the fleet moves on to new areas; nevertheless catches have been rather stable over the past decade.

The scallop stocks in Svalbard, Bjørnøya and Jan Mayen were depleted in three fishing seasons between 1985–1987, when up to 45,000 tonnes of scallops were dredged in a single season. The available data show declining populations more than ten years after dredging ceased.

2.1.2 A brief note on scallop biology in the study area

The Iceland scallop (Figure 2.1), *Chlamys islandica* (Müller, 1776), is a widely distributed sub-arctic species. It is found in the Pacific Ocean, in North Japan and Korean waters; its distribution in the North Atlantic reaches south to Cape Cod on the American East coast, West Greenland, all around Iceland (except for the South coast), West and South coasts of

Svalbard and Bjørnøya and the western coast of Norway south to Stavanger. The Arctic current that flows south along the East Greenland coast prevents the build-up of scallop beds there because the water temperature is too low (Wiborg 1963a; Pedersen 1994; Eiríksson 1986). The largest scallop densities have been found between 50–110m depth, although some banks extend down to nearly 600m (Eiríksson 1986; Hansen and Nedreas 1986; Rubach and Sundet 1987; Pedersen 1994).



Figure 2.1 *Chlamys islandica*.

Growth rate varies seasonally but also between the areas under study, probably in relation to feeding conditions and temperature (MacDonald and Thompson 1985; Vahl 1980). Most growth takes place during the phytoplankton bloom, from April to June (Vahl 1978; Thorarinsdottir 1993). There are also age-related changes in growth rate. In Iceland growth decreases from 8–10mm y⁻¹ during the first year to 0–3mm y⁻¹ for the older shells, aged above 15 years (Eiríksson 1986).

As a result of the variation in growth rate between regions, age and size at maturity and maximum age are also different in the scallop populations of Norway, Greenland and Iceland. The scallops reach maturity at 40–50mm shell height (SH) at an age of 5–7 years in Norway and Iceland, but a lower size for age is found in Greenland, where 30–55mm SH corresponds to an age of 4–9 years (Wiborg 1963a; Eiríksson 1986; Pedersen 1989, 1994). Iceland scallops grow to a maximum size of 80–100mm and have been found to live up to 20 years in Iceland (Eiríksson 1986) and up to 35 in Greenland (Pedersen 1989).

Sexes are separated (Wiborg 1963a), with a sex ratio approaching 1:1 in Icelandic and offshore Norwegian populations (Eiríksson 1986; Rubach and Sundet 1987). Spawning takes place between the end of June

and end of July, the precise timing being apparently influenced by rising sea temperatures (Skreslet and Brun 1969; Sundet and Lee 1984; Eiríksson 1986; Pedersen 1988a) and feeding conditions (Thorarinsdottir 1993; Arsenault and Himmelman 1998). The spat settles six weeks after spawning (Gruffydd 1976; Thorarinsdottir 1991), although this period increases to ten weeks in Greenland (Pedersen 1988a). Prior to metamorphosis the larvae attach themselves with byssal threads, preferably to hydroids and filamentous benthic algae (Harvey et al. 1993; Harvey and Bourget 1995).

Scallops are filter feeders, and therefore favour areas with strong currents and low sediment load. They are found on sandy, gravelly or shell-sand bottoms. Iceland scallops thrive best in temperatures between -1.4°C and 10°C (Wiborg 1963a; Nicolajsen 1984; Pedersen 1994; Eiríksson 1986) but can cope with small increases above 10°C (Jónasson et al. 2004).

2.1.3 Iceland

2.1.3.1 The stock and the fishery

Dredging of Iceland scallops took place for the first time in 1969 in Jökulfjörður and Ísafjarðardjúp, both in NW Iceland (Eiríksson 1970a, 1971a, 1971b; Anonymous 1973, 1974, 1994). During the 1970s and early 1980s the fishery extended to other areas of the country as new scallop beds were found (Figure 2.2), namely Breiðafjörður, Hvalfjörður and Faxaflói in West Iceland (Eiríksson 1970b, 1971a; Anonymous 1973, 1974, 1994), Húnaflói and Skagaströnd in North Iceland (Eiríksson 1970c, 1971a; Anonymous 1973, 1981), and the bays and fjords from Þistilfjörður to Berufjörður, in Northeast-East Iceland, of which Vopnafjörður had the best scallop beds (Anonymous 1973, 1982). Nevertheless, the scallop beds found in Breiðafjörður, West Iceland, were the largest by far and they have made up between 60–100% of the annual landings since the beginning of the fishery (Anonymous 2003). During the first years of the fishery the stock was made up of old scallops that had accumulated with time. There was a steady increase in the size of the fishing fleet operating in Breiðafjörður and catches from this area increased nearly every year up to over 12,000 tonnes in 1986 (Figure 2.3). The decrease between 1973 and 1975 was due to low market prices.

Technical improvements, such as more efficient dredges, more powerful engines and better positioning equipment on board allowed the increase of catch per unit effort (CPUE) during the 1990s despite the continuous decline of the stock index (Figure 2.4) and average SH of the scallops, which decreased as the older individuals became rarer (Figure 2.5).

The stock index is an estimate of the density of scallops within the beds. It is estimated for each bed with the formula $((w A_{\text{bed}}) A_{\text{swept}}^{-1}) q^{-1}$

where w is the average weight of scallop catch from all the tows taken within a bed, A_{bed} is the area of the scallop bed in km^2 , A_{swept} is the area swept within the bed in km^2 and q is the catchability index. Thus the total stock index in Breiðafjörður for any given year is the sum of the indices of all beds.

In 1990 it was estimated that the stock index had diminished by 30% with respect to its estimated size in 1982 (Anonymous 1990a). The fleet kept decreasing simultaneously with catches and during 2003 only three boats were dedicated exclusively to scallop dredging (Figure 2.6). The rest of the fleet were multipurpose boats that fished cod with line or gill-nets and / or inshore / offshore shrimp during winter (Eiríksson 1997).

Catches have been unusually low since 2000 onwards, coinciding with unusually high natural mortality among the older scallops. Thus, in spring 2003, the stock index in Breiðafjörður had decreased by 45% in weight since spring 2002 and by a further 12% since autumn 2002, meaning that the stock had been reduced to one-third of its average size during the period 1993–2000. As a precautionary measure the fishery has been closed since the fishing season 2003–2004.

The causes for this decline are being investigated but are still unclear. It is most likely that several factors have contributed to the current situation:

- the fishing effort may have been too high considering the trend of the stock index (Figure 2.4) and annual variability of environmental factors,
- bottom sea temperature in summer has increased by 2–3°C during recent years (Eyðal 2003; Jónasson et al. 2004),
- cyst-forming protozoan parasites (Coccidia) have been detected in adult scallops (Kristmundsson et al. 2004).

However, the increase of natural mortality has shown great variability among the different scallop beds within Breiðafjörður (Jónasson et al. 2004), so there might be other reasons to explain the observed mortality.

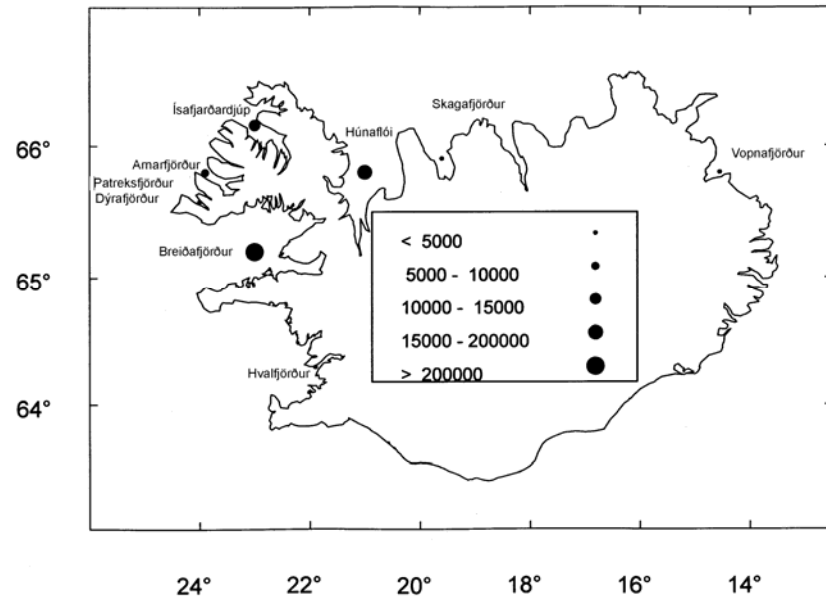


Figure 2.2 Map showing the scallop fishing areas around Iceland and their relative importance regarding total catch since the beginning of the fishery in 1969.

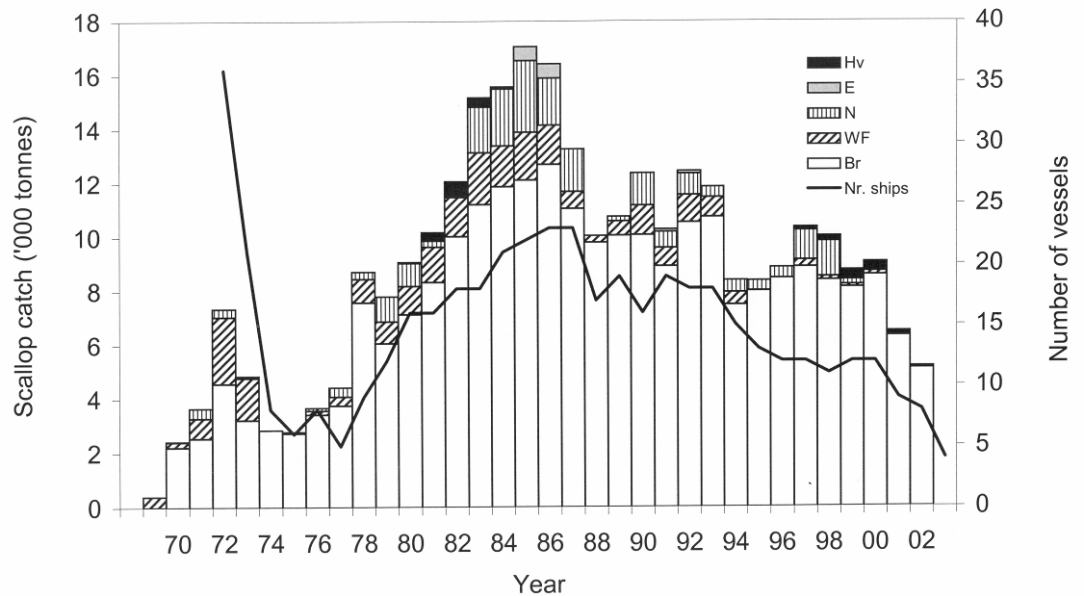


Figure 2.3 Scallop catches and fleet size since the beginning of the fishery.
Br: Breiðafjörður, WF: (Western Fjords) Arnarfjörður, Ísafjarðardjúp, Patreksfjörður and Dýrafjörður; N: (North) Húnaflói and Skagafjörður; E: (East) Vopnafjörður, Hv: Hvalfjörður, Nr. ships: number of vessels in the fishery in Breiðafjörður. Catch data from Anonymous (2003).

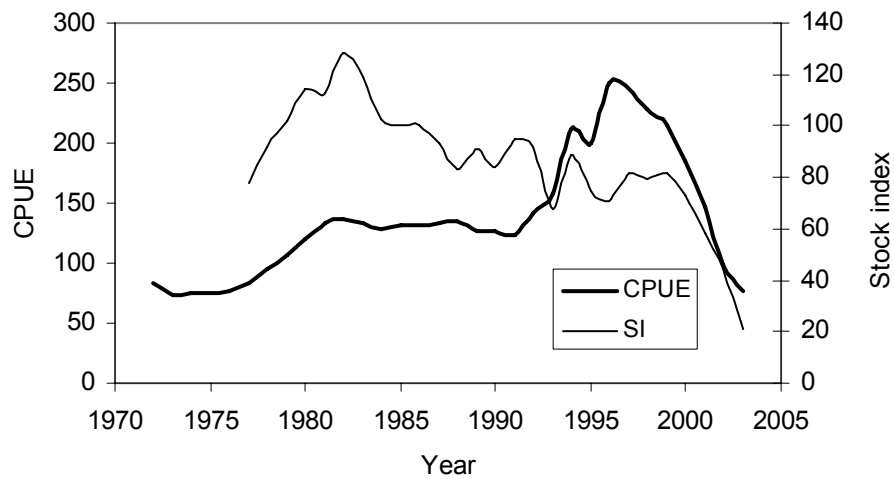


Figure 2.4 Catch per unit effort (CPUE, in kg nm⁻²) and stock index trends since the beginning of the fishery. Stock index data from Anonymous (2003).

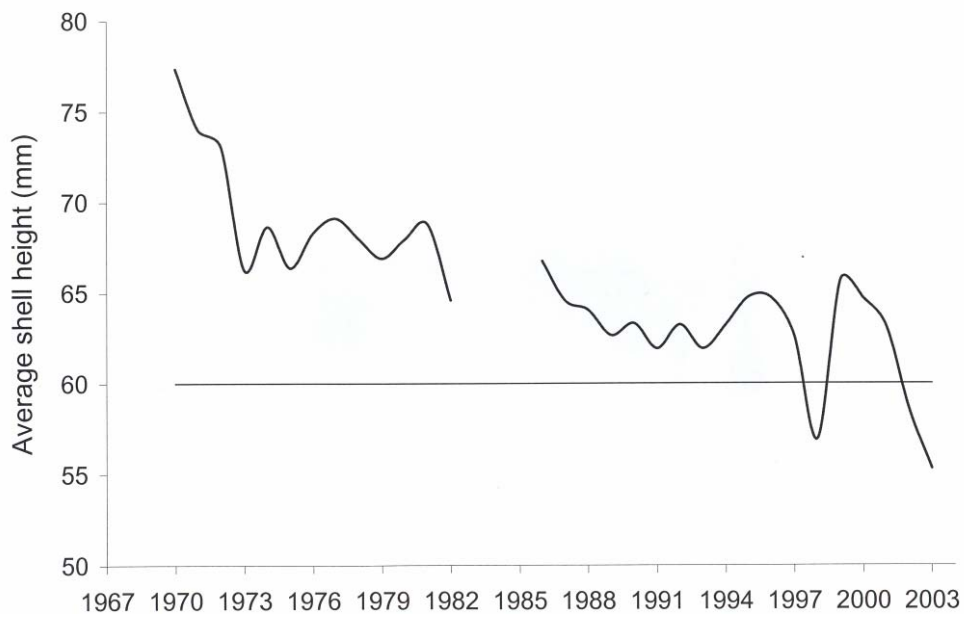


Figure 2.5 Average shell height of scallops in Breiðafjörður during the period 1970–2003. The horizontal line indicates the minimal landing size, 60 mm SH.

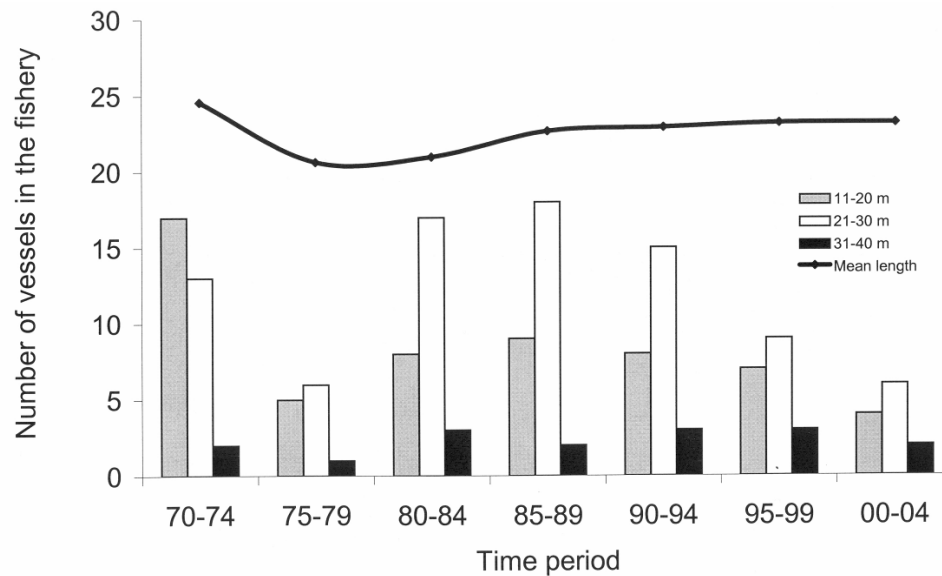


Figure 2.6 Number of vessels in the fishery and mean length of vessels in the scallop fleet since 1970, grouped in five year intervals.

2.1.3.2 Fishing gear

During the first years of the fishery in Breiðafjörður, a rigid box-type dredge of Icelandic design was used until two Isle of Man models, the Blake and the Connolly dredges, were introduced in 1972. These scallop dredges consisted of a heavy metal frame to which a bag with a belly of steel rings joined with chain links was attached. The Blake was a sledge-type dredge, whereas the Connolly was a roller dredge. Roller dredges slide better over the seabed because of the wheels at each side of the frame. The width of the metal frame varied with boat size, and together with the diameter of the steel rings (subjected to management rules) determined the efficiency of the gear. The Blake dredge was widely used and adapted to the fishery in Breiðafjörður, becoming stronger and up to three times heavier (800–1,000 kg), with sizes from 1.5 to 2.7m width. The frame had two runners strengthened by horizontal bars, and a stone guard to prevent big boulders from entering the bag. In front of the ring bag, a tickler chain disturbed the bottom to increase the catch, and the bottom of the bag was attached to a tail bar that kept the bag spread. However, an improved design of roller dredge was created in North Iceland in 1988 and has since become the most widely used dredge in Iceland (Eiríksson 1997) (Figure 2.7). The Icelandic roller dredge is equipped to fish on both sides, and with its articulated bar, chain groundrope and wheels on both sides of the frame, it has proven to be far more efficient than other types. First trials took place in Húnaflói, North Iceland, and by 1991–1992 all scallop boats in Breiðafjörður had this new dredge. Since 1995 it has been used by all scallop trawlers (Eiríksson, pers. comm.).



Figure 2.7 The roller dredge used in Iceland. The stone guards can spin around the axis, allowing the dredge to slide over boulders.

2.1.3.3 Management

The fishery was open to all boats at the beginning, and 48 licenses were issued for the fishing season in 1972, although not all of them were used. The fleet landed 3,000 tonnes in only two months, prompting managers to restrict access to the fishery from 1973 onwards. Only local boats could apply for licenses and the catch had to be processed in towns in Breiðafjörður. In addition, logbooks were made mandatory to monitor catches and the fishery was limited to a 5,000-tonne quota. Nevertheless, landings remained below this figure during the period 1973–1977 due to the low market prices. The Ministry of Fisheries also restricted the number of processing plants after 1976, and from 1978 onwards each plant had a catch quota related to the total allowable catch (TAC) for the nearby scallop beds. The system changed again in 1984 and since then catch quotas have been allocated to the boats, which can transfer quotas among themselves. The TAC is set for one fishing year, from 1st September to 31st August, and the quota given to each boat is based on its average share of landings in years previous to the enforcement of the individual boat quota system. The Marine Research Institute recommends an annual TAC to the Ministry of Fisheries, which has accepted the recommendations of the MRI most years. Catches often exceeded the quota, but the extra catch has usually been less than 15% of the recommended TAC (Figure 2.8).

To estimate the TAC, detailed CPUE reports from the logbooks (daily catch, fishing hours, gear, crew, fishing ground, boat) are added to the information collected on annual surveys during which 120 standardized tows are taken. The minimum landing size is 60mm SH. Given the stock

size and CPUE reached during the 1990s, the only possibility to increase catches would have been developing more efficient gear that would reduce shell breakage and indirect fishing mortality (Eiríksson 1997).

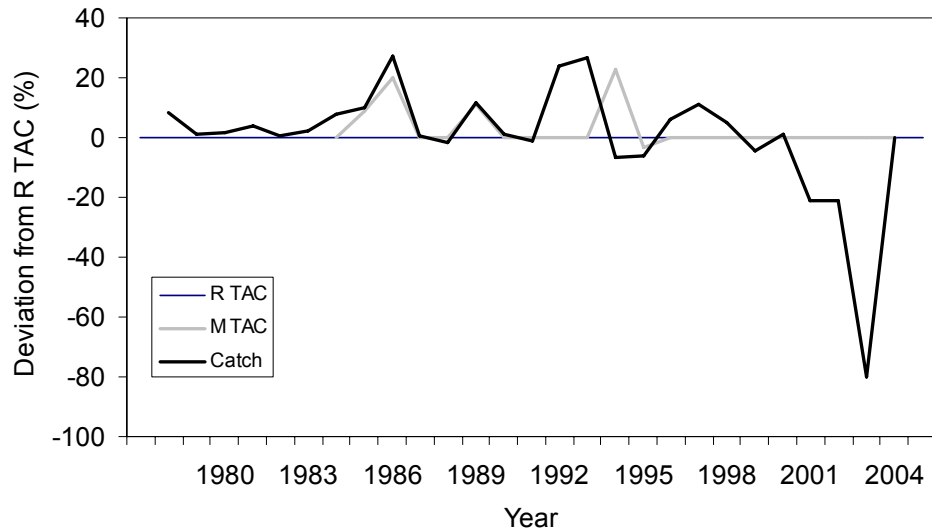


Figure 2.8 Comparison among scallop catches and total allowable catch for Breiðafjörður. R-TAC: total allowable catch recommended by the MRI, M-TAC: total allowable catch as issued by the Ministry of Fisheries.

2.1.3.4 Research

The Danish Ingolf Expedition collected samples of Iceland scallop in 1895 and 1896 in many locations all around Iceland except in the South coast, where it was absent (Jensen 1912). Scallops were mentioned also in general studies on the Icelandic marine fauna (Madsen 1949; Óskarsson 1952; Hauksson and Gunnarsson 1973). Surveys to investigate the possibility of commercial use of the stock commenced in 1969 in the Western Fjords and continued in the early 1970s in Breiðafjörður, North and East Iceland (Eiríksson 1970a, 1970b, 1970c, 1971a, 1971b; Anonymous 1973, 1974, 1981, 1982, 1990a). Several surveys during the period 1971–1986 included searches for new scallop beds in different areas. From 1973 onwards, research efforts have focused mostly on age structure and stock size of the scallop population in Breiðafjörður and to a lesser extent in other areas. In addition, a project was run between 1989 and 1994 to investigate settlement, growth and age at maturity of scallops to assess the feasibility of suspended culture of this species. Growth rates were indeed higher than on the sea bottom, and cultured scallops reached in three years the same size as five-year-old scallops collected from the nearby beds. However, it was considered that the four years that cultured scallops need to reach market size would make the enterprise very risky economically (Thorarinsdóttir 1991, 1993, 1994; Anonymous 1994). Research effort has recently increased considerably due to the sudden

decrease in stock size in Breiðafjörður since 2000 (Figure 2.4), coinciding with observed high natural mortality among older scallops. Thus, in addition to annual stock assessment surveys, samples are taken at roughly two-month intervals for monitoring of shell condition factor (i.e. weight of muscle, gonads, etc.) and clucker ratio (% of live vs. recently dead individuals by size groups). Cluckers are empty shells still joined by the hinge that indicates a recent death, as they unhinge within roughly 200 days (Jónasson et al. 2004). Moreover bottom temperatures are being registered daily at two to three major scallop fishing areas. In addition, the infection of adult scallops by a protozoan parasite is being thoroughly investigated (Kristmundsson et al. 2004).

2.1.4 Greenland

2.1.4.1 The stock and the fishery

The commercial fishery began in 1983 as a private initiative in the Nuuk area (Nicolajsen 1984; Eiríksson and Nicolajsen 1984), although the occurrence of Iceland scallop in West Greenland as far north as 76° had been long known (Posselt 1898; Jensen 1912). The Greenland Home Rule carried out a series of surveys between 1984 and 1988 (Figure 2.9) to assess the possibility of developing a commercial scallop fishery in West Greenland (Pedersen 1987a, 1988b). There were scallop beds in most of the communities investigated, some of them apparently with potential for a small-scale commercial fishery. The stock was mostly made up of old scallops, between 60 and 100mm, which had accumulated at high densities in small areas. The scientists applied a conservative approach when advising the TAC, limiting catches to 10% of the scallop stock over 65mm SH, yet most scallop beds showed signs of overfishing two years after the surveys.

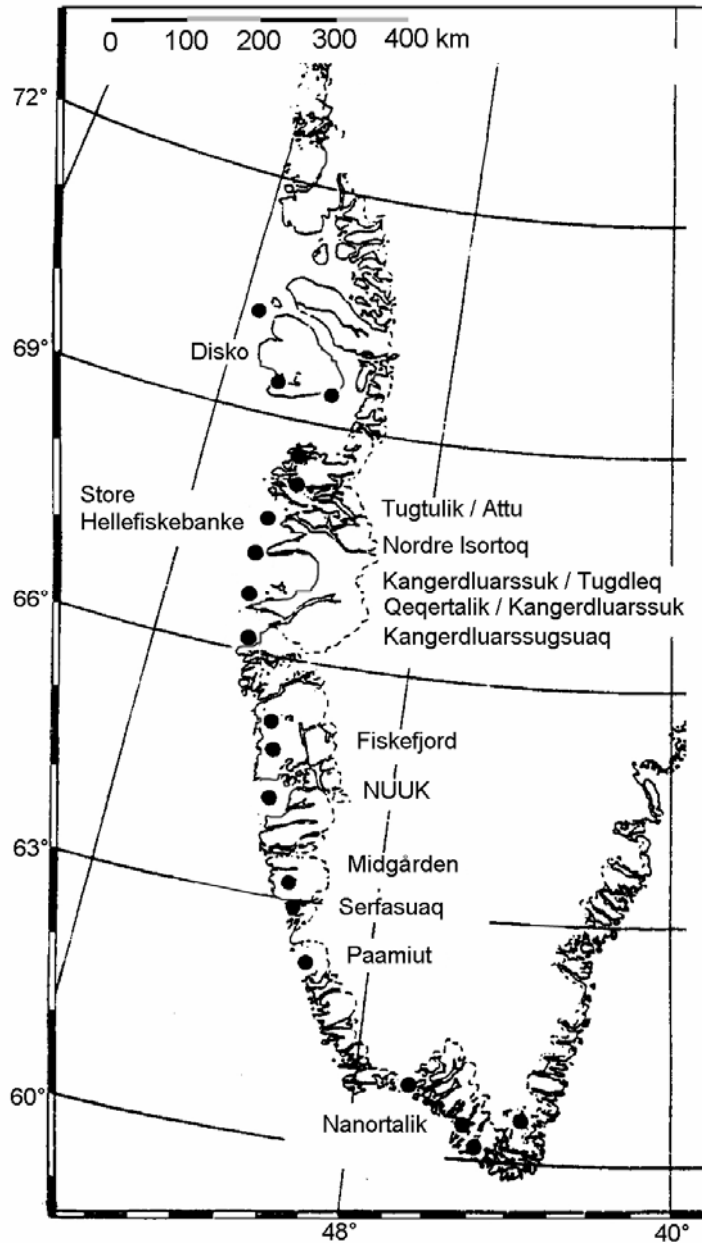


Figure 2.9 Map of West Greenland showing the locations investigated during the period 1984–1988. Modified from Pedersen (1994).

Stock assessment was very difficult due to the lack of knowledge of the scallop population. Thus the scientists analysed survey data assuming the conditions listed below, admitting that the reliability of their estimations would be greatly jeopardized by any departure of the scallop stock from these assumptions, especially items 1 and 2 (Pedersen 1988c, 1988d):

- No other species but scallops are present in scallop beds,
- Scallops are not very mobile, so scallops will not be replenished from neighbouring areas if an area is dredged over,
- The average catch per m² is known,
- Dredge efficiency (% of available scallops actually caught) is known,
- The total area of the scallop bed is known.

Uncertainty about dredge efficiency was another major drawback. There were differences in catchability not only among dredges, but also among tows with the same dredge on different bottom types, currents and slopes (Pedersen 1988a).

Growth rates and yield of scallops varied among areas, since both are affected by feeding conditions and sea temperature. These two factors differ among years, depending on inflow of polar water carried by the East Greenland current after it turns around Cape Farewell (Pedersen 1988a; Buch 2000).

Recruitment has always been an important problem. To this day it is not known if scallop larvae drift northwards with the West Greenland current or if recruitment processes are local. The length distributions indicate very low recruitment, but some studies suggest that for scallops there could be a density-dependent process in particular areas (Vahl 1982), so there was the possibility of an increase after fishing started. This, however, would depend largely on the fluctuation of environmental factors, especially in those areas in which sea temperature bordered on the survival limits of scallops (Claereboudt and Himmelman 1996; Tammi et al. 1997). Yet for stock assessment it had to be assumed that recruitment was constant and as the fishing grounds collapsed shortly after their discovery, questions on recruitment accumulated. Juvenile scallops were sometimes found among the catch, but they could not be considered a representative sample, as the scallop dredge is not appropriate for sampling undersized scallops. In addition, it was suspected that juveniles might have a distribution different from adults. In any case, the scarce data on the younger year-classes collected during the surveys were not reliable enough to estimate year-class strength (Nicolajsen 1984; Pedersen 1986; Engelstoft 1995). Stock assessment surveys were carried out in the following areas:

Nuuk (Godthåb)

This has always been the main fishing ground with the largest scallop beds (Figure 2.10). Unlike other areas, the fishery can operate here all year round because it is permanently free of sea ice.

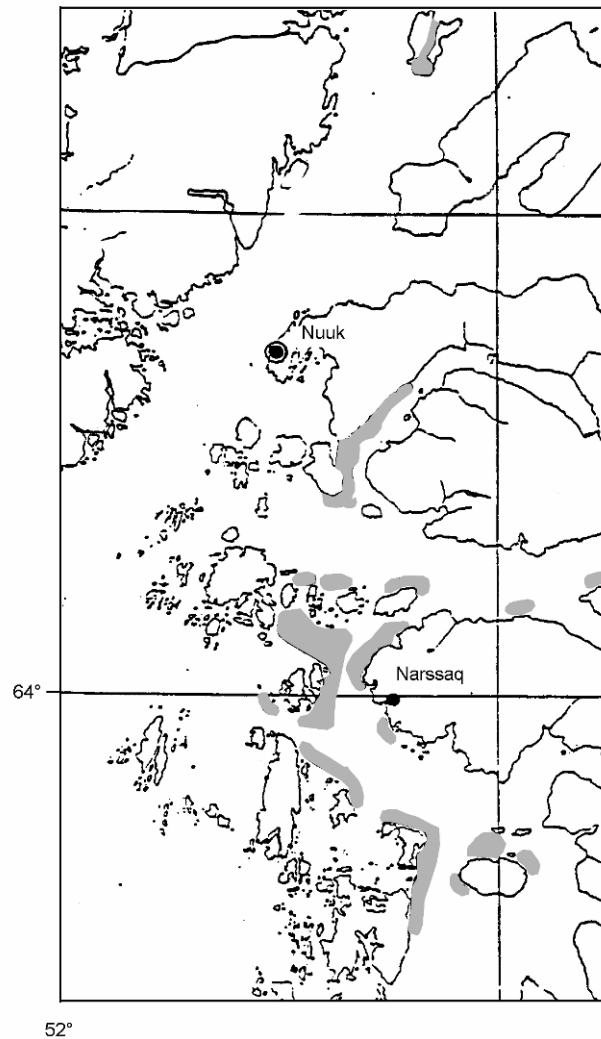


Figure 2.10 The scallop beds (shaded in grey) around Nuuk. The total stock size for these grounds was estimated at 13,000 tonnes. Modified from Eiríksson and Nicolajsen (1984).

The first survey was conducted in 1984 and used four different dredge designs (Table 2.1) but without replicated tows. The results were published in two reports (Eiríksson and Nicolajsen 1984; Nicolajsen 1984) that are not easily compared because the 18 scallop beds found were grouped in 6 management areas in the first report but 11 in the second. The first report estimated the stock at 9,000 tonnes and the second at 13,000 tonnes (Table 2.2). Both stressed the need to regulate the fishery and the uncertainty of the method used to calculate the stock size and recommended a maximum TAC equal to 10% of the initial stock size. Scallops were found in greater densities on hard bottoms with sand, gravel and boulders, in fjord areas and at 20–80m depth, with great variability in growth rates from place to place (Nicolajsen 1984; Eiríksson and Nicolajsen 1984).

The second survey, in 1986, set out to investigate if the data collected since 1984 in the surveys and the commercial fishery could detect changes in length distribution and density of the stock. Catches decreased considerably in 1986 compared with 1985 (Table 2.3) and a precautionary approach was advised again because the scarce data available, both from surveys and log books, were not reliable. Besides, for a stock constituted mostly of 20-year-old scallops (Tables 4 and 5), even a TAC of 10% could lead to overfishing, especially under the poor recruitment conditions observed (Pedersen 1986).

As feared, the stock had decreased to 8,500 tonnes by 1987 and to 4,400 by 1994. At this point there were two possibilities: decrease the quota further or fish the stock down, close the area to all fishing and wait about ten years for its recovery (Pedersen 1988a; Engelstoft 1995).

The number of small boats (8–20 BRT) that joined the fishery in winter fell from 10–15 in 1985 to 3–4 in 1987 as catches declined. Eventually the processing plant where small boats took their catch had to close in 1998, when prices of untreated scallops grew higher than those for processed meats (Pedersen 1988a). The literature does not mention if any of the 3–4 trawlers (100 BRT) still working in the area in 1985 and 1986 pursued other fisheries afterwards.

Table 2.1 Dredges used in stock assessment surveys in Greenland. Catchability was fixed in each survey.

Survey	Dredge	Width (m)	Mesh size (mm)	Ring Ø (mm)	Catchability	Type	Reference
Nuuk 1984	Manx	1.9	125	75	0.10	Sledge	Nicolajsen 1984
Nuuk 1984	KIS	1.9	125	75	0.15	Sledge	Eiríksson and Nicolajsen 1984
	Manx	2.4	120	65		Sledge	
	Saarullik	2.3				Sledge	
	Polarfisk	2.0				Sledge	
Paamiut, Qaqortoq, Nanortalik 1984	Manx	1.9	120–140		0.15	Sledge	Nicolajsen 1985a
Maniitsoq, Kangerdluarssugs-suaq 1985	KIS	2	140		0.10	Sledge	Nicolajsen 1985b
Attu 1986		1.9	120		0.20		Pedersen 1987b
W Greenland 1988		2.4	120	75		Icelandic sledges	Pedersen 1988a
		3.6	95	55			
Aasiaat, Attu, Kangaatsiaq 1988	KIS	0.9	120				Pedersen 1988c
Fiskanæsset 1988	KIS	0.9	120		0.20	Sledge	Pedersen 1988d
Maniitsoq 1987		1.9	120–140	65		Icel. roller	Pedersen 1988e
		2.0	140			Sledge	
		1.2	140			Sledge	
	KIS	0.9	120			Sledge	
Sisimiut 1988		1.9	120–140	65	0.20	Icel. roller	Pedersen 1988f
	KIS	0.9	120		0.20	Sledge	

Table 2.2 Stock parameters from the communities investigated.

Comm	Year	Man. unit	M catch (kg m ⁻²)	Density (kg m ⁻²)	T catch (tonnes)	Stock size (tonnes)	Area (km ²)	Reference
Nuuk	1984	a		0.248		1,984	8.00	Nicolajsen 1984
		b		0.317		3,804	12.00	
		c		0.879		879	1.00	
		d		0.160		320	2.00	
		e		0.289		1,156	4.00	
		f		0.642		642	1.00	
		ALL	0.197	0.422		9,044	28.00	
Nuuk	1984	1	0.118		20	129		Eiriksson and Nicolajsen 1984
		2	0.203		347	2,239		
		3	0.171		29	187		
		4	0.122		42	271		
		5	0.155		239	1,542		
		6	0.192		263	1,697		
		7	0.212		212	1,368		
		8	0.206		423	2,729		
		9	0.289		297	1,916		
		10	0.158		79	510		
		11	0.195		65	419		
Paamiut	1984	ALL	0.183	1.27	2,016	13,017		Nicolajsen 1985a
		1	0.004	0.024	2	13		
Nanortalik	1984	2	0.009	0.055	8	52		Nicolajsen 1985b
		3	0.003	0.017	1	6.5		
		4	0.016	0.103	45	290		
		5	0.039	0.252	5	32		
		6	0.037	0.239	4	26		
		ALL	0.0207	0.133	63	404	4.88	
Kang.	1985	A	0.111	1.110	7.3	73		Nicolajsen 1985b
		B	0.224	2.240	1.9	19		
		C	0.240	2.400	1.1	12		
		ALL	0.191	1.917	10.3	104	0.65	
Attu	1986		0.284	1.420	30	298	0.21	Pedersen 1987b
	1988	1	0.084	0.429		90	0.21	Pedersen 1988c
		2	0.225	1.124		236	0.21	
		3	0.135	0.680		34	0.05	
		4	0.169	0.850		85	0.10	
Maniitsoq	1985	Kang.				750		Nicolajsen 1985b
Maniitsoq	1987	Kang.				150		Pedersen 1988e
Fiskenæsset	1988	Mid				375	0.75	Pedersen 1988e
Fiskenæsset		Ser				100	0.20	
Sisimiut	1988	Qeq. & Kgr.	0.190	0.950	0.783	3,800	4.00	Pedersen 1988f
Sisimiut		Kgr Td	0.164	0.821	0.292	370	0.45	
Sisimiut		N Is	0.262	1.308	0.35	785	0.60	

Average data for some of the communities as given in the reports are shown in italics. Most of them do not give detailed information for each management unit and therefore, average data cannot be estimated from the numbers in this table. Comm: Community, Man. Unit: Management unit, M catch: Mean catch, T catch: Total catch, Kang: Kangerdluarssugs-suaq, Qeq: Qeqertalik, Kgr: Kangerdluarssuk, Kgr Td: Kangerdluarssuk Tugdleg, N Is: Nordre Isortoq, Mid: Midgarden, Ser: Serfasuaq.

Table 2.3 Catches and Total Allowable Catch (TAC) in Greenland.

Year	Nuuk	Nan	Paam	Man	Tu/At	Qeq	SMud	Mud	Saq	Kan	NDB	SDB	She	Unk	Total	TAC	Reference
1984	300	100	10		?										410	1,300	Pedersen 1988a
1985	1,333			340	?	20									1,693		Pedersen 1989
1986	510			254										100	864		Pedersen 1989
1987	500					29								100	629	850	Pedersen 1989
1988	700					20									720		Pedersen 1988a
1989														641			Pedersen 1994
1990														737			Pedersen 1994
1991	502				190			439	19					816	1,966		Pedersen 1994, *
1992	963				910				24					17	1,913		Pedersen 1994, *
1993	600				346			175	30					256	1,407		*
1994	341				88			55	94					873	1,453		*
1995	534				132			48	28					1,601	2,342	1,800	*
1996	184													992	1,176	1,800	*
1997	370							68	463					1,044	1,944	1,800	*
1998														2,200	2,200	1,800	*
1999	680				76	30	2	13	751	6	938	65	0	49	2,610	1,800	Siegstad 2000,*
2000	586				185	10	60	45	475	6	555	100	0	31	2,053	1,800	Siegstad 2001,*
2001	676				21	141	0	99	140	542	125	1	5	4	1,754	2,320	Siegstad 2001,*
2002	501				132	75	0	0.2	340	1,135	3	16	29	9	2,240	2,320	*

Nan: Nanortalik, Paam: Paamiut, Man: Maniitsoq (Kangerdluarssuqssuaq area), Tu/At: Tugtulik /Attu, Qeq: Qeqertarsuatsiaat (Fiskenæsset), SMud: South Mudderbugten, Mud: Mudderbugten, Saq: Saqqaq / Sisimiut, Kan: Kanaarsuk / Sisimiut, NDB: North DiskoBay, SDB: South, Disko Bay, She: Store Hellefiskebanke, Unk: origin unknown, *: Siegstad pers. comm., ?. some dredging took place in Tugtulik /Attu in 1984 and / or 1985 but figures are unknown.

Table 2.4 Population parameters estimated for the stock in Nuuk under assumption of $F = 0.15$.

Mean height (mm)	85.6
Mean weight (g)	120
Age	15–25
Age at recruitment	8.8
Natural mortality	0.12
Biomass / recruit (g/m)	315
Production / recruit (%)	12
Yield / recruit (g/m)	15
Annual yield (tonnes)	1,221
Muscle (% of weight)	10

Data from Nicolajsen (1984).

Table 2.5 Parameters for the von Bertalanffy growth equation.

Community	Year	Area	H_{∞} (mm)	K (year ⁻¹)	T_0 (years)	Age 65 (years)	Age 65 R (years)	Reference
Nuuk	1984	A	173.0	0.081	-0.235	5.56		Nicolajsen 1984
		B	147.0	0.108	-0.285	5.12		
		C	131.0	0.121	-0.106	5.56		
		E	131.0	0.121	-0.106	5.56		
		F	131.0	0.121	-0.106	5.56		
		ALL	128.5	0.073	-0.875	8.85	9	
Attu	1986		99.3	0.160	-0.600	6.04	7	Pedersen 1987a
W Greenland	1986		94.4	0.094	1.100	13.51	12.5	Pedersen 1987b
Maniitsoq	1987	Kang	90.7	0.187	-1.940	4.80	9	Pedersen 1988d
Maniitsoq		Fiskefjord	102.9	0.124	-1.560	6.49	10.5	
Fiskenæsset	1988	Mid	86.3	0.190	-2.090	5.27	13	Pedersen 1988e
Fiskenæsset		Ser	93.9	0.140	-1.320	7.10	13	
Sisimiut	1988	Qeq & Kgr	111.6	0.070	0.080	12.56	13	Pedersen 1988f
		Kgr Td	89.0	0.190	-2.130	4.77	9	
Sisimiut	1988	N Is	99.4	0.120	-1.490	7.35	11	

Age at 65mm was estimated from them but it disagrees with the results shown in the report. This is probably due to the asymptotic growth assumption of the equation, which does not apply to bivalves. H_{∞} : Maximum height, K: growth coefficient, T_0 : theoretical age at zero length, Age 65: age at 65mm estimated from the available parameters, Age 65 R: age at 65 mm estimated from the age vs length plots shown in the reports. Kang: Kangerdluarssugssuaq, Qeq: Qeqertalik, Kgr: Kangerdluarssuk, Kgr Td: Kangerdluarssuk Tugdleq, N Is: Nordre Isortoq, Mid: Midgarden, Ser: Serfasuaq.

Nanortalik and Paamiut (Frederikshåb)

The survey carried out in 1984 found only small scallop beds in Nanortalik and Paamiut. The stock in Nanortalik was estimated at 400 tonnes, whereas that in Paamiut was only 13 tonnes (Table 2.2). Around 10% of the stock was fished and since then there has been no dredging (Table 2.3). It was thought that scallops were very scarce here because of poor growth in the cold and nutrient-poor water from the Polar current, which

surrounds the southern tip of Greenland and reaches these two areas. The bottom topography, with very sharp slopes and uneven surfaces, also made dredging very difficult (Nicolajsen 1985a).

Maniitsoq (Sukkertoppen) and Kangerdluarssuqssuaq

These areas were surveyed first in 1985. Close to Maniitsoq there were extensive areas of seabed covered with empty shells, but a bed of live scallop was found in the Kangerdluarssuqssuaq area. The stock was estimated to be 750 tonnes (Table 2.2) and a TAC of 75 tonnes was advised (Nicolajsen 1985b). However, landings during that year amounted to 300 tonnes of scallops (Table 2.3). The community was optimistic regarding the possibilities of employment linked to the new fishery. Despite the scarcity of the resource, in 1986 the local processing plant in Maniitsoq obtained equipment to process 25 tonnes of scallops a day. The Maniitsoq commune paid for this and also for the dredges. The reasons behind this investment were many. Scallops had to be processed to get higher returns, but it was difficult to establish a processing method because the number of workers in the processing plant was highly variable. Some of them only worked there when they could not go to sea. Also, the fishing grounds were four hours away, the trawlers were small (8–14m); therefore, fishing was very irregular, being dependent on the weather.

In 1986, 28 trawlers were given licenses to catch scallops, and catches declined by 25% soon afterwards. The processing method changed then to optimize the use of the raw material and the percentage of processed product increased from 16 to 32% of the weight of the landings. However, market prices started to decline in autumn 1986 and eventually led to the closure of both the fishery and the processing plant in 1987 (Pedersen 1988a, 1988e).

A new survey was carried out in 1987 to assess the Kangerdluarssuqssuaq stock, which was found to be only 150 tonnes. There had been a significant decrease in the average size of scallops, and the percentage of small scallops had increased considerably. Thus, in 1985, over 28% of the scallops were 90mm in height, whereas in 1987, 25% of them were 12mm (two to three years old). Yield also decreased. In 1985, for scallops > 65mm SH (ten years old), gonad and muscle accounted for 30% of the weight but in 1987 they represented only 22%. New recruits would take around ten years to reach the minimal landing size and make the stock fishable again (Table 2.5) (Pedersen 1988e).

Scallop beds in the neighbouring areas of Kangerdluarssuk, Alangua and Fiskefjord were also investigated, but not one of them could be exploited commercially. The scallops were big enough, but the beds were small and widely distributed over the area.

In Kangerdluarssuk it was not possible to estimate the stock size outside the sampled stations. Scallops of marketable size were found only in

one station but their yield was around 25%, low compared to other localities.

Scallops from Alangua were larger, indeed few of them were < 80mm SH, but the stock size and biological parameters were not investigated. Besides, previous fishing in the area had shown poor results.

The stock in Fiskefjord had been previously fished, but it could not be estimated outside the sampling area. Most scallops were of marketable size but recruitment was low. Yield in 1986 was 16% but this was probably a result of the samples being collected after the scallops had spawned. In any case, the distribution of the scallop beds made this stock unsuitable for commercial dredging (Pedersen 1988e).

Qeqrtarsuatsiaat (Fiskenæsset)

Some minor scallop beds were found in 1985 and surveyed again in 1987 prior to the start of a very small-scale winter fishery (under 30 tonnes per year) in May of that year (Figure 2.11). The stock estimation was just under 500 tonnes, and a TAC of 48 tonnes was recommended (Table 2.2). The 1988 landings were hand-processed in the fish factory in Ervanga and sold as muscle, and also muscle with gonads. The very good quality and low price of these products enabled them to compete successfully with those from Iceland and Norway (Pedersen 1988d).

Dredging started again in 1999 after a ten-year pause with rather high catches considering the estimated size of the stock (Table 2.3). The scallops were on average 85mm SH and had the lowest growth rates from all areas that were investigated between 1984 and 1988 (Table 2.5).

Several other locations in this area were surveyed in 1988, but nothing was found south of Qeqrtarsuatsiaat, probably because of the high suspended load in the water caused by the nearby glacier (Pedersen 1988d).

Attu

Experienced skippers carried out the first survey to search for scallops in this area back in 1985, using private trawlers with facilities for hand processing of the catch on board. Only one scallop bed suitable for commercial fishing was found (Figure 2.12), with an estimated stock size of 300 tonnes (Pedersen 1987b).

A second survey took place in 1988 around Aasiaat and Attu in areas 30–60m deep that were not marked on sea charts. Scallops were found in Aasiaat but not in sufficient numbers to start a fishery.

Five localities around Attu had scallop beds, three of them already mapped. One of the localities, which had its stock estimated at 300 tonnes in 1986 had decreased to 90 tonnes in 1988 (Table 2.2). It was unclear whether this difference in stock size had been caused by fishing, as there was no information on scallop dredging in the area during the previous two years. It may have been a result of the uncertainty of the methods used to estimate the stock size. The remaining four scallop beds summed

just under 500 tonnes. The recommended annual catch was 20 tonnes because recruitment was very low. Dredging resumed in 1991 with rather variable catches (Table 2.3). Most scallops were around 80mm SH except from one location where they were 100mm due to very good environmental conditions. Growth rates in Attu were higher than in any of the other investigated areas (Table 2.5) (Pedersen 1988c).

Sisimiut (Holsteinsborg)

This area was explored in 1985 and 1988. Private trawlers surveyed several locations in 1985, Strømfjord, Itiudleq, Kandgerdlussuaq and Ikertoq, but scallops were found only in Kandgerdlussuaq. A total of 6.6 tonnes were landed in ten days. The trawlers surveying other areas found only mussels.

The 1988 survey was carried out with a research vessel, and scallop beds with some potential for commercial fishing were found in three localities: Qeqertalik, Kangerdluarssuk Tugdleq and Nordre Isortoq. The stock for all three was estimated at 5,000 tonnes, and therefore around 500 tonnes could be fished, although it was pointed out that these figures were uncertain (Pedersen 1988f).

The beds at Qeqertalik were at 15–60m depth, and the scallops were relatively small, about 75mm SH. Many 60mm individuals were 10–20 years old, so it was estimated that it might take 15 years for the recruits to enter the fishery. This stock was estimated to be 3,800 tonnes (Figure 2.13) (Table 2).

Scallops in Kangerdluarssuk Tugdleq were larger, most of them being 87mm SH, and faster-growing, requiring 11 years to recruit to the fishery. However, the stock was much smaller, 370 tonnes, and average catches of live scallops were low due to the large abundance of empty shells (Figure 2.14) (Table 2).

Nordre Isortoq had a stock of 785 tonnes but the bottom was hard and uneven, making catches rather variable (Figure 2.15) (Table 2). Scallops were on average 80mm SH; there were also small scallops and the estimated time needed to reach marketable size was 13 years (Table 2.5).

There are no figures of catches from these locations in the early years, but new beds within the Sisimiut area, Saqqaq and Kanaarsuk, have been dredged since 1991 and 1999, respectively (Table 2.3).

The scallop beds in most of these locations, except for Nuuk, Attu and Sisimiut, were exhausted in a very short time, probably a result of both overfishing and the lack of sound stock estimations. Pedersen (1986) pointed out that stock sizes had been calculated using the method described by Beverton and Holt, despite the fact that this equation assumes constant recruitment, which seems to be non-existent or very rare in Greenlandic scallop beds.

From 1995 onwards and following the discovery of new scallop beds by the fishermen, there was a northward shift of the fishery. Fishing in

Nuuk and Attu / Tugtulik (south of Disko Bay) continued, but fishing now also takes place in Mellemfjord, Mudderbugten and Søndre Upernavik, all of them north of Disko Bay (Table 2.3) (Engelstoft, pers. comm.).

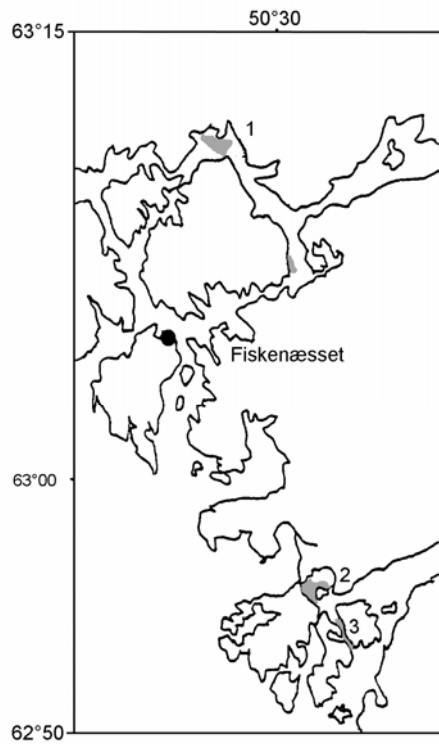


Figure 2.11 The scallop beds (shaded in grey) at Qeqertarsuatsiaat (Fiskerøsset). The overall stock size was 475 tonnes. Modified from Pedersen (1988e).

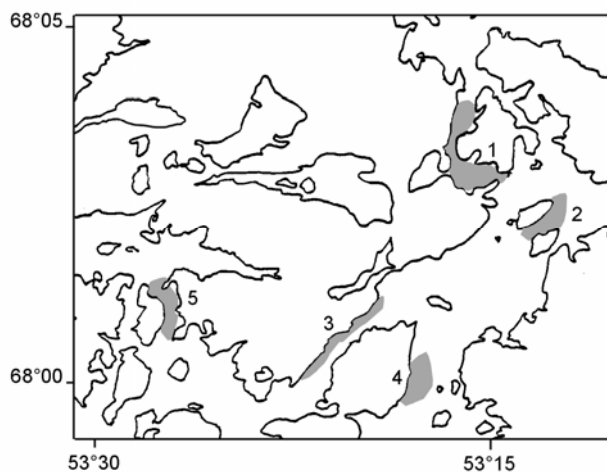


Figure 2.12 The scallop beds (shaded in grey) at Attu. The bed discovered in 1986 (number 4) was estimated to be nearly 300 tonnes, but it had decreased to 90 by 1988. The other beds found in 1988 totalled around 500 tonnes. Modified from Pedersen (1988c).

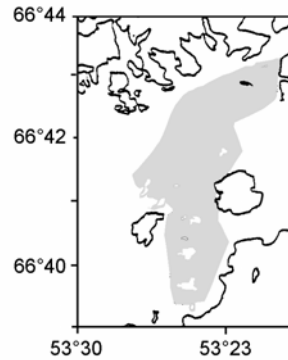


Figure 2.13 The scallop beds (shaded in grey) at Kangerdluarssuk and Qeqertalik, estimated to be 3,800 tonnes in 1988. Modified from Pedersen (1988f).

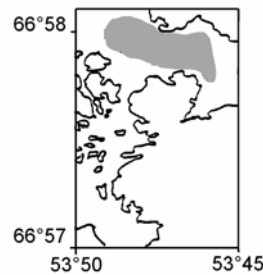


Figure 2.14 The scallop beds (shaded in grey) at Kangerdluarssuk Tugdleq. The stock size was estimated to be 380 tonnes. Modified from Pedersen (1988f).

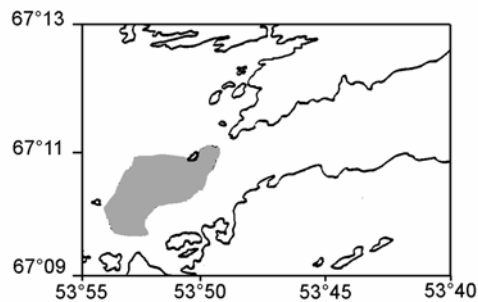


Figure 2.15 The scallop beds (shaded in grey) at Nordre Isortoq. The stock size was nearly 800 tonnes but the sea bottom was hard and uneven and catches were very variable. Modified from Pedersen (1988f).

2.1.4.2 Fishing gear

Several different dredge types were used in the surveys (Table 2.1), depending on the size and horsepower of the vessels and also on location, as it was found that dredges varied in performance under different conditions, such as bottom type, currents and slope (Pedersen 1994).

Pedersen and Boje (1987) carried out a comparative study between one Manx dredge manufactured in Iceland and two Greenlandic KIS

dredges, aided by underwater photography and divers and concluded that catchability was better with the Manx dredge, 37% versus 24%, and 21% for the KIS dredges.

2.1.4.3 Management

Licenses have been issued since the beginning of the fishery to limit the number of vessels operating to four or five in the Nuuk area. The minimal landing size was set at 65mm SH and annual catch quotas have been set every year since the beginning of the fishery. These quotas were to be 10% of the stock > 65mm SH (Pedersen 1989, 1994; Anonymous 1998a).

A quota is still set every year for Nuuk, Attu, Sisimiut and Mudderbogtten, based on the stock assessment studies carried out during the 1980s and in 1994. There are no quotas for the fishing grounds discovered after 1995, but the Greenland Institute of Natural Resources advises a total catch of 2,000 tonnes for all West Greenland. This figure is based on landings during the last 10–15 years and the stability of catches (Engelstoft, pers. comm.), and it seems to be appropriate since there have been no major fluctuations in overall annual landings (Table 2.3).

2.1.4.4 Summary of research

There are old records of scallop beds found in West Greenland, dating from the end of the 18th century, as cited in Posselt (1898) and Jensen (1912). However, research on scallop beds with a view to commercial use of the stock did not start until 1984 with mapping of resources, stock size estimations (Nicolajsen 1984; Eiríksson and Nicolajsen 1984) and a study on catchability of different dredges (Pedersen and Boje 1987). Pedersen (1994) published a study on population parameters based on survey data from the period 1984–1988.

The most recent report described a study to transfer scallops from areas with lower growth rates to other places where growing conditions were better in order to regenerate exhausted fishing grounds. However, the high mortality among the juveniles after transplantation and the small growth rates of adult scallops made the project unfeasible (Engelstoft 2000).

The reports cited in this review provide nearly all the scientific knowledge accumulated during the last 20 years concerning the scallop stock in Greenland. Other aspects of the fishery such as by-catch have never been studied (Engelstoft and Siegstad, pers. comm.).

2.1.5 Norway: Svalbard, Bjørnøya and Jan Mayen

2.1.5.1 The stock and the fishery

Scallops have been traditionally used as bait in Norway, but this fishery decreased after WWII and stopped during the 1950s (Sundet 1985). The possibility of starting a commercial fishery was not considered until the

1960s. The first surveys took place in 1961 and 1962 in Tromsø, Kvænangen fjord, and between Vestfjord and Kirkenes, in North Norway (Wiborg 1962, 1963a). The best scallop bed was found in Balsfjord, near Tromsø, covering 70–100,000m². Most shells were > 60mm and all individuals reached maturity at 50mm shell height (Wiborg 1963a). Another survey in North Norway found several beds with shells > 75mm SH and in densities of 35–40 shells m⁻², but no information is given about their distribution (Wiborg 1963b).

Jan Mayen

In the mid-1980s, traditional fisheries were declining and the industry was looking for alternative resources. Trawlers turned to the offshore grounds in Jan Mayen in 1985, starting the Norwegian large-scale scallop fishery. A total of 27 licenses were issued the first year and 20 trawlers took part in the fishery. They all were 40–70m in length and most of them had on-board mechanized processing facilities. Seven of these trawlers were specially built for the occasion, while the rest came from other fisheries or had been previously used as supply boats. The fishery was not as profitable to ships without on-board processing because quality declined during the long time at sea, yet five such ships took part during 1986. Catches approached 13,000 tonnes in this year (Table 2.6) (Anonymous 1988).

The first survey in Jan Mayen, also in 1986, estimated the stock at 31,000 tonnes distributed over two scallop beds, one of them being 60 km² and the other 15 km² (Figure 2.16) (Rubach and Sundet 1987). The stock was made up of large, old scallops with growth rates as slow as in West Greenland (Table 2.7). The second stock assessment, in May 1987, estimated that there were 8,000 tonnes left and showed a decline in number of scallops < 65mm SH (Anonymous 1988). The area was therefore closed to dredging in August 1987 (Aschan 1991), after a catch of 1,500 tonnes had been taken (Table 2.6).

Subsequently, 13 of the 26 Norwegian trawlers were sold to Greenland and several of the remaining ships were sold in Norway to pursue other fisheries (Anonymous 1988).

Table 2.6. Scallop catches (in tonnes) in Jan Mayen, Bjørnøya and Svalbard (areas I–XII).

Catch area	20	21	22	23	25	35	36	Total
	Bjørnøya	IX	X, XII	XI, XII	I–VII	Jan Mayen		
Year								
1987	12,227	3,840	9,392	621	16,397	1,487	134	44,098
1988	5,041	1,166	2,533		10,295			19,035
1989			843		3,755			4,598
1990	3,269	656			2,325		587	6,837
1991	5,510				479			5,989
1992	5,140			732	524			6,396
1993	2,277							2,277
1994	982			2,085				3,067
1995	2,135				1,921			4,056

Arabic numbers indicate the spatial division of the Directorate of Fisheries and Roman numbers the division used in the reports (see Figure 17). Data from the Norwegian Directorate of Fisheries.

Table 2.7 Population parameters and additional information from the different scallop beds in Jan Mayen, Bjørnøya and Svalbard.

Bank	Jan Mayen	Bjørnøya	Sørkapp	Sjubreflaket	Nordgat	Klovningen	Breibogen	Moffen
Area		XII	IX	V	IV	III	II	I
> 65mm (%)	64	91.5	50.6	64	60	93	82.5	55.8
Mean length	77.2	76.6	71.5	71.2	69.3	77.1	73.4	71.7
ML < 65mm	50.1	60.4	58.9	59.1	60.1	60.3	58.1	55.8
% Males	44.8	43.9	54.2				53.1	53.9
Age at 65	9	9	11.5				13.5	12
Muscle 65 (g)	5	7	5				6.5	7
Muscle 85 (g)	10	13	10.5				12.5	14
Bank area (km ²)	60	343	85	300*	55**	**	340*	680
Stock 1986 (tonnes)	31,000		11,400	45,000	11,100		146,000	205,000
Stock 1987 (tonnes)	8,000	23,000	14,000				70,000*	98,000
Depth MD	70–100	70–110	60–100	26–96	24–116		40–70	30–70
Dredging	suitable	very good	good	good	favourable	variable	favourable	boulders >20cm

ML: mean length, Muscle 65 and Muscle 85: grams of muscle at shell height 65 and 85mm respectively, stock size estimated considering only scallops > 65mm SH, Depth MD: depth interval with maximum density of scallops, Dredging: dredging conditions, *: partially within protected area, **: whole bed within protected area, *: stock size outside protected area. Data from Rubach and Sundet (1987) and Anonymous (1988)



Figure 2.16 Map of Jan Mayen showing the areas surveyed, circled in black, and the scallop beds (shaded in grey). Modified from Rubach and Sundet (1986).

Bjørnøya and Svalbard

The first searches of scallop beds in Bjørnøya were conducted in 1968 and 1969. Scallops were found between 80–135m depth, but marketable-sized scallops were below 105m depth. Recruitment was very scarce, most individuals were 6–11 years old, and 91% of scallops were in the length interval 50–85mm SH. The study concluded that a commercial fishery would be difficult to develop, partly because of rough bottom conditions (Wiborg 1970). The next survey was carried out in 1973 and investigated both Bjørnøya and Spitsbergen. Scallops in Spitsbergen were also around 80mm SH and 10–14 years old, but muscle and gonad weight were larger in Bjørnøya. This second study was more optimistic about commercial use of the stock, but it indicated that only a small percentage of the total stock biomass should be taken, given the poor recruitment and low growth rates (Wiborg et al. 1974).

Rubach and Sundet (1987) surveyed Jan Mayen, Bjørnøya and Svalbard in 1986 and estimated the stock size at about 418,000 tonnes, Bjørnøya and the Klovningen bed excluded (Table 2.7) (Figure 2.17). However, the beds from Nordgat and Klovningen and part of the beds in Sjubreflaket and Breibogen were within the national park north of Spitsbergen, so the fishable stock would be several thousand tonnes less. These new fishing grounds were considered suitable for dredging, but the scarcity of recruitment and the long time needed for scallops to recruit to

the fishery (Table 2.7) required very careful management. Just over 2,000 tonnes were taken in 1986 from the Svalbard area (Anonymous 1988).

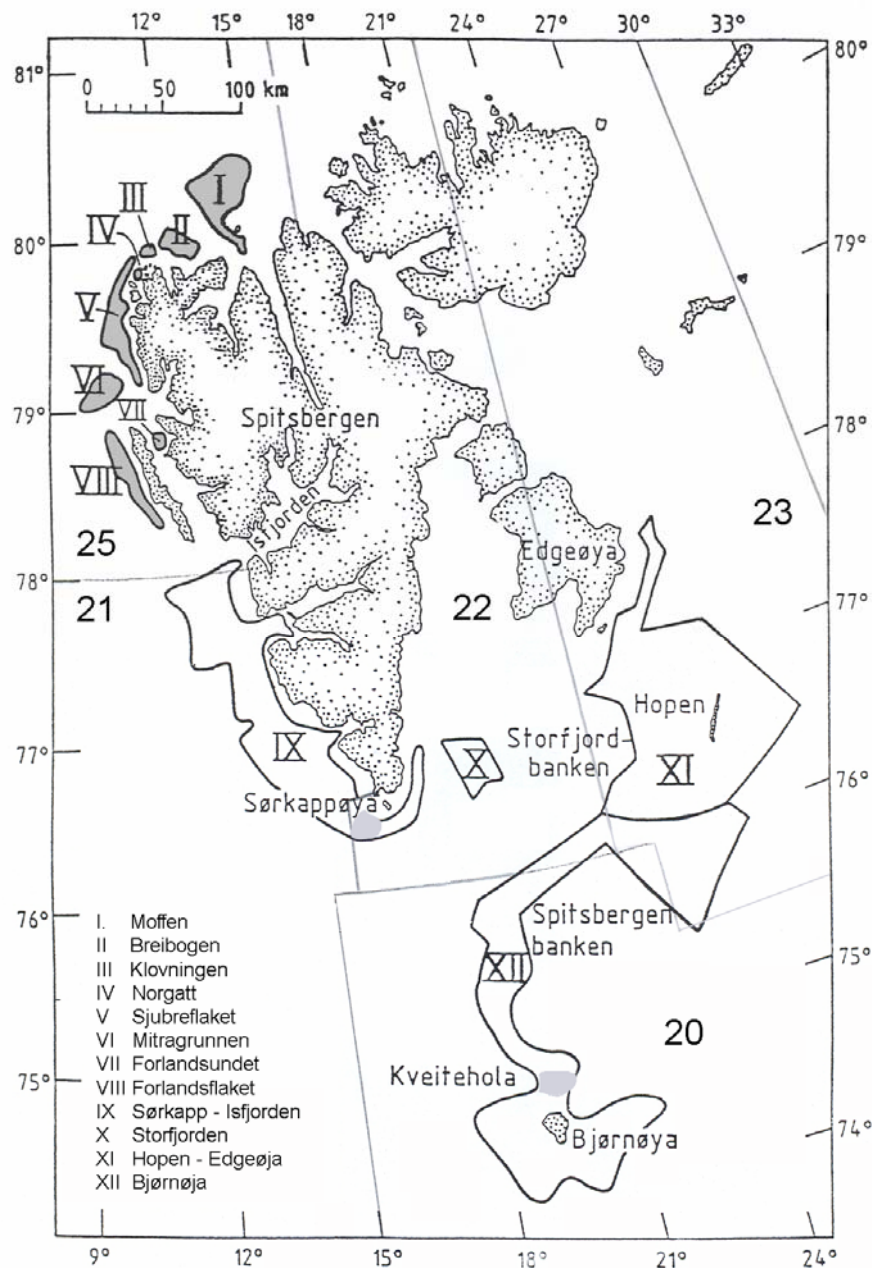


Figure 2.17 Map of Svalbard and Bjørnøya showing the areas surveyed, marked with Roman numbers, and the spatial division used by the Directorate of Fisheries, numbered in Arabic numbers. The scallop beds surveyed in 1986 are shaded in grey. Modified from Rubach and Sundet (1986).

The survey carried out in 1987 estimated the stock off Bjørnøya at 23,000 tonnes of scallops > 65mm SH, and the Sørkapp bed was found to be

3,000 tonnes larger than previously thought. On the other hand, the Mof-fen bed had decreased greatly (Table 2.7) (Anonymous 1988).

During 1987, total catches rose to 41,000 tonnes despite the recom-mendations from the scientists. Nineteen ships took part in the fishery but 72% of the catches were taken by only four of them. In 1988, the fleet dredging in Svalbard dropped to seven trawlers and catches fell to 7,000 tonnes according to Anonymous (1988), although these data do not agree with those from the Norwegian Directorate of Fisheries (Table 2.6). Comparisons between scientific and official sources are difficult due to the different spatial divisions of the study area.

Catches between 1989 and 1995 have been between 2,000–7,000 ton-nes, most of them from Bjørnøya, except for 1989, when most catches were from Mof-fen and Breibogen (Table 2.6) (Anonymous 1990b). Bjørnøya opened in 1991 with a fixed quota of 2,000 tonnes, and both Jan Mayen and Svalbard areas were surveyed again. Mof-fen was found to have been overfished in 1990. Besides, there was hardly any exchange of spawn and recruitment was local, meaning that recovery time would be very long (Anonymous 1992).

Nevertheless, commercial and experimental dredging continued until 1995, mostly in Bjørnøya and Mof-fen. There were juvenile scallops, but they would need seven or eight years to recruit to the fishery. A new scal-lop bed, Parryflaket, was found near Mof-fen but the information available about commercial dredging there is unclear (Anonymous 1992, 1995, 1996, 1997, 1998b).

2.1.5.2 Management

By mid-1987 it was obvious that the offshore scallop fisheries needed regulation and several management options were considered (Anonymous 1988):

- introduction of quotas (for total catch, area or trawler),
- control fishing effort,
- fixing a minimal size at capture,
- opening / closure of scallop beds,
- seasonal regulation of the fishery, based on the seasonal variations of muscle weight due to food availability and physiological changes associated to spawning cycles (Sundet and Vahl 1981; Sundet and Lee 1984).

However, each of these options had certain requirements that the scallop fishery lacked. Thus, catches must be known accurately for quotas to be effective. In this case, only the number of processed meats was known, and estimation of total catch was not good because the percentage of scallops broken and discarded during dredging and processing was un-

known. Therefore the total mortality was not accurately known and the estimation of quotas would not be practical.

Similarly, regulating the fishery by limiting fishing effort required a model incorporating fishing mortality in order to estimate how much fishing mortality is generated by a certain effort (expressed as number of ships, or number of fishing days, for example). This was not possible because catches were not known with accuracy. Nevertheless, limiting participation in the fishery could be used to prevent the fishing capacity of the fleet becoming larger than the resource can sustain. In fact, comparison of catches in 1987 and 1988 in relation to the total size of the stock suggests that fishing effort was above the maximum sustainable yield (MSY).

Minimal landing size can be used as a criterion to close or open an area to the fishery. It can be estimated from the effort or yield per recruit and spawning stock biomass. The problem is that dredges are not very selective and sorting is necessary on board. The result of this measure depends on whether scallops survive the process of sorting and to what extent the fleet can avoid dredging over areas with many small shells.

The closure / opening of areas, combined with monitoring, does not demand as much accuracy in the estimation of stock as the other methods, but it demands monitoring of the stock in the selected area. This option raises the following points:

1. Criteria to close / open an area. This decision could be based on size and / or variability in the harvested stock. Both changes in size of fishable stock and the proportion below the minimal landing size need to be monitored. Data from the commercial fishery plus survey data can be used to monitor the stock. It is possible to have observers on board to close or divide the fishing area if a large proportion of scallops are under the minimal landing size. Areas can be closed regardless of length distribution if there are indications of drastic reductions in stock size.
2. Which scale is appropriate considering the size of the fishing area? There are two possibilities to choose the scale: a) using natural demarcations for management, or b) dividing the beds into smaller units and managing them independently. This last option can be applied in the short or long term to ensure that the stock can recover after fishing without overly affecting the fleet. Data on stock size and spawning time are needed. This imposes a practical limit on the size of units used in the regulations, as too small units can reduce further the effect of regulations on the stock.
3. Seasonal closures based on spawning time or the variations in condition linked to the spawning cycle. These are not very reliable because mature scallops can spawn spontaneously under stress and spawning cannot be predicted to happen in a single moment during

the year. Besides there was not enough information available on the biology of this stock to investigate spawning patterns.

It was therefore suggested to lower the minimal size of landing to 60mm SH as this would have least impact on the biomass per recruit obtained but would increase the fishable stock from 200,000 to 290,000 tonnes. A fishing mortality of 0.2 would correspond to catches of around 50,000 tonnes whole weight, or four to five tonnes of muscle. In addition, Jan Mayen, Møffen and Bjørnøya were closed to the fishery at least until surveying the areas again in 1988 (Anonymous 1988).

Dredging continued in Bjørnøya until 1995 and in the beds northwest of Spitsbergen until 1992 and again in 1995. The Møffen bed was also dredged in 1992 and 1994 (Table 2.6), but there is hardly any information concerning the scallop stocks in Jan Mayen, Bjørnøya and Svalbard and their management after 1988.

2.1.5.3 Research

The reports from the Danish Ingolf expedition (Jensen 1912) mentioned the presence of scallops in Jan Mayen in 1882, but the first surveys to assess the offshore scallop resources, estimate stock size and collect biological information took place around Bjørnøya during 1968–69 (Wiborg 1970). Spitsbergen was surveyed in 1973 but not thoroughly. Nevertheless a scallop bed of 69 km² was detected north of the island, although density and average size of the scallops was lower than in Bjørnøya, where some experimental fishing was carried out during the same survey (Wiborg et al. 1974) and again in 1979 (Venvik 1979).

Thorough surveys to map, estimate the magnitude of scallop resources and investigate their population dynamics in Jan Mayen and Svalbard were conducted in 1986 and 1987 (Rubach and Sundet 1987; Anonymous 1988).

Additional research was carried out to find an appropriate storage method that would ensure maximum quality of the scallop muscle. This was a priority, as at the beginning of the fishery, on-board mechanical processing was very limited and the catch had to be stored on board for several days (Anonymous 1988; Larsen 1991).

The effect of dredging on the benthic communities was also investigated. No changes were detected in Jan Mayen after the closure of the fishery, apart from an increase in *Ophiura robusta*. In the Svalbard area, although the dominant species were the same in 1987 and 1988, number of species and diversity decreased after dredging started. Mortality of by-catch might have been higher than in other scallop fisheries since on-board mechanical processing included heating to 80°C and everything in the length range of 45–70mm went through the process (Aschan 1988, 1991; Aschan and Sundet 1990; Anonymous 1995).

2.1.6 Overview

The main Icelandic scallop beds in Breiðafjörður have shown signs of decline since the early 1980s, but stock indices stabilized somewhat during the 1990s before the decline became more pronounced from 1998 onwards. Catches remained at 8,000–9,000 tonnes until 2000 due to technological improvements and increase of fishing effort. However, natural mortality, estimated from the percentage of cluckers (empty shells still joined by the hinge that indicates a recent death) found in samples from several locations, rocketed during the period 2000–2003 and the stock decreased by 70% in Breiðafjörður and by 45–80% in smaller beds in Northwest Iceland (Jónasson et al. 2004).

This increase in natural mortality was thought to be linked to the increasing sea temperature registered in Icelandic waters over recent years and especially during the period 2000–2003, as upper tolerance limits for *C. islandica* were thought to be around 10°C and enhanced natural mortality of scallops following rising sea temperatures had been recorded in Norway and Canada (Dickie and Medcof 1963; Wiborg 1963a). However, recent research on scallops from several locations in Iceland has shown that temperature tolerance of *C. islandica* in summer is a few degrees above the temperatures registered over the last years in Breiðafjörður (Jónasson et al. 2004). Nevertheless, it is very likely that other factors have influenced the observed decline in the scallop stock, and overfishing must be in part responsible.

The Greenland Home Rule effort to develop a new fishery based on a scarce resource must be understood in the social and economic context of Greenland at that time. Greenland got its 200-mile EEZ in 1977, as the annual cod catches off West Greenland fell from 400,000 tonnes to around 50,000 tonnes. The closure, however, allowed Greenlanders to increase their own catch from 15,000 to 60,000 tonnes. Nevertheless, by this time it was evident that temperature was decreasing, affecting the distribution of cod, which was not found as far north as earlier in the century. On the other hand, most people already lived in the bigger settlements, close to cod fishing grounds, with landing and processing facilities. This was the result of a governmental plan from 1948 to reorganize the fishing industry. Extremely severe winters in 1982 and 1984 caused cod biomass to decrease by 70%, and although the stock recovered somewhat between 1988–1990, it finally collapsed in 1991. Many cod-based settlements found themselves without fishing resources, especially for inshore fishing (Hamilton et al. 2000). With this background, all possibilities to create employment and maintain the fishing industry had to be explored.

It was estimated that a catch of 100 tonnes of scallop could generate 500 working days to distribute among 12–15 people, assuming that each fisherman would process 300 kg of scallops a day to produce 60 kg of

meats and that one scallop vessel with a four-man crew could catch roughly 1,500 kg of scallops a day (Pedersen 1988e, 1988f).

The surveys in West Greenland found scallop beds in most of the communities investigated, some of them apparently with some potential for a small-scale commercial fishery. The main problem was the impossibility of accurately estimating stock size and the appropriate fishing mortality, due to the lack of background data (Pedersen 1988c, 1988d) and resources to implement a monitoring programme to collect biological data prior to exploitation. Nevertheless, and despite the closure of some of the beds found in the 1980s, the fishery continues and catches are rather stable.

The scallop fishery in Jan Mayen, Svalbard and Bjørnøya started with a very different goal. It was a private enterprise. Encouraged by the discovery of scallop grounds, the very high prices of scallop meats in the market, and probably the lack of regulation, fishermen started dredging the offshore beds without previous sound research of the stock. In fact, Sundet (1985) acknowledged that the scallop fisheries in Bjørnøya and Hopen Island were promising, adding that this assumption was based on the availability of “bottom area sufficient for scallop growth and not on the knowledge of an actual standing stock”. By the time the first reports were published stressing that assessment was difficult and very careful management was required, it was too late. Catches had reached 45,000 tonnes and the stocks collapsed shortly afterwards.

The pelagic dispersal of scallop larvae may suggest that recruitment to a given scallop bed depends on influx of larvae from other beds. However, many scallop aggregations are far apart and have a precise location that in some cases has been known for centuries. In addition, scallops from different locations show variability in spawning time and growth rates. Moreover, most scallop beds are found in areas influenced by tides, gyres and water circulation regimes that favour larval retention in relatively fixed geographical areas, and genetic research performed in some scallop stocks has detected genetic differentiation among scallops from different locations. All this evidence suggests that scallop beds may be self-recruiting and therefore too high a fishing effort may lead to recruitment overfishing, which takes place when recruitment is jeopardized due to depletion of the spawning stock. This poses a difficult problem for management, as the minimum spawning stock biomass required for a successful recruitment is unknown (Sinclair et al. 1985). Recruitment overfishing might have been the case in some scallop beds in Breiðafjörður that became depleted after intensive effort. The assumption of self-recruitment adopted in Greenland is therefore a conservative management approach that seems to have been overlooked in Iceland and Norway.

Inadequate management may also lead to growth overfishing, or fishing above the MSY of the stock. This seems to have been the main reason for the collapse of the Iceland and Norway stocks.

It would have been desirable for Greenland, Iceland and Norway to establish a joint monitoring programme to study recruitment. In the case of Norway it would have been useful to assess the possibilities of recovery, apart from the obvious scientific interest. For Iceland and Greenland, however, better knowledge of the dynamics of scallop populations would have enabled them to plan better management of their resources. Scallop beds in Greenland might be relic populations from much larger beds, as found by Pedersen (1988a). Some beds around Disko Island were surrounded by an extensive area covered with empty shells. Carbon¹⁴ analysis indicated that the shells were between 60 and 450 years old, and some of them even 6,300 years old. This stresses further the need for careful monitoring and management of scallop stocks in the Arctic. It may be argued that political and economic constraints do not always allow for the expensive and time-consuming research required for understanding the population dynamics of a new resource. In addition, conservative management requires a data collection from surveys and commercial fishing spanning at least a few years. The required fisheries data are age composition of the catch, annual CPUE and fishing effort. This information is fed into a model to estimate the removal and weight at age of scallops for any given fishing mortality. The goal is to optimize yield-per-recruit. The model can be used to regulate the fishery by regulating the age and size of capture (gear selectivity) and control fishing effort by regulating fishing mortality under the assumption of self-recruiting populations. Basically, this consists of fishing only the older scallops so each year-class has the chance to spawn over several years. It has been shown that this strategy increases significantly yield and egg production (Sinclair et al. 1985).

This strategy could have been adopted in Greenland, Iceland and in Bjørnøya a few years after the fishery started. However, the management in Iceland seems to have focused on maximizing landings each year instead of favouring a conservative approach for a long-term use of the resources. Catches have been kept stable in Greenland so far with a fixed quota based on landings during previous years, but no research has been carried out since the 1980s that could lead to improvements in management. Norway is a different case because the offshore stocks were wiped out so quickly that hardly any data had been collected before the fishery collapsed, but the conservative approach could have been tried in Bjørnøya, where scallop dredging has taken place occasionally over the past 15 years. Recent survey data from the Svalbard area indicate that the stock may be recovering (J. Sundet, pers. comm.).

Other scallop fisheries have followed a similar pattern to those reviewed here and yet the fishery has recovered. The largest Canadian

C. islandica fishery started in 1993 on the Grand Beds off Newfoundland, and by 1996 catches had reached 21,000 tonnes. Fishing mortality proved to be too high for a stock that consisted mostly of old scallops and some beds became depleted in a short time with the consequent decline in landings (Naidu et al. 1997).

The fishery for the weathervane scallop, *Patinopecten caurinus*, started in Southeast Alaska in the late 1960s and depleted the stock in less than ten years. There was no dredging for several years from 1978 onwards. However, the stock recovered in the 1980s and after dredging resumed, new management plans were implemented to ensure resource conservation. Catches have varied greatly among years ever since, with production between 90 and 770 tonnes of muscle, but dredging has not been interrupted again (Kruse et al. 2000).

Similarly, in the Isle of Man fishery for *Pecten maximus*, the stock has recovered since 1991 after a long period of declining catches. The fishery relies nowadays on the strength of the recruited year-class instead of old scallops, and density is much lower than in the 1950s (9–20 scallops 100m^{-2} versus < 3 scallops 100m^{-2} since 1990). Nevertheless, CPUE has increased on many grounds since 1991 (Brand 2000; Beukers-Stewart et al. 2003).

Scallops have highly variable recruitment, influenced by several abiotic and biotic factors, not yet fully known (Young et al. 1989). This characteristic makes scallop stocks more sensitive to recruitment failure, especially if the fishery depends on the strength of the recruited year-class (Beukers-Stewart et al. 2003). It is interesting to note that a model developed by Smith and Rago (2004) showed that unexploited scallop populations in equilibrium had a large biomass and very low recruitment. When a fishery is introduced into the model, recruitment shows increased variability as the population oscillates towards a new equilibrium point with a much smaller biomass. As in this model, the Iceland scallop populations reviewed here had large average stock sizes and low recruitment levels. When the fishery started in Breiðafjörður, the mean density was 20–30 shells m^{-2} and most of them were $> 70\text{mm}$ SH. Length distribution graphs from Breiðafjörður and NW Iceland show how the population consisted mostly of adult shells (Eiríksson 1970a, 1986). It can be argued that dredges do not sample adequately the smaller shells and they are underrepresented, but since juvenile Iceland scallops are often attached to larger empty shells that are caught with the dredge it is probably safe to assume that even allowing for underestimation of the smaller length groups, recruitment was very scarce. The same can be said of the West Greenland populations, made up mostly of individuals $> 75\text{mm}$ SH and with very low recruitment levels (Pedersen 1994), and the Svalbard area, where all individuals seemed to be sexually mature and it was suspected that spawning did not take place every year (Rubach and Sundet 1987). Recent data from Greenland and Svalbard are not available, but in

Breiðafjörður the stock index has oscillated with a decreased trend and recruitment has been highly variable in spatial and temporal terms during the period 1993–2003, being very low in the late 1990s (Jónasson 2005).

Variability in stock size may be due to spatial variation in habitat quality, spatial concentration of the fishery, larvae dispersal and trends in mean size. Within the area occupied by a scallop population there are differences in the habitat that make some sites more favourable, influencing growth rates and the potential for egg production and larval survival (Dickie 1955; Claereboudt and Himmelman 1996; Tammi et al. 1997; Robinson et al. 1999; Smith and Rago 2004). Concentration of fishing effort on these areas can have a negative effect on spawning and therefore recruitment by dispersing non-caught shells and thus affecting fertilization (Oresanz et al. 1991). Furthermore, diminished scallop abundance also leads to lower larvae densities (Tremblay and Sinclair 1988), making scallop populations vulnerable to fishing.

Smith and Rago (2004) proposed that fisheries should focus on avoiding recruitment overfishing rather than optimizing yields. They proposed closure to fishing of the most productive areas as a strategy to reduce recruitment variability and increase yields. If egg production within the closed area is larger than the ratio between yield from the whole area and yield from the open area, recruitment would increase and compensate for yield losses after the closure. The more productive areas would export larvae to the less productive. This strategy assumes that the excess of effort is not redistributed over the remaining open areas.

The current situation of the scallop stocks of Iceland and Norway allows for experimenting with management strategies different from those used in the past. Both fisheries are closed nowadays and considering their trends over the past 30 years it is very likely that fishermen will be willing to cooperate with management actions geared to rebuild the stock and make the fishery sustainable in the future. A detailed description of the alternative management options is out of the scope of this paper; therefore, only a brief suggestion for future action follows. The first step could be re-designing the stock assessment surveys. Iceland, Norway and Greenland use the swept area method for scallop stock assessment. This is a widely used method based on random sampling theory, and it assumes that scallop density is randomly distributed over the study area. However, this assumption does not apply to sedentary species, such as scallops, with aggregated distribution patterns that are persistent in time and space and depend largely on environmental conditions. For these reasons, geostatistical sampling techniques, such as kriging, constitute a better approach. These model-based methods take into account the spatial organization of the resource and their location on regular grids or fixed stations. Kriging consists of modelling the covariance between sampling units as a function of the distance between them and assigning to each sampling unit an optimal weight to estimate the average density of the

resource within the study area (Caddy and Defeo 2003; Nicolajsen and Conan 1987).

Secondly, indicators of fishing pressure and reference points should be monitored as indicated in the FAO Code of Conduct for Responsible Fisheries. As scallop populations within a given location are structured as metapopulations, these variables should be estimated for the different scallop beds. Within a metapopulation there are scallop beds acting as larval sources and beds acting as larval sinks. These should be identified. According to the source-sink hypothesis, all year-classes are present in source areas, whereas in sink areas recruitment does not occur regularly and only a few year-classes will be present (Caddy and Defeo 2003).

The next step would be closing permanently a large percentage of the source areas and implementing rotational closures in the remaining scallop beds. Permanent closure of at least some source areas would ensure larval supply and it would also protect other benthic species that are vulnerable to dredging and are in some cases very important for scallop settlement, such as bryozoans (Harvey et al. 1993; Hall-Spencer and Moore 2000; Murawski et al. 2000; Caddy and Defeo 2003). Rotational closures accompanied by decreased effort have been successfully implemented in the scallop fisheries in Georges Bank, which had reached a long-term low catch per vessel in the early 1980s (Sinclair et al. 1985). However, following the closures, harvestable scallop biomass had increased by a factor of 15 according to survey data from the period 1994–1998 (Murawski et al. 2000). Closures have shown to be effective to increase yield-per-recruit, and what it is more important, reduces the risk of recruitment and growth overfishing (Murawski et al. 2000; Hart 2003), but they require a decrease of fishing effort. Rotational closures distribute fishing effort over the open areas but at the same time are less restrictive for the fishery than permanent closures (Caddy and Defeo 2003; Hart 2003).

Finally, another measure that could be applied to prevent recruitment overfishing would be increasing the minimal capture size and regulating the fishing mortality at age to ensure that all year-classes are present in the population and that each individual has the chance to reproduce for several years. Sinclair et al. (1985) estimated that if this approach had been applied to the Georges Bank scallop stock, landings and egg production per recruit would have been 58% and 25% higher than they were. Note that Anonymous (1998) recommended decreasing the minimal landing size to increase the fishable stock in Svalbard.

Closures are difficult to implement due to their impact on social and economic issues but they are necessary in view of the decreasing biomass trends of many target species. The main benefits of closures may not be increased catches in the future, as has been shown in the scallop beds of Georges Bank, but the knowledge we may gain from monitoring and research carried out within their limits (Smith and Rago 2004).

The fisheries examples cited above show us that management that focuses on long-term use of a resource rather than on quick returns can succeed if the stock is given a chance for recovery. Research and monitoring of the target species and its environment are necessary at all steps, but especially under anomalous circumstances. Good knowledge of the environment of a target species is probably the best tool for understanding the dynamics of its populations.

2.2 Impact of scallop dredging on the macrobenthic community in Breiðafjörður, West Iceland

E. Guijarro Garcia and S. A. Ragnarsson

2.2.1 Abstract

Effects of scallop dredging on benthic communities in West Iceland were investigated by analysing existing by-catch data from scallop stock assessment surveys and effort data from the commercial scallop fishery. By-catch represented 28% of the total catch, with eight benthic macrofaunal taxa alone making up nearly 98% of the by-catch.

Modiolus modiolus and *Cucumaria frondosa* dominated in terms of abundance and biomass in most of the study area regardless of intensity of fishing effort.

The macrofaunal benthic community in Breiðafjörður consisted mostly of hard-shelled molluscs, holothurians, crabs and starfish. Emerging epifauna was absent in the samples taken over the past ten years.

These results suggested that our study was carried out within an already altered community that would have suffered the greatest impact during the early years of the scallop fishery. However, the available data are not enough to endorse this assumption with complete certainty.

2.2.2 Introduction

Scallop dredging can have direct and indirect impact on benthic fauna and habitats, including enhanced mortality on animals that are killed or injured following direct contact with the gear (Anonymous 1998c; Jenkins et al. 2001) and subsequently become more prone to predation (Kaiser and Spencer 1994a; Veale et al. 2000a).

Long-lived, slow-growing epizoans often have a fragile body structure and are especially vulnerable to encounters with the gear, whereas taxa protected by exoskeletons or thick shells are more resilient (Gislason 1994; Hall-Spencer and Moore 2000; Kaiser et al. 2000; Hall-Spencer et al. 2002).

Scallop dredges can also increase the sediment load, relocate boulders and destroy topographical features (Caddy 1973; Eleftheriou and Robertson 1992; Gislason 1994). Differential mortality among taxa and habitat destruction may cause important short- and long-term changes in faunal assemblages that are regularly disturbed by fishing gear (Kaiser et al. 1996; Collie et al. 2000; Tuck et al. 1998; Kaiser et al. 1998; Bradshaw et al. 2000; Hill et al. 1999; Jenkins et al. 2001; Kenchington et al. 2001).

However, the magnitude of the impact caused on benthic communities depends to a large extent on the bottom type. Benthic communities on sandy bottoms are in general more resilient to disturbance than those on gravelly, sandshell bottoms (Eleftheriou and Robertson 1992; Hall 1998).

Scallop dredging targeting *Chlamys islandica* commenced in Iceland in 1969 (Eiríksson 1970a). The largest scallop beds are located in Breiðafjörður, West Iceland, although some dredging has taken place also in the north and northwest of the country. Breiðafjörður has provided between 80 and 100% of the total annual catches since the beginning of the fishery (Anonymous 2003). Fishing vessels ranged between 15–25m in length in 1972 and during the years of highest catches, up to 25 vessels took part in the fishery (Eiríksson 1997). Due to declining stocks only eight vessels between 15–33m have taken part in the fishery during recent years. Fishing effort has always been unevenly distributed throughout the year. There is very little dredging from March to July, with only 0.5–2% of the annual catch landed during these months. Catch percentage for the remaining months ranged from 6 to 19%, with maximum landings (> 11%) between September and December.

By-catch data have been collected since 1993. The data sets analysed here were collected during the annual research surveys within Breiðafjörður, and from the commercial fishery log books.

This contrasts with many previous studies that have investigated the effects of scallop dredging using manipulative field experiments where the size of the study areas was much smaller and the time scales shorter (Eleftheriou and Robertson 1992; Currie and Parry 1994; Jenkins et al. 2001).

The goal of this study was to investigate the effects of dredging on the spatial and temporal trends of non-target species caught as by-catch in the scallop fishery in Breiðafjörður, West Iceland.

2.2.3 Material and methods

The study area

The scallop fishery is concentrated in the middle-inner part of Breiðafjörður (Figure 2.18). The scallop beds are generally found between 20 and 70m depth. Their distribution is greatly influenced by bottom topography, characterized by many channels with orientation SW-NE or W-E within which the scallops accumulate (Eiríksson 1986).

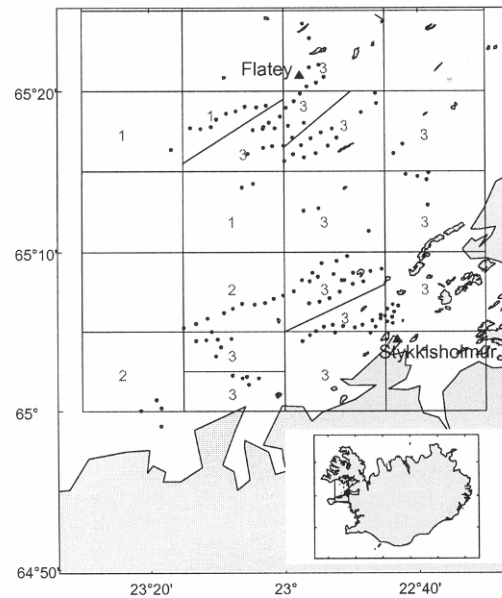


Figure 2.18 Map of the study area showing its location within Iceland (insert). The grid shows the division into rectangles used in surveys and commercial fishing, and the dots show the sampling stations. Note that four of the rectangles are split in two parts.

Survey and commercial data

By-catch data have been collected regularly since 1993. The scallop fishing grounds are divided into 19 rectangles and triangles (called hereafter rectangles for simplification) measuring 5x6nm (9.3 x 11.1 km). Most sampling took place within the nine rectangles subjected to the highest fishing effort during the past ten years, with nearly 85% of the samples collected there. Between 107 and 124 tows were taken in each survey.

Two different dredges were used in the surveys. A sledge dredge, 1.5m wide and weighing 470 kg, was used until 1997. From 1998 onwards a roller dredge of Icelandic design, 1.2m wide and 835 kg in weight, has been used. This dredge can operate equally on both sides.

The dredge was towed at a speed of 3–4 knots during five to ten minutes at fixed stations, with their geographical position recorded with GPS. The average swept area and standard deviation per tow were $978 \pm 150 \text{ m}^2$. After weighting the catch with a crane scale, a random subsample was taken from the catch in each tow to sort the live scallops, scallop cluckers and by-catch species. Scallops and all by-catch species were counted and weighted to estimate their abundance and biomass.

Data on scallop catches and dredging time from the commercial fishery are available since 1972. Dredging time is the time elapsed between the beginning and the end of the fishing operations each fishing day. Skippers record in which rectangle they dredge.

Data analysis

The rectangles were used as a spatial unit for the analysis, as log books lack positioning data for individual tows. The area of the scallop beds within each rectangle is known. Thus, assuming that effort is evenly distributed within the scallop beds, fishing pressure (as percentage of scallop bed dredged) was estimated with the equation used in the ICES Ecosystem Effects of Fishing Working group report (Anonymous 1991):

$$\% \text{ area of scallop bed dredged} = 100(d \times v \times t) A_i^{-1}$$

where d is the dredge width (km); v is the towing speed of the vessel (km/h); t is the time spent fishing (hours) and A is the area of scallop bed i (km²).

Fishing takes place mainly during autumn, whereas the stock assessment surveys are in April. For this reason, annual fishing effort was estimated for the period April-March, called fishing year hereafter. The results of any given survey were then compared to the fishing pressure of the previous twelve months.

Regarding by-catch data, we considered the use of production more convenient than using either biomass or abundance alone. Production was estimated according to Warwick and Clarke (1993) and Veale et al. (2000b):

$$P = (B A^{-1})^{0.73} \times A$$

being B = biomass in kg and A = abundance. $B A^{-1}$ is the medium body size and 0.73 the average exponent of the regressions of annual production and body size for macrobenthic invertebrates (Brey 1990). Since the area dredged during the surveys is known, production km⁻² was used to enable comparisons with fishing pressure.

The production data (P km⁻² hereafter) required log transformation, which decreased the variance but also conferred more weight to the rarer species. Thus rarer species were eliminated or aggregated to the taxonomic level of genus.

One-way ANOVAs were performed to test whether P km⁻² of the most abundant by-catch taxa differed between the sledge and roller dredges.

Multivariate analysis was performed on survey and commercial fishery data. Log-transformed mean P km⁻² data of invertebrate by-catch taxa from each rectangle were used in hierarchical cluster analysis. This technique categorized the rectangles into three groups (called areas hereafter), within which the faunal assemblage was homogeneous, to eliminate at least partly location effects and increase the probability of identifying the impact of dredging within each area, assuming that similar faunal assemblages would be found under similar environmental conditions.

Similarities Percentage (SIMPER) analysis was used to determine which species contributed most to the similarities and dissimilarities among areas. By-catch faunal assemblages within each area were statistically compared with analysis of similarities (ANOSIM) (Clarke and Warwick 1994).

The diversity indices number of species (S), Pielou's evenness (J') and Shannon's diversity (H' , $\log_e$) were estimated for each area and their trends compared with fishing effort and abundance of by-catch species. They were also statistically compared among groups with one-way ANOVA and Tukey tests.

The relationship between biomass and abundance of by-catch species within each area was analysed with partial and cumulative abundance / biomass comparison (ABC) plots. In healthy communities dominated by long-lived species, biomass curves lie well above abundance curves, whereas in disturbed communities both curves overlap or cross each other. The W statistic estimated with the curves varies from -1 to +1. The maximum value indicates dominance in biomass and evenness of abundance, and the opposite for value -1 (Warwick and Clarke 1994).

The relationship between average production and total fishing pressure within each area was investigated for the most abundant taxa with regression tests. The data were aggregated per rectangle and year and not transformed because the deviation from normality was very slight. Differences in log-transformed mean P km⁻² of the most abundant taxa among years, areas and depth, as well as area:year interactions were tested with three-way ANOVA. Depth was considered as a factor because the sampling stations are fixed. Mean depth data for each rectangle were aggregated into 5m depth intervals for the analysis.

2.2.4 Results

A total of 42 by-catch taxa were recorded in the annual scallop stock assessment surveys from 1993 to 2001, including 19 demersal fish species, two pelagic invertebrate taxa and the burrowing bivalve *Arctica islandica*. These taxa were excluded from the analysis, as the dredge samples them inadequately. Only eight of the remaining benthic taxa were present in more than 60% of the tows (Table 2.8).

The estimated total weight of benthic by-catch in the surveys was 97.7 tonnes, or 32.8% of the weight of the scallop catch. Biomass of the ten most abundant by-catch species (*Modiolus modiolus*, *Cucumaria frondosa*, *Echinus esculentus*, *Hyas araneus*, *Strongylocentrotus droebachiensis*, Asteroidea, *Buccinum undatum*, *Eupagurus bernhardus*, *Arctica islandica* and *Neptunea despecta*) amounted to 96.7 tonnes, or 98.9% of the total biomass of benthic by-catch. *M. modiolus* and *C. frondosa* alone constituted 32.3 and 25.3% respectively, or 31.6 and 24.6 tonnes of the benthic by-catch. Biomass of the remaining most abundant taxa ranged

from 0.5% or 0.56 tonnes for *N. despecta* to 12.8% or 12.4 tonnes for *E. esculentus*.

Catchability of scallops was significantly greater with the roller dredge compared to the sledge dredge when tested with one-way ANOVA ($F = 29.3$, $p < 0.001$), but only three of the by-catch taxa differed significantly in $P \text{ km}^{-2}$ between the two dredge types; *N. despecta* ($F = 4.35$, $p = 0.03$), *E. esculentus* ($F = 31.08$, $p < 0.001$), and *C. frondosa* ($F = 38.48$, $p < 0.001$). However, the annual variability of their abundance in the catch was so large that it was difficult to ascertain if the difference was due to the dredge alone.

The survey area was split into three areas with cluster analysis (Figure 2.19). Areas 1 (4.1% of the total scallop bed area, mean depth 47.4m) and 2 (5.7%, 36.1m) are in the outer part of the study area, whereas area 3 (90.2%, 35.7m) is in the inner part of the study area, towards the head of the fjord. Production of the most abundant by-catch taxa within each area is shown in table 2.9.

The ANOSIM test revealed that the benthic assemblages differed significantly between the three areas (global $R=0.8$, $\alpha = 0.001$). The pairwise tests concluded that areas 2–3 and 1–3 were highly significantly different, with R -values 0.82 and 0.84 and significance levels 0.01 and 0.002 respectively. Although R -values in the range 0.5–0.74 indicate that there are similarities in the faunal assemblages of two areas yet being clearly different (Clarke and Gorley 2001), the test comparing areas 1–2 was not significant despite R being 0.6. Statistical power was probably too low to detect these differences due to the limited number of samples.

Species richness showed a slight increasing trend in areas 1 and 3, but it was very variable in area 2. Trends for evenness and Shannon's diversity showed an overall decrease during the period 1993–2001 and were very similar within areas 1 and 3. They differ slightly in area 2, where evenness had a decreasing trend but diversity did not have any (Figure 2.20). Mean values of the diversity indices are shown in Table 2.10.

Spatial distribution of fishing effort has shifted between areas during the period 1973–2001. In area 1 most fishing effort took place from 1973 to 1979 but it represented less than 27% of the total annual effort. Since 1980 it decreased to less than 10% but for the sudden increase in 1998 due to intensive fishing of a small scallop bed. Fishing effort in areas 2 and 3 has varied greatly. In area 2 it decreased from 12–48% to less than 10% during the years 1987–1991 and it has remained very low since then. However, fishing effort in area 3 has increased steadily from 47–79% during 1980–1987 to 82–100% since 1988, save for a decline between 1993–1997 (Figure 2.20).

Evenness and diversity seemed influenced by variability in production of the dominant species in each area, with lower values in years of increased production of *M. modiolus*, Asteroidea, *E. esculentus* and *C. frondosa* (Figure 2.21). However, interpretation of the trends of diversity

indices is not straightforward. Evenness was positively correlated with fishing pressure in area 3 ($F = 5.75$, $p = 0.012$) but dispersion was rather large, 0.05. No other significant correlations were found.

The ABC plots based on abundance and biomass data of the by-catch taxa for the period 1993–2001 showed more pronounced signs of disturbance and had lower values for the W statistic in areas 1 and 3 than in area 2 (Figure 2.22).

Significant positive relationships between total fishing pressure and mean $P \text{ km}^{-2}$ were found in area 1 for *H. araneus* ($F = 7.98$, $p = 0.030$) and in area 3 for *B. undatum* ($F = 36.24$, $p < 0.001$), *E. bernhardus* ($F = 14.51$, $p < 0.001$), *H. araneus* ($F = 9.16$, $p = 0.003$) and *S. droebachiensis* ($F = 18.04$, $p < 0.001$) in area 3 (Figure 2.23).

$P \text{ km}^{-2}$ of all taxa differed significantly between areas, and for most taxa also between years and depth. The exceptions were Asteroidea and *H. araneus* with no significant differences between years, and *N. despecta* with no significant differences between depths. The interaction area:year was significant for *B. undatum*, *E. esculentus* and *M. modiolus* (Table 2.11).

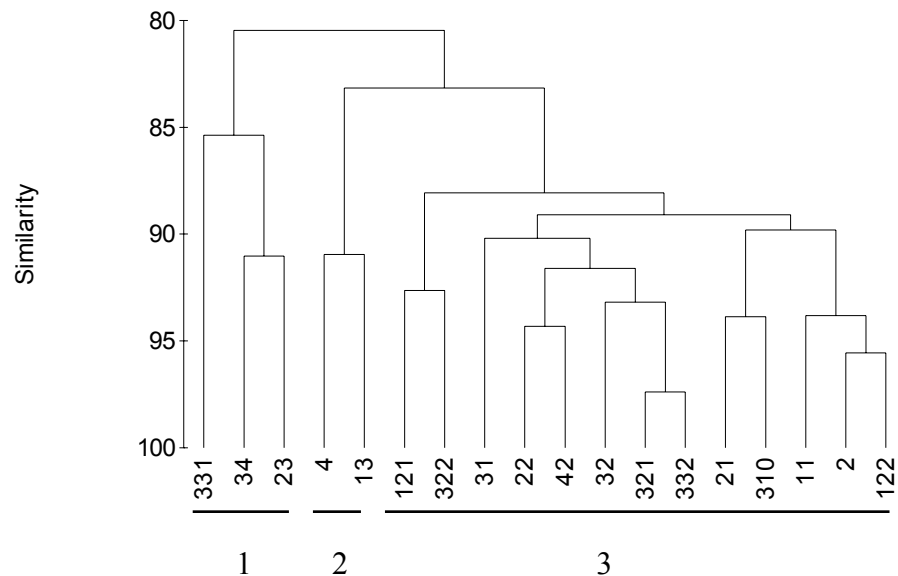


Figure 2.19 Results of the cluster analysis performed on average production data for the period 1993–2001 within each rectangle, indicating the three areas in which the study area was divided and the rectangles included within each of them.

Table 2.8 Average biomass (kg 1000m⁻²), abundance (number 1000m⁻²) and production (kg 1000m⁻²) $\pm$ standard deviation for all by-catch species captured in annual scallop stock assessment surveys during the period 1993–2001. The last column indicates the percentage of sampling tows in which each taxon was found.

TAXA	Biomass (kg 1000 m ⁻²)	Abundance (nr 1000 m ⁻²)	Production (kg 1000 m ⁻²)	% Tows
ANTHOZOA				
Unidentified species	1.61 $\pm$ 1.08	24.23 $\pm$ 20.94	0.51 $\pm$ 0.35	0.9
MOLLUSCA				
<i>Arctica islandica</i>	5.22 $\pm$ 22.49	56.09 $\pm$ 80.84	1.28 $\pm$ 3.55	11.2
<i>Astarte borealis</i>	2.37 $\pm$ 17.24	155.09 $\pm$ 296.14	0.75 $\pm$ 2.31	17.5
<i>Astarte crenata</i>	1.39 $\pm$ 1.58	271.22 $\pm$ 318.67	0.89 $\pm$ 1.02	1.8
<i>Astarte elliptica</i>	1.27 $\pm$ 2.90			1.7
<i>Clinocardium ciliatum</i>	1.45 $\pm$ 2.10	48.48 $\pm$ 57.97	0.56 $\pm$ 0.78	9.8
<i>Musculus discors</i>	0.10 $\pm$ 0.03			0.2
<i>Musculus niger</i>	0.49			0.1
<i>Modiolus modiolus</i>	33.96 $\pm$ 68.59	961.05 $\pm$ 2061.27	12.73 $\pm$ 25.78	93.6
<i>Mytilus edulis</i>	2.99 $\pm$ 9.37	91.31 $\pm$ 207.64	1.13 $\pm$ 3.31	12.8
<i>Serripes groenlandicus</i>	1.77	50.62	0.68	0.2
<i>Buccinum undatum</i>	3.68 $\pm$ 4.83	151.18 $\pm$ 176.94	1.53 $\pm$ 1.93	75.3
<i>Neptunea despecta</i>	2.08 $\pm$ 1.95	30.91 $\pm$ 35.35	0.65 $\pm$ 0.58	28.5
<i>Colus islandicus</i>	0.44 $\pm$ 0.55	28.12 $\pm$ 21.64	0.19 $\pm$ 0.18	0.3
CRUSTACEA				
<i>Carcinus meanes</i>	3.46	95.62	1.31	0.1
<i>Eupagurus bernhardus</i>	2.21 $\pm$ 2.92	101.53 $\pm$ 113.51	0.92 $\pm$ 1.12	67.4
<i>Hyas araneus</i>	12.41 $\pm$ 13.29	130.84 $\pm$ 129.27	3.58 $\pm$ 3.72	66.5
<i>Munida tenuimana</i>	0.06	28.12	0.05	0.1
<i>Pandalus montagui</i>	0.14 $\pm$ 0.23	30.23 $\pm$ 8.83	0.08 $\pm$ 0.10	0.6
<i>Sclerocrangon boreas</i>	0.34 $\pm$ 0.25	24.84 $\pm$ 13.36	0.17 $\pm$ 0.12	0.6
<i>Sclerocrangon ferox</i>	0.38 $\pm$ 0.41	28.80 $\pm$ 2.55	0.18 $\pm$ 0.15	0.2
ECHINODERMATA				
<i>Asteroidea</i>	6.49 $\pm$ 14.89	69.54 $\pm$ 67.17	1.69 $\pm$ 3.06	78.2
<i>Cucumaria frondosa</i>	37.40 $\pm$ 41.91	82.59 $\pm$ 84.89	7.06 $\pm$ 7.56	68.1
<i>Echinus esculentus</i>	16.00 $\pm$ 24.86	182.15 $\pm$ 282.39	4.59 $\pm$ 7.04	83.9
<i>Strongylocentrotus droebachiensis</i>	10.61 $\pm$ 16.58	254.57 $\pm$ 289.77	3.76 $\pm$ 5.29	80.4
TUNICATA				
Unidentified species	2.84 $\pm$ 3.18			0.4
CNIDARIA				
Unidentified species		399.56		0.1
PISCES				
<i>Agonus cataphractus</i>	0.43 $\pm$ 0.34	19.04 $\pm$ 12.20	0.18 $\pm$ 0.12	1.1
<i>Ammodytes marinus</i>	0.02 $\pm$ 0.00	22.50	0.02 $\pm$ 0.00	0.1
<i>Ammodytes tobianus</i>	0.07 $\pm$ 0.04	21.46 $\pm$ 9.17	0.05 $\pm$ 0.02	0.6
<i>Anarhichas lupus</i>	2.78 $\pm$ 5.60	5.42 $\pm$ 7.67	0.43 $\pm$ 0.85	0.2
<i>Cottunculus microps</i>	5.34 $\pm$ 2.38	70.19 $\pm$ 52.18	1.53 $\pm$ 0.17	0.2
<i>Gadus morhua</i>	2.44 $\pm$ 4.97	110.66 $\pm$ 442.62	0.50 $\pm$ 0.88	1.2
<i>Hippoglossoides platessoides</i>	0.80 $\pm$ 1.23	23.96 $\pm$ 28.78	0.30 $\pm$ 0.44	0.6
<i>Leptagonus decagonus</i>	0.07 $\pm$ 0.12	25.48 $\pm$ 11.19	0.04 $\pm$ 0.06	0.3
<i>Limanda limanda</i>	1.58 $\pm$ 1.20	29.7 $\pm$ 17.5	0.48 $\pm$ 0.29	1.5
<i>Lumpenidae</i>	0.27 $\pm$ 0.11	45.45 $\pm$ 18.45	0.17 $\pm$ 0.07	
<i>Microstomus kitt</i>	3.73 $\pm$ 4.73	19.69 $\pm$ 8.75	0.75 $\pm$ 0.79	0.2
<i>Myoxocephalus scorpius</i>	3.41 $\pm$ 5.21	34.56 $\pm$ 26.71	0.83 $\pm$ 1.14	1.9
<i>Pholis gunellus</i>	72.7 $\pm$ 105.6	20.3 $\pm$ 7.1	47.2 $\pm$ 57.9	0.3
<i>Pleuronectes platessa</i>	5.27 $\pm$ 6.48	19.8 $\pm$ 15.3	1.26 $\pm$ 1.37	1.6
<i>Pollachius virens</i>	0.66 $\pm$ 0.00	30.4	0.29	0.1
<i>Raja batis</i>	7.62 $\pm$ 0.00	89.99	2.30 $\pm$ 0.00	
<i>Raja radiata</i>	2.78 $\pm$ 4.38	9.22 $\pm$ 7.19	0.55 $\pm$ 0.70	1.0
<i>Triglops murrayi</i>	2.60 $\pm$ 5.53	74.24 $\pm$ 98.57	0.94 $\pm$ 1.91	0.4

Table 2.9 Results from SIMPER analysis. Mean and standard deviation of production (tonnes km⁻²) of the macrobenthic by-catch taxa in each of the three areas.

TAXA	Area 1	Area 2	Area 3	1 vs 2	1 vs 3	2 vs 3
MOLLUSCA						
<i>Astarte</i> spp.		0.70 ± 0.46	3.86 ± 4.04	18.62	18.15	5.93
<i>Buccinum undatum</i>	3.52 ± 4.10	0.46 ± 0.21	9.45 ± 6.51	4.52	3.73	8.13
<i>Clinocardium ciliatum</i>	1.01 ± 90.4	0.48 ± 0.44	2.75 ± 2.77	4.19	6.43	6.79
<i>Modiolus modiolus</i>	119.8 ± 79.86	5.19 ± 0.69	85.16 ± 4.85	8.21		7.41
	3					
<i>Mytilus edulis</i>	±	1.31 ± 1.18	5.33 ± 5.92	20.06	20.83	4.09
<i>Neptunea despecta</i>	3.01 ± 0.71	2.32 ± 0.06	4.69 ± 1.66			
<i>Colus islandicus</i>	±	0.17 ± 0.24	0.32 ± 0.83	8.42		9.09
CRUSTACEA						
<i>Eupagurus bernhardus</i>	1.81 ± 1.31	0.57 ± 0.68	6.49 ± 3.48	5.15	3.77	8.25
<i>Hyas araneus</i>	6.84 ± 8.59	1.38 ± 1.71	24.07 ± 8.80	5.58	4.78	10.07
<i>Pandalus montagui</i>			0.18 ± 0.31		5.52	6.25
<i>Sclerocrangon</i> spp.			0.34 ± 0.61		5.15	5.83
ECHINODERMATA						
Asteroidea	3.73 ± 3.69	11.44 ± 1.37	10.86 ± 5.46	4.29		
<i>Cucumaria frondosa</i>	26.77 ± 28.31	10.99 ± 2.63	49.89 ± 22.13		3.83	4.13
<i>Echinus esculentus</i>	34.91 ± 49.56	6.91 ± 0.74	24.57 ± 9.34		3.52	
<i>Strongylocentrotus droebachiensis</i>	9.68 ± 13.36	0.46 ± 0.37	25.18 ± 18.42	6.58	6.05	11.09
CNIDARIA						
Anthozoa	0.66 ± 1.15		0.90 ± 1.63	6.65	8.35	6.71

Columns 1 vs. 2, 1 vs. 3 and 2 vs. 3 show the contribution of each taxon to the dissimilarity between areas in pairwise comparisons, expressed as a percentage

Table 2.10 Mean and standard deviation (s.d.) of the diversity indices, species richness (S), evenness (J') and Shannon's diversity (H') for each area.

Area	S		J'		H'	
	Mean	s.d.	Mean	s.d.	Mean	s.d.
1	6.79	2.41	0.54	0.19	1.03	0.48
2	7.62	2.63	0.70	0.10	1.39	0.34
3	10.43	1.35	0.76	0.10	1.77	0.26

Table 2.11 Results of the three-way ANOVA used to test for effects of area, year, depth and area:year interaction on production of the most abundant by-catch taxa.

TAXA	df	M square	F	p	TAXA	df	M square	F	p
<i>B. undatum</i>					<i>N. despecta</i>				
area	2	53.85	34.11	0.000	area	2	14.34	21.27	0.000
year	8	3.68	2.33	0.017	year	8	1.58	2.34	0.019
depth	82	1.52	0.96	0.569	depth	69	0.48	0.71	0.945
area:year	13	3.66	2.32	0.005	area:year	16	1.08	1.61	0.068
<i>E. bernhardus</i>					<i>H. araneus</i>				
area	2	50.26	30.16	0.000	area	2	68.45	55.65	0.000
year	7	3.76	2.25	0.028	year	8	1.49	1.21	0.288
depth	80	1.88	1.13	0.216	depth	80	0.97	0.79	0.900
area:year	13	2.14	1.28	0.217	area:year	9	2.45	1.99	0.037
<i>Asterioidea</i>					<i>C. frondosa</i>				
area	2	9.48	5.29	0.005	area	2	34.32	31.59	0.000
year	8	3.53	1.97	0.046	year	8	7.84	7.21	0.000
depth	79	2.52	1.4	0.014	depth	81	1.33	1.22	0.100
area:year	16	2.32	1.29	0.193	area:year	16	0.88	0.81	0.665
<i>E. esculentus</i>					<i>S. droebachiensis</i>				
area	2	166.84	96.98	0.000	area	2	225.37	102.8	0.000
year	8	12.05	7.00	0.000	year	8	9.12	4.16	0.000
depth	77	2.13	1.23	0.089	depth	81	3.51	1.60	0.001
area:year	16	5.75	3.34	0.000	area:year	14	2.89	1.32	0.189
<i>M. modiolus</i>									
area	2	257.09	144.69	0.000					
year	8	25.75	14.49	0.000					
depth	83	2.78	1.55	0.001					
area:year	16	2.91	1.64	0.053					

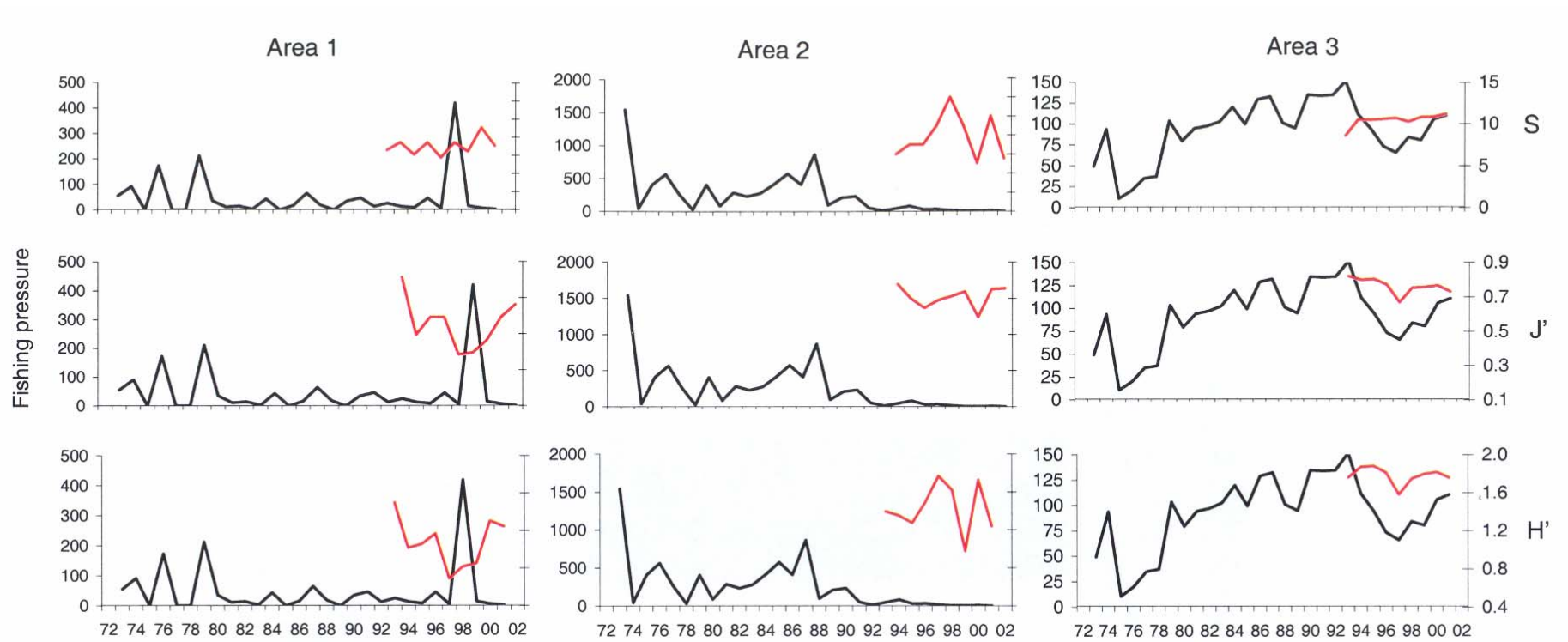


Figure 2.20. The diversity indices (S = species richness, J' = evenness, H' = Shannon's diversity) for the period 1993–2001 and trends of fishing effort, expressed as average percentage of rectangle area swept by dredging for each of the three areas during the fishing years 1972–2001. Note the different scales in the y-axis for each area.

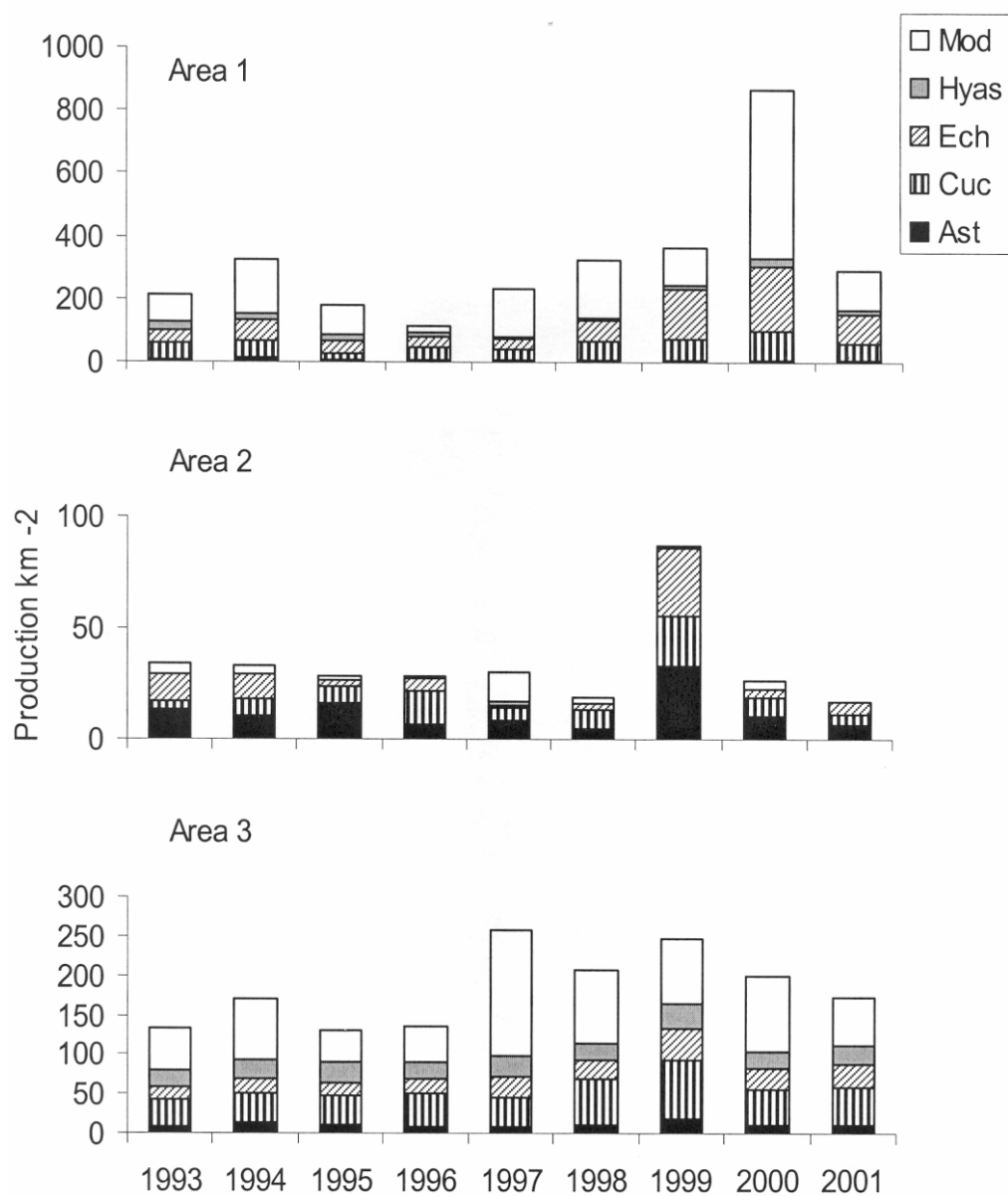


Figure 2.21 Annual variability in production (Pr km^{-2}) within each area of the by-catch taxa that have a major influence on the diversity and evenness indices. Note the different scales in the y-axis. Mod= *Modiolus modiolus*, Hyas= *Hyas araneus*, Ech= *Echinus esculentus*, Cuc= *Cucumaria frondosa*, Ast= *Asteroidea*.

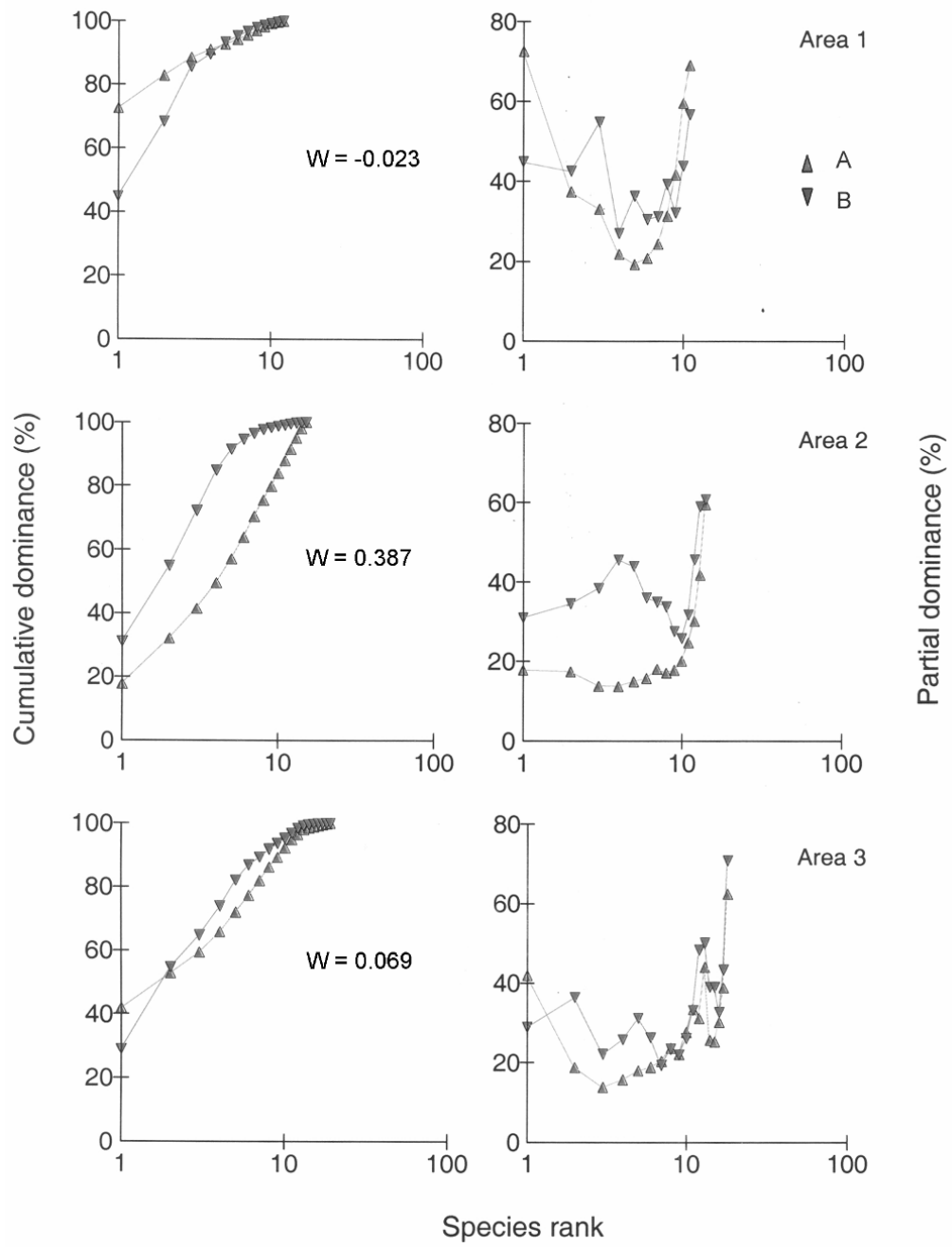


Figure 2.22 ABC plots of cumulative (left column) and partial dominance (right column) for each of the three areas. The green line represents average abundance in nr km^{-2} , the blue line represents average biomass in gr km^{-2} .

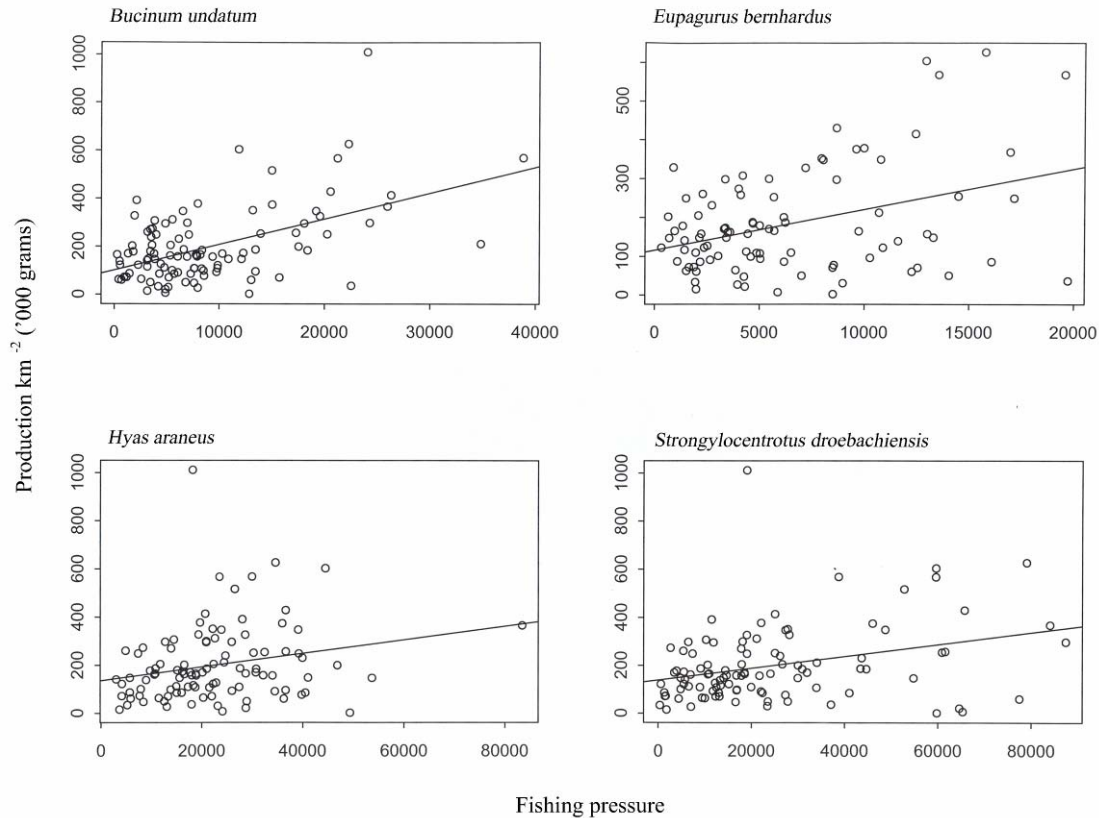


Figure 2.23 Regression of average production and fishing pressure for four species in area 3 for which the slope and intersection were significantly different from 0. The data were aggregated per fishing year and rectangle.

2.2.5 Discussion

The macrobenthic community in Breiðafjörður was in several respects very similar to disturbed communities described elsewhere (Riesen and Reise 1982; Collie et al. 1997; Freese et al. 1999; Hill et al. 1999; Collie et al. 2000; Kaiser et al. 2000; Veale et al. 2000b). Diversity and species richness were in general low, and among the dominant taxa were starfish, large-sized bivalves, hard-shelled gastropods and crabs. All three indices – species richness, evenness and diversity – had the highest values in area 3 despite of the higher fishing pressure, although species richness and diversity would be supposed to be higher in undisturbed sites and / or at early stages of disturbance (Collie et al. 1997; Currie and Parry 1996, Veale et al., 2000b), which is not the case here. The differences in size and sampling effort among areas have probably influenced our results, since diversity indices are very sensitive to sample size. Species richness showed an increasing trend in all areas, whereas fishing pressure has been declining during the same period. The increase in species richness in disturbed communities is usually concomitant with a decrease of diver-

sity and evenness, caused by the punctual increase of one or more species (Warwick 1996). This agrees with our results, where trends of evenness and diversity were decreasing in most cases. The use of a different dredge from 1998 onwards had a minor influence on catches of by-catch taxa. Only *C. frondosa*, *E. esculentus* and *N. despecta* were significantly more abundant in the samples after the roller dredge was implemented, but it was difficult to ascertain if this was due to the dredge alone.

M. modiolus and *C. frondosa* were dominant species in areas 1 and 3; of higher fishing pressure. Neither of these species seemed to be very vulnerable to handling of the catch on fishing vessels. Unlike crabs and sea urchins, that very often presented broken limbs and tests, holothurians and bivalves rarely suffered evident physical damage (Guijarro, pers. obs.). We lack data to investigate if physiological stress increases significantly the mortality of these species, but their abundance suggests that they are rather resilient. However, they have been described as sensitive to fishing activities elsewhere (Kaiser et al. 1996; Collie et al. 1997, 2000; Hall-Spencer and Moore 2000; Veale et al. 2000b).

A. islandica showed higher average production in area 3; but these results are not very meaningful as *Arctica* is a burrowing bivalve confined to sandy bottoms and the scallop dredge is not an appropriate sampling gear for sediment infauna.

The positive significant relationship between production of *B. undatum*, *E. bernhardus* and *H. araneus* and fishing pressure was most likely a long-term scavenger response as shown in other studies (Kaiser and Spencer 1994b; Collie et al. 1997; Anonymous 1998c; Collie 1998; Hill et al. 1999). While trends were found for the remaining taxa in all areas, these were not significant due to the high variability and / or low statistical power as a result of low sample size.

The ANOVA test detected strong location effects on $P \text{ km}^{-2}$ for all taxa. These could be due to differences in bottom type and biotic factors among areas, but we lack data to discuss these results further. *A. islandica*, *M. modiolus*, *E. esculentus* and *C. frondosa* had significant differences in $P \text{ km}^{-2}$ among years. *Echinus* and *Cucumaria* gave also significant results when testing the differences among dredges, and therefore increased catchability may account partly for their annual variability. Nevertheless there were few significant interactions area:year, suggesting that variability in $P \text{ km}^{-2}$ among areas and years follows similar trends for most of the taxa. Depth also influenced greatly $P \text{ km}^{-2}$ of most taxa. Considering that areas 2 and 3 had very similar mean depth, the question remains to which extent are the differences in macrobenthic fauna between areas 2 and 3 due to the very low fishing pressure in area 2 since 1993, as the ABC plots suggest.

The data used in this study do not show clear evidence of major impact of scallop dredging on distribution and abundance of by-catch taxa. However, scallop dredging started in 1972, whereas by-catch data are

available only since 1993 and the existing information from non-dredged areas is very limited. This is a major drawback in this study, as effects of fishing are more severe in the early phase of the fishery, which involves the loss of epibenthic biogenic structures and their associated fauna (Hall-Spencer and Moore 2000; Kaiser et al. 1996; Jennings and Kaiser 1998). It is therefore possible that scallop dredging had already altered the benthic community by removing effectively the sensitive species before collection of by-catch data started. Thus the current macrofaunal assemblage might be very resilient towards physical disturbance, hence the apparently small effect of fishing effort on the benthic community in Breiðafjörður.

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3. The shrimp fisheries

E. Guijarro Garcia

3.1 The northern shrimp (*Pandalus borealis*) offshore fishery in the Northeast Atlantic

3.1.1 A brief note on the biology of *Pandalus borealis* within the study area

3.1.1.1 Distribution

Pandalus borealis Krøyer, 1838 (northern shrimp, deep-sea prawn, pink shrimp or great northern prawn) was formerly regarded as a circumboreal species of discontinuous distribution, present in both the North Atlantic and North Pacific (Figure 3.1). The Pacific subspecies, *Pandalus borealis eous* Makarov, 1935, was raised to species level as *P. eous* by Squires (1992), but there is still some reluctance to accept this division (Bergström 2000). In the Atlantic, *Pandalus borealis* ranges along the American East coast from Cape Cod to Baffin Island. In West Greenland it is found from Cape Farewell (59°5'N) up to Melville Bay (75°N), whereas in East Greenland it is known to extend at least to Angmagssalik (just below 70°N). It is also present in the Davis Strait, Iceland, the Faroes, the western fjords of Norway and Sweden, the Skagerrak, the northern North Sea, the Barents Sea, Svalbard, north of Novaya Zemlya and the Kara Sea. In the Pacific *P. eous* is found from Point Barrow in Alaska, to the Columbia River in Washington state, including the Aleutian Islands and the British Columbia coast. It is also present in the Bering and Chukchi seas. In the Northwest Pacific, it is found off the Kamchatka Peninsula, Southeast Siberia, Korea and south to Honshu, Japan. In all, the species is present between 35°N to 82°N (Horsted and Smidt 1956; Shumway et al. 1985; Bergström 2000).



Figure 3.1 *Pandalus borealis*.

On a smaller spatial scale, larvae, juveniles and adults may show differential distribution. In Greenland, larvae and juveniles were normally found in relatively shallow waters or near land. Preference of deeper waters shown by adult shrimp in the study area might be related to temperature, which is more stable as depth increases. Juveniles can withstand a wider range of salinity and temperature than adults (Horsted and Smidt 1956). The distribution of adult shrimp at different depths has also been found to be correlated to shrimp size in the Barents Sea, off North Iceland and in the Flemish Cap, with larger shrimp found in deeper waters (Skúladóttir et al. 1991; Aschan 2000a; Skúladóttir and Nicolajsen 2002). Larval drift is thought to be crucial for recruitment to certain areas, as seems to happen in Disko Bay, Greenland (Carlsson and Smidt 1978). Shrimp are known to migrate vertically, ascending in the water column in the evening and returning to the bottom in the morning (Horsted and Smidt 1956; Shumway et al. 1985; Bergström 2000).

The vertical distribution of *P. borealis* extends from 20 to 900m, although the depth of maximum abundance varies with latitude, the higher the latitude the deeper the highest concentrations (Horsted and Smidt 1956; Shumway et al. 1985). In West Greenland there are also differences in mean size at different depths, with larger shrimp normally being more abundant in deeper water (Smidt 1969; Hassager 1992). There are as well seasonal migrations between different depths, probably in search of more favourable temperature (Shumway et al. 1985).

3.1.1.2 Environmental requirements

Temperature, substratum and salinity are important factors influencing the distribution of *P. borealis* (Shumway et al. 1985). The optimal temperature range seems to be between -1.6°C and 8°C , although they are most common in waters above 0°C and they die in temperatures below -1.6°C (Smidt 1960; Shumway et al. 1985; Bergström 2000). Temperatures below 0°C do not impede spawning in the Barents Sea, but reproduction is very difficult below -1°C . There are very few egg-bearing females and the egg loss and embryo death are substantial (Lund 1988a).

Temperature is a key factor for the survival of the Greenlandic shrimp stock because it is at its distribution limit. Therefore, even a small but prolonged decrease in temperature can have drastic consequences. Shrimp was indeed absent from Sisimiut and neighbouring fjords for four to five years after the unusually cold winter of 1948–49 killed all the stock (Horsted and Smidt 1965; Smidt 1965). The shrimp populations in Greenland waters require stable water temperatures above 0°C and therefore are most abundant in the deeper waters far from land (Horsted and Smidt 1956; Smidt 1969). Development of larvae, juveniles and adults is also positively correlated with water temperature, as higher temperatures favour more frequent moulting. Length and age at female maturity are also largely influenced by sea temperature. Shrimp in warm waters reach

maturity at a younger age and smaller size than shrimp in cold water (Shumway et al. 1985; Nilssen and Hopkins 1991, Skúladóttir and Pétursson 1999).

Changes in environmental conditions may trigger a shift in local distribution of shrimp populations, and temperature has been linked to such changes in Greenland and Barents Sea, to cite some examples. In Greenland it was observed that shrimp migrated into a fjord to avoid a mass of cold water just outside the fjord. There are also seasonal migrations of adults accompanying water masses with optimal temperature, as is the case of berried females (Horsted and Smidt 1956; Carlsson and Smidt 1978; Nilssen and Hopkins 1991; Aschan 2000a).

Salinity requirements range from 33–35‰, but there are records of *P. borealis* found in areas with salinity as low as 23.4‰. The preferred substrata are soft, muddy bottom or sand silt (Horsted and Smidt 1956; Shumway et al. 1985; Bergström 2000). Shrimp seem to be favoured by high particulate organic carbonate (POC) in the sediment (Shumway et al. 1985; Bergström 2000) and, in fact, most fishing areas in Greenland are located within patches of high POC (Ramseier et al. 2000). However, Pedersen et al. (2002) did not find a good correlation between larval shrimp abundance in West Greenland and temperature and salinity of water masses, chlorophyll *a* concentrations and zooplankton abundance, but they suggested that environmental conditions affect year-class strength and patterns of larval transport.

3.1.1.3 Biology

Life cycle

The pelagic larvae go through six zoea stages before becoming postlarvae. These are found in shallow waters, although actual depth varies among locations. In the Barents Sea, the greatest density of larvae was found between 10–25m (Horsted and Smidt 1956; Lysy 1978; Haynes 1983; Shumway et al. 1985).

Postlarvae need six moults before they metamorphose into juveniles. The onset of male sexual characteristics in juveniles can be observed from a size around 6mm carapace length (CL), when the male copulative structure starts developing. Development of the appendix masculine on the 2nd pleopod starts when juveniles reach 6.5mm length (Figure 3.2). The time at which external indications of sexual differentiation take place seems to be determined by size and not age (Stickney and Perkins 1977).

Development of sexual characters and sex change are usually classified into seven stages, juveniles being the first one. The morphology of the endopod of the 1st pleopod (Figure 3.3) is used to distinguish among mature males, transitionals and females. Females that have never spawned may have head roe but they still have the ventral external spines intact just before spawning. These external spines disappear after carrying the eggs between the pleopods for some months prior to hatching

(Figure 3.4). Females may then enter a resting period, characterized by lack of roe, or become ready to spawn again the following year, in which case they develop head roe during the months before spawning (McCrary 1971; Hansen and Aschan 2001)

Average life expectancy is variable among regions but it ranges between 3 and 8.5 years (Shumway et al. 1985).

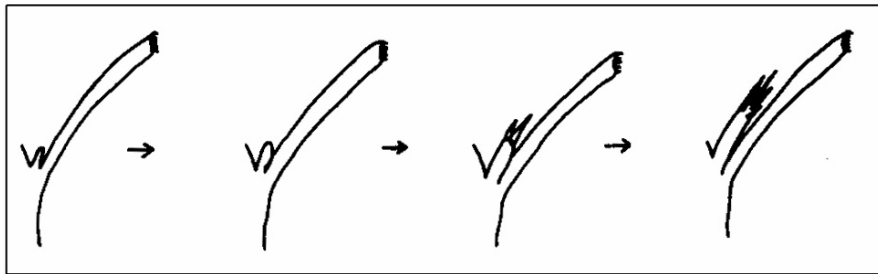


Figure 3.2 Development of the appendix masculina on the second pleopod of juvenile *Pandalus borealis*. Modified from Stickney and Perkins (1977) in Shumway et al. (1985).

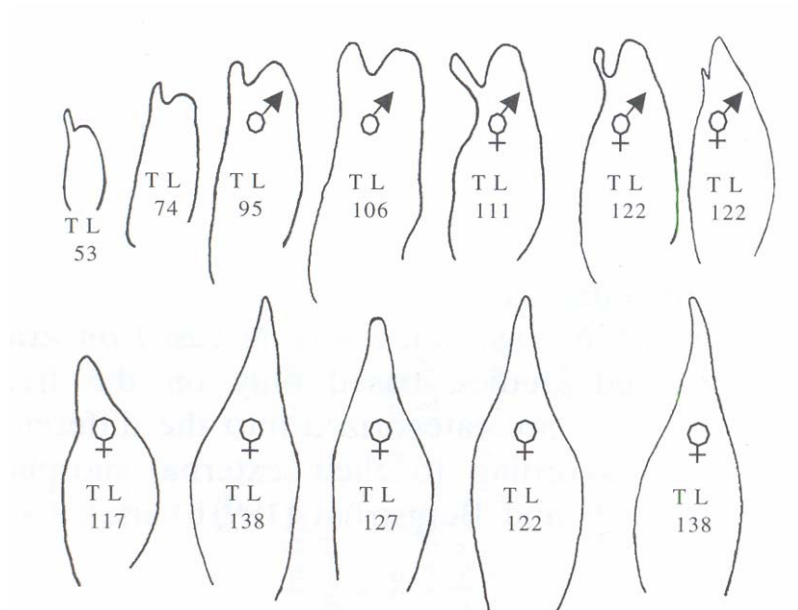


Figure 3.3 Changes in the shape of the first pair of pleopods during the transition from male to female. Modified from Bergström (2000).

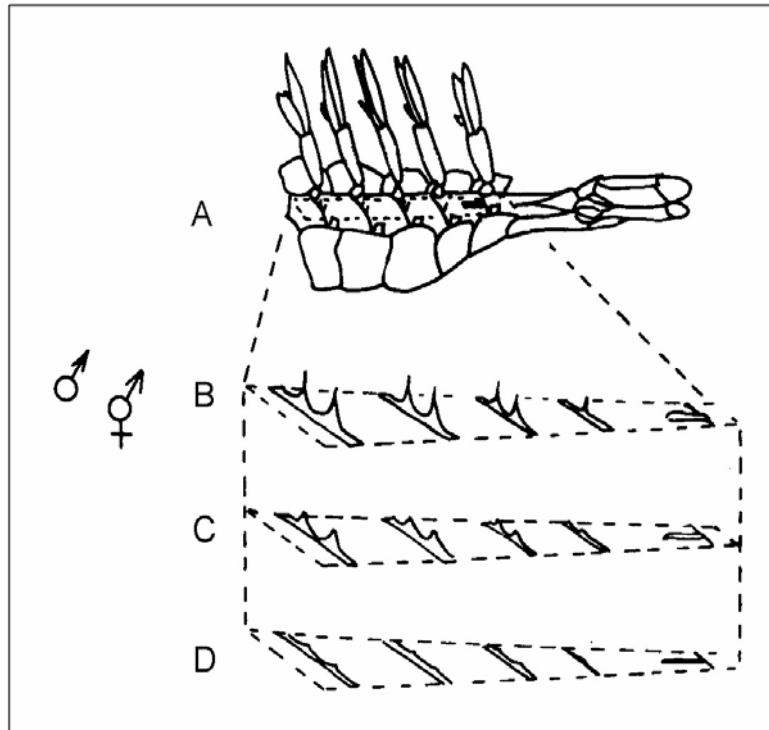


Figure 3.4 Diagrammatic view of *Pandalus borealis* showing the external spines. A: mature male with intact spines, B: mature male and intersex with intact spines, C: late stage transitional, multiparous female with reduced spines, D: multiparous female without spines. Modified from McCrary (1971) in Shumway et al. (1985).

Nutrition and growth

Shrimp are opportunist omnivores acting both as predators and scavengers (Shumway et al. 1985). Stomach content analysis of shrimp in Greenland showed that they feed on small crustaceans, polychaetes, foraminifera, radiolarians, excrement pellets, sand and shrimp belonging to own or other species (Horsted and Smidt 1956). Samples from Norway contained, in addition to the former, remains of Holothurioidea, Porifera, Copepoda, tintinnids, diatoms and peridineans. This indicates that shrimp also feed in the water column during the nocturnal vertical migrations (Wollebæk 1903; Horsted and Smidt 1956). Detritus have also been reported as food items. Shumway et al. (1985) compiled a more complete list based on studies from Scandinavia, Alaska, United Kingdom and Japan.

Growth takes place all year round for males, although growth rates are low in winter. All mature females grow during summer and sometimes also every second winter in areas where egg bearing occurs at two-year intervals, such as in the offshore Icelandic populations (Skúladóttir et al. 1991). In inshore waters, growth may occur from spring to autumn, being followed by a stagnation period during which no growth takes place

(Nilssen and Hopkins 1991). Growth rates depend on food availability, which shows wide seasonal variation in the arctic and subarctic regions linked to temperature. Thus, growth rates are faster in warmer waters and slower in the northernmost locations, such as Iceland, Svalbard and Greenland (Shumway et al. 1985; Bergström 2000). However, local variations in water temperature, population density and recruitment may induce variability in growth rates between year-classes and / or close populations (Parsons et al. 1989; Nilssen and Hopkins 1991; Skúladóttir 1998a; Skúladóttir et al. 1991).

For example, in the Barents Sea, where temperature is very variable between years and areas because it depends on the location of the polar front and the influx of warm Atlantic water, there are marked spatial and temporal variations in growth rates and age and / or length at sex change. Local differences among water masses, as those registered in several locations in Spitsbergen, seem to account for the two-year difference in age at maturity observed on shrimp sampled in different locations (Rasmussen 1953; Aschan 2000b; Hansen and Aschan 2000). Variable size and age at sex change has also been observed in Icelandic shrimp populations. Off the Northeast coast of Iceland, where North Icelandic winter water at 2–3°C and Arctic bottom water at < 0°C are found under the warmer upper layer, shrimp spawn for first time at age six and their L_{50} (length at which 50% of the females are mature) is 23.0–24.9mm. On the other hand, Vestfjörður and Snæfellsnes, on the West coast, receive with the Irminger current, warm Atlantic water at around 7°C and shrimp spawn at age 3 and L_{50} 17.6–19.8mm and 17.2–22.1mm respectively. The largest shrimp are found in the Denmark Strait, where bottom temperature is 0–2°C and females attain maturity at L_{50} between 26.5 and 29.3mm (Stefánsson 1962; Skúladóttir 1993, 1995a, 1998a; Skúladóttir et al. 1991; Skúladóttir and Pétursson 1999; Vilhjálmsen 1994). Similarly, the fishing grounds in Greenland show three different development patterns with sex change taking place at ages four to six. The slowest type was found in the Disko Bay and Nuuk, with sex change at age six, and the fastest type was found in Qaqortoq and Nanortalik, with sex change at age four. In the intermediate area, Paamiut and Aasiat, sex change takes place at an intermediate age, as in Jan Mayen (Horsted and Smidt 1956).

Age and growth estimates are based on length frequency data as shrimp do not have hard structures suitable for age estimation. The main problem of this method is overlapping of the older size classes due to lack of moulting during the ovigerous period, and the large variability of growth rates among regions, seasons, sexes and age classes (Shumway et al. 1985; Bergström 2000; Nilssen and Hopkins 1991). The Sund deviation method modified by Skúladóttir (1981) seems to overcome this problem and it identifies more year-classes than previous methods (Petersen 1892; Sund 1930). It consists of subtracting length frequency distribution

(LFD) of a given sample from the mean LFD spanning several years, and it shows strong year-classes with positive deviations from the mean LFD.

Reproduction

Northern shrimp are protandric hermaphrodites, meaning they are born males and become females for the rest of their lives following a transitional phase, although it has been reported that some individuals may develop directly as females in a Swedish fjord (Bergström 2000).

The males are either immature or mature, but the transitional phase has three stages and the female phase, three. The time at which sex change occurs seems to be greatly related to individual size. As growth rates depend on food availability and temperature, age at sex change or maturity is very variable among the different shrimp populations, decreasing with increasing temperatures as described above (Horsted and Smidt 1965; Shumway et al. 1985; Bergström 2000; Carlsson 1997a; Carlsson and Kanneworff 1999). In the Denmark Strait, sex change starts at age five but takes mostly place at age six (Skúladóttir 1997) and shrimp off Svalbard change sex at age five, compared to age two in southern Norway (Rasmussen 1942).

There is not much known about mating, but it seems to take place offshore in summer or autumn within 36 hours after the female moults. The fertilization is external and occurs right before the eggs are laid (Hoffman 1973, Shumway et al. 1985; Bergström 2000).

Spawning takes place once a year, between summer and early autumn, but in low temperature areas females may spawn every second year as a response to energetic demands derived from egg production (Teigsmark and Øynes 1983a; Skúladóttir et al. 1991). There are some variations in hatching between areas caused by differences in water temperature (Shumway et al. 1985). Thus the Greenlandic stock between Disko Bay and Nanortalik spawns in July–August and hatches in April, but in areas where the water is colder, the period between spawning and egg hatching (ovigerous period) is longer (Horsted and Smidt 1956; Bergström 2000). Offshore shrimp populations in North Iceland have an ovigerous period of 10 months, compared to 5.5 months in the inshore populations off the West coast, and the female shrimp spawn every second year at bottom temperatures of 0°C (Skúladóttir et al. 1991). Fecundity usually increases with body size as larger shrimp can carry more eggs, but varies with the size of the egg mass, that ranges between 600–5,000 eggs, although figures around 2,000 are most common. In some regions, size of the egg mass is inversely related to shrimp abundance and bottom temperature. Since shrimp attain larger sizes in lower temperatures, fecundity is higher in northernmost populations (Horsted and Smidt 1956; Shumway et al. 1985; Nilssen and Hopkins 1991; Bergström 1997). However, fecundity of populations close to their northern distribution limits may be negatively affected by low temperatures. At 73°N in West Greenland, only

50% of female shrimp carried eggs, compared to 90% between 66°–68°5'N. This difference may be due to the spawning being every second year. However, 20–40% of the eggs north of 71°N were dead. These differences were thought to be related to the lower water temperature in the northernmost location (Lund 1988a, 1990a).

Mortality

Mortality coefficient (Z) estimates range from 0.5–2.0 in the few available studies, with highest estimates in areas of high fishing intensities and predation. Mortality is also thought to be high among females following spawning (Shumway et al. 1985).

3.1.1.4 Population structure

The sex ratio and age composition of any population depends on natural and fishing mortality, recruitment, strength of each year-class and also season and location in those populations with horizontal migration patterns. Size composition within populations varies with depth, distance from shore, time of the day and season. Changes in abundance have been shown to be related to hydrographic conditions, predation and fishing pressure (Shumway et al. 1985).

3.1.1.5 Predators and parasites

Cod (*Gadus morhua*), Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes marinus*), eelpouts (*Lycodes* spp.), sea birds, i.e. Brünnich guillemot (*Uria lomvia*) and some marine mammals, such as harbour seals (*Phoca vitulina*), ringed seal (*Phoca hispida*), bearded seal (*Erignatus barbatus*), harp seal (*Phoca groenlandica*) and white whale (*Delphinapterus leucas*), are some of the main shrimp predators in the North Atlantic, with shrimp constituting an important part of their diets (Horsted and Smidt 1956; Smidt 1965; Shumway et al. 1985; Bergström 2000; Lilly et al. 2000).

The parasite isopod *Phryxus abdominalis* has been identified from Greenland and Iceland samples. It is found under the tail in both sexes (Horsted and Smidt 1956).

3.1.2 Iceland

3.1.2.1 The fishery

The shrimp (*Pandalus borealis*) commercial fishery commenced in the Vestfirðir region in Iceland in 1936 (Hallgrímsson and Skúladóttir 1979), although there are detailed records of some experimental fishing carried out in 1924 in Ísafjarðardjúp (Hallgrímsson 1993). For 30 years, only inshore grounds were exploited, but from 1969 onwards the Marine Research Institute of Reykjavík (MRI) launched regular surveys with the only goal of finding offshore shrimp grounds, as the species had been

frequently recorded in deep-sea fishing grounds all around Iceland. The search was carried out between 1969 and 1993 with variable success (see Hallgrímsson 1993 for review). Most new grounds were found off North and East Iceland (Þorsteinsson and Eiríksson 1971; Eiríksson 1971; Anonymous 1975a, 1976a, 1978a, 1980a, 1980b, 1984a, 1989; Einarsson 1975; Hallgrímsson and Einarsson 1978), although some very profitable fishing areas were also discovered in the Denmark Strait (Anonymous 1977a). Fewer grounds were found South and West of Iceland, where shrimp is absent or in too low a density to support a profitable fishery (Þorsteinsson 1970; Anonymous, 1974a, 1977a, 1987a, 1994a; Hallgrímsson and Einarsson 1978). A resume of the search surveys carried out during the period 1968–1993 is shown in Table 3.1.

The offshore shrimp fishery began in 1974. The percentage of offshore catches ranged between 1–47% of total annual shrimp landings during the period 1974–1983, but since 1984 they have represented between 68 and 94% of annual catches every year. Most of the offshore catch is taken in waters off North Iceland (Figure 3.5). Landings also increased from the maximum of 7,300 tonnes in 1973, prior to the onset of the offshore fishery, to 76,000 tonnes in 1995 (Data from Anonymous 1979a, 1981a, 1982a, 1987b, 1988a, 1996a, 2005). This paper focuses on the offshore fishery because catches from the inshore fishery constitute a minor part of the annual landings.

The sudden increase of catches in 1984 was to a great extent stimulated by the catch restrictions that were applied to most fish stocks for the first time, encouraging many skippers to switch to shrimp trawling (Anonymous 1985a). At the same time, new fishing grounds were discovered in East Iceland. These factors led to the growth of the fleet to 160 vessels, much more than in previous years. The number of ships in the offshore shrimp fishery increased gradually until the Marine Research Institute (MRI) recommended decreasing effort and issuing licenses because both biomass estimates and mean size of shrimp had declined (Anonymous 1988a, 1988b, 1990, 1991, 1993, Skúladóttir 1989a).

The first trawl survey for stock assessment of offshore shrimp was carried out in 1987 and a TAC was established for offshore shrimp grounds. By this time the first signs of overfishing had been detected, with catches and standardized CPUE declining despite the discovery of new shrimp grounds (Figure 3.6). Standardized CPUE decreased in North and Northwest Iceland from 126 kg hour⁻¹ in 1985 to 94 kg hour⁻¹ in 1989; and from 199 kg hour⁻¹ in 1986 to 91 kg hour⁻¹ in 1989 in North-east Iceland (Anonymous 2005).

Good recruitment from the year-classes 1987–1990 allowed the allocation of higher quotas from 1991 to 1994–1995, and catches, CPUE and fleet size rose accordingly despite the fact that stock size indices estimated from survey data oscillated between 45,000 and 65,000 tonnes (Figure 3.7) (Anonymous 1994b). The discovery of shrimp grounds in the

Flemish Cap in 1996 attracted part of the fleet and fishing pressure on the Icelandic offshore stock lightened somewhat during 1996 (Anonymous 1997b). Nevertheless, much smaller quotas had to be implemented from 1997–98 onwards. From 1990–1994, the stock production model seems to have underestimated the stock size, what probably benefited the shrimp stock. It must be born in mind that the quota for any given year was calculated according to the stock size estimated the previous year. Thus the 60,000-tonne quota for the fishing year 1994–95 was based on the stock and CPUE indices from 1993–94 (roughly 70,000 tonnes). Actually, the MRI initially advised a TAC of 45,000 tonnes in spring 1994, but since the stock showed signs of increase in 1993 and 1994 due to good recruitment and the decline of the immature cod stock, the TAC was raised to 60,000 tonnes in November 1994 assuming that the shrimp stock would remain large (Anonymous 1994c and 1995). The original quota of 40,000 tonnes advised by the MRI for the fishing season 1995–96 was increased by the Ministry of Fisheries to 63,000 without consulting the MRI (Anonymous 1996b).

The time lag between data collection, estimation of quota and actual fishing explains partly why catches remained stable and quotas increased while the stock declined after 1998 according to the stock production model (Anonymous 2003). Another added problem that contributed to the very high quota in 1997–98 was the underestimation of the cod stock. Cod was incorporated into the model in 1991, but only the immature part of the cod stock was considered. However, according to the annual report of the MRI, the increased migrations of cod to northern Icelandic waters led to an important decrease of the shrimp stock. In fact, the biomass of the cod and shrimp stocks follows asynchronous trends (Figure 3.8) and from 2000 onwards the total cod stock index estimated for North Iceland has been used in the stock production model (U. Skúladóttir, pers. comm.).

According to a new statistical model for marine ecosystems, Globally Applicable Area Disaggregated General Ecosystem Toolbox (GADGET), the average mortality rate of the shrimp stock due to predation by cod during the period 1983–2004 amounts to 0.41, whereas the average mortality due to fishing is 0.19. However, it is possible that untimely increases in quota might have contributed partly to the observed stock reductions.

Table 3.1 Shrimp search surveys with positive results.

Year	Area	Main results	Reference
Inshore			
1968	East	150–773 kg hour ⁻¹ in Seyðisfjörður	Eiríksson 1968 Skúladóttir 1969
1969	East	Only one fjord with up to 60 kg hour ⁻¹	Skúladóttir 1970
	North	434 kg hour ⁻¹ in a small area	Eiríksson 1968
	West	28–62 kg hour ⁻¹ in Jökuldjúp	Skúladóttir & Eiríksson 1970
1970	West	Shrimp found but widely distributed, possibilities of commercial fishing in Jökuldjúp	Þorsteinsson & Eiríksson 1971
1971	East	3,300 kg in 20 minutes in Berufjörður	Þorsteinsson 1970
1973	North	100–200 kg hour ⁻¹ in Bakkaflóadjúp and Héraðsdjúp	Anonymous 1973
1974	West	> 100 kg hour ⁻¹ in Kolluáll, Breiðafjörður	Anonymous 1974a
		140 kg in 10 minutes in Flettyarsund	Anonymous 1975a
	Northwest	640 kg hour ⁻¹ in Tálknafjörður	
1975	Northeast	Good fishing ground in Öxarfjörður	Anonymous 1976a
1977	East	Good grounds in Reyðarfjörður and Seyðisfjörður	Anonymous 1978a
1983	East	Good grounds in Reyðarfjörður and shallower areas of Bakkaflóadjúp, Héraðsflóadjúp, Berufjarðarál, Lónsdjúp and Hornafjarðardjúp.	Anonymous 1984a
1996	North	Up to 250 kg hour ⁻¹ in Eyjafjörður, but catch decreased quickly.	Anonymous 1997a
1997	North	157 kg hour ⁻¹ in a small area in Eyjafjörður, not suitable for commercial fishing.	Anonymous 1998a
Offshore			
1969	North	10–150 kg hour ⁻¹ in Eyjafjarðaráll	Skúladóttir 1970
1970	North	250–300 kg hour ⁻¹ east off Grímsey	Þorsteinsson & Eiríksson 1971
1971	Northwest	320 kg hour ⁻¹ in Djúpáll	Anonymous 1973
1973	Southwest	600 kg hour ⁻¹ west off Eldey	Anonymous 1974a
1974	North	Large shrimp (140 individuals kg ⁻¹) found in Reykjafjarðaráll	Anonymous 1975a
1975	East	85–200 kg hour ⁻¹ in two areas off Vattarnes, very little or nothing found in other areas	Anonymous 1976a
1976	North	20–300 kg hour ⁻¹	Anonymous 1977a
	East	14–160 kg hour ⁻¹	
	West	20–130 kg hour ⁻¹	
	Denmark Strait	150 kg hour ⁻¹ , of very large shrimp, 50 individuals kg ⁻¹	
1977	North and Northeast	Good banks on Norðurkantur and in Öxafjarðardjúp, 240 kg hour ⁻¹	Anonymous 1978a
1978	Denmark Strait	Good catches on Dohrnbanki and Stredebanke	Anonymous 1979a
1979	North	Good catches between Kolbeinsey and Grímsey.	Anonymous 1980b
1983	East	Shrimp grounds found on Tangafllak, Héraðsflóadjúp, Seyðisfjarðardjúp, Berufjarðarál and Lónsdjúp.	Anonymous 1984a
1986	Southwest	Good catch in Grindavíkurdjúp	Anonymous 1987a
1988	East	Up to 600 kg hour ⁻¹ on Rauðatorg	Anonymous 1989
1993	Southwest	Large shrimp found in Grindavíkurdjúp and Skerjadjúp	Anonymous 1994a

The MRI of Iceland has carried out several search surveys every year, both on inshore and offshore grounds, using both research and private vessels. An exhaustive list of all search surveys would be too extensive; therefore, this table only shows the most relevant results. However, the literature listed includes information on every search survey carried out.

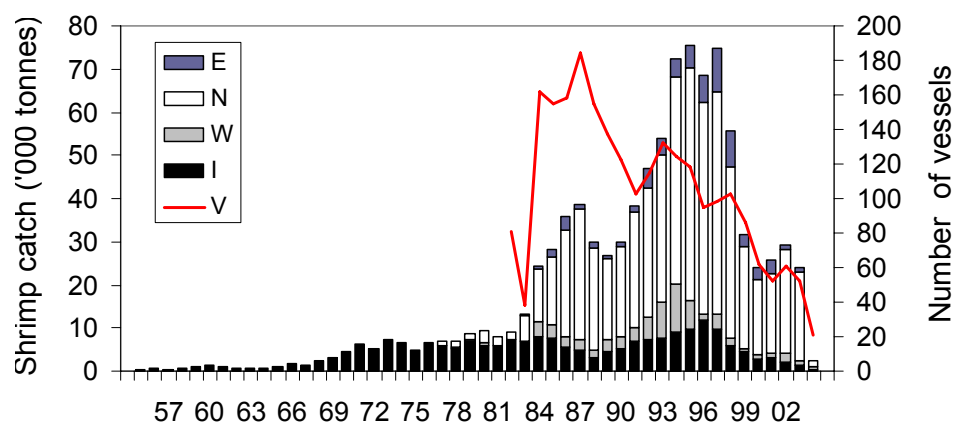


Figure 3.5 Iceland. Annual shrimp catch and number of vessels that took part in the off-shore fishery since 1982. E: East, N: North, W: West, I: Inshore, V: Vessels in the fishery. Data from Anonymous (1979a, 1981a, 1982a, 1985a, 1986a, 1987b, 1988a, 1996a, 2005).

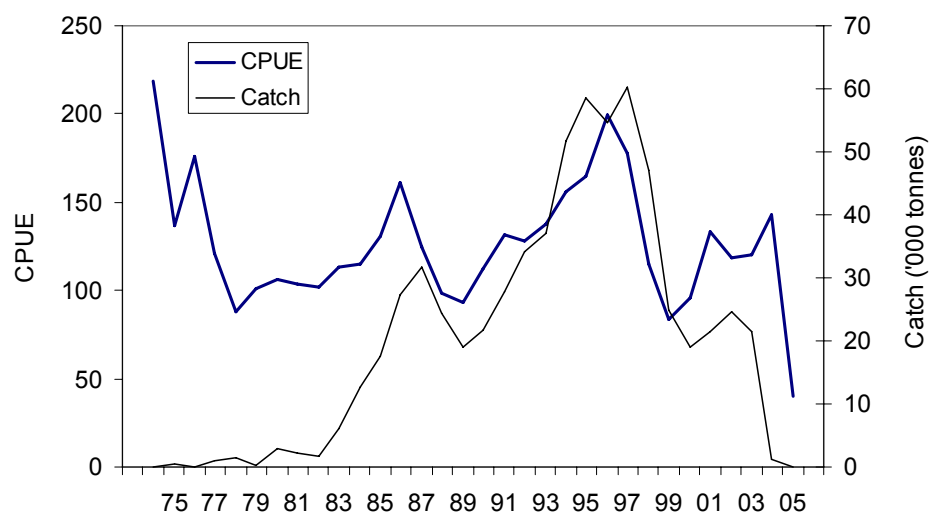


Figure 3.6 Iceland. Trends of catch per unit of effort (CPUE), standardized to trawl size, and offshore shrimp catch from North and East Iceland 1979–2003. Data from Anonymous 2005.

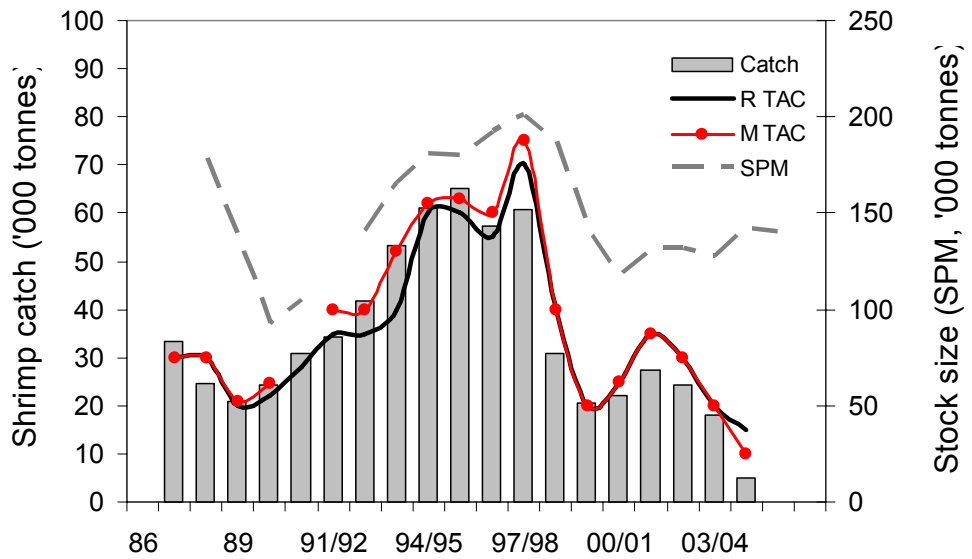


Figure 3.7 Iceland. Annual offshore shrimp catch, total allowable catch (TAC) recommended by the Marine Research Institute (R TAC), TAC set by the Ministry of Fisheries (M TAC) and shrimp stock index as estimated with the stock production model (SPM). From 1991 onwards, TAC were set for fishing years, i.e., from September to August. Data from Anonymous (2003, 2005).

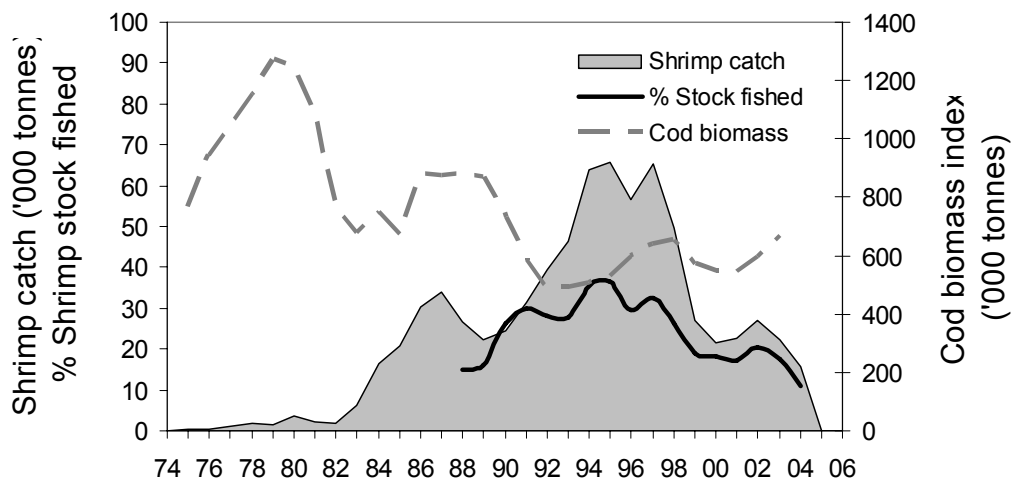


Figure 3.8 Iceland. Trends of offshore shrimp catch and percentage of the shrimp stock fished annually according to the stock production model (left y-axis) compared to cod biomass index for Iceland waters, including fish of age 3 and older. Data from Anonymous (2005).

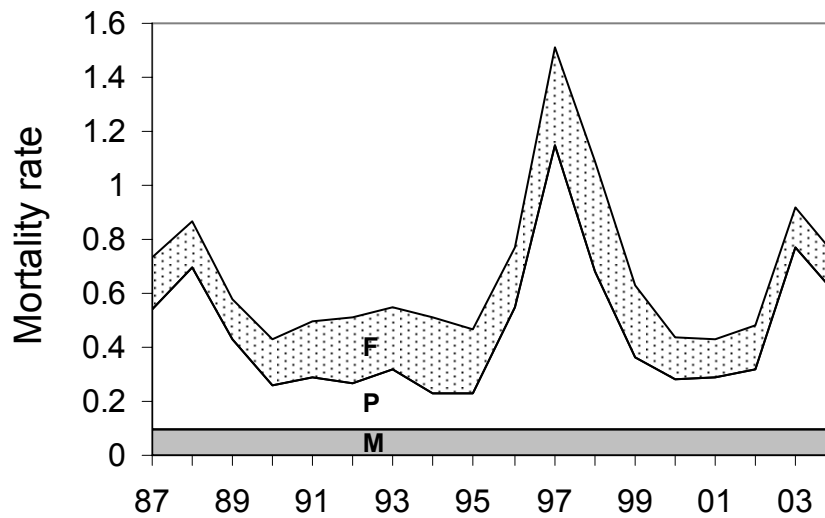


Figure 3.9 Iceland. Shrimp mortality during the period 1973–2004 for individuals fully recruited to the fishery (>20 mm carapace length). M: Natural mortality, P: mortality due to predation by cod, F: Fishing mortality. Modified from Anonymous (2005).

3.1.2.2 Management

The Icelandic shrimp fishery has been managed since its beginning by a license system, mandatory logbooks, minimum mesh size and minimum landing size (CL > 15mm in the offshore fishery and CL > 13mm in the inshore fishery. The abundance of undersized specimens in landings must be below 30% (Anonymous 1981b; U. Skúladóttir, pers. comm.).

A TAC system was implemented for the inshore fishery in 1964 (van den Hoonaard 1992) and for the offshore fishery in 1987 (Table 3.2). In the inshore fishery, the quotas are based on the stock index estimated from survey data and they are distributed among the fleet. Every year ships get the same percentage of the TAC. In the offshore fishery, the TAC recommended by the MRI is built on the stock production model and / or GADGET, which take into account cod predation, recruitment, CPUE and survey indices. The internal transferable quota (ITQ), which means that ships can buy and sell quota among themselves, was implemented in Iceland in 1990. However, the ITQ is rather limited because the transference must be done among ships registered in the same area (U. Skúladóttir, pers. comm.).

The use of 7–9mm sorting grids for juvenile shrimp, or alternatively an 8m-long, 40mm-square mesh codend to minimize catches of juvenile shrimp is dictated by the Ministry of Fisheries. The regulations specifying the areas in which sorting grids or square mesh codend must be used have been released every year since late 1990s (U. Skúladóttir, pers. comm.).

By-catch of juvenile fish is limited in the inshore fishery by closing areas where they exceed a quoted reference level that is implemented by the regulations and depends on species and age group. By-catch of adult

fish in the offshore fishery seems to have ceased after the implementation of sorting grids in 1995. The Nordmøre grid is the most widely used sorting device in Iceland (Figure 3.10).

Table 3.2 Overview of management measures for the shrimp stocks in Iceland.

Inshore		
1960	Logbooks mandatory	Hallgrímsson 1977 Hallgrímsson & Skúladóttir 1979
1962	Minimum mesh size 32mm	Skúladóttir 1969
	License mandatory	Hallgrímsson 1977
1962–67	TAC in Ísafjarðardjúp	Jónsson 1990
1974	TAC in all areas	Jónsson 1990
	Minimum mesh 36mm	Hallgrímsson 1977
1975	Closure of areas if by-catch of juvenile fish exceeds threshold	Anonymous 1978a
1990	ITQ for all vessels	Skúladóttir, pers. comm.
1995	22mm Nordmøre sorting grid used in certain areas	Anonymous 1996a
Offshore		
1974	Logbooks mandatory	Skúladóttir, pers. comm.
	36mm minimum mesh size	
1974–1990	License mandatory	Skúladóttir, pers. comm.
1990	TAC and ITQ system	Skúladóttir, pers. comm.
1995	22mm Nordmøre sorting grid mandatory	Anonymous 1996a
1997–2002	7–9mm sorting grid for juvenile shrimp in the areas 12°–18°W, north of 65°30N	Skúladóttir, pers. comm.
2003	As above, also in area 18°–20°W, south of 66°45'N or 8m long 40mm square mesh codend	Skúladóttir, pers. comm.

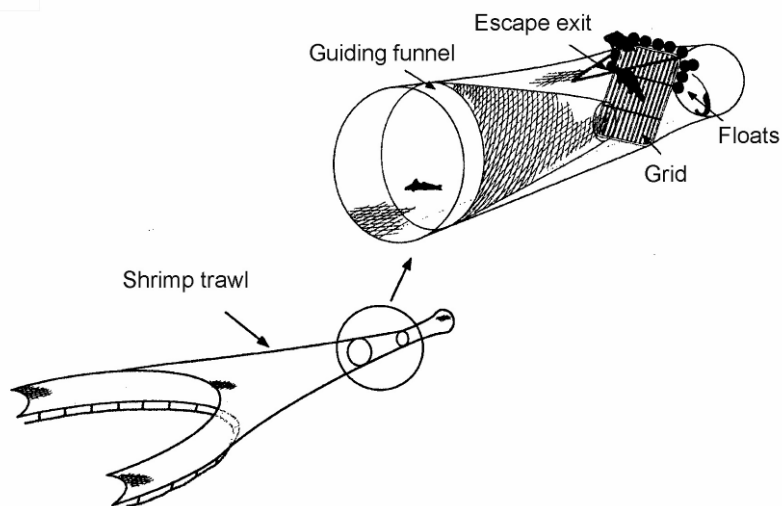


Figure 3.10 The Nordmøre grid. The funnel directs the fish and shrimp to the grid. the shrimp goes through but the fish is directed to the escape exit. From Isaksen (1992).

3.1.2.3 Research

Research has focused mainly on stock assessment, analysis of biological data, compilation of fishery statistics dating to the early years of the in-

shore fishery and stock identification based on genetic studies and size at sex change (Table 3.3). The MRI has carried out several standardized inshore and offshore surveys every year, since 1973 and 1988, respectively. The main goal of the surveys is to collect biological data to investigate the population structure and to estimate the stock biomass index. In addition, surveys gather information on fish by-catch, especially gadoids, redfish and Greenland halibut. Fishing vessels also regularly supply shrimp samples, although this is not mandatory.

As the inshore fishery grew during the early years, the development of more selective and efficient gear to prevent the catch of juvenile fish and undersized shrimp became a priority. A large by-catch leads often to the closure of certain areas, especially following the introduction in 1967 of bigger trawls to fish in deeper waters that used larger gear and towed faster than the inshore boats (Thorsteinsson 1992).

The first deep-sea shrimp fishing experiments in 1969 and 1970 were carried out with a trawl with two codends, one above the other, and separated by a fine mesh. The shrimp would go to the upper codend, whereas fish would go to the lower one. Its bigger mesh size would also allow smaller benthic invertebrates and juvenile fish to escape. This gear proved to be very successful after some minor modifications, although in muddy bottoms it was necessary to trawl with the lower codend open. However, results were not as good when this same gear was tried in deeper waters for a combined *Nephrops*-shrimp fishery with harder substrata and no further research was done on the double-codend trawl (Þorsteinsson 1969, 1970; Thorsteinsson 1973; Anonymous 1971).

In the following years more shrimp trawls of both Icelandic and foreign design were tested. Some of them had bobbins that decreased by-catch of demersal species by keeping the towed net above the bottom. However, results were not very satisfactory as the gear that decreased most of the by-catch of juvenile fish was heavier and had an excessive drag on smaller boats. Besides, it captured between 30–40% less shrimp than other gear (Anonymous 1973; Thorsteinsson 1973, Þorsteinsson 1976). A shrimp trawl without wings, designed to minimize catch of juvenile gadoids was tried in 1975 and 1976 in several fishing grounds with varying results (Anonymous 1977b, 1978b).

Table 3.3 Research carried out on the Icelandic shrimp stock, including collection of biological data for population studies and stock assessment and research to improve the fishing gear.

1965–	Marking – recapture to investigate migrations	Skúladóttir 1969
1967	Sorting machine to discard smaller shrimp. Trawl with double codend to fish shrimp and fish simultaneously	Þorsteinsson 1969
1968–	Improvement of fishing gear to decrease catches of juvenile shrimp and fish:	Þorsteinsson 1970 ⁽¹⁾ Anonymous 1971 ⁽¹⁾ Thorsteinsson 1973 ^(1, 2, 5) Anonymous 1973 ⁽²⁾ Þorsteinsson 1976 ^(2, 4) Anonymous 1977b ^(3, 6) Anonymous 1978b ^(3,) Anonymous 1974b ^(4, 5) Anonymous 1975b ⁽⁴⁾ Anonymous 1976b ^(4, 6) Thorsteinsson 1974 ⁽⁴⁾ Thorsteinsson 1980 ^(4, 6) Þorsteinsson 1980 ^(4, 6) Þorsteinsson 1981 ⁽⁶⁾ Thorsteinsson 1981 ⁽⁶⁾ Þorsteinsson 1995 ⁽⁶⁾ Thorsteinsson 1989 ⁽⁷⁾ Thorsteinsson 1992 ⁽⁷⁾ Þorsteinsson 1993 ⁽⁸⁾ Þorsteinsson 1991 ⁽⁸⁾ Þorsteinsson 1994a ⁽⁸⁾ Þorsteinsson 1994b ⁽⁸⁾ Þorsteinsson 1994c ⁽⁸⁾
	– double codend trawl ⁽¹⁾	
	– trial of different trawl designs ⁽²⁾	
	– shrimp trawl without wings ⁽³⁾	
	– mesh size experiments ⁽⁴⁾	
	– shortening of ground ropes and bridles ⁽⁵⁾	
	– increased net slack in side panels ⁽⁶⁾	
	– use of square mesh in codend ⁽⁷⁾	
	– use of sorting grids ⁽⁸⁾	
1968–78	Inshore surveys to collect biological and catch data	Annual reports 1968–78
1968–93	Search for fishing grounds	See Table 3.1
1974–83	Shrimp larvae	Anonymous 1976a Anonymous 1979a Anonymous 1981c
1979–	Inshore stock assessment surveys	Anonymous 1979a Annual reports (Hafrannsóknir) since 1979
1980?	Shrimp sampling from offshore grounds	Anonymous 1981b
1984	Marking experiments in West Iceland	Skúladóttir 1985
1985–	Sampling in Denmark Strait	NAFO SCR Documents
1986	Different shrimp populations within Icelandic waters	Anonymous 1987a Jónsdóttir et al. 1998
1987–	Stock assessment for offshore grounds	Hallgrímsson 1993 Skúladóttir 1989b Skúladóttir 1995a Annual reports (Hafrannsóknir) since 1987

Research on gear selectivity included the following studies:

- Effect of using different mesh sizes to avoid landing of undersized shrimp without jeopardizing catches (Anonymous 1974b, 1975b, 1976b; Thorsteinsson 1974, 1980; Þorsteinsson 1976, 1980).
- Shortening of ground ropes and bridles, which resulted in decreased catch of both shrimp and by-catch species (Thorsteinsson 1973; Anonymous 1974b).
- Increasing the net slack of the side panels. The idea was letting the net be loose, so the mesh would not close during towing and small

shrimp and fish could escape through the side panels. With 10% net slack in the side panels the escape rate of small shrimp increased without loss of bigger shrimp, and quite unexpectedly, average catches were higher than with the conventional trawl. This gear was successfully used for 10–20 years in the inshore fishery (Anonymous 1976b, 1977b; Thorsteinsson 1980, 1981; Þorsteinsson 1980, 1981, 1995).

- Use of square mesh in the codend. Even during towing, square mesh remains open, facilitating the escape of small shrimp and 0-group gadoids. The results were highly satisfactory. Average size of shrimp in the catch increased, and many fishermen adopted this gear (Thorsteinsson 1989, 1992). Square-mesh codend became mandatory in all inshore and certain offshore fishing grounds in 2003 (Table 3.2).

Another development to prevent fish by-catch consisted of equipping shrimp trawls with grids of vertical bars spaced 22mm. The Nordmøre grid is the most widely used and it is installed several metres ahead of the codend. It leads to an opening in the upper part of the trawl. Shrimp pass through the grid and go into the codend but fish are directed to the opening and can thus escape. The use of the grid was strongly recommended except in areas where shrimp was very large, as in the Dohrn Bank in the Denmark Strait (Þorsteinsson 1991, 1993, 1994a, 1994b, 1994c).

3.1.3 Greenland

3.1.3.1 The fishery

After the collapse of the cod, halibut and redfish fisheries in the late sixties, shrimp became the main marine resource in Greenland, making up 90% of its export value (Carlsson and Smidt 1976; Pedersen 1994; Rätz 1997a). Most of the research done on the Greenland shrimp stock refers to the spatial division adopted by the North Atlantic Fisheries Organization (NAFO) and so does this review (Figure 3.11).

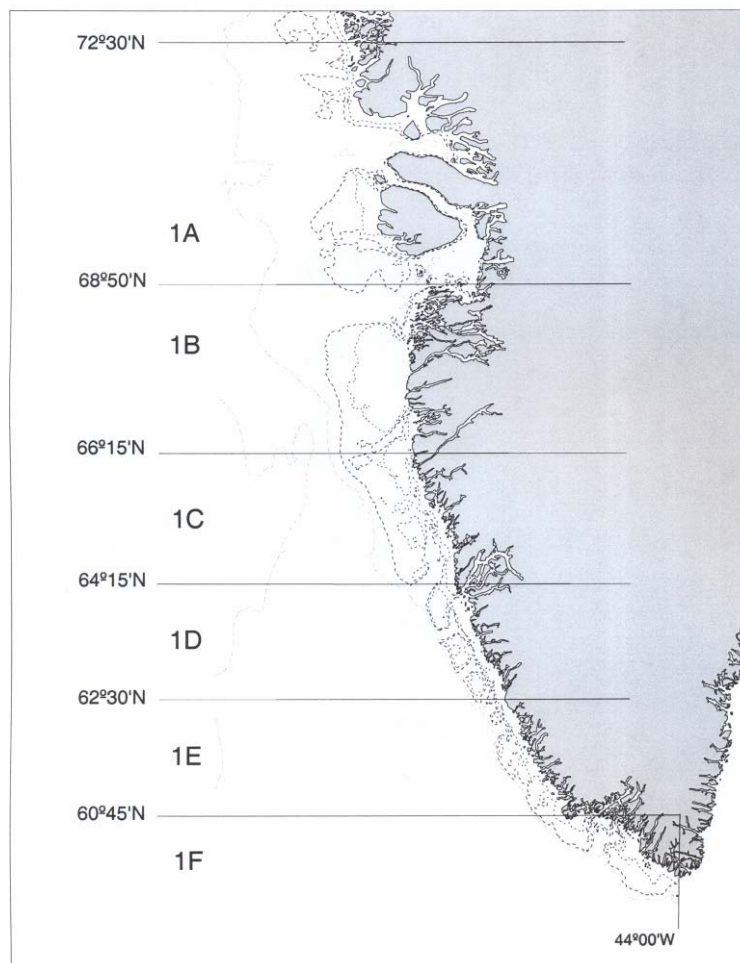


Figure 3.11 Greenland. Spatial division of West Greenland used by the North Atlantic Fisheries Organization (NAFO). Map by M. Storr-Paulsen.

West Greenland

The fishery started in 1935 on a very small scale in the Sisimiut (Holsteinsborg) area (Subarea 1B) following the collapse of the Greenland halibut fishery. Three or four vessels took part in the fishery between the years 1936–1939. Fishing ceased due to World War II and resumed in 1947 with much lower catches because the shrimp was smaller. Extreme weather conditions killed the local stock in 1949. The fishery moved then to the nearby Qasigianguit (Christianhaab) in Disko Bay (Subarea 1A), but the catch was landed and processed in Sisimiut. Fishing took place between June and October. Five ships trawled within the 400m depth contour. However, the transport inflicted great losses on the catch and the processing plant in Sisimiut was finally closed in 1950 (Smidt 1965, 1969; Carlsson 1976). The Qasigianguit fishery continued nevertheless and in 1951 two other trawlers started fishing in deeper waters (Horsted and Smidt 1956).

Fishing started in Qaqortoq (Julianehaab, Subarea 1E) with two trawlers in 1950. The establishment of freezing and canning plants in the town and vicinity during the same year allowed an increase in catches and fleet size, with four to five extra ships that operated all year round if catches were large enough (Horsted and Smidt 1956).

Shrimp catches started to increase in the late 1960s as cod landings commenced their decline and by 1970, 170 trawlers between 20 and 150 GRT were involved in the fishery. Until then, the best fishing grounds were those in the shallow waters of Disko Bay. Catches there were stable but fishing was not possible during winter. The southern fjords were open all year round, but catches were lower and very variable (Smidt 1965, 1969; Carlsson 1976; Carlsson et al. 1992).

From 1970 onwards, catches in the offshore shrimp fishery in West Greenland increased greatly and have constituted the largest percentage of the landings ever since (Figure 3.12). The offshore grounds are those more than three miles from the coast. The inshore fleet concentrates mostly off Disko Island and consists of ships under 80 GRT, plus few bigger vessels with quota to fish in both areas (Andersen 1994; Hvingel 2002a, 2004a). Both the inshore and offshore fisheries operate on the continental shelf, between 59°–74°N and 150–600m depth (Figure 3.13).

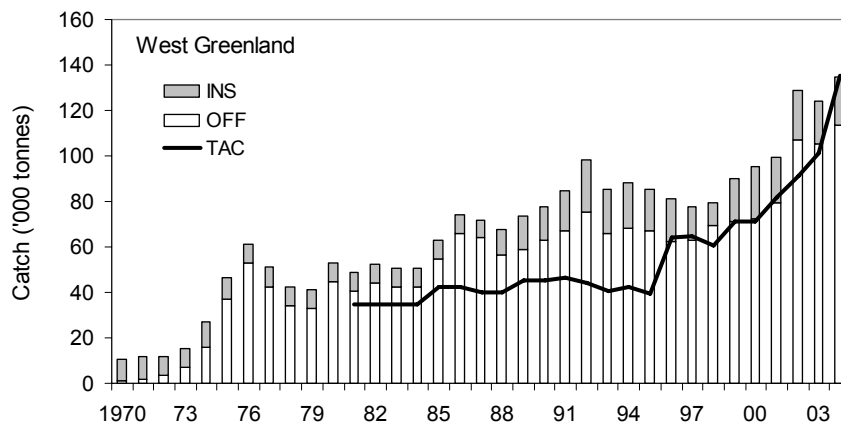


Figure 3.12 Greenland. Annual shrimp catches in West Greenland during the period 1970–2004. INS: Inshore fishery, OFF: Offshore fishery, TAC: Total allowable catch for the offshore fishery. After introducing the ITQ system in 1991, catches decreased between 1993–1998 and the fleet was reorganized. Between 85–97% of the inshore catch is from Disko Bay (Andersen 1994; Hvingel 2002a). Data from Hvingel (2004a).

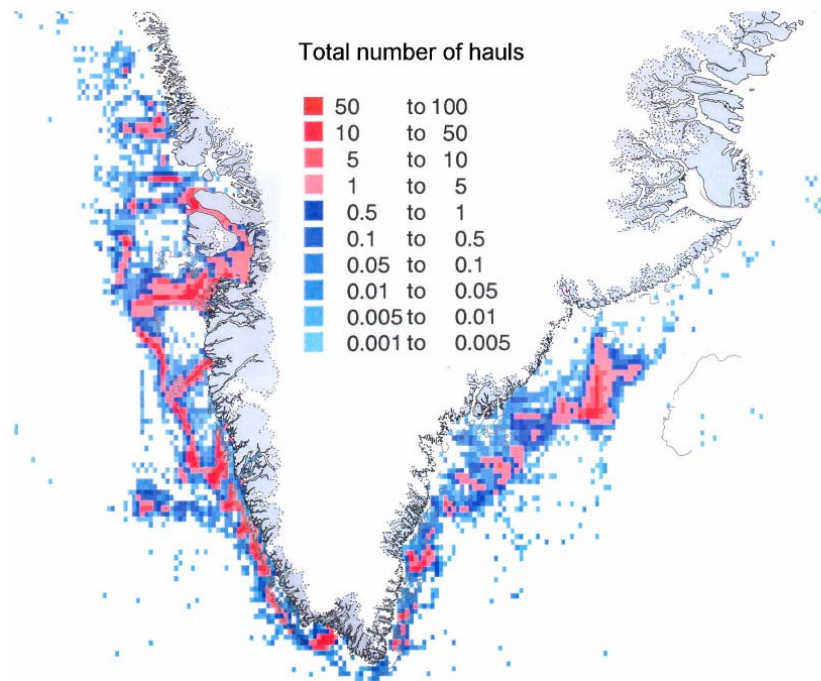


Figure 3.13 Greenland. Distribution of fishing effort of the shrimp fleet during the period 1982–2002 according to logbooks. The colour code indicates total number of hauls in each square. Map supplied by M. Storr-Paulsen.

Offshore catches south of 71°N within Subarea 1 increased in the early 1970s, from less than 1,000 tonnes to roughly 60,000 tonnes in 1976. Catches were largest in Subarea 1B all but two years during the period 1970–1990 (Carlsson 1991). The Greenlandic fleet increased to 27 ships after several trawlers from the cod fishery joined the ships of the Royal Greenland Trade Department (RGTD), which at the time accumulated the largest fishing effort in the offshore fishery. Besides, there were 56 ships from Denmark, Faroe Islands, Norway, France and Canada, although their number decreased to 30 in 1981. In 1975, effort of the RGTD ships concentrated within Subarea 1B, mostly between 67°N–68°N. During the years 1976–1978, fishing effort increased and expanded between 66°N–69°N, but it concentrated mostly close to 69°N (Carlsson 1980a, 1981a).

New shrimp grounds were found in 1984 in Subarea 1A in Uummanaq (Dundas), Svarten Huk, Søndre Upernavik, Upernavik and Tugtorqortoq (between 70–74°N). The fleet was restricted in 1986 to a maximum catch of 400 tonnes per trip north of 72°52'N, and in 1987 the Greenland Home Rule set a TAC for the area between 71°N and 72°52'N. Distribution of fishing effort in these new grounds was very uneven and CPUE decreased every year (600 kg hour⁻¹ in 1987 vs. 300 in 1988). It was feared that fishing effort had been too much considering that low water temperature in the area might hamper recruitment (Lund 1988a, 1988b, 1989a, 1990b). Catches north of 71°N decreased from 11,000 tonnes in 1986–1987 to 1,000 tonnes in 1991 (Parsons et al. 1992).

South of Subarea 1A, the logbooks from the ships above 50 GRT in the offshore fleet show a southward shift of effort during the period 1975–2003 (Figure 3.14). Shrimp grounds north of 65°N were preferred in the seventies and early eighties, but from 1987 to 1996, catches increased in areas 1C and 1D (Figure 3.15) and by 1994 over 50% of the offshore catch was from Subareas 1C–1F. The southward shift of the fishery could be explained by changes in the distribution of shrimp biomass and / or improvements in gear that permitted trawling in areas that were not accessible before. An important consequence of this movement of the fleet is that effort might be concentrating in smaller areas, since the shelf narrows towards the south of Greenland. Fishing takes place all year round but maximum catches are taken in mid-summer, although in some years there is another peak in autumn (Lund 1989a; Carlsson 1991, 1993; Parsons et al. 1992; Hvingel 1996, 2002a, 2004a; Hvingel et al. 1997; Hvingel and Folmer 1998).

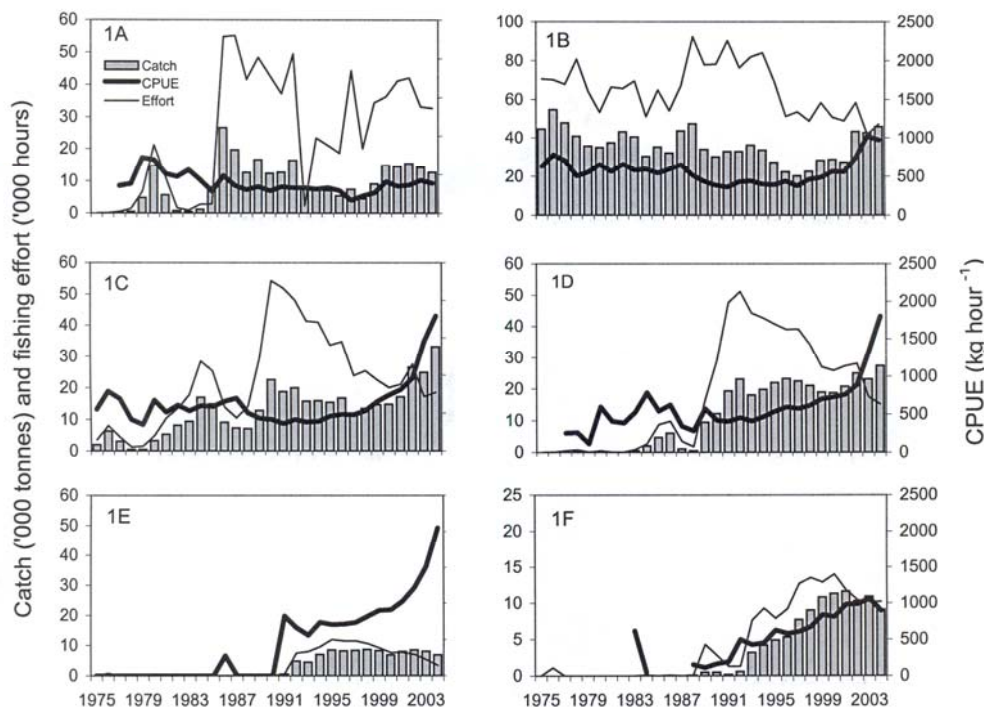


Figure 3.14 Greenland. Distribution of the annual offshore shrimp catch in West Greenland showing the southward displacement of the fleet (see map in Figure 3.12). Shrimp catch (in thousand tonnes, represented by columns) and fishing effort (thin line, in thousands of trawling hours) refer to the left y-axis. Unstandardized CPUE refers to the right y-axis. It is represented by the thick line and measured in kg of shrimp per trawling hour. Note that the scales in the left y-axis are different for Subareas 1B and 1F. Data from Hvingel (2004a).

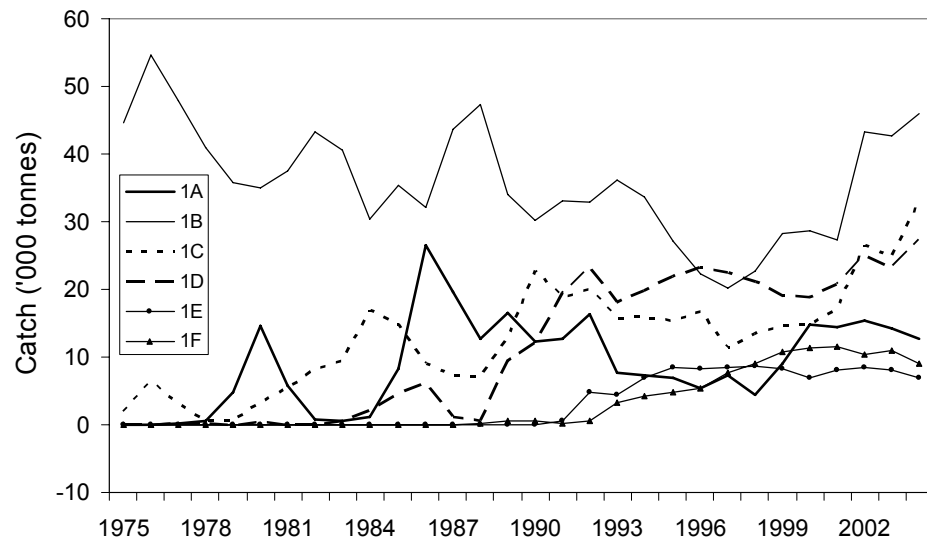


Figure 3.15 Greenland. Spatial distribution of catches within Area 1 during the period 1975–2003. Data from Hvingel (2004a).

This shift had reduced fishing effort in Subareas 1A and 1B to 32% and 37% respectively by 1996, compared to the 1990 values of 42% and 47%. Overall effort for Subarea 1 remained, however, rather stable. Landings declined during 1993–1995 following the extinction of the strong year-class from 1985 that had kept up the fishery in the years 1989–1993. The good year-classes from 1990 and 1991 made possible the increase of catch rates in 1995 and 1996 despite the fact that CPUE data showed that the shrimp stock had been reduced by 46–60% during the period 1976–1996 and the large variability of biomass observed during the period 1976–1988 (Folmer et al. 1996a; Hvingel et al. 1996; Siegstad 1996). The increasing trend in shrimp biomass that started in 1998 reached a record biomass of over 650,000 tonnes in 2003 and 2004 (Siegstad 1999; Kanneworff and Wieland 2001, 2002, 2003; Wieland et al. 2004), and total catch for West Greenland (inshore and offshore) has increased gradually since 1998 from 80,000 tonnes to 141,000 tonnes in 2004 (Hvingel 2004a).

East Greenland and Denmark Strait

Shrimp is present along the East coast from Cape Farewell to 70°N down to 800m depth, but the highest shrimp densities are found from 150–600m depth (Hvingel 1999). An Icelandic research vessel found the Dohrn Bank grounds in 1976, but they were not surveyed until 1978. Fishing started north of 65°N following the survey (Hallgrímsson 1981; Skúladóttir 1989b). Norway started fishing in this area in 1979 and Greenland, Denmark, Faroe Islands and France joined the fishery in 1980 (Skúladóttir 1995b). The main fishing grounds were in Strede and Dohrn

Banks and on the slopes of the Storfjord Deep (Figure 3.16), and fishing took place mostly from January to June (Carlsson 1990a).

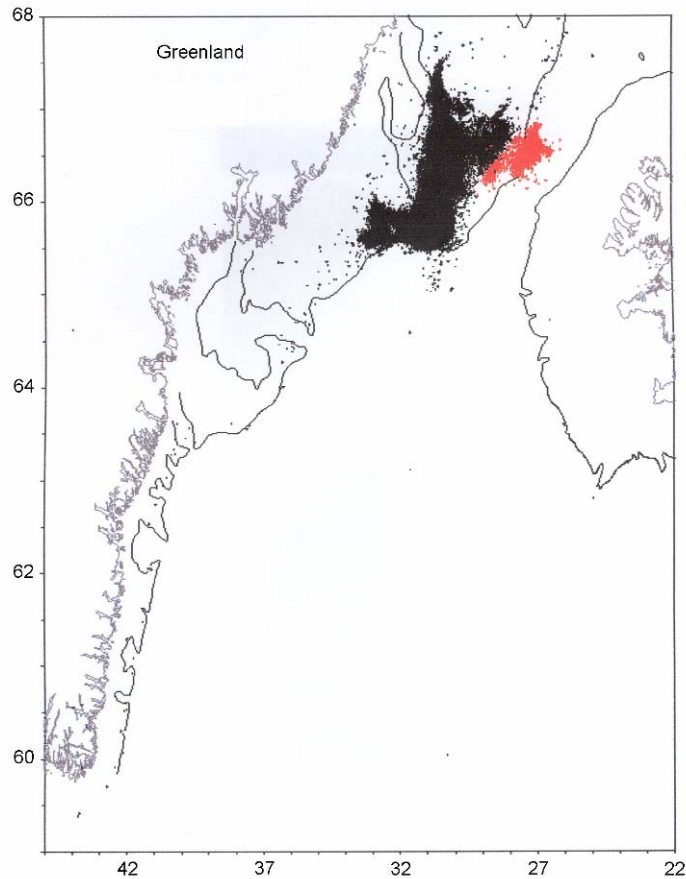


Figure 3.16 Greenland. Distribution of hauls in Denmark Strait (Dohrn and Strede banks). Black dots correspond to Greenlandic, Faroese and Danish trawlers during the period 1987–1992, grey dots correspond to Icelandic trawlers during the period 1990–1992. The black line shows the 400 m isobath. Map from Hvingel (2004b).

Catches reached 15,000 tonnes during the period 1978–1988 (Figure 3.17), exceeding sustainable levels and causing biomass to decline below an amount enough to produce the maximum sustainable yield (B_{MSY}). In fact, there was an increase in the proportion of males in commercial catches during the period 1988–1990, suggesting that the fishery had reduced female abundance or that stronger year-classes were recruiting. Fishing effort and catches decreased by 75% during the nineties in these banks north of 65°N, mainly due to both the discovery of new shrimp grounds south of 65°N where the CPUE was much higher and the onset of the shrimp fishery on the Flemish Cap (off Newfoundland). This decline of fishing effort allowed for a certain recovery of the stock (Figure 3.18).

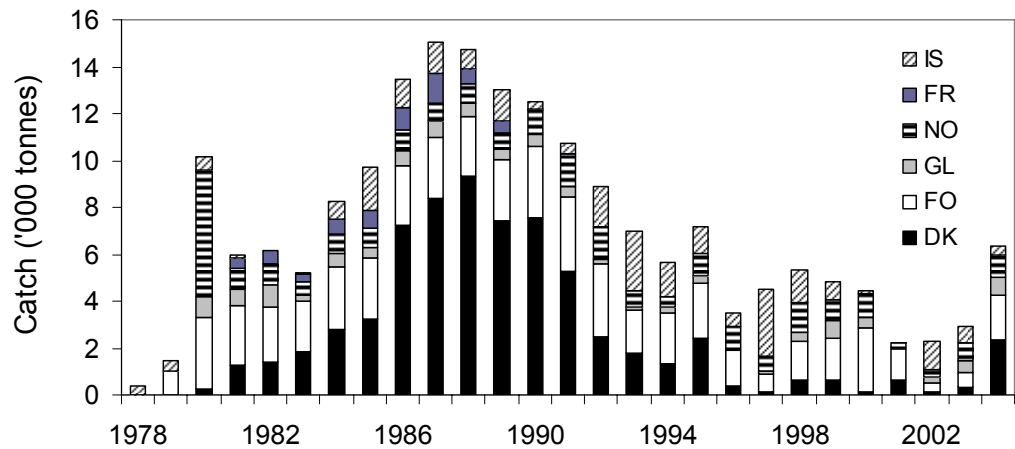


Figure 3.17 Greenland. Annual shrimp catch in East Greenland north of 65°N during the period 1978–2004. DK: Denmark, FO: Faroe Islands, GL: Greenland, NO: Norway, FR: France, IS: Iceland. It should be noted that the Icelandic fleet operates within their EEZ, although the shrimp stock is the same. Data from Hvingel (2004b).

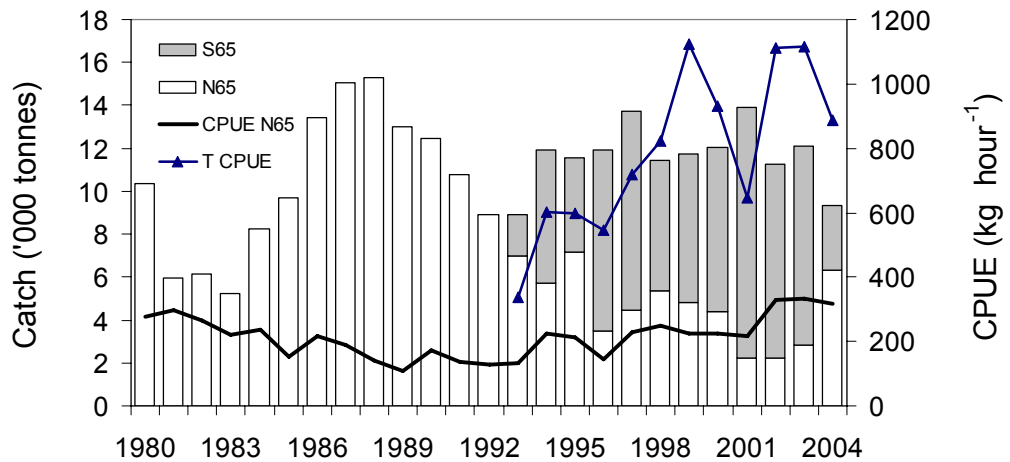


Figure 3.18 Greenland. Annual shrimp catch off the east coast. Catches from the Dohrn and Strede banks are represented by white columns (N65), catches from the new banks found in 1993 south of 65°N are represented by shaded columns (S65). The smooth line represents unstandardized CPUE north of 65°N as kg of shrimp per trawling hour (CPUE N65). The line with the markers represents sum of unstandardized CPUE for all East Greenland following the discovery of the new grounds (T CPUE). Total effort from 1993 onwards is not represented because at this scale the variation could not be appreciated. Data from Hvingel (2004b).

The new fishery starting in 1993 in two areas south of 65°N reached to Cape Farewell (Figure 3.19), and kept landings above 8,000 tonnes for more than ten years (Figure 3.18). Catches from these new banks, discovered by Greenlandic fishing vessels, were higher than catches from the northern grounds between 1996 and 2003, and vessels from Denmark, Norway and the Faroe Islands started fishing there as well (Figure 3.20).

The CPUE south of 65°N seemed to follow an increasing trend despite a large decrease in 2001, which was nevertheless compensated by the dominance of large shrimp in the catch according to the skippers. On the other hand, fishing effort varied between years without following a clear trend (Hvingel 1999, 2001, 2004b; Skúladóttir 1990, 1995b, 1998b; Skúladóttir et al. 1991; Cadrin and Skúladóttir 1998; Smedstad and Torheim 1990).

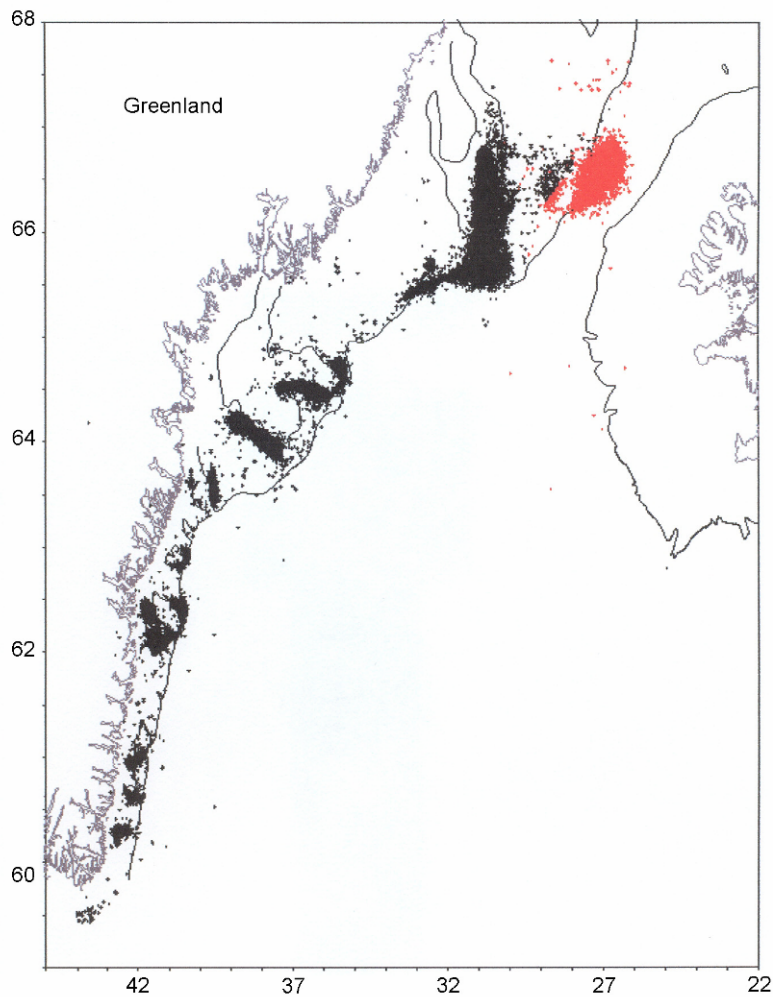


Figure 3.19 Greenland. Distribution of hauls off East Greenland during the period 1993–2002. Black dots represent Greenlandic, Faroese and Danish trawlers, grey dots represent the Icelandic fleet. The black line shows the 400m isobath. Map from Hvingel (2004b).

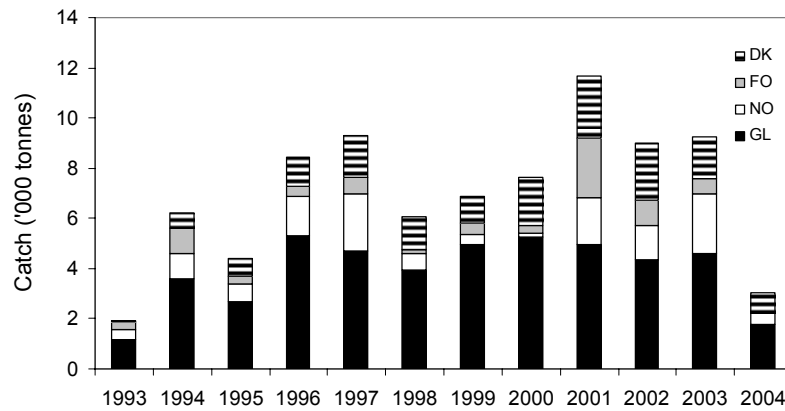


Figure 3.20 Greenland. Annual shrimp catch in the banks south of 65°N from the different fleets. DK: Denmark, FO: Faroe Islands, NO: Norway, GL: Greenland. Data from Hvingel (2004b).

According to the surplus model used to estimate maximum sustainable yield (Cadrin and Skúladóttir 1998), the fishery should aim for maximum catch of 8,000 tonnes and $F < 0.35$. However, this analysis was limited to the stock north of 65°N, as the biomass in the southern grounds could not be estimated from CPUE or catches from the northern grounds. Besides, the inclusion in the model of fishing data from the south increased the rate of population growth to unrealistic values. It should be considered that increases in CPUE could be caused by technological improvement rather than by rising stock biomass, in which case the model would not be as useful (Cadrin and Skúladóttir 1998). Despite these considerations, the TAC was set beyond the figures advised by scientists (Figure 3.21).

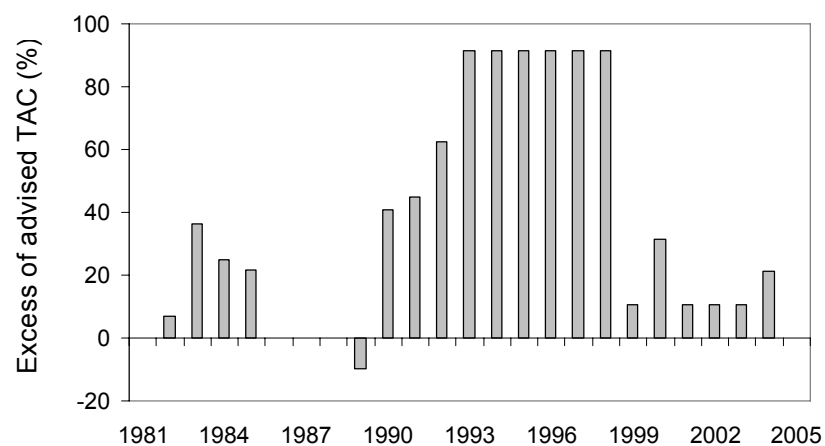


Figure 3.21 Greenland. Difference between the TAC advised by scientists for the Denmark Strait and East Greenland and the TAC adopted by managers, expressed as percentage of the advised TAC. Data from Carlsson (1988), Skúladóttir (1993) and Hvingel (2004b).

The trawlers that took part in the fishery during the first years were from 130 to 750 GRT, but by 2001 they were between 1,000 and 3,000 GRT and had increased to 1,000–4,000 GRT in 2004. These factory trawlers were from Norway, Greenland, Denmark and Faroe Islands, but they operated in Greenland waters, where 70%–90% of the total catches are obtained. The vessels used to operate throughout the year but during the nineties the fishing season gradually decreased to the period from November to April, when catches are highest (Carlsson 1981b; Skúladóttir 1998b; Hvingel 1999, 2001, 2004b).

3.1.3.2 Management

West Greenland

For management purposes, the shrimp stock in West Greenland is assessed as one population within NAFO Subareas 1 and Division 0A (Hvingel et al. 1997). Management advice has been based, as for other North Atlantic shrimp stocks, on qualitative assessment of biomass and length distribution trends in relation to catches, as described in the Research section (3.3).

The need for fishing regulations arose due to fluctuation in catches in the early years of the fishery. It seemed difficult that the main stock in Disko Bay could be overfished, since it was surrounded by large virgin shrimp grounds. Yet a decrease of mean size of shrimp was observed in the catches. Experimental fishing with different mesh sizes to avoid capturing undersize shrimp was not satisfactory and it was suggested to fish at greater depth (Smidt 1965, 1969).

Diverse management tools have been implemented since 1975, such as excluding foreign ships from the fishery, limiting catches by TAC and licenses, increasing mesh size, regulating shrimp discards and recording all catches (Table 3.4). The first TAC, based on catch per unit area of shrimp ground in the Disko Bay fishery, considered fishable ground plus the surrounding areas supplying adults and larvae for the yield estimation. The TAC for each area depended thus on its geographical position, and it was reduced in fishing grounds lacking shrimp supplying areas. The breakdown of the TAC for West Greenland into smaller spatial units was decided as a precautionary approach in case there was larval drift or migration of adults among the inshore and offshore grounds. Splitting the quota would counteract the concentration of effort within small areas and the possibility that these areas might be overfished (Carlsson and Smidt 1976; Horsted 1991).

Logbooks and TAC were applied to the inshore fishery in 1997, long after they had been implemented in the offshore fishery in 1986. Until 1997, inshore catches of ships smaller than 50 GRT, which lack processing facilities on board and were not subjected to offshore TAC regulations, had been estimated from the sales slips of landings. This method caused an uncertainty in estimations of catches and effort because some

of these ships fished offshore but their catch was not included in the offshore TAC (Horsted 1991; Hvingel 2002a).

Table 3.4 Regulations for the management of the Greenland shrimp stock.

Year	Regulation	References
1976	Mesh size regulation, 20–22mm Fish at greater depths Joint TAC for Canada and Greenland in offshore grounds within subarea 1 based on catch/ area unit	Carlsson & Smidt 1976 Horsted 1991
1977	Spatial breakdown of TAC: – Creation of shrimp box (68°N–69°30'N east of 59°W) – Division A, north of 69°30'N – Division B, south of 68°N plus Div. 1C – Divisions 1D – 1F Minimum mesh size of 40mm (1976???)	Horsted 1991 Anonymous 1977c
1979	Law forbidding discards of shrimp < 2 grams	Horsted 1991
1980	Shrimp box gets smaller (east of 56°W)	Horsted 1991
1981	Fishery closed to all but Greenlandic and Canadian fleet. Separate TAC for Canada and Greenland due to EEC issues, Canadian fleet restricted to Division 0A	Horsted 1991 Siegestad 1998 Hvingel 2002a
1986	Logbooks mandatory for all ships > 50 GRT (most of them in offshore fishery)	Hvingel et al. 1997
1990	New TAC breakdown: – Northwest Greenland (71°–72°52.5'N east of 58°W plus 69°30'–72°52.5'N west of 58°W) – West Greenland (offshore south of 71°N, east of 58°W and south of 69°30', west of 58°W) – Area between 68°–70°45' N east of 56°W – Area 69°30'–70°45' N east of 56°W (only ships 75–250 GRT allowed) Quotas allocated to individual vessels through licenses	Horsted 1991
1991	Individual Transferable Quotas (ITQ) for offshore fleet Introduction of observers in offshore fleet Mandatory to land part of catch in processing plants	Arnason & Friis 1995 Hvingel 2000 Schmidt, pers. comm.
1992	Further restrictions to Canadian fleet	Hvingel 2000
1997	Logbooks mandatory for all ships TAC extended to all ships < 50 GRT (most of them in inshore fishery)	Hvingel et al. 1997
2000	Sorting grids with 22mm grid space in all shrimp fishery area Ships must go to grounds at least 5 nm away if by-catch exceeds legal limits (10% of catch)	Engelstoft 2002 Engelstoft 1996
2004	Law to report catches in units of live weight instead of packaged product weight	Hvingel 2004a

Shrimp discards have been another cause for concern because they are difficult to estimate. Discarding of shrimp over 2 g has been prohibited by law since 1979 (Table 3.4) but larger shrimp have a higher market price and thus are preferred by fishermen, especially by those with low quotas. Discards were explicitly included in the TAC during the first years, until 1979, when there was no mention of them in the paragraph with the recommended TAC. Reports from ensuing years failed to include unreported shrimp discards in the TAC, therefore assuming that they remained constant. The discard issue was raised again in 1990 and observers were allocated to trawlers from 1991 onwards. This measure, together with the increase of price for smaller shrimp and the obligation to

take part of the catch to processing plants inland has contributed to the decrease of discards (Anonymous 1977c; Horsted 1991).

Another measure to achieve a more accurate record of catches has been the implementation of a new law in 2004 mandating that landings have to be reported as live weight rather than as product weight. This law allows correcting the underestimations of catches caused by the extra weight in packaging units that has been unreported until 2003 (Hvingel 2004a).

By-catch of finfish is discussed in detail in the next section, so only regulations concerning this problem are addressed here. Sorting grids with 22mm of grid space have been mandatory since 2000. Besides, the maximum catch of fish by-catch per haul is regulated by law and ships are required to move to different fishing grounds at least five miles away when the legal limit of by-catch is exceeded (Engelstoft 2002).

The Ministry of Fisheries also limits the fleet size that had become a problem because the expansion of the fishing grounds encouraged the industry to invest in the fleet beyond the possibilities of the fishery. Thus new regulations were issued during the 1990s (Table 3.4) to adjust the fleet size and optimize short- and long-term economy while maintaining the stock (Horsted 1991).

East Greenland and Denmark Strait

During 1978–1980, the International Council of Northwest Atlantic Fisheries (ICNAF, predecessor of NAFO) advised a cautious approach to shrimp fishing as representatives of the different nations involved in the fishery did not agree on the stock size. The first estimates were very unrealistic and based only on catches taken during a few months, therefore the council advised that the countries interested on taking part in the fishery should start surveying the area and carrying out stock assessment to enlarge the available database (Carlsson 1980b, 1981b; Anonymous 1982b).

The stock off East Greenland and in Denmark Strait has always been assessed as a single population, even after the discovery of the southernmost banks. The first TAC was issued in 1981, but it only applies to the shrimp fishing grounds within Greenlandic waters. Management of the shrimp fishing grounds within the Icelandic EEZ is considered unnecessary because catches are below 2,000 tonnes and the area is covered by ice in most years (Anonymous 1983; Carlsson 1983a; Hvingel 1999).

Reporting shrimp catches to Greenland for all ships > 80 GRT was mandatory from the beginning of the fishery in 1978 until 1987, when log-books were implemented for all ships. The legal mesh size was 40mm, as in West Greenland (Hvingel 1999; Carlsson and Hvingel 2000).

3.1.3.3 Research

Shrimp were found in West Greenland during two different expeditions carried out by Professor Adolf Jensen in 1908 and 1925 west of the Great

Hellefiske Bank (south of Disko Island). In 1935, shrimps were found in Nuuk Fjord (Godthaab), Maniitsoq district (Sukkertoppen) and Disko Bay, but the survey was confined to waters shallower than 250 metres. Research on the West Greenland shrimp stock started after World War II, with mapping of the trawling grounds and studies on shrimp biology (Table 3.5, Horsted and Smidt 1956). This early work continued with the discovery of new grounds and mark-recapture experiments to determine whether shrimp would migrate with the masses of warm-bottom water (Smidt 1960).

Table 3.5 Surveys carried out between 1928 and 1954 and their main results

Area	Year	Expedition	Main results
Upernavik and Uummannaq	1928	Godthaab	Shrimp widely distributed
Sisimiut	1948–49	Adolf Jensen	Bottom unsuitable for trawling
	1934–38	Private	Experimental trawling, discovery of good shrimp grounds
	1949	Adolf Jensen	Failed to find new trawling areas
	1951–54	Adolf Jensen	Recovery of stock after its collapse in 1949, by 1954 large shrimp dominated catches
Maniitsoq	1955	Adolf Jensen	Survey in Itivleq fjord, unsuitable for fishing
	1935	Dr. Hansen	Experimental trawling
Disko Bay	1950	Adolf Jensen	Low catches, bottom unsuitable for trawling
	1935	Dr. Hansen	Found shrimp
	1947	Adolf Jensen	Confirmed existence of good trawling areas
	1948–53		Experimental trawling, 100–200 kg/hour, best areas Ilulissat, Qasigianguit and Qeqertasuq
Nuuk	1946	Dr. Hansen	Suitable areas for trawling found
	1950–53	Adolf Jensen	Irregular catches, 0.5–270 kg / hour, better in Narssaq area
Qaqortoq	1946–53	Adolf Jensen	Found extensive areas suitable for commercial fishing
Vaigat	1948–49	Adolf Jensen	Low catch, unsuitable bottom
Disko Fjord	1948–49	Adolf Jensen	Few <i>P. borealis</i> , other shrimp species present
Aasiat	1949	Adolf Jensen	60 kg/h, low catches, especially with temperature < 0°C
Paamiut	1951	Adolf Jensen	Experimental trawling, 6–52 kg / hour, shrimp grounds too small for commercial use
Nanortalik	1951–54		Found areas suitable for commercial fishing
Qeqertasuaq (Disko Island)	1954	Dana	Experimental trawling, 130–200 kg /hour

Horsted and Smidt 1956

The surveys carried out between 1946–1954 provided descriptions of shrimp grounds, biology of *P. borealis*, detailed lists of associated fauna in the different districts and hydrological information from the Qaqortoq and Nanortalik areas (Horsted and Smidt 1956).

After 1963, research in the West Greenland stock concentrated on the offshore grounds and from the 1970s onwards it has focused on stock assessment and improvement in survey design. Additional research effort has been devoted to improvement of gear selectivity, sampling of juveniles and by-catch of demersal fish, which is discussed below (Table 3.6).

Stock assessment and estimation of TAC are based on biological as well as catch data. Assessment is made with a surplus production model

(ASPIC), that includes predation by cod, survey biomass indices of shrimp with caparace length > 17mm, CPUE indices, cod biomass and cod predation on shrimp, and it is based on the precautionary approach. The Bayesian method is used to estimate likelihood distributions of parameters relevant to management, i.e. investigate the effect of five different TACs on the stock. The assessment assumes that increases in CPUE may be derived from an increase in efficiency rather than in shrimp biomass, and it consists of keeping maximum fishing mortality equal to the fishing mortality necessary to achieve maximum sustainable yield of the fishery ($F_{LIM} = F_{MSY}$). Fishing mortality is reduced if the stock biomass decreases below the biomass required to obtain the maximum sustainable yield (B_{MSY}) (Cadrin and Skúladóttir 1998; Anonymous 1999, NAFO 2003; Hvingel 2002b; Hvingel and Kingsley 2002).

Stock assessment of shrimp is jeopardized by the biology of the species. First, the spawning stock biomass is entirely made up by females and it has to be assumed that there are enough males. Besides, the stock-recruitment relationship it is not known. Secondly, there are no hard parts to measure age and growth is stepwise as the individuals moult. Since there is no moulting during the nine months of egg bearing, several year-classes can belong to the same size group. These aspects prevent the use of virtual population assessment (VPA), a method widely applied to other species (Carlsson and Smidt 1976; Horsted 1991).

The first stock estimations were made by calculating the yield per unit area based on the stable catches from Disko Bay. The calculation would include fishable grounds and surrounding areas to supply larvae and adults, and it would consider only the spawning stock biomass. This method was applied to new grounds found in 1975, and the fishable stock was estimated at 17,000 tonnes. By the end of 1976, this figure had risen to 40,000 tonnes due to all the new fishing grounds found in that period (Carlsson and Smidt 1976; Horsted 1991).

CPUE data have also been used in combination with survey results, although it must be taken into account that they do not give an accurate idea of the stock size, as increasing experience of the skippers and technical improvements can raise CPUE indexes independently of stock size trends (Horsted 1991; Hvingel 1996). More recently, a model has been used to obtain indices for standardization of CPUE data. This model incorporates information on vessels, fishing area, month and year (Hvingel et al. 1996). Photographic surveys of the offshore fishing grounds were carried out during the period 1977–1985 to estimate total biomass and changes in distribution, but they were interrupted because their results did not agree with those from the trawl survey (Kannevorff 1986; Carlsson and Kannevorff 1987a).

The nations that took part in the fishery during the first years also surveyed the fishing grounds off West and East Greenland until 1988 and 1992 respectively, but very few foreign surveys were conducted in West

Greenland after the fishery was closed to all nations but Canada and Greenland in 1981 (Table 3.6). The first annual trawl survey off East Greenland focused only on the fishing grounds, but extended to cover the main stock distribution area north of 65°N in the following years (Andersen et al. 1994b).

Table 3.6 Research carried out on the Greenlandic shrimp stock since 1960.

Year	Research	Main results	References
West Greenland			
1963–64	Search for new fishing grounds	Offshore grounds found	Horsted 1969
1969	Mesh size	Mesh > 24mm reduced catches greatly, continue use of 20–22mm mesh	Smidt 1969
1969	Tagging experiments	Low recovery, tags did not affect shrimp	Horsted 1969
1977–85	Photographic surveys	Disagreement with trawl survey	Kannevorff 1979 Jørgensen & Kannevorff 1980 Kannevorff 1981 Kannevorff 1983 Kannevorff 1984 Carlsson & Kannevorff 1987a Kannevorff 1986
1979–88	Foreign surveys	Biomass estimates, biological information, effort, yield, discards and by-catch	<i>Norway</i> Ulltang & Torheim 1979 Jakobsen & Torheim 1980 Jakobsen & Torheim 1981a Jakobsen & Torheim 1983a Smedstad & Torheim 1984a <i>France</i> Dupouy & Fréchette 1979 Fréchette & Dupouy 1979 Minet 1979 Derible et al. 1980 Dupouy et al. 1981a Dupouy & Fontaine 1983 Bertrand et al. 1988a Bertrand et al. 1988b <i>Canada</i> Parsons 1979 Parsons 1980

Table 3.6 (Cont.)

Year	Research	Main results	References
1980–	Fisheries data	Catches and CPUE estimated from landings and logbooks	Carlsson 1980a Carlsson 1983b Carlsson 1984a Lund 1988b Carlsson 1988 Carlsson and Kanneworff 1989a Lassen and Carlsson 1990 Carlsson 1990b Lund 1990b Carlsson & Lassen 1991 Carlsson & Kanneworff 1991a Carlsson & Kanneworff 1992a Carlsson & Kanneworff 1993a Carlsson et al. 1993a Carlsson 1993 Siegstad 1994 Siegstad et al. 1995 Siegstad 1996
1988–	Offshore annual stock assessment	Biomass estimations, length distribution, biological information	Carlsson & Kanneworff 1989b Lund 1989b Carlsson et al. 1990 Carlsson & Kanneworff 1991b Carlsson & Kanneworff 1992b Carlsson et al. 1993b Andersen et al. 1993a Andersen et al. 1994a Carlsson et al. 1995a Folmer et al. 1996a Carlsson & Kanneworff 1997a Carlsson et al. 1998 Carlsson et al. 1999 Carlsson & Kanneworff 2000 Kanneworff & Wieland 2001 Kanneworff & Wieland 2002 Hvingel 2002b Hvingel 2003 Kanneworff & Wieland 2003
1989	Gear selectivity	43mm mesh the most selective	Christensen 1990
1990–99	Growth rates	New analysis of survey samples Growth may be correlated to bottom temperature	Carlsson 1997a Carlsson & Kanneworff 1999
1997	Relationship catch versus depth	Catches seemed to increase with depth Shrimp most abundant at 400m depth	Carlsson 1997b Kingsley & Carlsson 1998
1991–	Inshore annual stock assessment (Disko Bay)	Biomass estimations, length distribution, biological information	Carlsson et al. 1992 Andersen et al. 1993b Carlsson and Kanneworff 1993b Andersen et al. 1994a Carlsson et al. 1995b Folmer et al. 1996b Carlsson and Kanneworff 1997b Carlsson and Kanneworff 1998b

Table 3.6 (Cont.)

Year	Research	Main results	References
1993	Grid devices	Problems with selectivity of grid, flat fish blocked grid but round juvenile fish escaped	Valdemarsen et al. 1993
1993–94	Gear selectivity	Mesh size of 45 and 60mm decreased catch of shrimp < 22mm cpl by 40–50% and larger shrimp by 15–30% No differences found between diamond and square mesh of 45mm High variation in selectivity, but mesh selection was detected	Lehmann et al. 1993 Boje and Lehmann 1994
1997	Estimation of year-class strength and biomass index from commercial fishery data	First year-class is over-estimated and the fourth year-class is under-estimated The new biomass index indicates biomass of shrimp >17mm	Carlsson and Kannevorff 1997c Hvingel et al. 1996 Hvingel et al. 1998
1998–2001	Survey improvement	Reduction of strata & towing time, sampling stations placed randomly, enlargement of study area, reduction of codend liner mesh to 20mm. These measures led to more efficient sampling and better statistical analysis	Carlsson et al. 1998 Kingsley et al. 1999 Carlsson et al. 2000 Folmer and Pennington 2000 Kingsley 2000 Kingsley 2001
1991, 2000	Sampling of juveniles	There are no concentrations of age groups 1 and 2 Side bags w/ mesh size 6mm, improve 1-group sampling	Carlsson and Kannevorff 1997d Wieland 2002a
2001	Precision of length measurements	Training of personnel and standardization of data collection needed to avoid bias	Wieland 2001
2002–03	Abundance and growth of juveniles	Mean length seems to be correlated to bottom temperature	Wieland 2002b Wieland 2003
2002	Model for stock dynamics	Includes all available biotic and abiotic information	Hvingel and Kingsley 1998 Hvingel and Kingsley 2002

Table 3.6 (Cont.)

Year	Research	Main results	References
East Greenland			
1980–92	Foreign surveys	Biomass estimates, biological information, effort, yield, discards and by-catch	<i>Norway</i> Jakobsen 1980 Jakobsen & Torheim 1981b Jakobsen & Torheim 1983b Smedstad & Torheim 1984b Smedstad 1985 Smedstad & Torheim 1985 Smedstad & Torheim 1986 Smedstad & Torheim 1987 Smedstad 1988 Smedstad 1989 Smedstad & Torheim 1989 Smedstad & Torheim 1990 Smedstad & Torheim 1991 Smedstad 1992 <i>France</i> Minet et al. 1980 Dupouy et al. 1981b Dupouy et al. 1983 Biseau et al. 1984 Bertrand et al. 1988a Bertrand et al. 1988b Poulard et al. 1986 Poulard & Fontaine 1985 <i>Faroës</i> Hoydal 1980
1980–88	Fisheries data	Estimation of TAC	Carlsson 1980a Carlsson 1981a Carlsson 1983b Carlsson 1984b Carlsson 1986 Carlsson & Kannevorff 1987b Carlsson 1988
1981–88	French research	Fisheries and biological data collected during fishing trips	Dupouy et al. 1981b Dupouy et al. 1983 Biseau et al. 1984 Poulard & Fontaine 1985 Poulard et al. 1986 Bertrand et al. 1988a Bertrand et al. 1988b
1989–90	Search surveys for new fishing grounds off SW, SE and E Greenland	Unexploited areas investigated in Qaqortoq, from Cape Farewell to 65°30'N and 67°30'N–77°36'N, catches too small for commercial fishing, nor reason to enlarge stock assessment survey area	Lehmann 1989 Lehmann 1990

Table 3.6 (Cont.)

Year	Research	Main results	References
1989–	Stock assessment survey	Biomass estimations, length distribution, biological information Hvingel 2001 Hvingel 2004b	Carlsson and Kanneworff 1989c Carlsson and Kanneworff 1990 Carlsson and Kanneworff 1991c Carlsson and Kanneworff 1992c Carlsson and Kanneworff 1993c Carlsson and Kanneworff 1993d Andersen et al. 1994 Carlsson and Kanneworff 1995 Carlsson 1996 Carlsson and Hvingel 2000 Hvingel 1999 Hvingel 2001 Hvingel 2004b
	Sexual maturity of females		Skúladóttir 1995a
	Surplus production model	Based on the assumption that the net growth rate of a stock is related to its biomass. Allows better estimations of maximum sustainable yield (MSY), biomass needed to produce MSY (B_{MSY}) and fishing mortality to maintain MSY (F_{MSY}) and therefore provides with better management advice.	Cadrin and Skúladóttir 1998

3.1.3.4 By-catch in the Greenlandic shrimp fishery

The presence of many benthic species was noted in the first surveys off West Greenland. Horsted and Smidt (1956) made a detailed list of the animal life found on the shrimp grounds they investigated. They recorded sponges, anthozoans, hydroids, polychaetes, nemerteans, jellyfish (2 species), amphipods (3), isopods (1), mysids (1), euphasids, shrimp (11), crabs (5), echinoderms (17), bivalves (14), gastropods (13), chaetognats (1), ascidians and 40 fish species. In general, the most common fish by-catch species in shrimp grounds at 300–400m depth with soft bottom and water temperature above 0°C were Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes marinus*), longear eelpout (*Lycodes seminudus*) and Vahl's eelpout (*L. vahlii*). In smaller numbers there were Arctic cod (*Boreogadus saida*), Atlantic cod (*Gadus morhua*), Atlantic poacher (*Leptagonus decagonus*), seasnail (*Liparis sp.*) and sea tadpole (*Careproctus reinhardti*), among others.

In threshold fjords with water below 0°C and 150m depth, shrimp became smaller and was not the dominant species. Fish by-catch was dominated by long rough dab (*Hippoglossoides platessoides*) and longear eelpout (*Lycodes seminudus*). Invertebrates dominated areas of hard bottom (Horsted and Smidt 1956).

Smidt (1965, 1970, 1971) also found that the most abundant fish by-catch species were Greenland halibut, long rough dab, redfish and eelpouts, but he did not provide figures in his papers.

Available by-catch records for the period 1970–1990 were not comparable to recent data because they correspond to only part of the fleet, and data from several Subareas were often pooled together. Eight Greenlandic trawlers fishing in Areas 0 and 1 reported that by-catch ranged from 0.8 to 23.1% of the shrimp catch during the years 1977–1983. Redfish made up most of the by-catch and it was the only by-catch species recorded separately (Carlsson 1984a). Other by-catch data collected during surveys include redfish and Greenland halibut (Pedersen and Lehmann 1989). Norwegian surveys reported by-catch of mostly redfish, but also Greenland halibut and cod in both West and East Greenland (Jakobsen and Torheim 1980, 1983b; Smedstad and Torheim 1984a, 1987). The first survey to assess the stocks of by-catch species took place in 1987 and identified 27 taxa. However, the coefficient of variation was over 25% for many of them and the biomass of some of the species was clearly underestimated. Cod biomass was the largest, close to 430,000 tonnes, followed by Greenland halibut (58,000 tonnes) and roundnose grenadier (*Coryphaenoides rupestris*, 43,000 tonnes). However, biomass of deep-sea redfish (*S. mentella*) was estimated at 8,000 tonnes despite being the most abundant by-catch species recorded in all other surveys (Yamada et al. 1988).

More recently, nearly 130 fish by-catch species have been recorded in the shrimp survey off West Greenland. However, the by-catch was dominated in both abundance and biomass by juvenile Greenland halibut and redfish. Other common species, but not so abundant, were long rough dab, Atlantic wolffish (*Anarhichas lupus*), spotted wolffish (*A. minor*), cod and starry skate (*Raja radiata*) (Carlsson and Kannevorff 1998a; Storr-Paulsen 2004). Trends in abundance and biomass of these species are shown in Figure 3.22.

Greenland halibut has always been most abundant in Disko Bay and NAFO Subarea 1BN (between 67°–68°50'N, 50°–59°45'W), and it is also found further north (beyond 71°N) than redfish and in the eastern part of the area covered by the shrimp survey (Pedersen and Lehmann 1989; Pedersen and Kannevorff 1995). During the period 1988–2002, length ranged from 5 to 75cm, but with frequency modes around 11–13cm and 18–25cm. The largest fish was found in the deeper strata, at 400–600m depth. Variability in abundance between years was considerable but biomass tended to increase (Figure 3.22a) (Pedersen and Lehmann 1989; Engelstoft 1996, 1997, 2002; Jørgensen and Carlsson 1998; Storr-Paulsen 2004).

Redfish was found mostly in NAFO Subareas 1BN and 1C (67°–68°50' and 64°15'–66°15' respectively, both 50°–57°W). Redfish dominates in the western part of the area covered by the shrimp survey. Length

ranked from 4–57cm, but frequency modes were most years at 7 and around 13cm. The largest fish was found at 400–600m depth. Both abundance and biomass vary greatly among years (Figure 3.22b) (Pedersen and Lehmann 1989; Pedersen and Kannevorff 1995; Engelstoft 1996, 1997, 2002; Jørgensen and Carlsson 1998; Storr-Paulsen 2004).

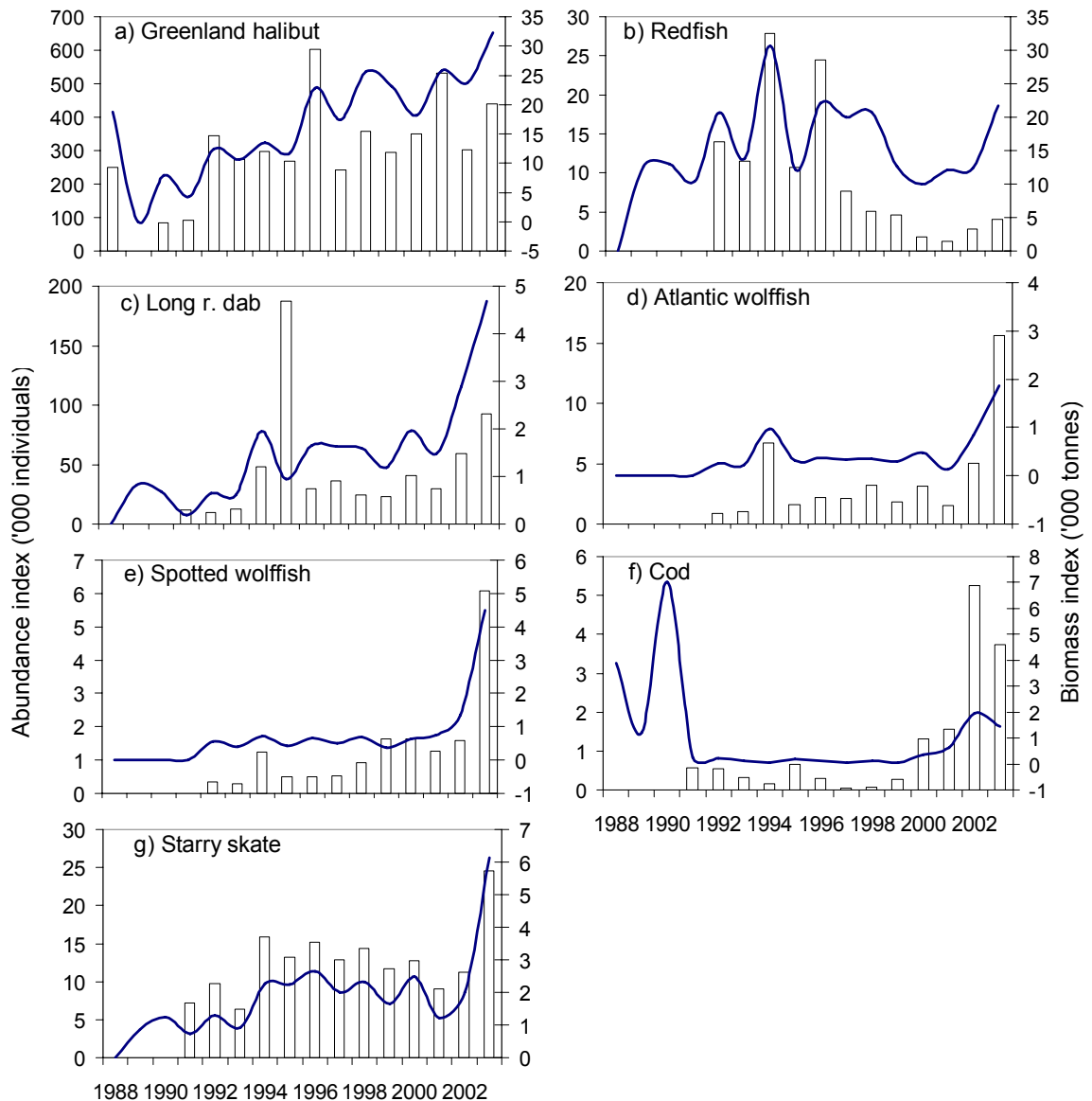


Figure 3.22 Greenland. Abundance (in thousands of individuals, bars, left y-axis) and biomass (in thousands of tonnes, lines, right y-axis) indices of several demersal fish species off West Greenland, based on data from the annual shrimp assessment survey. Note that the scales of y-axis differ between graphs. Long r. dab: Long rough dab. Data from Storr-Paulsen (2004).

Differences in length distribution between sampling areas and different depth strata suggest that juvenile redfish and Greenland halibut migrate

from shallow to deeper water, and westward and southward from an area between 67°–69°30'N (Kannevorff and Pedersen 1992; Pedersen and Kannevorff 1992).

Available information for the remaining species is much scarcer. Abundance and biomass of long rough dab seem to be increasing (Figure 3.22c). The length range is from 5–43cm, with frequency modes at 10–12, 15 and 30–32cm between 1996 and 2002 (Engelstoft 1996, 1997, 2002; Jørgensen and Carlsson 1998).

Atlantic and spotted wolffish were much more abundant in 2003 than in previous years (Figure 3. 22d and 3.22e). Atlantic wolffish ranged from 5–70cm length during the period 1996–2002, but most individuals were < 35cm and with higher abundance of fish between 8–12cm and 25–30cm (Engelstoft 1996, 1997, 2002; Jørgensen and Carlsson 1998).

Atlantic cod is mostly found in the southern part of the survey area. Cod was more abundant during 2002 and 2003 than in previous years but biomass is very low compared with the biomass peak in 1990, assumed to be due to the 1984–85 year-classes recruited from Iceland (Figure 3.22f). Length range of cod was usually 15–60cm except for 1996 when it was 25–42cm. Frequency modes were at 23–27 and 34–38cm (Engelstoft 1997, 2002; Jørgensen and Carlsson 1998).

Biomass and abundance trends of starry skate (Figure 3.22g) oscillated during the period 1988–2002 but increased greatly during 2003 (Pedersen and Kannevorff 1995; Jørgensen and Carlsson 1998).

Other by-catch species, such as Arctic cod (*Boreogadus saida*), sculpins (*Triglops* sp.) and sea snails are very abundant in number (Smidt 1971; Pedersen and Kannevorff 1995) but no data are collected on these, probably because they have no commercial interest.

Rätz (1997a) recorded 66 by-catch fish species in annual groundfish surveys in West and East Greenland during the period 1982–96. The most abundant species in number were deep-sea redfish (*S. mentella*, 21%), redfish (*S. marinus*, 15.1%), Atlantic cod (14.5%) and long rough dab (4.7%). However, cod was most abundant in terms of biomass (45.7%), followed by redfish (27%), deep-sea redfish (14.6%), unidentified redfish and long rough dab, each of which contributed 2.4% (Figure 3.23). All these species represented 92% and 96% of the by-catch in abundance and biomass respectively. There are some differences in abundance and biomass of by-catch species during the years 1988–96 in West Greenland among Figures 3.22 and 3.23. This can probably be explained by the differences in the investigated areas during the different surveys. By-catch data from the shrimp survey represent all Subarea 1 (see Figure 3.11), whereas the groundfish survey data used by Rätz (1997b) had its northernmost limit at 67°N.

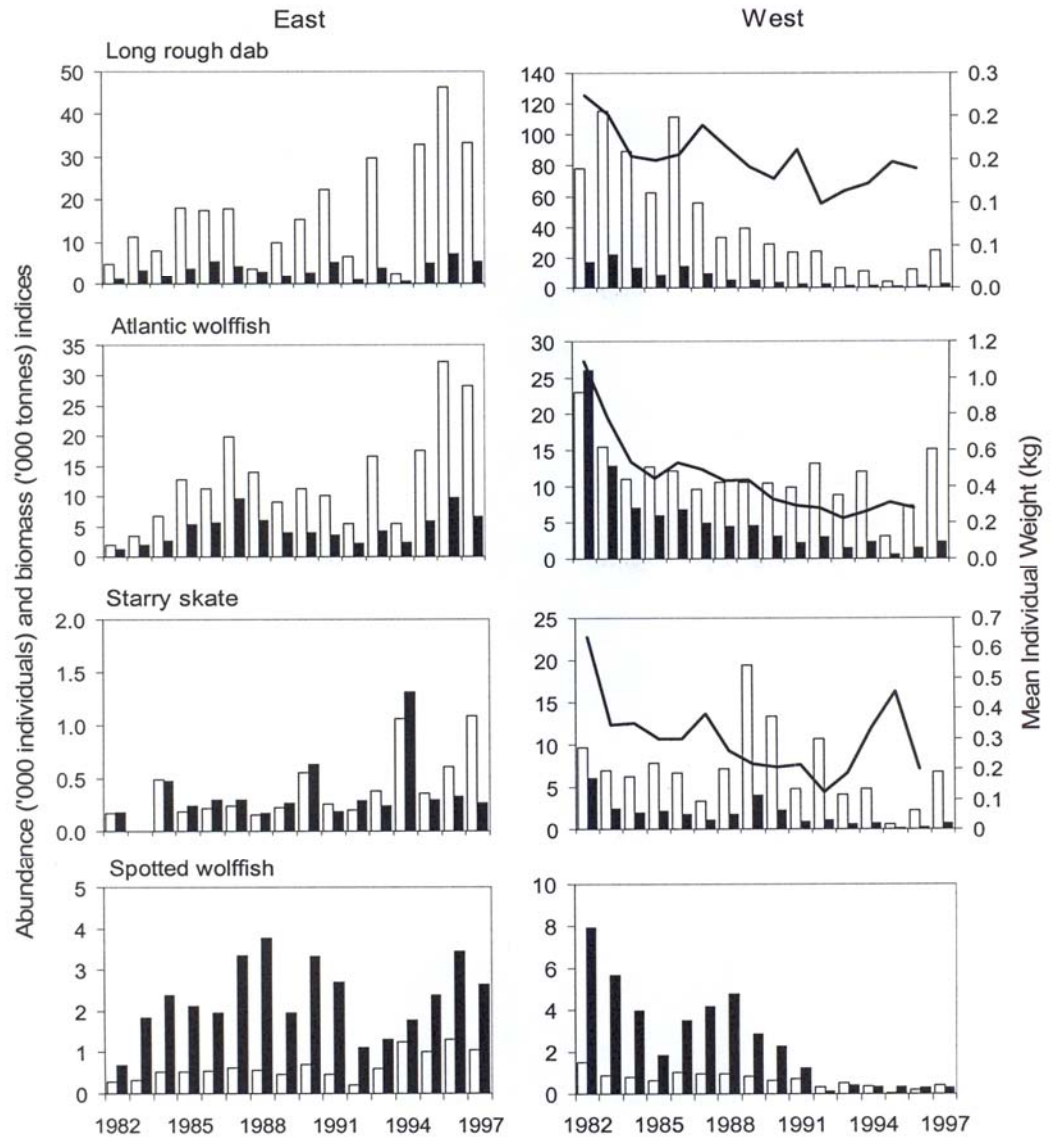


Figure 3.23 Greenland. Abundance ('000 individuals, white bars) and biomass ('000 tonnes, black bars) indices of the most abundant demersal fish species in East (left column) and West (right column) Greenland, estimated from the annual groundfish survey data. The black line represents mean individual weight (MIW, in kg) and refers to the right y-axis. These data were not available for samples from East Greenland. Data from Rätz (1998b).

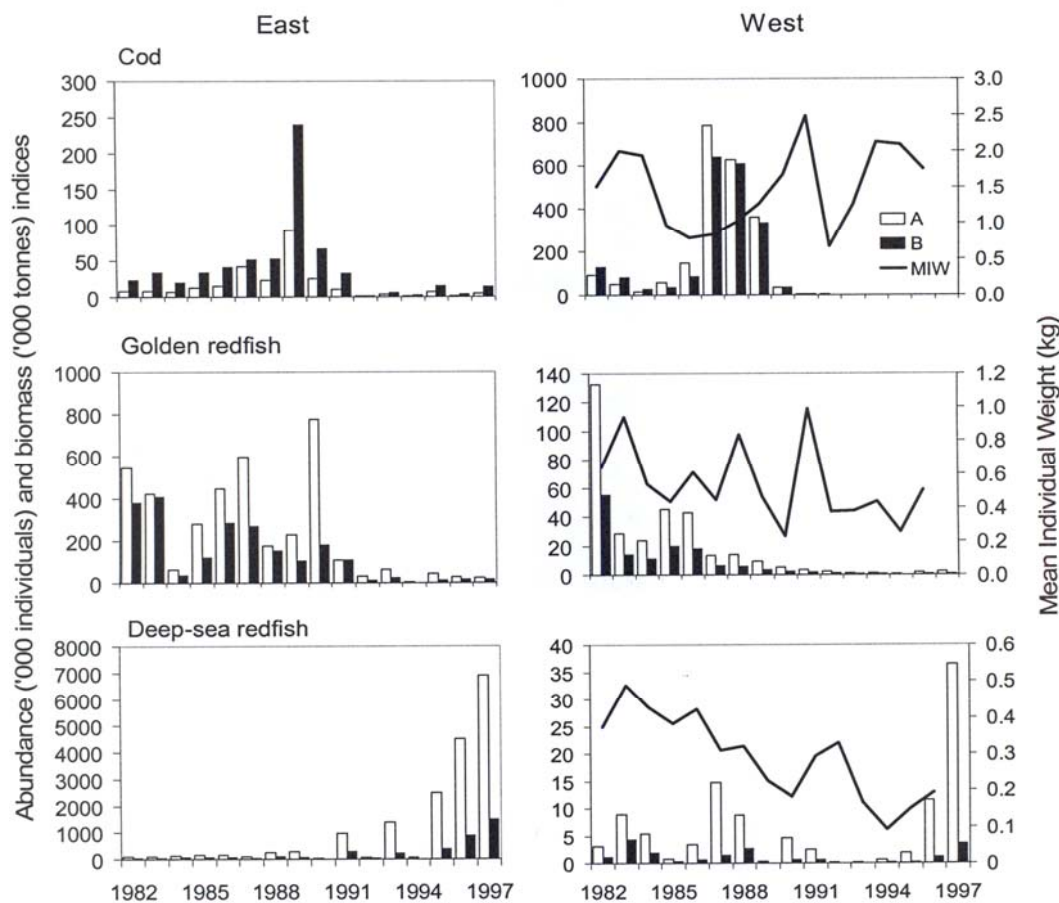


Figure 3.23 (Cont.) Greenland. Abundance ('000 individuals, white bars) and biomass ('000 tonnes, black bars) indices of the most abundant demersal fish species in East (left column) and West (right column) Greenland, estimated from the annual groundfish survey data. The black line represents mean individual weight (MIW, in kg) and refers to the right y-axis. These data were not available for samples from East Greenland. Data from Rätz (1998b).

Fish were evenly distributed during the 1980s off West and East Greenland, until mean individual weight declined by 25–50% in the 1990s (Figure 3.24), indicating that the stocks were made up of juveniles (Rätz 1997b). The stocks of spotted wolffish and starry skate in West Greenland were thought to be severely depleted considering their biomass trends since 1982 (Rätz 1998a).

It is known that shrimp grounds overlap with important nursery grounds of redfish, Greenland halibut, cod and Arctic cod (Smidt 1969; Pedersen and Lehmann 1989). Spawning of redfish is unknown in West Greenland. It is thought that they are recruited from breeding areas southwest of Iceland (Anonymous 1984b). However, northwest, west and southwest of Disko Island are very important nursery grounds for Greenland halibut. This spatial distribution of nursery grounds might be related to the hydrography of the area, food availability or predator-prey

relationships among these species (Pedersen and Kanneworff 1995). In fact, stomach content of redfish > 20cm and Greenland halibut > 14cm consists mostly of shrimp and juvenile redfish (Pedersen and Riget 1993). Cod, redfish, long rough dab and starry ray also prey on shrimp (Pedersen 1994).

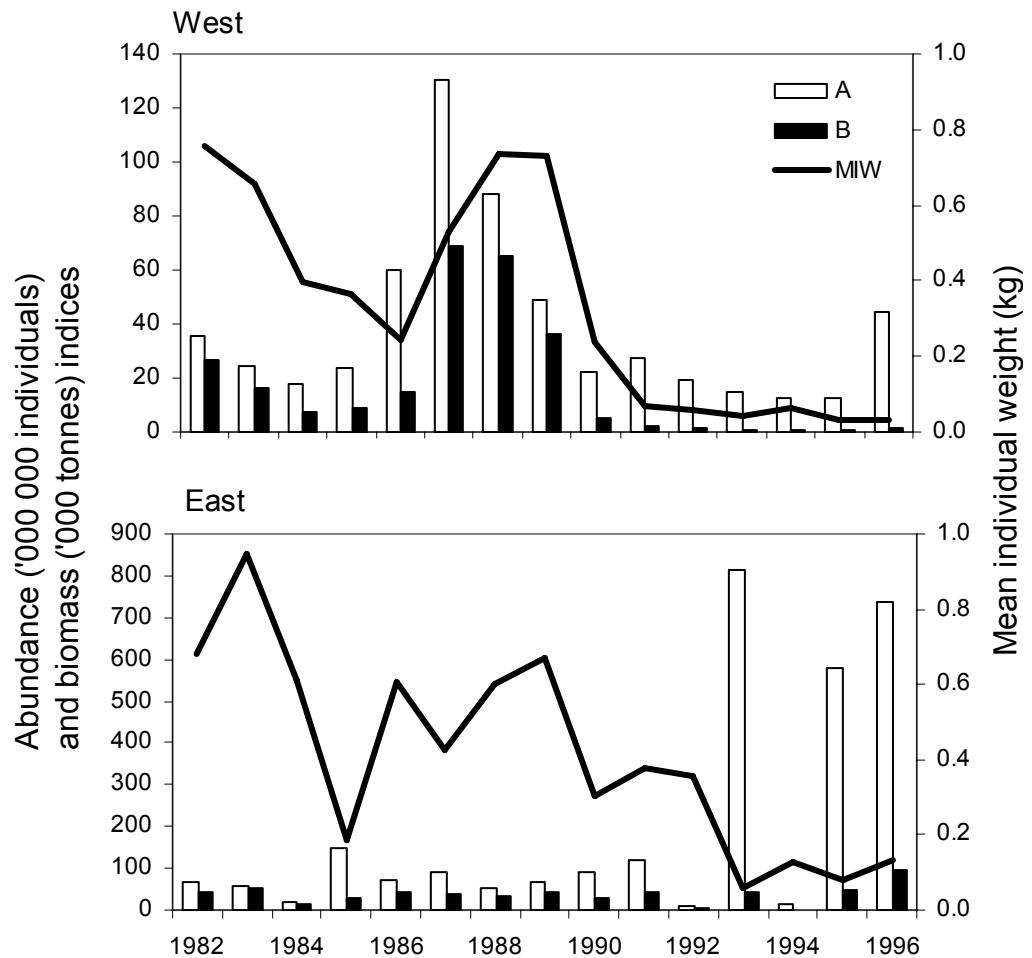


Figure 3.24 Greenland. Indices for abundance, expressed as '000 000 individuals (white bars) and biomass, expressed as '000 tonnes (black bars) of 66 demersal fish species recorded off the West and East coasts during the period 1982–1996. Mean individual weight (MIW, black line) is expressed in kg and refers to the right y-axis. Note that the left y-axis have different scales. Juvenile *Sebastes* spp., *S. mentella* and *S. marinus* represented 71.5% of the total abundance, followed by *Gadus morhua* (14.5%) and *Hippoglossoides platessoides* (4.7%). In terms of biomass, *G. morhua* represented 45.7% of the total, followed by *Sebastes* spp., *S. mentella* and *S. marinus* (44%) and *H. platessoides* (2.4%). Data from Rätz (1997b).

Disagreement of by-catch data from the surveys and commercial fishing makes it difficult to estimate accurately the impact of the shrimp fishery. First by-catch estimations for redfish and Greenland halibut in the 1988 shrimp survey were 12% and 7%, whereas fishermen reported less than

1.6% (Pedersen and Lehmann 1989). The introduction of observers in 1991 might have influenced the increase of by-catch reports from the commercial fishery from 1% in 1987 to 3% in 1998 (Hvingel 2002a), and the use of sorting grids since 2000 and other regulations (see Table 3.4 above) have been considered effective to decrease mortality of demersal fish in the shrimp fishery. Nevertheless, regular data on fish by-catch have been collected since the annual shrimp stock assessment survey started in 1988. Biomass estimates for demersal fish species obtained during the shrimp surveys are considered reliable and they provide an accurate estimate of the state of the demersal stocks. They are supported by results from other studies on vertical distribution of shrimp and fish (Pedersen and Kanneworff 1995; Storr-Paulsen 2004).

The observed general decrease in abundance and biomass of the investigated demersal fish stocks has been attributed to the rising mortality, especially of juveniles, caused by the growing fishing effort in the off-shore shrimp grounds (Rätz 1992, 1997b; Pedersen 1994; Pedersen and Kanneworff 1995; Storr-Paulsen 2004). The fact that mean individual weight started to increase again in East Greenland in 1994 but not in West Greenland suggests recruitment failure caused by the shrimp fishery (Rätz 1998b).

The changes in climate and surface currents registered in Greenland during the last century that overlap during certain years with the observed variability in recruitment and biomass of the main commercial species may have also affected the rest of the by-catch species (Smedstad and Torheim 1990; Pedersen 1994; Horsted 2000; Buch et al. 2002).

3.1.4 Barents Sea, Svalbard area and Jan Mayen.

3.1.4.1 The fishery

Barents Sea and Svalbard area

The shrimp fishery started in the Barents Sea in 1973 with 30 Norwegian trawlers after a pilot study had mapped the shrimp resources in 1970 and 1971 (Strøm and Rasmussen 1970; Strøm 1971; Anonymous 1976c). However, other nations have traditionally taken part in the Svalbard shrimp fishery. Their catches are distributed according to historical rights as stipulated in the Svalbard Treaty and the regulation of a Fishery Protection Zone around the islands (Standal 2003).

It has been estimated that 69% of the distribution area of shrimp in the Svalbard zone lies within Norwegian waters, but 80% of the total catch corresponds to Norway (Standal 2003). Russian landings have been much smaller after joining the fishery in 1974 (ICES 2003). The Faroes have fished most years during the period 1978–2001 (Figure 3.25). Other countries belonging to the EU have participated sporadically (Anonymous 1986b, 2004). It has been suggested that the rapid increase of

catches in the Barents Sea could have been greatly influenced by the quota restrictions adopted within the Greenland economic zone in 1977 (Berenboim et al. 1980). Figure 3.26 shows the distribution of the shrimp stock in the Barents Sea and Svalbard area.

Catches have shown great fluctuations since they reached a maximum in 1985 (Figure 3.25), due to variations in stock size caused by irregular recruitment and predation from cod, but also because of variations on effort provoked by market prices (Standal 2003). Thus, in 1975 there was no shrimp to be found in Spitsbergen and the fleet moved to new grounds found East of Bjørnøya and Hopen (Anonymous 1976c).

Stock estimations from 1977 supposed that the areas of largest concentrations were confined within 15% of the shrimp distribution area; density was too low outside these grounds for a commercial fishery. The stock was estimated to be 15,500 tonnes in Spitsbergen, distributed over an area of 10,300 km²; and 13,300 tonnes in Hopen, over an area of 12,300 km² (Anonymous 1978c). However, the fishery was constrained by sea ice conditions and the high variability in catches within the different areas. CPUE ranged during the years 1978–1979 from 24 to 105 kg hour⁻¹ in Hopen, from 86 to 188 kg hour⁻¹ in Bjørnøya and from 120 to 205 kg hour⁻¹ in West Spitsbergen (Anonymous 1979b).

Nevertheless, catches of the Norwegian fleet increased from about 40,000 to 82,000 tonnes, and total catches went up to 128,000 tonnes during 1980–1985 (Figure 3.25), partly due to the stock increase when the year-classes from 1977 and following years recruited to the stock. Migration of juvenile cod and haddock into the shrimp grounds prompted the closure of large areas within the shrimp grounds between 1983 and 1988. On the other hand, although shrimp abundance off the island Spitsbergen showed an increase from 8 to 19% during the period 1986–1988, the stock of the Svalbard area had been greatly reduced to about one-third of its size in 1984 (Figure 3.27). This decline was caused by poor recruitment, increased mortality by predation and input of cold water (below -1°C) in certain areas, and it might have also been influenced by overfishing. As a result, catches in Svalbard decreased to 1980 levels (Teigsmark and Øynes 1983a; Anonymous 1984c, 1985b, 1986b, 1987c, 1988c; Tveranger and Øynes 1985; Høyen 1986; Høyen and Øynes 1986; Berenboim et al. 1987).

Nevertheless, the recruitment of the strong year-class of 1983 in 1988 caused the stock to rise to 300,000 tonnes between 1987 and 1991 (Figure 3.27). This increase was detected by the Norwegian surveys, but not by the Russians, who estimated that the stock had declined by 40% in 1988 compared to that of 1987 (Berenboim et al. 1989). The large input of warmer Atlantic water and less predation due to the decline of the cod stock during these years might have also contributed to the biomass increase. The trend reversed again in 1991 and the stock declined by 50%, probably because of the increased effort since 1989 and the rise of the

cod stock coinciding with the collapse of capelin and herring stocks, thus effecting heavier predation pressure on the shrimp (Hysten et al. 1987; Hysten and Øynes 1988; Mukhin and Sheveleva 1991; Aschan et al. 1993; Aschan et al. 1994, 1995). However, despite the declining biomass trend (Figure 3.28), in 2001 the government allowed the renewal of licensed ships, which is what led to the growth of the fleet beyond the capacity of the fishery (Standal 2003) (see management section).

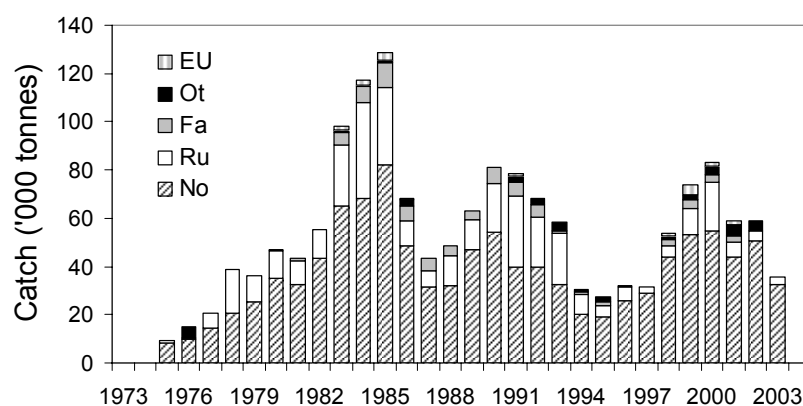


Figure 3.25 Barents Sea and Svalbard area. Shrimp catches of the international fleet, expressed in '000 tonnes. No: Norway, Ru: Russia, Fa: Faroe Islands, EU: European Union countries, Ot: Others. Data from Anonymous (1986b, 1996b, 2004).

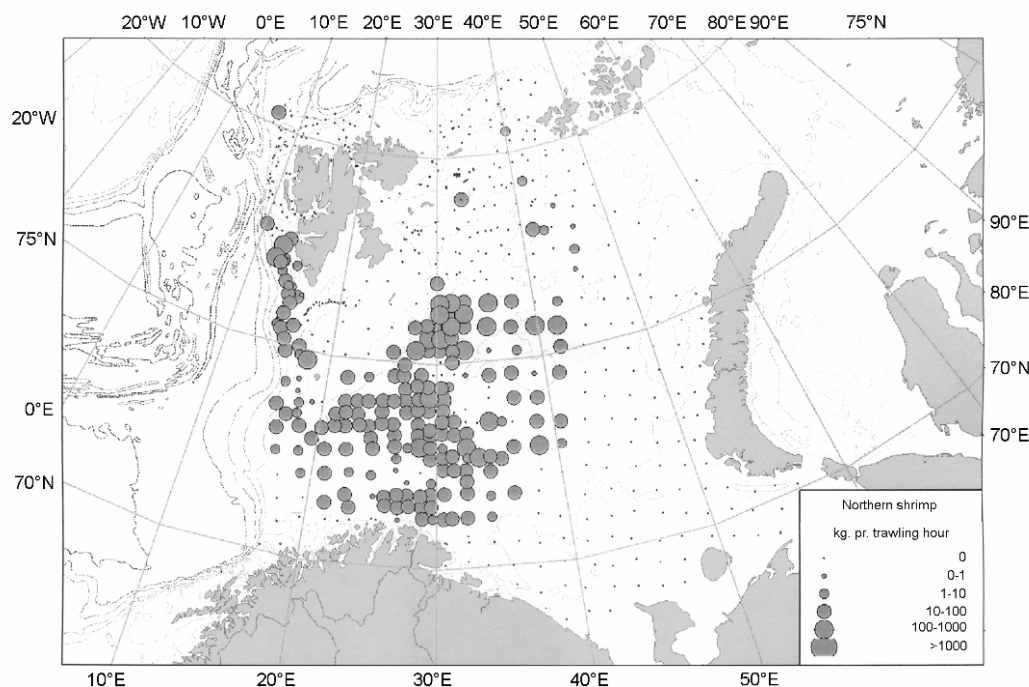


Figure 3.26 Distribution of shrimp in the Barents Sea and Svalbard area according to survey data from 2004. Larger circles correspond to larger shrimp concentrations. No scale provided in the original source. From ICES (2005).

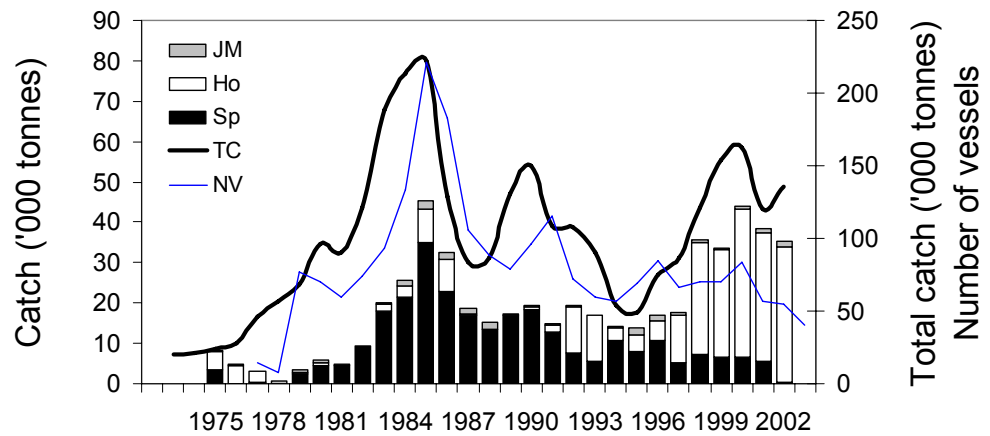


Figure 3.27 Barents Sea and Svalbard area. Norwegian shrimp catches from Jan Mayen (JM), Hopendypet (Ho) and Spitsbergen (Sp), expressed as '000 tonnes. The black line represents total catches (TC) and fleet size (NV) is represented by the thin blue line. Both refer to the left y-axis. JM: Jan Mayen, Ho: Hopendypet, Sp: Spitsbergen, TC: Total catch for the Barents Sea north of 62°N, NV: Number of vessels. Catches during the years 1973–74 amounted to 7300–7500 tonnes, most of it from the Barents Sea. A small percentage corresponds to the inshore fishery. Data from Anonymous (1976c, 1984c, 1986b, 2004).

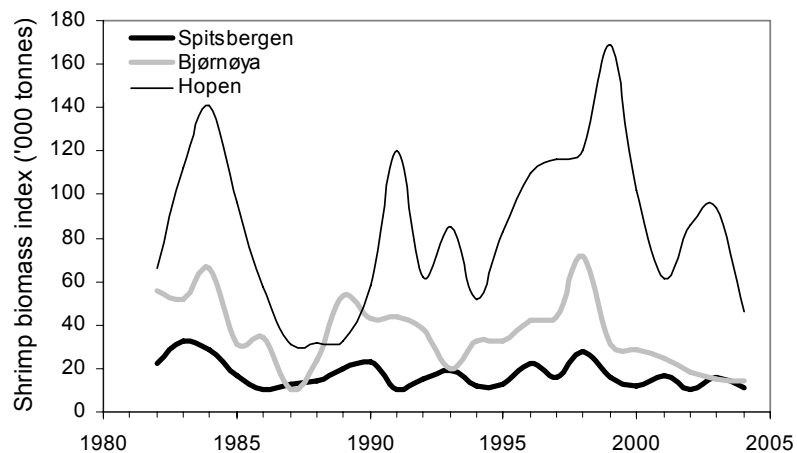


Figure 3.28 Shrimp biomass index estimated from the Norwegian surveys for Spitsbergen, Bjørnøya and Hopen Island during the period 1984–2004. Data from Anonymous (2004).

Jan Mayen

The fishery started in 1975–76 with 15 Norwegian trawlers following a pilot survey carried out in 1974. Average catches were 150 kg hour^{-1} , but the grounds were small and ice conditions restricted fishing operations to summer and autumn (Anonymous 1974c, 1977d; Øynes 1977).

Annual catches showed great variability and depended not only on stock size, but also on accessibility to the area, fleet size and fishing conditions in Greenland, the Barents Sea, Svalbard and the Flemish Cap. Catches peaked in the 1970s, when they nearly reached 9,000 tonnes.

Most of this was taken by Norwegian vessels. The fleet consisted mostly of medium size ships, 1,000–2,000 HP, but the largest percentage of catches during the 1990s corresponded to ships over 2,000 HP (Aschan et al. 1996a).

3.1.4.2 Management

There is no TAC for the shrimp stock in Svalbard due to the lack of knowledge about stock structure and the problem to define management units (Hansen and Aschan 2000). The fishery is managed with minimum carapace length (15mm), fishing licenses, number of effective fishing days and maximum number of juvenile cod, haddock, redfish and Greenland halibut captured as by-catch (Table 3.7, Aschan and Sunnanå 1997; Aschan 1999a, 1999b; Hansen and Aschan 2000). Since 1983, fishing grounds have been closed when the number of juvenile fish surpasses a determined threshold. Thus in 1983 the Norwegian-Soviet Fisheries Commission imposed closure of grounds when the number of juvenile haddock and cod was > 300 individuals shrimp tonn^{-1} . This rule was also applied to juvenile Greenland halibut from 1992 onwards (Veim 1999). This strategy is based in the future market price of the by-catch. If it would be higher than the value of the present shrimp catch, the fishing areas would be closed. However, a good estimate of maximum allowable juvenile fish in the by-catch is very difficult to obtain. Accurate estimation of such parameters requires good information on year-class strength, average yield per fish, cannibalism rates, knowledge on the magnitude of predation on the shrimp stock and a good prediction of market prices for by-catch fish species that will depend on supply and demand among other factors (Veim 1999; Aschan 1999a).

The maximum allowable number of juvenile fish has been revised several times since the enforcement of the regulation, and especially after the obligatory use of sorting grids started in January 1993. The grid prevents catches of all fish under roughly 15–20cm, so the rules about closure of grounds were changed in 1995 to allow by-catch of up to 1,000 cod or haddock per tonne of shrimp (Veim 1999; Aschan 1999a, 1999b). Maximum by-catch was recently limited to eight cod and haddock, or ten redfish or three Greenland halibut per ten kg of shrimp (Anonymous 2004).

Table 3.7 Management regulations for the shrimp fishery in Svalbard and Jan Mayen.

Year	Regulation	Reference
1973	License mandatory for trawlers > 50 GRT	Ulltang 1981
1974	Mesh size in cod end with stretched net must be at least 30 and 35mm south and north of 65°N, respectively	Ulltang 1981
1983	Joint Soviet-Norwegian Fisheries commission decides to close shrimp grounds when by-catch of juvenile cod and haddock > 300 individuals tonne ⁻¹ of shrimp	Veim 1994
1989	Maximum catch of cod and haddock limited to 8 individuals per 10 kg of shrimp Mesh size 35mm (stretched mesh) north of 64°N and 40mm in Jan Mayen Minimum caparace length established at 15mm, maximum 10% of catch may be < 15mm	
1991	Sorting grid in Norwegian and Russian EEC and in Jan Mayen, bar spacing in Barents Sea and Spitsbergen is 19mm	ICES1998
1992	URSS and Norway agree to restrict by-catch of Greenland halibut to 300 individuals metric tonne ⁻¹	
1993	Use of sorting grid (20mm bar space) mandatory in Barents Sea to prevent catches of fish > 18cm	ICES 2004
1996	Restrictions on number of days at sea Restrictions on number of vessels per country	
1997	Closure of Svalbard area to nations without historical fishing rights.	Standal 2003

Despite the measures taken, the stocks of by-catch species have declined over the years. The five by-catch species of commercial value found in the Barents Sea and Svalbard area, cod (*G. morhua*), redfish (*S. mentella* and *S. marinus*), Greenland halibut (*R. hippoglossoides*) and haddock (*M. aeglefinus*) are all outside safe biological limits, meaning that regulating by-catch according to shrimp catches was not a good solution. In fact, the bioeconomical model may in certain cases protect the shrimp stock rather than the by-catch species. As it is, the model estimates the by-catch criterion by current shrimp catch and future yield of fish. Therefore it is most likely that closures are applied when shrimp stocks are small and fish stocks are large, as happened in 1993, rather than the other way around. The reason behind this is the lack of conservative factors in the model. These, however, are very difficult to incorporate in the short term due to lack of data. In this situation of poor health of the fish stocks the best solution is probably to put aside economical considerations and apply a more conservative biological approach (Aschan 2000b; Reithe and Aschan 2004).

Nevertheless, the main management problem the fishery faces currently is the large increase in capacity that the fleet has developed since the late eighties, motivated by the lack of TAC. Until 1998, the government limited the capacity of the fleet by controlling the renewal of licensed ships. However, fishermen with 34m (250 GRT) vessels for cod and shrimp wanted to improve them to fish in ice and lengthen the fishing season. This required very powerful vessels that could not be built under the legal size restriction of 34m and 250 GRT. Eventually the government gave up and allowed vessel renewals. Before 1999, the shrimp fleet was on average made up of vessels 25 years old and 35m in length. Between 1999 and 2000, 25 new trawlers were built, cod fishermen owning

modern vessels applied for shrimp licenses and twin and triple trawls came into use. The fleet became very diverse, with everything in the range between small vessels and 65m trawlers with triple trawl. The following figures illustrate very well the proportion of these changes (Standal 2003):

1. The fleet consisted of 166 ships in 1985, but 108 in 2001. However, annual catches in the Svalbard area increased by 50% between 1997–2000.
2. Catches from ships between 35–50m have remained stable during the period 1990–01 despite the fact that the number of ships has declined by 40%.
3. The number of shrimp trawlers > 50m rose by 140% whereas the number of shrimp trawlers < 50m declined by 138% from 1990 to 2002.
4. In 1996 only three trawlers had twin trawls, in 1997 they were 32 and in 2002 they were 36, two or four of which had triple trawls.

The development of the fleet has created a conflict of interest between fishermen, the government and the society, which is very difficult to solve. The new fleet requires a large income to keep going independently of the price of shrimp on the market. On the other hand, owners of small boats complain about the arrival of cod fishermen into the shrimp fishery, as the fleet increase they provoked resulted in the drop of profitability. Actually, the smaller range of the fleet would benefit from a TAC, as the Institute of Marine Research has advised in recent years. Stricter management would probably lead to improvement of the stock, which is in the long-term interest of society, but it would be difficult to implement. It would also have an adverse effect on the Norwegian fishery at least during the first years because the stock would have to be divided among the involved countries (Standal 2003).

3.1.4.3 Research

The Norwegian Directorate of Fisheries supported surveys to search for shrimp fishing grounds in the Svalbard area since 1923 (see review by Strøm and Øynes 1974). From 1970 to 1992, the Institute of Marine Research in Bergen carried out the surveys in the Barents Sea and Svalbard area (Strøm and Rasmussen 1970; Strøm 1971). The former USSR also had its own Barents Sea surveys since 1984, until both countries agreed in 1992 on continuing the stock assessment with joint surveys and common methodology (Table 3.8). This same year the Norwegian Institute of Fisheries and Aquaculture Ltd. (Fiskeriforskning) was appointed to carry out all research on shrimp in collaboration with the Norwegian College of Fisheries Science at the University of Tromsø (Aschan and Sunnanå 1997).

Table 3.8 Surveys carried out in Svalbard and Jan Mayen since 1970.

Year	Survey	Main results	Reference
Svalbard			
1970	Search	– <i>Spitsbergen</i> : 140–150 kg hour ⁻¹ – <i>Hopen</i> : 50 kg hour ⁻¹ , 120 kg of juvenile redfish, 20 kg of cod and 20 kg of juvenile haddock – <i>Bjørnøya</i> : 24 kg hour ⁻¹	Strøm and Rasmussen 1970
1971	Search	– <i>Bjørnøya</i> : Most hauls > 50 kg hour ⁻¹ , redfish most abundant by-catch species, up to 150 kg	Strøm 1971
1974	Mapping	Mapping of shrimp grounds in Svalbard and Barents Sea	Strøm and Øynes 1974
1976	Search	Large shrimp found in Kongsfjord, 170–180 individuals kg ⁻¹	Strøm 1976
1980–90	Norwegian stock assessment surveys	Collection of catch data, by-catch and biological information to estimate stock size, abundance of juveniles of marketable species and investigate the structure of the shrimp population.	Hylen et al. 1987 Hylen and Øynes 1986 Tveranger and Øynes 1986 Hylen and Øynes 1988 Hylen et al. 1989 Hylen and Ågotnes 1990 Hylen et al. 1984 Tavares and Øynes 1980 Teigsmark and Øynes 1981 Teigsmark and Øynes 1982 Teigsmark and Øynes 1983a Teigsmark and Øynes 1983b
1986–91	Russian stock assessment surveys	Collection of catch data, by-catch and biological information to estimate stock size, abundance of juveniles of marketable species and investigate the structure of the shrimp population.	Berenboim et al. 1986a Berenboim et al. 1987 Berenboim et al. 1990 Hylen and Ågotnes 1990 Mukhin and Sheveleva 1991
1987–00	By-catch	– Estimation of cod taken as by-catch, – Bioeconomic management of the shrimp fishery with by-catch of commercial species	Hylen and Jacobsen 1987 Veim 1994 Aschan 1999a Aschan 1999b Aschan 2000b
1992–96	Joint Norwegian and Russian stock assessment surveys	Collection of catch data, by-catch and biological information to estimate stock size, abundance of juveniles of marketable species and investigate the structure of the shrimp population.	Berenboim et al. 1992 Aschan et al. 1993 Aschan et al. 1994 Aschan et al. 1995 Aschan et al. 1996b
1997	Evaluation of surveys	Assessment of the three approaches used during the period 1980–97.	Aschan and Sunnanå 1997
Jan Mayen			
1974	Search	– Eight areas surveyed, two of them with catches > 500 kg hour ⁻¹ , and three with 100–500 kg hour ⁻¹ , – Four areas surveyed, best catches in NW ground, 60 tonnes in 69 hauls.	Anonymous 1974c Torrisen 1974
1976	Search	Large shrimp found SE and SW of the island, 130–160 individuals kg ⁻¹	Strøm 1976
1977	Experimental fishing	Winter fishery is not profitable	Olsen 1977
1979	Survey	Collection of catch data and biological information.	Torheim 1980
1995	Mapping	Larger shrimp found at depth > 300m, capelin, polar cod and long rough dab widely distributed, cod and Greenland halibut caught sporadically.	Aschan 1995

The main goals of the surveys are to estimate stock size and to increase knowledge on the population structure. Besides, the by-catch data can be used to estimate abundance of some fish species. The surveys cover the known shrimp grounds, or roughly 164,000 km² in the Barents Sea and

74,000 km² in Svalbard, and are stratified by depth in Svalbard but by fishing grounds in the Barents Sea. Since their beginning, the surveys have undergone several modifications to improve results. Thus the original design of random stations within strata changed into a design with fixed stations in a regular grid within the strata, and later to fixed stations in a depth stratified system (Aschan et al. 1993; Aschan and Sunnanå 1997).

The impact of cod on shrimp populations in the Barents Sea also was investigated. Berenboim et al. (1986b) were the first to describe the predator-prey relationship between cod and shrimp in the Barents Sea. A later study concluded that cod prey on shrimp of all age groups and the percentage of the shrimp stock eaten by cod ranged from 15 to 58% during the years 1981–1997 (Berenboim et al. 1999) (Table 3.9).

Table 3.9 Other research carried out in the Barents Sea shrimp stock.

Year	Research	Main results	Reference
1963–	Trawl selectivity	- Effect of different mesh size - Sorting panels - Use of sorting grids	Thomassen and Ulltang 1975 Nilsenn et al. 1986 Isaksen 1984 Rasmussen and Øynes 1974 Isaksen et al. 1992 Valdemarsen et al. 1996
1983– 2000	Growth	- Differences in growth rates at first female maturity at different depth - Three populations identified with different growth rates	Hansen and Aschan 2000 Hansen and Aschan 2001 Teigsmark 1983
1986–88	Analysis of survey data	- Alternative method to model stock density	Stolyarenko 1986
1988	Shrimp catchability	- Shrimp orientation (dependent on currents) may affect trawl catchability	Ivanov et al. 1988 Ivanov and Stolyarenko 1988
1991	Stock assessment	- Estimation of TAC	Berenboim et al. 1991
	Egg quality	- Egg volume and content increased towards high latitudes	Clarke et al. 1991
1991–	Genetic studies to identify sub-populations	- Very high genetic variation within locations, - Genetic gradients linked to water masses, - No sub-populations identified.	Kartavtsev et al. 1991 Rasmusen et al. 1993 Aschan 1997 Martinez et al. 1997 Drenstig et al. 2000
1997	Survey evaluation	Improvement of data collection with the changes in the survey during the period 1980–1997	Aschan and Sunnanå 1997
1999–	By-catch	- Bioeconomic model - By-catch estimates	Aschan 1999a, 199b Hysten and Jacobsen 1987 Veim 1994 Reithe and Aschan 2004
2000	Predation by cod Stock structure	- Cod predation affects greatly shrimp population dynamics - Distribution of shrimp of different sizes is depth dependent	Berenboim et al. 1986b Berenboim et al. 2000 Aschan 2000a
2003	Precision of abundance estimates Larval dispersal	- CV of estimates varies with the distribution of sampling locations. - Shrimp larvae travel between 0–330km	Harbitz and Aschan 2003 Pedersen et al. 2003

By-catch of commercial fish species in the shrimp grounds and bioeconomical management options for fishing areas with large catches of juvenile cod and haddock have also been investigated in the Barents Sea and Svalbard area (Hysten and Jacobsen 1987; Veim 1994; Aschan 1999a, 1999b, 2000b; Reithe and Aschan 2004).

The first shrimp samples from Jan Mayen were obtained in 1950 (Rasmussen 1953; Øynes 1977), but search for shrimp grounds did not start until the seventies (Table 3.11, Anonymous 1974c; Torrisen 1974; Strøm 1976; Olsen 1977). The distribution of the stock was mapped in 1979, and more surveys followed in 1980, 1981, 1994 and 1995. The Russians also surveyed the area intermittently between 1974 and 1990 (Aschan et al. 1996). These Norwegian and Russian surveys are merely mentioned in Norwegian annual reports and the results of most of them have not been published. However, some of the Norwegian data have been compiled (Aschan et al. 1996). The latest survey to map and assess the resources in the area was carried out in 1995 (Aschan 1995).

Genetic investigations have been carried out to identify shrimp sub-populations in the Barents Sea, Svalbard, Jan Mayen and the Norwegian coast, among other locations in the NE Atlantic (Table 3.9). Genetic variation was found to be very high within locations and there are genetic gradients linked to water masses, but distinct sub-populations were not identified. However, it was possible to define 14 biologically homogeneous subareas on the basis of growth rates that can be used in production models and multispecies virtual population analysis (Kartavtsev et al. 1991; Rasmussen et al. 1993; Aschan 1997; Martinez et al. 1997; Drengstig et al. 2000).

Research on selectivity of shrimp trawls must be mentioned here even though fishing experiments may have not been carried out within the study area. Mesh selection experiments started in 1968 and continued during the following years with comparisons of three different mesh sizes (Thomassen and Ulltang 1975). During the years 1975–78, the Institute of Fishery Technology Research carried out extensive research on the effectiveness of sorting panels in Norwegian shrimp trawls. These panels were attached to the aft belly with the purpose of directing fish towards the fish leading channel. The channel consisted of two small meshed “walls” that lead to the fish release in the lower belly. The upper part of the leading channel was a 60mm mesh that allowed shrimp to go through and enter the codend. Results were very good in trawls used in the in-shore fishery, but variable in the offshore shrimp trawls. The selectivity of the offshore shrimp trawls improved with the use of vertical side-sorting panels instead of the original horizontal panels (Isaksen 1984). Nilssen et al. (1986) also investigated mesh selection by adding bags made of finer mesh at different places in the trawl. They confirmed that most selection occurs at the codend, but they also found that by capturing

the shrimp that passed under the trawl, the catch increased by 27% per unit of swept volume.

The first trials to use a sorting device to minimize by-catch took place in 1970 and were performed on three different trawls, among them the “Kodiak” design used in the Norwegian offshore shrimp fishery. The sorting device consisted of a net with mesh size 130mm that would let the shrimp in but would direct fish outside the trawl. Results with the experimental trawl were highly satisfactory, with a reduction in fish by-catch in the range 75–98% (Rasmussen and Øynes 1974). Sorting grids have been successfully developed, and the newer designs allow fish to escape unharmed from the trawl without markedly reducing the shrimp catch (Isaksen et al. 1992; Valdemarsen et al. 1996). The Nordmøre grid is now mandatory in the shrimp fishery in Norwegian waters (Isaksen et al. 1990; Soldal 1995; Soldal and Engaas 1997; Valdemarsen and Misund 2003; ICES 2005). A comprehensive list of references regarding research on gear selectivity in Norway has been compiled in the ICES CM report 1998/B:2 (ICES 1998).

3.1.4.4 By-catch in the Norwegian offshore shrimp fishery

By-catch data from the Norwegian fishery are scarce and comparisons are not straightforward because papers from different years present results in different units and the shrimp stock assessment survey has undergone several modifications since 1970.

Barents Sea and Svalbard area

The first surveys searching for shrimp fishing grounds reported catches of Greenland halibut (*R. hippoglossoides*), polar cod (*B. saida*), haddock (*M. aeglefinus*), wolffish (*A. lupus*), redfish (*Sebastes* spp.), cod (*G. morhua*), capelin (*M. villosus*) and even one Greenland shark (*Somniosus microcephalus*). Close to Bjørnøya were also found grenadier (*C. rupertis*) and long rough dab (*H. platessoides*). These were small catches though, on average 143 kg of by-catch per haul in Jan Mayen and 40 kg in Bjørnøya, all species combined. Besides, most of the fish caught were juveniles (Strøm and Rasmussen 1970). Despite the low figures recorded in 1970, Teigsmark and Øynes (1981) pointed out that abundance of species of commercial interest, such as cod, haddock and Greenland halibut was more abundant in 1970. The records of both surveys are difficult to compare, especially because Strøm and Rasmussen (1970) did not record by-catch systematically and expressed their results in weight or numbers, often pooling the weight of several species. The average abundance and biomass of by-catch estimated from the survey data included in their papers do not show the decline mentioned by Teigsmark and Øynes (1981).

By-catch in the Norwegian offshore fishery was regularly recorded only during the period 1981–86 (Table 3.10), and after that it is not even mentioned. Off West Spitsbergen, redfish was usually the most common

by-catch species. In 1981 it accounted for 44% of by-catch, followed by polar cod (6.2%), cod (1.3%), Greenland halibut (1%) and capelin (1%). The remaining 47% of the by-catch was not identified. In 1982, cod was very scarce (0.5%) and 75% of it was below the minimal landing size. Juvenile haddock was caught in the shallower stations south of Spitsbergen. Capelin was the most abundant species (76.5%), followed by polar cod (8.1%). Redfish (7.4%) was caught in most tows but it was most abundant at depths between 200 and 250m and > 350m. The remaining species, Greenland halibut and long rough dab constituted 0.7 and 3.7% of the by-catch, respectively. Only 3% of the by-catch was not identified. Abundance of juvenile cod and haddock increased greatly in 1984, leading to the closure of areas where densities of these were high. Even though, in some cases up to 4,000 individuals were caught per trawling hour. In 1986, polar cod was the most abundant species (37.2%), cod was as abundant as in 1985 (3.8%) but haddock (0.1%), redfish (34.8%), Greenland halibut (1.4%) and capelin (2.4%) had declined (Teigsmark and Øynes 1981, 1983a; Hylen et al. 1984; Hylen and Øynes 1986). Other species present in the benthic assemblage were blue whiting (*Micromesistius poutassou*), saithe (*Pollachius virens*) and wolffish (*A. lupus*) (Godø and Nedreaas 1986).

Hylen and Jacobsen (1987) compiled data from surveys and commercial fishery to estimate by-catch of cod in the shrimp fishery north of 69°N. Cod recruited to the fishery at age one, and by-catch of cod aged one to three during the years 1982 and 1983 amounted to yield losses of 20,000 and 30,000 tonnes respectively.

Sorting grids were introduced in 1991 to minimize by-catch of fish species but seasonal catches of juvenile cod, haddock and redfish still remained a problem (Aschan 1999a). The stocks of commercial by-catch species have decreased greatly, stressing the need for alternative by-catch management methods (see management section).

Table 3.10 By-catch of commercial species in the shrimp fishery in Barents Sea and Svalbard area, in average number of fish per haul and per 3 nm trawled.

Year	Co	Ha	Rf	Gh	Ca	Pc	Lrd	Ot	Reference
1981	3	0	39	2	25	94	55	16	Teigsmark and Øynes 1981
1982	1	0	27	1	72	137	31	22	Teigsmark and Øynes 1982
1983	5	3	302	13	684	74	56	115	Teigsmark and Øynes 1983a Teigsmark and Øynes 1983b
1984	31	14	519	25	23	41	84	92	Hylen et al. 1984
1986	26	4	215	6	15	250	43	55	Hylen and Øynes 1986

Co: Cod, Ha: Haddock, Rf: Redfish, Gh: Greenland halibut, Ca: Capelin, Pc: Polar cod, Lrd: Long rough dab, Ot: Others.

Jan Mayen

By-catch data from Jan Mayen are even scarcer than from Svalbard. Very few surveys have been carried out there, and results have not been always published. The first surveys recorded that by-catch was very limited:

polar cod, few Greenland halibut, long rough dab and some capelin (Torrissen 1974; Strøm 1976). During the period 1979–1995, blue whiting, cod and Arctic cod have also been recorded in some years (Table 3.11). It is likely that changes in species composition are caused by the hydrographic conditions (Aschan et al. 1996).

Other by-catch fish species caught in Jan Mayen were snake blenny (*Lumpenus lampretaeformis*), spotted snake blenny (*Leptoclinus maculatus*), two horned sculpin (*Icelus bicornis*), pogge (*Agonus cataphractus*), Atlantic poacher (*Leptagonus decagonus*) and short horned sculpin (*Mioxocephalus scorpius*) (Torheim 1980; Aschan 1999b).

Table 3.11 By-catch in Jan Mayen.

Mean weight (kg) of fish per 3 nm trawled							
Year	Gh	Lrd	Bw	Ca	Pc	Co	Ac
1979	0.55	32.95	148.73	46.45	200.95	0.18	0.00
1980	3.82	10.98	1.40	0.33	2.83	0.83	0.00
1981	8.25	7.13	0.04	0.11	0.69	0.00	0.00
Mean number of fish per 3 nm trawled							
Year	Gh	Lrd	Bw	Ca	Pc	Co	Ac
1994	0.17	6.11	0.00	78.06	31.28	0.00	0.00
1995	0.09	10.09	0.00	1680.18	52.97	0.00	5.24

Gh: Greenland halibut, Lrd: Long rough dab, BW: Blue whiting, Ca: Capelin, Pc: Polar cod, Co: Cod, Ac: Arctic cod. Data from Aschan et al. (1996a).

3.1.5 Discussion

The three shrimp fisheries analysed in this review have followed very different trends. The Icelandic fishery increased rather steadily, except for a decline between 1987–1989, and peaked at 66,000 tonnes in 1995. Catches decreased abruptly between 1998–2000 and for the last few years have remained below 30,000 tonnes. Most of the shrimp catch is from the fishing grounds off North Iceland.

The Greenlandic fishery has grown spectacularly since its beginning in 1970 due to both the gradual expansion of the fishing grounds from the Disko Island area to most of the continental shelf in both West and East Greenland, south of 73°N and 67°N respectively, and to the fleet improvement. It seems unlikely that these two factors could lead to future increases in catch. The Greenland Home Rule has restricted since 1990 further growth of the fleet because of its excessive fishing capacity. Shrimp exports are a very important source of income and therefore the conservation of the stock and high catches will represent the main challenge in the management of this fishery.

Catches from the shrimp fishery off Svalbard, Jan Mayen and in the Barents Sea have oscillated in most years between 40–80,000 tonnes, although they reached nearly 130,000 tonnes in 1985. There is no TAC to

regulate this fishery. Otherwise management is very similar within the study area and it is based on licensing, minimum landing size, mesh size, use of sorting grids to decrease by-catch and temporal closures depending on by-catch of juvenile fish.

Unlike in Greenland, where cod has been practically absent most years since 1970, the Icelandic and Norwegian offshore shrimp stocks seem to depend largely on the cod stock size (Figures 3.29 and 3.30), although shrimp is not the main prey species of cod, and its consumption is highly correlated with predator size. In general, cod > 20cm prefer fish and it is only young cod that prey on shrimp (Pálsson 1994). Research on cod stomach contents in Iceland revealed that shrimp was mostly consumed by cod of age 3 or sizes 15–19 and 20–24cm, but even within this age and size range shrimp only constitutes a small part of the diet (Magnússon and Pálsson 1989, 1991). Shrimp consumption is also very variable among seasons and years (Pálsson 1983). Magnússon and Pálsson (1989) estimated that shrimp represented between 0.8 and 19% of cod diet (ages 2–8 years) in March 1980–1986, but 3.4–32.4% in October–November 1979–1983 and 1985. A stock-production model using survey data estimated shrimp consumption by cod in the offshore grounds off North Iceland to be within the range of 4,700–15,800 tonnes during the period 1978–1997, with an average annual consumption of 11,560 tonnes (Stefánsson et al. 1994). However, the impact of fishing should not be overlooked, as catches during the same period and in the same area ranged from 1,140 to 42,000 tonnes, with an average annual catch of 16,800 tonnes.

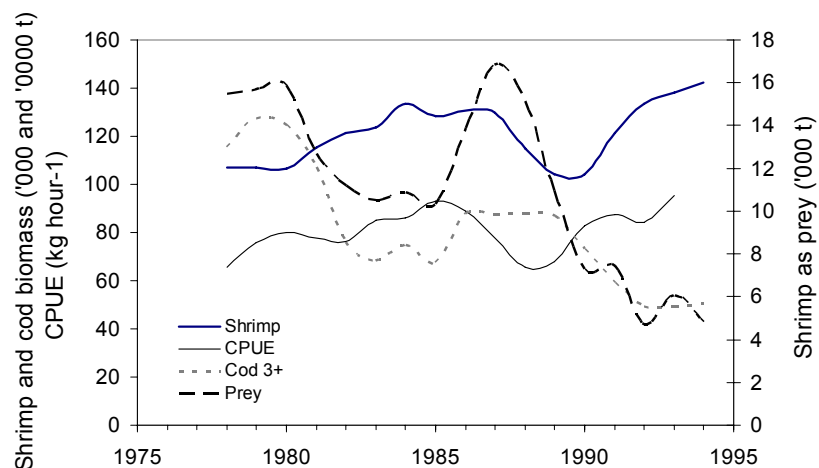


Figure 3.29 Iceland. Trends of shrimp and cod 3+ (age 3 and older) biomass (in '000 and '0000 tonnes, respectively) and CPUE (in kg hour⁻¹), in left y-axis, and shrimp consumed by cod (in '000 tonnes, right y-axis) in Icelandic waters during the period 1978–1993. Data from Stefánsson et al. (1994) and Anonymous (2003).

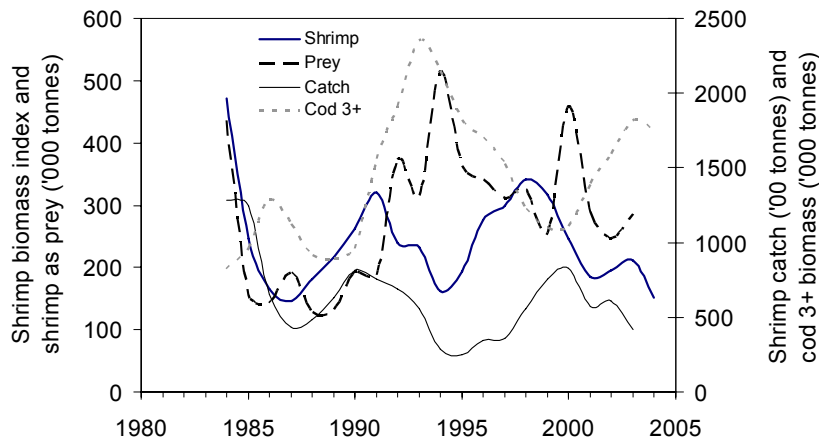


Figure 3.30 Barents Sea and Svalbard area. Trends of shrimp biomass index and shrimp consumed by cod (in '000 tonnes, left y-axis), cod 3+ (age 3 and older) biomass (in '000 tonnes) and shrimp catch (in '00 tonnes), both in right y-axis, in the Barents Sea during the period 1984–2004. Data from Anonymous (2004).

In the Barents Sea, shrimp biomass follows trends opposite to those of biomass of cod age 3+ and predation on shrimp, and the trend of shrimp catch is very similar to that of shrimp biomass, as in Iceland (Figure 3.30). The amount of shrimp eaten by cod during the period 1984–2004 has been estimated to be between 129,000 and 516,000 tonnes, or 282,000 tonnes on average per year. However, the ICES *Pandalus* Assessment Working Group (ICES WGPAND) warned that these figures may have been overestimated, and in fact the figures for biomass of shrimp consumed by cod are in some years higher than the shrimp index. Landings of shrimp for the same period have ranged from 25,000 to 128,000 tonnes, or 62,500 tonnes on average per year (ICES 2005). Cod is therefore a very important factor in the management of the shrimp stocks. The modelling department of the MRI in Iceland has been working for years on the development of BORMICON, a multispecies model that uses ecological information and variables, such as cannibalism, predation and growth, among many others, to investigate stock trends in Boreal ecosystems (Stefánsson and Pálsson 1998).

Another problem for management of the shrimp stocks is the by-catch of commercial fish species. Andrew and Pepperell (1992) gave a rough estimate of the by-catch:shrimp ratio for temperate areas of 5:1, according to FAO data from 1980. Furthermore, extrapolating FAO data from 1986, they estimated by-catch in the world shrimp fisheries at 16.5 million tonnes year⁻¹, or 20.5% of the total world catch for all species.

Within the study area of this paper, sorting grids are widely used and have been apparently successful in preventing the capture of fish > 18cm, yet abundance and biomass trends of many by-catch species are declining and the commercial fish species are below safe biological limits in the

Barents Sea. A detailed discussion on the by-catch problem is out of the scope of this paper, but there are some observations relevant to this study:

- a) Research and literature on by-catch in the NE Atlantic shrimp fisheries is astonishingly scarce, considering how little is known about their impact on demersal communities within the study area and the economical status of the countries involved. The use of sorting grids has reduced the landings of fish by-catch by 99% in some shrimp fisheries, and it has been estimated that by-catch of cod and haddock in the Barents Sea is about 1% (for each species) of the shrimp landings. However, in shrimp fisheries where sorting grids are not used, such as in the Norwegian Deeps, by-catch of commercial fish species has ranged from 13 to 45% of the shrimp catch (ICES 2005). Interestingly enough, most of the available literature on by-catch within the study area corresponds to Greenland, which has more limited resources than Iceland and Norway. Survey data collection has improved over the past two decades, but it is not enough yet.
- b) By-catch data from the commercial fleet are extremely scarce in the literature. There should be systematic sampling of by-catch on board the commercial fleet. In Iceland, for example, observers have been sent to shrimp vessels but not to register by-catch, despite the requirements from the scientists responsible for shrimp research. By-catch data from the commercial fleet are limited to landings of marketable species above the legal minimum landing size, but there are no data on discards of undersized by-catch species or non marketable species.
- c) More resources should be allocated to develop more selective shrimp trawls.

The large fluctuations of environmental factors due to the alternation of cold and warm periods related to the large-scale atmospheric circulation over the North Atlantic also play a major role in fish and shrimp stock abundance in Greenland, Iceland and the Barents Sea. During cold periods, cold Arctic water masses predominate over warm and also more saline Atlantic water, leading to increased stratification of surface layers, shorter duration of phytoplankton blooms and therefore decline of zooplankton that affects pelagic species and their predators. This was the situation at the beginning of the 20th century until 1920, and after the climate deterioration period that started in the mid 1960s and culminated with the “Great Salinity Anomaly” during the 1970s. These climate changes influenced the following events, among others (Buch 2000; Jakobsson 1992; Jakobsson and Stefánsson 1988; Vilhjálmsson 1997; Hamilton et al. 2000; Anonymous 2005):

- a) the onset of the cod fishery in Greenland at the beginning of a warm period, peaking at 130,000 tonnes in 1936 and collapsing at the end of the 1960s when water temperature decreased,
- b) the onset of the shrimp fishery, coinciding with the beginning of the cooling period in the late 1960s–early 1970s,
- c) the distribution of capelin in West Greenland, that reached 76°N in 1936,
- d) drift of cod between Iceland and Greenland, that took place intermittently during the period 1920s–1960s and in 1984–85, when cold Arctic water blocked the Atlantic water carried by the Irminger current,
- e) collapse of the Icelandic capelin and herring fisheries in the 1980s,
- f) collapse of the capelin and herring stocks in the Barents Sea in the mid-1980s, which decreased significantly the food availability for cod,
- g) the increased migration of cod to North and East Iceland coinciding with the warming up of the ocean since 1997 has led to an important reduction of shrimp biomass

On a smaller spatial scale, annual variation in the distribution and recruitment of the shrimp stock in the Barents Sea seems to be related to the location of the Polar Front (Aschan et al. 2000; Høyen et al. 1984).

Changes in environmental conditions therefore influence many of the variables used in stock assessment, such as growth rates, recruitment, migrations and predator-prey relationships, and as Jakobsson (1992) stressed, good knowledge of the environmental characteristics of each ecosystem and understanding of their impact on the marine resources is essential for adequate management strategies.

3.2 Study of long-term changes in by-catch species assemblage in the Icelandic offshore shrimp fishery

E. Guijarro Garcia

3.2.1 Introduction

The shrimp fisheries worldwide are responsible for the largest percentage of total by-catch. Alverson et al. (1994) estimated that shrimp fishing generated 11.2 million tonnes of the annual 27 million tonnes of global discards. Accurate estimates of by-catch are difficult to obtain. Authorities and fishing vessels only keep records of incidental catch, that is, marketable by-catch. Andrew and Pepperell (1992) estimated the biomass of discards during 1986 for countries with shrimp catches over 5,000 tonnes year⁻¹ assuming 5:1 and 10:1 ratios of by-catch:shrimp catch. According to this, weight of by-catch would have been between 180–360 and 320–641 thousand tonnes in the shrimp fisheries of Iceland and Greenland. These figures are too high. Reported discards of fish in the Greenlandic shrimp fishery have been around 1% in weight of the total catch since 1975, and increased to 3% during 1987–1988, probably due to the introduction of observers on all offshore vessels (Hvingel 2004a). Thus, during the period 1973–2004 by-catch biomass in the Greenland fishery averages 0.6 thousand tonnes year⁻¹ assuming that by-catch is 1% of shrimp catches, but 1.8 thousand tonnes year⁻¹ if we assume that by-catch is 3% of the catch. Reported by-catch of the offshore shrimp fishery in Iceland during the period 1988–1995 averages 0.8 thousand tonnes year⁻¹.

In recent years, assessment and reduction of by-catch in the shrimp fishery has been the goal of much research that has yielded good results (see Andrew and Pepperell 1992; Saila 1983; Broadhurst 2000 for reviews and Research sections 3.1.3.3, 3.1.4.3 and 3.1.5.3 in this report for studies on shrimp trawl improvement within the study area). Nordmøre grids are the most widely used sorting device in the shrimp fleets of Iceland, Greenland and Norway to prevent by-catch. Sorting grids were implemented in Iceland in 1995. Although it is important to minimize the impact of shrimp trawls on benthic communities, other associated problems, such as habitat destruction, are still not solved.

Offshore shrimp fishing in Iceland started in the mid-1970s and since 1984 it has supplied a large proportion of total shrimp catches (see review above). By-catch data are available from the surveys that the MRI of Reykjavík conducts annually to estimate the size of the offshore shrimp stock. All fish by-catch is length-measured and counted. In addition there are data from the logbooks on by-catch species landed by the shrimp

fleet. These, however, represent an underestimate of by-catch in the commercial fishery since all undersized or non-marketable fish is discarded at sea.

The goals of this study were 1) to estimate the catch of non-targeted species and investigate spatial and temporal trends; 2) to analyse the impact of the shrimp fishery on the demersal fish community.

3.2.2 Material and methods

The study area

To avoid artefacts due to impact of fishing gear other than shrimp trawl it was decided that the study area would comprise all offshore shrimp fishing grounds where at least 90% of the fishing effort corresponds to shrimp trawling. Thus 59 rectangles were selected, most of them North of Iceland but also some from the NE and E.

Survey data

The data were obtained from the annual offshore shrimp surveys and the demersal fish survey carried out by the MRI. The sampling design of the surveys is based on stations with fixed positions. Only stations sampled ten or more years were included in the study. This restriction left a total of 119 stations from which 1,776 samples were taken during the period 1988–2003. Depth within the study area is between 100–700m.

By-catch species have been identified to species level when possible, and the number of individuals in each haul recorded. Since 1996 all fish species are also measured. The number of fish measured is fourfold the range in length for most marketable species, but fivefold for Greenland halibut and twofold for long rough dab. For the remaining species a maximum of 20 individuals per station are measured.

Commercial fishery data

Logbooks data for the selected time period and area were used to investigate the trends of fishing effort and by-catch in the shrimp fishery. Fishing effort is recorded as number of trawling hours in each fishing day.

Data analysis

Only demersal fish species are taken into account for analysis since the shrimp trawl does not sample pelagic fish and benthic invertebrate species adequately.

Some types of multivariate analysis cannot be performed on data that show a strong gradient (Clarke and Warwick 2001), such as fish communities in a large depth range. For this reason the rectangles have been classified according to depth strata as deep (D, > 450m), medium (M, 250–450m) and shallow (S, < 250m). Data from the deep and shallow strata were very scarce, with only 8 and 5% of the samples respectively,

so it was not advisable to compare diversity indexes between depths because they are largely dependent of sample size. Therefore data from the shallow and deep strata were only used to estimate abundance of the most common species at the different depth intervals with Similarity Percentages (SIMPER) analysis and compare the demersal fish assemblage with a multi-dimensional scaling ordination (MDS plot). The MDS technique involves the calculation of similarity matrixes, in which all possible pairs of samples are compared in terms of present species and their biomass. The data are then plotted in a dimensionless graph, in which proximity between two points (samples) indicates similar faunal composition and abundance of each species between them. Thus, samples that are similar in their species composition will appear close in the plot, whereas samples with distinctly different species composition will be drawn apart. External variables – fishing effort in this case – can be superimposed onto the plotted data to assess their influence in the ordination. In this case, superimposed data are represented by bubbles. The bubbles are scaled to the maximum value of the factor they represent, meaning that the bigger the bubble, the higher the value of the plotted datum. The stress value printed in the superior right corner of the ordination indicates goodness of fit of the regression on which the ordination is based, the closer to 0, the better the regression. The data were square root transformed prior to analysis to give more weight to the rarer species (Clarke and Warwick 2001).

Pooled data for the period 1988–2003 on average abundance from the medium stratum were also square root transformed and analysed with MDS ordinations to investigate the spatial distribution of by-catch species and fishing effort. Abundance of by-catch species and fishing effort data were superimposed to the ordinations to analyse if there were any relationships between these two factors.

The same technique was used to investigate the variability in fish abundance between years and analyse if it was related to patterns of fishing effort.

Fishing effort was estimated as the sum of trawling hours within any given rectangle each year.

The diversity indexes species richness (S), evenness (J') and Shannon's diversity (H' , $\log_e$) were estimated for the study period to investigate if there were changes in their trends that could be associated with the use of sorting grids. Average of each index was estimated for each rectangle within the medium depth stratum and each year. Data were then grouped in three periods, prior to the use of the sorting grid (< 1995), the year in which the sorting grid was implemented (1995) and the years afterwards (> 1995).

3.2.3 Results

A total of 71 demersal fish species were recorded during the shrimp and demersal fish annual surveys during the period 1988–2003. Redfish (*Sebastes* spp.) figures as the most abundant on average and had the highest CPUE, but these are juveniles from only 15 stations that were not identified to species level. They were followed by Arctic cod (*Boreogadus saida*), golden redfish (*Sebastes marinus*) and snake blenny (*Lumpenus lampretaeformis*), with mean abundance 1,061, 971 and 620 fish km⁻², respectively. These species were found in 71.5, 49.2 and 8.7% of the stations, respectively. However, the most widely distributed species were Greenland halibut (*Reinhardtius hippoglossoides*), Arctic cod and long rough dab (*Hippoglossoides platessoides*) (Table 3.12). Only 12 species were present in more than 25% of the stations, and 35 species were present in less than 1% of the stations (Table 3.12).

The large depth gradient within the study area influenced the species composition within the study area (Figure 3.31). The most abundant species in the shallow stratum were long rough dab, snake blenny and golden redfish, whereas in the medium stratum polar cod, golden redfish and eelpouts (Zoarcidae) were the dominant taxa (Table 3.13). In the deep stratum also dominated polar cod and eelpouts (Zoarcidae and *L. eudipleurosticus*). According to the differential distribution of the identified *Lycodes* species along the depth gradient, the unidentified *Lycodes* species found in the deep stratum could be in their majority *L. eudipleurosticus*, which makes up 80% of the total number of *Lycodes* species at depth > 500m.

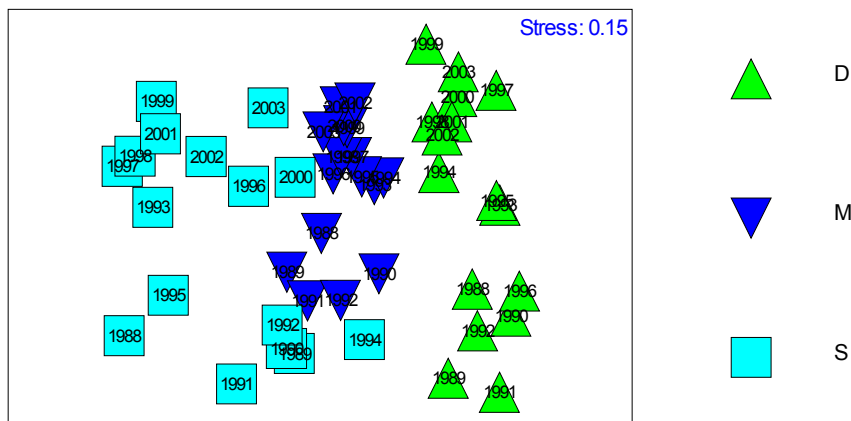


Figure 3.31 Multidimensional Scaling (MDS) plot showing variability in mean abundance (number of fish km⁻²) between depth strata and years. S: shallow (<250m), M: medium (250–499m), D: deep (>500m).

Table 3.12 Demersal species recorded in Iceland during the shrimp and groundfish annual surveys during the period 1988–2003.

Species	Common name	Abundance		CPUE		Samples
<i>Sebastes</i> spp.	Redfish	1265.7	± 2097.7	220.0	± 364.2	0.8
<i>Boreogadus saida</i>	Polar cod	1061.4	± 2533.0	188.7	± 465.5	71.5
<i>Lumpenus lampretaeformis</i>	Snake blenny	1028.3	± 1748.7	182.8	± 305.1	8.8
<i>Sebastes marinus</i>	Golden redfish	971.4	± 3775.1	176.1	± 663.3	49.3
<i>Lycodes</i> spp.	Eelpots	951.4	± 1453.7	182.8	± 309.0	30.9
<i>Chiropolis ascanii</i>	Yarrel's blenny	910.5		164.6		0.1
<i>Hippoglossoides platessoides</i>	Long rough dab	620.5	± 1464.3	118.4	± 274.5	49.4
Lumpenidae	Blennies	486.0	± 927.0	87.7	± 165.0	5.3
<i>Beryx splendens</i>	Golden eye perch	462.1	± 813.4	82.5	± 140.4	27.9
<i>Artediellus atlanticus</i>	Atlantic hookear sculpin	357.4	± 665.4	63.4	± 117.5	36.8
<i>Gadus morhua</i>	Atlantic cod	325.4	± 1234.7	64.1	± 239.2	44.9
<i>Lycodes eudipleuros-tictus</i>		294.1	± 560.4	52.7	± 102.7	30.7
<i>Lycodes vahli</i>	Vahl's eelpout	278.9	± 535.1	50.8	± 98.6	23.1
<i>Lycodes squamiventer</i>		259.4	± 112.3	45.4	± 16.5	0.1
<i>Lycodes seminudus</i>		235.0	± 454.1	42.2	± 78.7	18.2
<i>Lycodes reticulatus</i>	Arctic eelpot	216.0	± 365.0	38.7	± 64.7	19.2
<i>Eutrigla gurnardus</i>	Grey gurnard	198.5		33.1		0.1
<i>Leptagonus decagonus</i>	Atlantic poacher	192.9	± 305.5	36.0	± 59.2	44.2
<i>Liparis montagui</i>	Montagu's seasnail	181.5	± 229.2	33.2	± 42.2	1.6
<i>Sebastes mentella</i>	Deep-sea redfish	164.3	± 275.9	29.3	± 48.8	26.9
<i>Agonus cataphractus</i>	Poacher	164.1	± 245.0	30.2	± 43.1	0.2
<i>Coryphaenoides rupestris</i>	Rock grenadier	158.8		26.5		0.1
<i>Lycodes rossi</i>		153.8	± 302.5	27.2	± 54.1	1.2
<i>Pleuronectes platessa</i>	European plaice	142.6	± 325.0	26.0	± 59.0	1.0
<i>Reinhardtius hippoglossoides</i>	Greenland halibut	136.1	± 217.5	24.4	± 40.6	80.0
<i>Leptoclinus maculatus</i>	Spotted snake blenny	118.5	± 168.4	21.1	± 29.8	3.6
<i>Careproctus reinhardti</i>	Sea tadpole	109.0	± 157.3	19.4	± 27.5	37.5
<i>Liparis</i> spp.	Seasnails	108.2	± 221.3	19.1	± 38.6	7.4
<i>Lophius piscatorius</i>	Monk fish	105.9	±	17.6	±	0.1
<i>Paraliparis bathybius</i>		94.5	± 92.8	15.8	± 15.4	0.2
<i>Melanogrammus aeglefinus</i>	Haddock	85.7	± 157.0	19.1	± 43.0	7.0
<i>Raja radiata</i>	Starry ray	81.8	± 141.8	17.1	± 35.7	37.2
<i>Lycodes frigidus</i>		78.4	± 53.6	17.5	± 16.7	0.5
<i>Trisopterus esmarki</i>	Norway pout	74.1	± 91.6	13.3	± 16.4	1.6
<i>Molva dypterygia</i>	Blue ling	74.1	±	12.8	±	0.1
<i>Lycodes esmarki</i>	Esmark's eelpot	71.1	± 104.7	12.8	± 18.7	14.0
<i>Liparis fabrici</i>	Gelatinous seasnail	69.5	± 244.1	12.2	± 41.8	8.4
<i>Rhinonemus cimbrius</i>	Fourbeard rockling	66.2	± 52.9	12.2	± 8.9	0.2
<i>Chimaera monstrosa</i>	Rat-tail	63.5	±	11.9	±	0.1
<i>Anarhichas lupus</i>	Wolffish	62.9	± 171.2	18.4	± 57.6	3.0
<i>Icelus bicornis</i>	Twohorn sculpin	56.2	± 43.2	10.9	± 8.2	0.7

Table 3.12 (Cont.)

Species	Common name	Abundance			CPUE			Samples
<i>Microstomus kitt</i>	Lemon sole	49.8	±	55.4	9.4	±	10.6	0.1
<i>Merlangius merlangius</i>	Whiting	48.0	±	74.3	8.2	±	11.9	0.6
<i>Ammodytes tobianus</i>	Lesser sandeel	44.5	±	27.0	7.9	±	4.5	0.1
<i>Myoxocephalus scorpius</i>	Shorthorn sculpin	41.0	±	13.0	6.9	±	2.0	0.1
<i>Lycenchelys kolthoffi</i>	Checkered wolfeel	40.7	±	28.4	7.3	±	5.1	2.6
<i>Lycenchelys muraena</i>		38.9	±	34.4	7.0	±	6.5	0.4
<i>Sebastes viviparus</i>	Norway haddock	38.1	±	52.5	6.8	±	9.4	1.1
<i>Cottunculus microps</i>	Polar sculpin	37.6	±	39.1	7.6	±	7.2	2.3
<i>Lycodon flagellicauda</i>		35.9	±	36.3	6.4	±	6.3	0.5
<i>Gymnelus retrodorsalis</i>		35.7	±	28.4	6.5	±	5.3	0.8
<i>Onogadus argentatus</i>	Silver rockling	34.3	±	36.4	6.3	±	6.6	8.8
<i>Hyperoplus lanceolatus</i>	Greater sandeel	31.8			5.5			0.1
<i>Molva molva</i>	Ling	31.8	±	33.7	6.0	±	4.9	0.1
<i>Triglops murrayi</i>	Moustache sculpin	29.7	±	27.4	5.6	±	5.4	6.0
<i>Glyptocephalus cynoglossus</i>	Witch	28.9	±	31.7	5.9	±	5.8	1.9
<i>Anarhichas minor</i>	Spotted wolf-fish	27.8	±	31.5	5.2	±	6.5	25.2
<i>Raja clavata</i>	Thornback ray	22.7			3.8			0.1
<i>Raja hyperborea</i>	Northern skate	21.7	±	19.0	3.9	±	3.7	3.9
<i>Brosme brosme</i>	Tusk	19.1	±	18.3	4.4	±	3.9	0.5
<i>Cyclopterus lumpus</i>	Lumpsucker	18.2	±	13.3	5.3	±	4.5	1.4
<i>Ammodytes marinus</i>	Sandeel	15.9			3.1			0.1
<i>Cottunculus thomsonii</i>	Pallid sculpin	15.9			2.9			0.1
<i>Phycis blennoides</i>	Forkbeard	15.9			2.8			0.1
<i>Raja batis</i>	Grey skate	14.0	±	3.2	3.1	±	0.9	0.3
<i>Anarhichas denticulatus</i>	Arctic wolf-fish	13.6	±	6.5	2.5	±	1.2	2.4
<i>Gaidrosaurus vulgaris</i>	Three bearded rockling	12.7			2.2			0.1
<i>Liparis liparis</i>	Common seasnail	12.7			2.3			0.1
<i>Limanda limanda</i>	Common dab	11.3	±	2.0	2.9	±	0.9	0.1
<i>Raja lintea</i>	Sailray	10.6	±	0.0	1.8	±	0.1	0.1
<i>Squalus acanthias</i>	Dogfish	10.6			1.8			0.1
<i>Pollachius virens</i>	Saithe	9.6	±	2.0	2.1	±	0.5	0.3
<i>Hippoglossus hippoglossus</i>	Atlantic halibut	7.9			2.9			0.1
<i>Somniosus microcephalus</i>	Greenland shark	7.9			1.4			0.1

Abundance is given as number of fish km⁻², CPUE as number of fish caught hour⁻¹. The column Samples shows the percentage of samples in which each species was found.

Table 3.13 Mean abundance of species that contributed most to the dissimilarity in the demersal fish assemblage between depth strata according to SIMPER analysis.

Species	S	M	D
<i>Hippoglossoides platessoides</i>	1685.6	495.8	6.2
<i>Lycodes</i> spp.	121	593.9	482.5
<i>Lumpenus lampretaeformis</i>	842	566	1.9
<i>Sebastes marinus</i>	450.6	710.7	31.4
<i>Arteidiellus atlanticus</i>	58	372.1	10.7
<i>Boreogadus saida</i>	100	1044.8	694
<i>Beryx splendens</i>	127.5	374	67.7
<i>Lycodes vahli</i>	156.5	303.3	8.4
<i>Lycodes eudipleurostictus</i>	11.1	222	445.7
<i>Gadus morhua</i>	412.1	239.1	10.4
<i>Lycodes seminudus</i>	16.2	261	120.3
<i>Raja radiata</i>	126.6	84.3	14.1
<i>Lumpenidae</i>	471.6	216	0

S: shallow (<250m), M: medium (250–499m), D: deep (>500m).

Spatial trends in abundance of by-catch species

Average abundance of demersal by-catch fish species within each rectangle in the medium depth stratum for the period 1988–2003 was plotted in a MDS ordination (Figure 3.32A). The actual average abundance values were superimposed in the plot, represented as bubbles. The plot showed that fish are unevenly distributed, and there is no clear pattern of distribution.

Fishing effort data were superimposed over the same ordination (Figure 3.32B). Fishing effort in the different rectangles within the medium depth stratum ranged between 0.1–4.5 million trawling hours. Thus the biggest bubble would represent the maximum effort, which took place in only one rectangle, the medium-sized bubbles represent effort of two to three million trawling hours, and the smallest bubbles represent effort < 1 million trawling hours. There is no clear pattern in figures 3.32A and 3.32B to suggest that fish abundance is affected by increasing fishing effort.

However, the line plot representing number of trawling hours and fish abundance shows that the trends of fishing effort and fish abundance are asynchronous (Figure 3.33).

Finally, abundance data from each of the most common commercial by-catch species were also superimposed over the MDS ordination to compare their distribution with the distribution of fishing effort (Figure 3.34). Golden redfish, deep-sea redfish and Greenland halibut were most abundant in some of the rectangles where fishing effort is higher, and actually the distribution of Greenland halibut resembles rather closely the distribution of fishing effort. Plaice (*Pleuronectes platessa*) was found only in two rectangles, one of which with medium-high effort (in the 3 million hour interval). On the other hand, long rough dab and cod (*Gadus*

morhua) were most abundant in rectangles of lower effort (< one million trawling hours).

The available by-catch data from the commercial fishery correspond to landings of marketable fish by-catch, also called incidental catch (Jennings et al. 2001). During the period 1988–2000, shrimp fishing vessels landed at least 16 demersal fish species (Table 3.13) that summed nearly 6,500 tonnes. Of these, 50.6% were Greenland halibut and 35.0% were cod.

The spatial distribution of captured cod and Greenland halibut by the shrimp fleet with respect to the abundance of all by-catch species is shown in Figure 3.35. Whereas catches of Greenland halibut correlate well with the distribution of the species shown in Figure 3.34, catches of cod do not always concentrate in those rectangles where this species is most abundant, according to survey data.

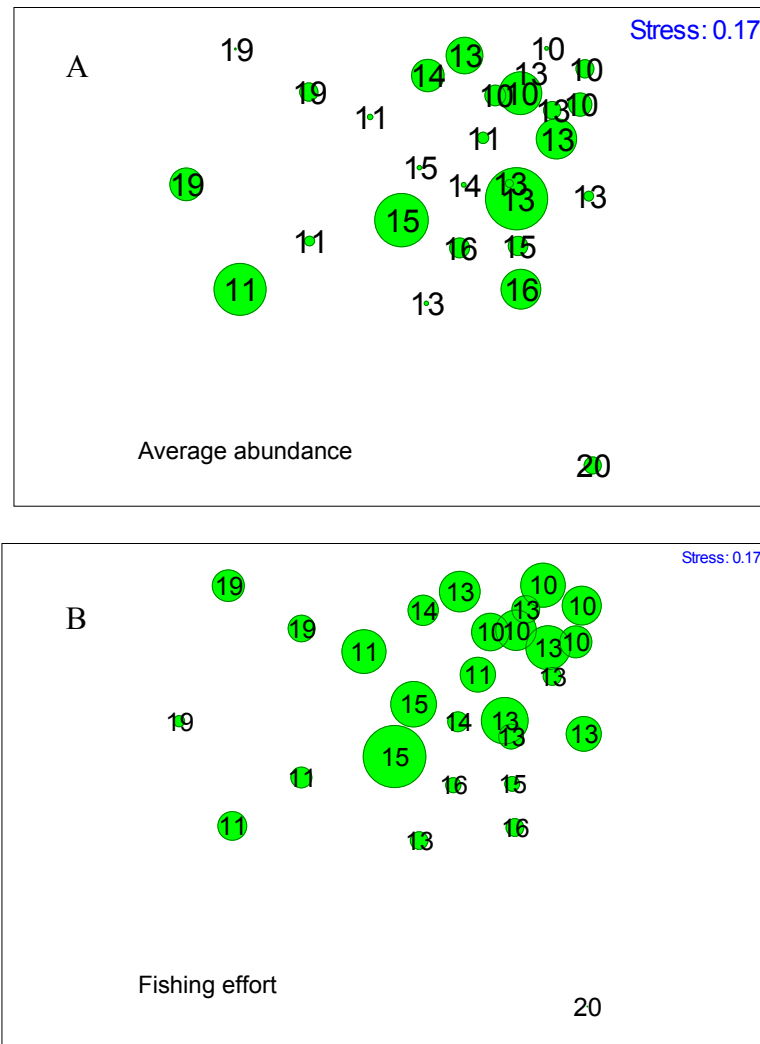


Figure 3.32 MDS ordinations based on average abundance data of all by-catch species from each rectangle within the medium depth stratum (250–499 m). The numbers indicate the strata number to which each rectangle belongs. The bubbles in figure A represent average abundance (mean number of fish km^{-2}) of all demersal fish species present in each rectangle during the period 1988–2003. The size of the bubble is proportional to the maximum value of the represented factor, mean abundance in this case. In figure B, the bubbles represent the total fishing effort (sum of trawling hours) in each rectangle for the same period.

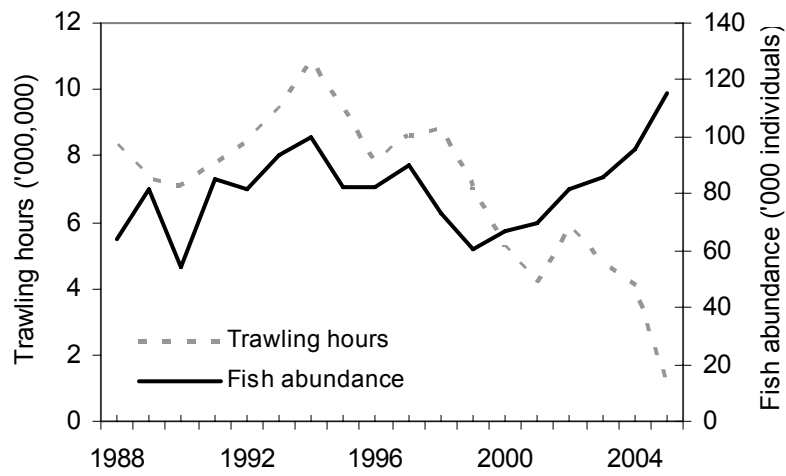
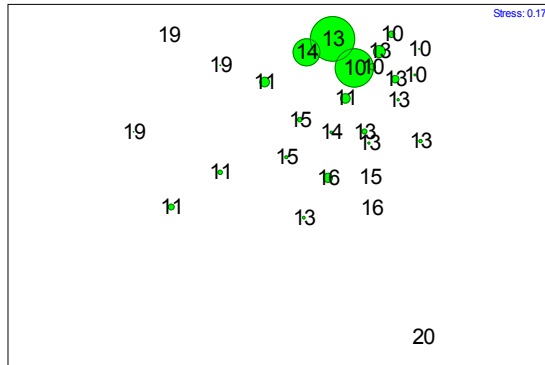
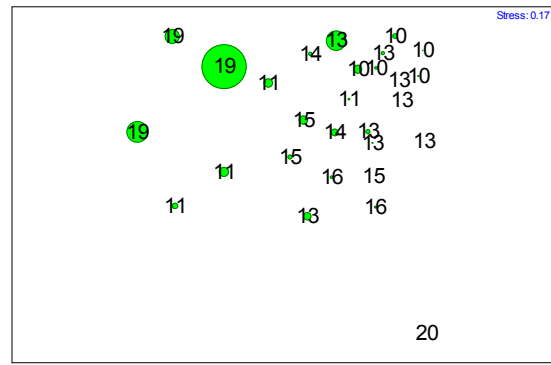


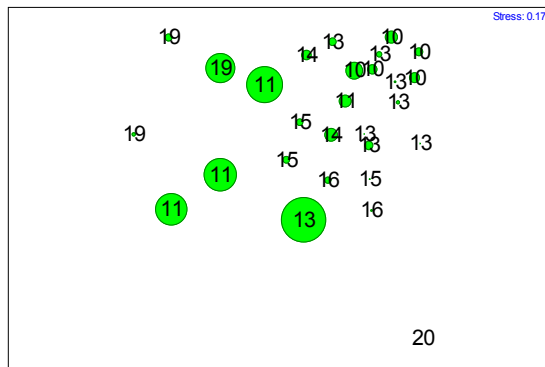
Figure 3.33 Fishing effort in the shrimp fleet, expressed as millions of trawling hours (left y-axis) and fish abundance recorded in the offshore shrimp surveys and demersal fish survey, expressed as number of individuals.



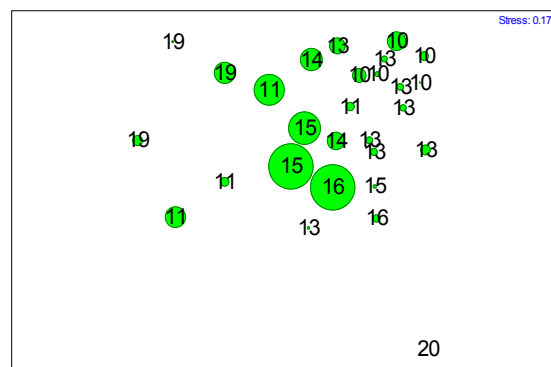
Sebastes marinus



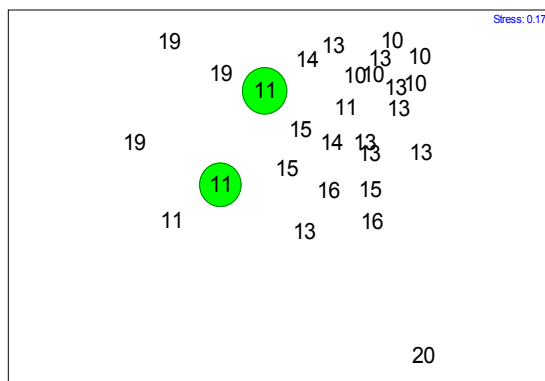
Hippoglossoides platessoides



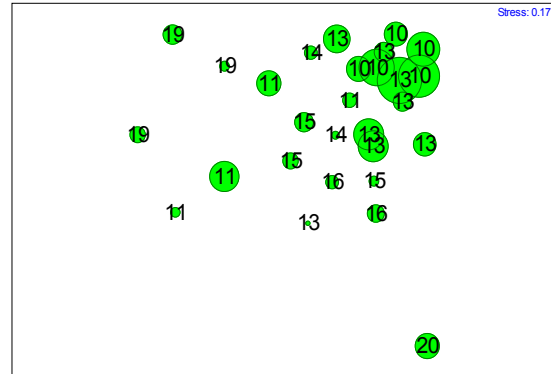
Gadus morhua



Sebastes mentella



Pleuronectes platessa



Reinhardtius hippoglossoides

Figure 3.34 MDS ordinations based on average abundance of demersal by-catch fish species, with average abundance of the most abundant commercial species overlapped. For simplicity, the sample labels refer to the strata number to which each rectangle belongs. Comparing these plots with Figure 3.32B it can be seen that the main distribution area of *R. hippoglossoides* coincide largely with the distribution of fishing effort. Similarly, the rectangles where *S. marinus* and *S. mentella* are most abundant also support some of the higher fishing effort within the medium depth stratum.

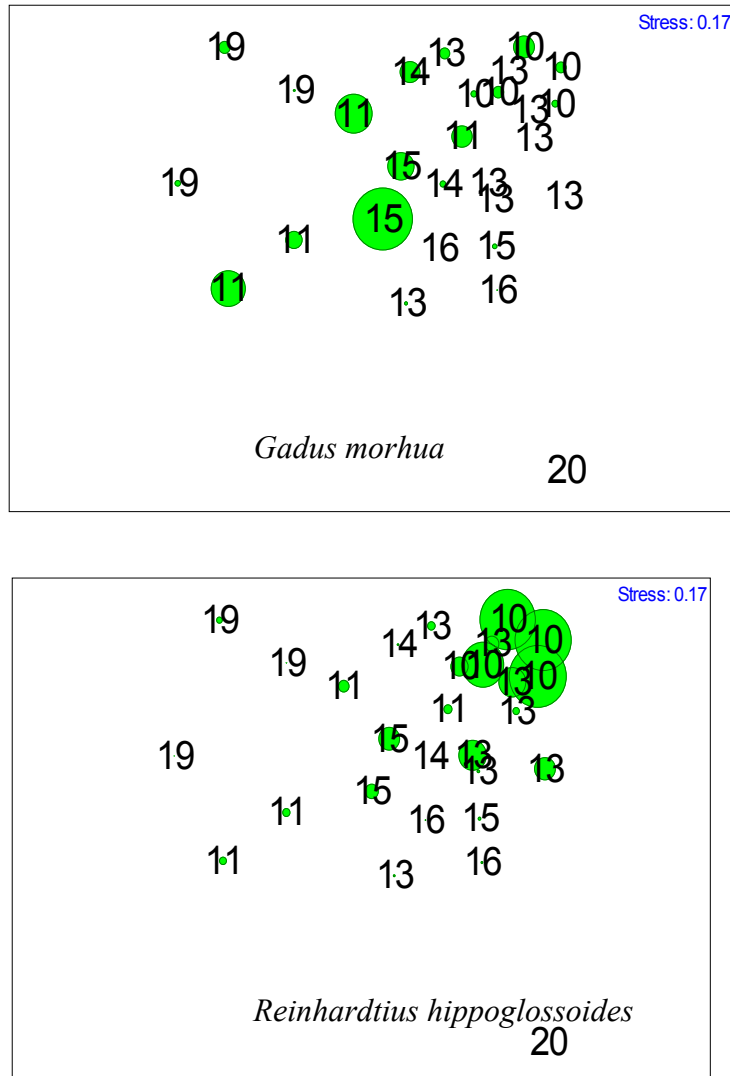


Figure 3.35 MDS ordinations based on average abundance of demersal by-catch fish species, with the weight of *G. morhua* and *R. hippoglossoides* landed by the shrimp fleet during the period 1988–2003 overlapped.

Temporal trends in abundance of by-catch species

Abundance of demersal fish by-catch species has varied greatly during the study period but has followed a decreasing trend in most years since 1994 (Figure 3.36). Of the most abundant and widely distributed species, only Arctic cod and long rough dab seem to follow an increasing trend. Species of commercial interest, such as cod, Greenland halibut and golden redfish show great annual variability but their abundance is decreasing or stable at very low levels (Figure 3.37).

The use of sorting grids in the Icelandic offshore shrimp fishery has been mandatory since summer 1995, and it seems to be very effective. Between 1988–1994, weight of landed by-catch oscillated between 2.4–6.6% of the shrimp catch. By-catch from the shrimp fleet dropped

drastically in 1995, when it represented 0.6% of the shrimp catch, and only in 1997, 1998 and 2000 there were some landings of fish species from five shrimp vessels (Table 3.14).

The trends of species richness and diversity follow a very slight increase following the introduction of the sorting grid but evenness seems to decrease (Table 3.15, Figure 3.38). Number of stations sampled every year has been rather stable, so annual sample size is not likely to have influenced these results.

Comparison of the diversity indexes before the implementation of the sorting grid, during 1995, and the years afterwards with one-way ANOVA gave significant results for all three of them, S, J' and H' ($\alpha=0.05$, $p=0.00$, $p=0.00$, $p=0.01$ respectively). These results could, however, be influenced by the variability in sample size (Table 3.15).

The trends of the annual mean of the species richness and Shannon's diversity, and especially this last one, coincide largely with the trend of sum of fishing effort (Figure 3.39).

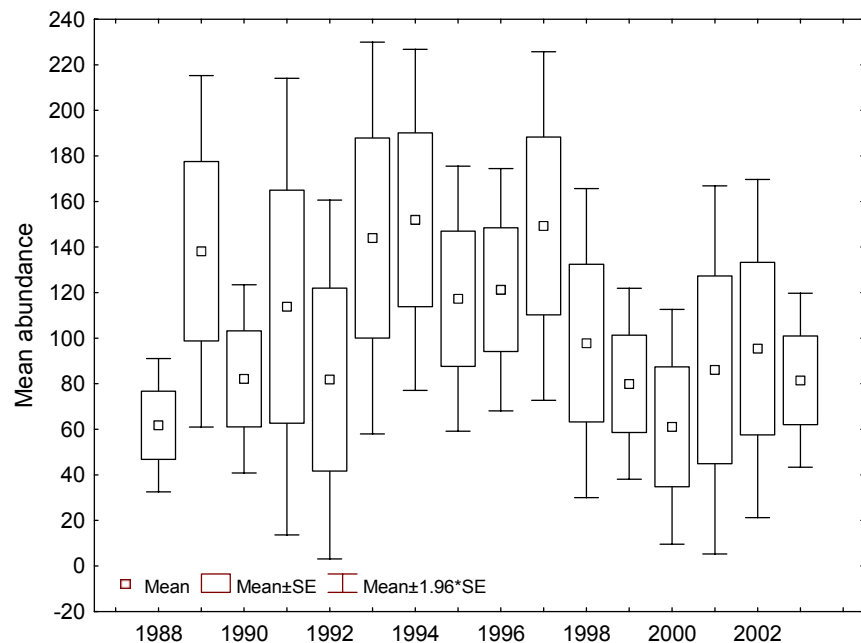


Figure 3.36 Boxplot showing annual average abundance (in number of fish km^{-2}) of demersal by-catch fish species.

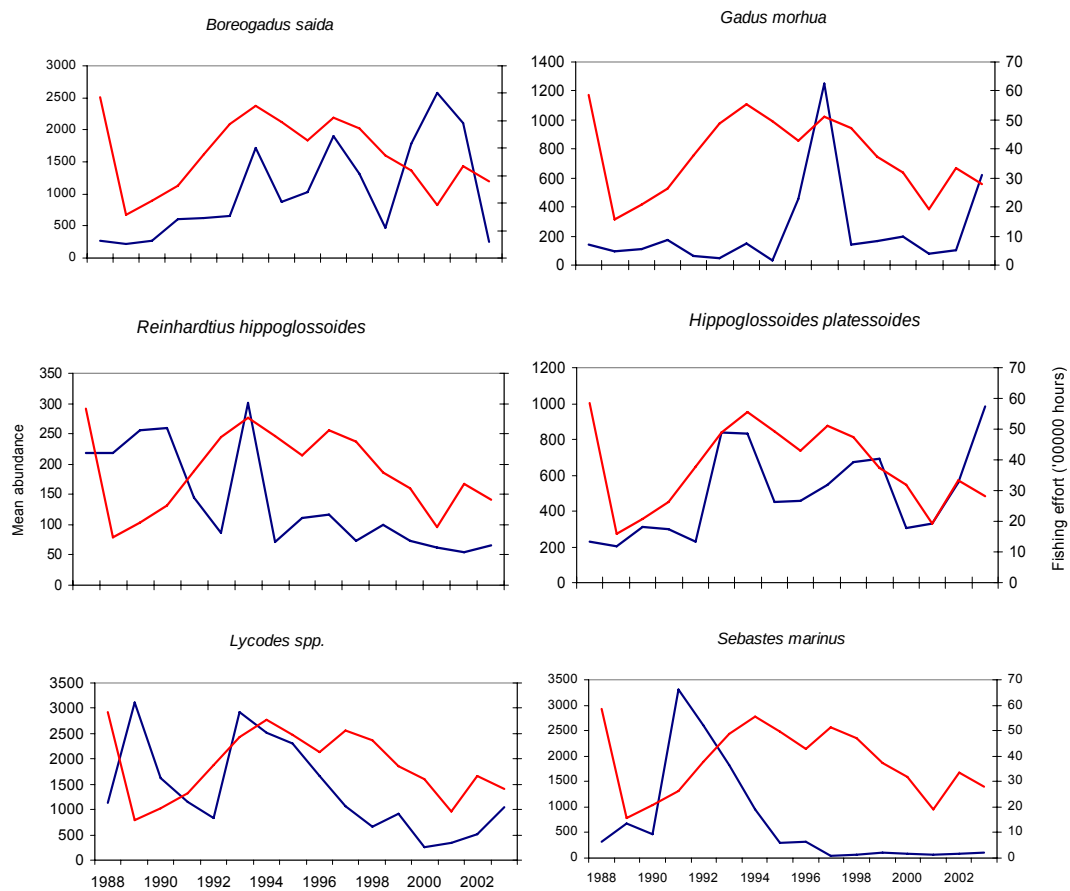


Figure 3.37 Abundance of selected fish species in number of fish km^{-2} (blue line, left axis) and fishing effort trends in '00000 hours (red line, right axis) during the study period. The plot for *Lycodes spp.* includes the most abundant and widely distributed species: *L. eudipleurostictus*, *L. seminudus* and *L. vahli*. Note that the values for the left y-axis vary between plots.

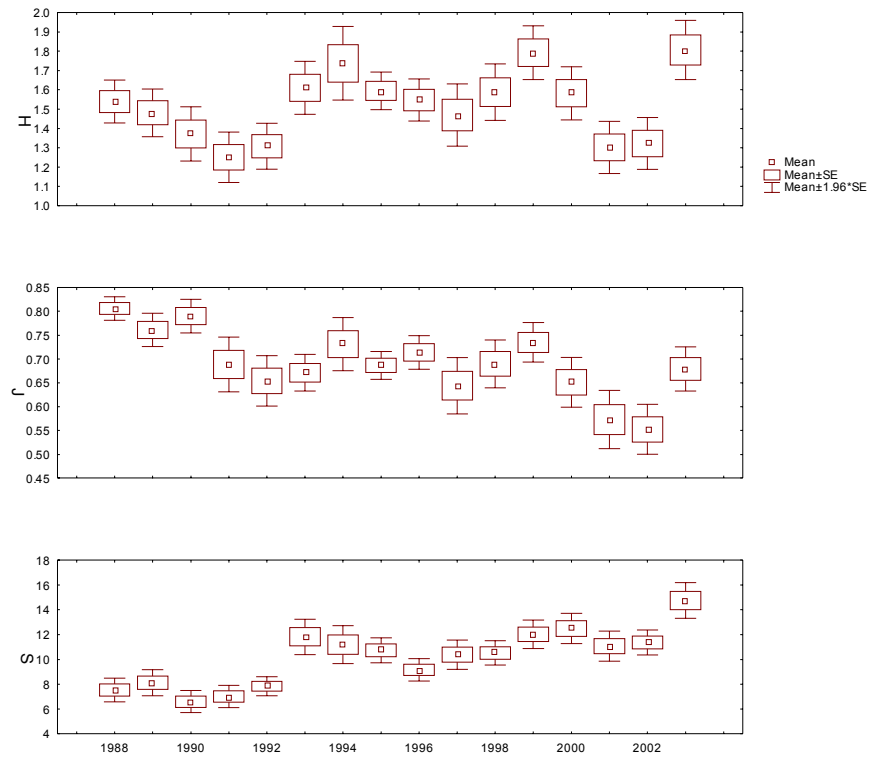


Figure 3.38 Diversity indexes for the medium depth stratum during the period 1988–2003. S : number of species, J : evenness, H : Shannon's diversity ($\log_e$).

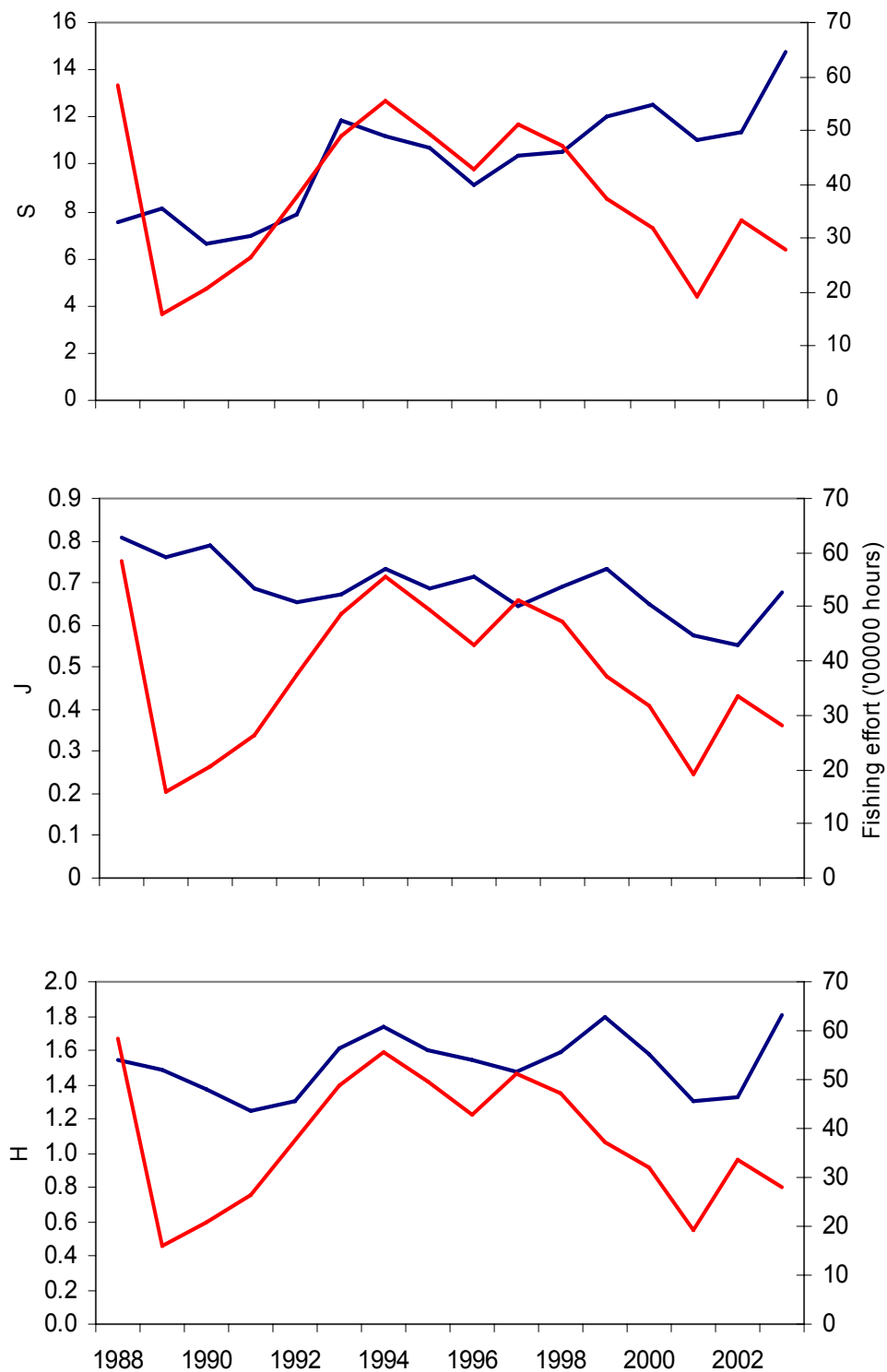


Figure 3.39 Trends of mean fishing effort (red line, expressed as '00000 hours) and the diversity indexes species richness (S), evenness (J) and Shannon's diversity (H).

Table 3.14 By-catch landed by the shrimp fleet during the period 1988–2000. Weight of catch is in tonnes.

Species	Common name	1988	1989	1990	1991	1992	1993	1994	1995	1997	1998	2000
<i>Gadus morhua</i>	Atlantic cod	197.93	189.45	116.82	81.49	124.57	215.74	198.95	10.63	6.54	7.06	
<i>Melanogrammus aeglefinus</i>	Haddock	15.08			0.76	0.26	3.35	5.94	1.64			
<i>Pollachius virens</i>	Saithe					6.95	0.83	0.06				
<i>Merlangius merlangius</i>	Whiting								6.56			10.70
<i>Sebastes marinus</i>	Redfish	3.40	19.38	8.05	6.66	5.99	11.43	10.92	3.21			
<i>Molva molva</i>	Ling				0.31							
<i>Anarhichas lupus</i>	Atlantic wolffish				0.23	0.63	1.37	0.72	0.18			
<i>Anarhichas minor</i>	Spotted wolffish	0.51			1.81	8.66	22.06	17.58	2.79			
<i>Lophius piscatorius</i>	Monk fish				0.25			0.08	1.38		0.16	
<i>Hippoglossus hippoglossus</i>	Atlantic halibut	0.31			0.34	4.89	43.49	7.72	8.44			
<i>Reinhardtius hippoglossoides</i>	Greenland halibut	373.78	274.06	198.30	347.39	267.89	308.13	239.45	88.32			
<i>Pleuronectes platessa</i>	European plaice					0.05	0.00	0.05	0.36			
<i>Limanda limanda</i>	Common dab						0.06					
<i>Hippoglossoides platessoides</i>	Long rough dab								0.53			
<i>Mallotus villosus</i>	Capelin	3.12										
<i>Cyclopterus lumpus</i>	Lumpsucker								0.06			
Unidentified		136.71	6.01		5.17	16.79	25.69	7.52	14.03			

Table 3.15 Diversity indexes for the years previous to the use of sorting grid (< 1995), the year in which it was implemented (1995) and the years afterwards (> 1995).

Years	S				J'				H'			
	Mean & St Dv		N		Mean & St Dv		N		Mean & St Dv		N	
< 1995	8.4	+	3.9	283	0.72	+	0.15	279	1.45	+	0.45	283
1995	10.7	+	3.4	45	0.68	+	0.10	45	1.59	+	0.33	45
> 1995	11.5	+	4.2	355	0.65	+	0.18	355	1.55	+	0.50	355

S: species richness, J': evenness, H': Shannon's diversity index ($\log_e$), N: number of samples.

3.2.4 Discussion

This study did not find a clear relationship between the observed temporal and spatial patterns of distribution of abundance of by-catch fish species and fishing effort. The obtained results are probably influenced by the 15-year gap in the analysed data set between the beginning of the fishery and the regular data collection on demersal species other than shrimp. This lack of knowledge on how the benthic assemblage was prior to the shrimp fishery is a major drawback to investigating the changes that fishing may have caused to demersal species (Bianchi et al. 2000).

On the other hand, the use of number of trawling hours as an estimate of fishing effort is not the most adequate option given the technological advances and fleet improvement that have taken place over the past 15 years. Incorporation of these factors into the estimation of fishing effort would have resulted in higher figures (Greenstreet et al. 1999).

The higher fish abundance was not always found in rectangles of lower fishing effort. Besides, distribution of Greenland halibut and redfish coincided largely with rectangles of medium effort (two to three million trawling hours).

Shrimp fishing has declined markedly over the past few years due to reduction of the stock size, but this restriction to fishing effort does not seem to have benefited the demersal fish species found in shrimp grounds, not even after the implementation of mandatory use of sorting grids in 1995. Fish abundance has kept decreasing rather steadily since 1992.

These findings suggest that there are factors other than fishing that also affect the composition of the fish assemblage. The effect of depth and bottom temperature has been at least partially removed by limiting the analysis to the depth interval where temperature was rather uniform, between 0–1°C on average, but bottom type and food availability, to name a few, are other factors that may act as ecosystem boundaries and have influenced our results.

Another influential factor that cannot be estimated due to lack of data prior to the beginning of the fishery is habitat destruction by the fishing gear.

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4. Vulnerable habitats in Arctic waters

S.A. Steingrímsson, J.H. Fosså, O.S. Tendal, S.Á. Ragnarsson

4.1 Deep-water corals

4.1.1 Distribution

There are several species of corals in the deep waters off Greenland, Iceland and Norway, both solitary and colonial, as well as the coral-like hydrozoans of the order Stylasterida. Habitat-forming, deep-water corals in the Arctic waters include soft corals (Alcyonacea, Pennatulacea and Gorgonacea) and stony corals (Scleractinia). The Gorgonacea corals have a growth form that resembles bushes or small trees, hence many of the species have common names like “sea tree” and “sea bush”. The two most conspicuous representatives of the gorgonians in Arctic waters are *Paragorgia arborea* and *Primnoa resedaeformis* (Figures 4.1 and 4.2). The soft corals do not form coral reefs, but where they occur they tend to be in high densities (Tendal 1992; Mortensen and Buhl-Mortensen 2004). The stony coral *Lophelia pertusa* (Figure 4.3b) is the only species that can build up coral reefs in the NE Atlantic. Other species of stony corals are solitary (Figure 4.3a) or only build bush-like structures, which are commonly occur in association with *L. pertusa*, such as *Madrepora oculata* and *Solenosmilia variabilis* (Zibrowius 1980; Jensen and Frederiksen et al. 1992; Mortensen et al. 1995).

Some of the deep-water coral species are well known to fishermen in the NE Atlantic because corals are often caught in bottom trawls, in gill nets and on fishing hooks when they fish for redfish, ling or tusk. The fishermen, however, are not always precise in their naming or how they distinguish between the species. The use of common names, such as “coral forest” and “glasskorall”, is therefore necessary when communicating with fishermen. With this in mind we have defined the following types of coral habitats and coral occurrence that can be used by fishermen, managers and scientists alike:

- *Coral reef*: Verified occurrence of living *Lophelia pertusa* and accumulating pieces of dead *Lophelia* skeleton.
- *Coral occurrence*: Discrete occurrence of coral species.

- *Coral forest*: Aggregation of gorgonians or pennatulaceans within a specified area.
- *Coral area*: Occurrence of *Lophelia pertusa*, Stylasterida, and octocorals within a specified area. This includes coral areas indicated by fishermen that have not yet been surveyed to investigate coral species composition.

Deep-water corals are patchily distributed in the Arctic waters, predominantly along the outer margins of continental shelves, on slopes and rises in the Arctic and on undersea ridges, e.g. the Reykjanes Ridge. In the North Atlantic they also occur on seamounts and in deep-water canyons.

Coral reefs are formed by the species *Lophelia pertusa*, that lives in water temperatures between 4 and 12°C (Frederiksen et al. 1992). The distribution of the ocean-bottom temperature will give a good indication where the coral can be expected to be found. The known dispersal pattern of warm water masses in Arctic waters suggests that it is possible that *Lophelia pertusa* grow as far north as the Barents Sea. A total of about 850 *Lophelia* reefs have been recorded along the whole coast of Norway, from Finnmark to the Swedish border (Figure 4.4 and 4.5). Large concentrations of reefs occur on the shelf off Norway along the shelf break, on shelf ridges and other topographical heights. Some records represent small reefs while others represent reef complexes up to 40km long. Coral reefs are also found in many of the Norwegian fjords.

Lophelia pertusa is common north of Lofoten and along the coast of Tromsø and Finnmark counties (Dons 1944; Fosså et al. 2000). It is not known whether the species is distributed further east, into Russian waters, nor if it is growing along the shelf edge between the Norwegian mainland and Bear Island. However, fishing maps strongly indicate that corals may grow on slopes of some banks in the Barents Sea (Figure 4.5). This area has a varied and rugged topography and some supply of Atlantic water. For example, maps indicate several places with “coral” and “sponge coral” in the Barents Sea, where the latter can be either octocorals or sponges. Possibly these sites represent the northernmost distribution of *Lophelia pertusa* (about 72°18'N, 14°50'E).

Lophelia pertusa has been found at 39 places in Icelandic waters (Carlgren 1939; Copley et al. 1996) (Figure 4.6). Its 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 875m with most occurrences between 500 and 600m depth.

A research programme was started in 2004 to map coral areas off Iceland using a Remote Operated Vehicle (ROV). The aim of the programme is to assess the species diversity and the status of coral areas in relation to potential damages by fishing practices. Intact *Lophelia* reefs were located in two places on the slope off the South coast of Iceland during the first survey (Figure 4.7).

There are no records of *Lophelia pertusa* off Greenland. However, it is possible that it might exist in the Southwestern fjords of Greenland, that are influenced by Atlantic water and have suitable environmental conditions for coral growth.

The distribution of other type of corals off Norway (Gorgonaceans and Pennatulaceans) is not well-known and there are no distributional maps available for such corals in the Norwegian waters. However, several of the gorgonian species, e.g. *Paragorgia arborea* and *Primnoa resedaeformis*, are widely distributed and many of them are associated with *Lophelia* reefs. Fishermen have reported that these species can form large stands (coral forests) in the fjords as well as on the shelf and break. Also, fishermen report that they are good fishing places for longline and gill net fisheries. Gorgonian corals are generally more common along the shelf break and on the slope than on the shelf area (Mortensen and Buhl-Mortensen 2004). Furthermore, recent studies indicate that large-scale topographic features on the bottom are important in controlling the abundance of gorgonian corals, probably by providing a good supply of food and larvae (Mortensen and Buhl-Mortensen 2004). Colonies of gorgonian corals rise up from the bottom and are normally oriented perpendicular to prevailing currents, what maximizes the volume of water passing through the colony. It also maximizes the encounter rate of food particles for the coral polyps and the epizoic animals associated with the colony, mainly crustaceans and ophiuroids (Buhl-Mortensen and Mortensen 2004).

The database of the BIOICE programme provides information on the distribution of benthic invertebrates in Icelandic waters, based on sampling at 579 locations within the territorial waters of Iceland. The results show that Gorgonacea corals occur all around Iceland (Figure 4.8). They were relatively uncommon on the shelf (< 500m depth) but were generally found in relatively high numbers in deep waters (> 500m) off the South, West and North Iceland. Similar patterns were observed in the distribution of pennatulaceans off Iceland. Pennatulaceans were relatively rare in water shallower than 500m but more common in deep waters, especially off South Iceland (Figure 4.9).

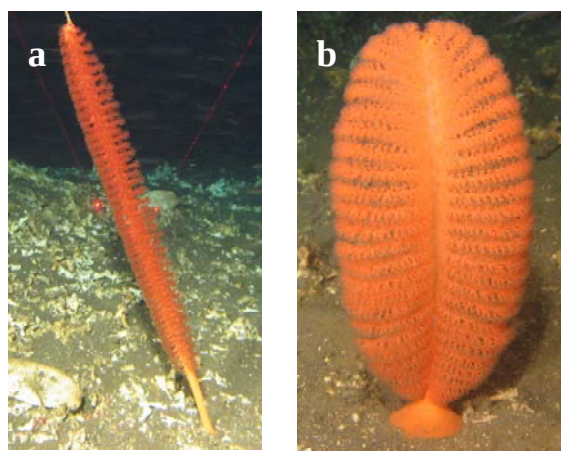


Figure 4.1 Representatives of the order Pennatulacea: a) *Virgularia* sp., b) *Pennatula* sp.

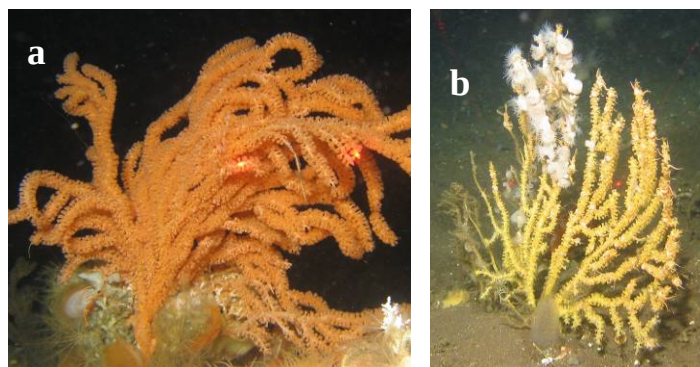


Figure 4.2 Representatives of the order Gorgonacea: a) *Primnoa resedaeformis*, b) *Paramuricea borealis*.

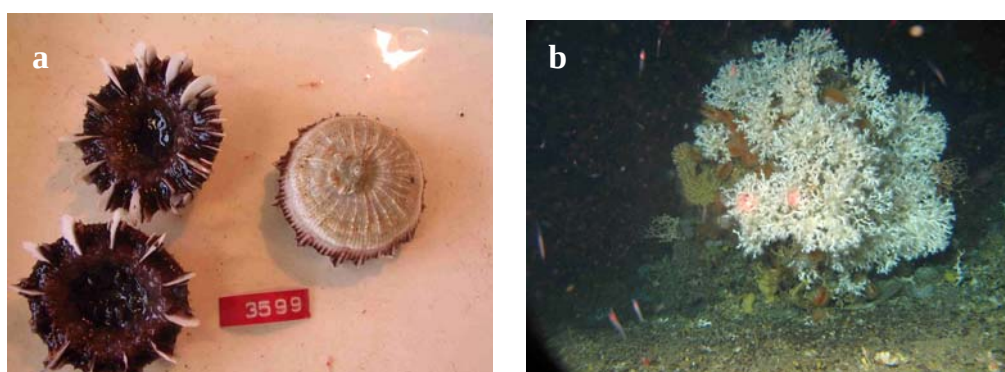


Figure 4.3 Representatives of the order Scleractinia: a) *Stephanocyathus* sp. (solitary coral), b) *Lophelia pertusa* (colonial coral).

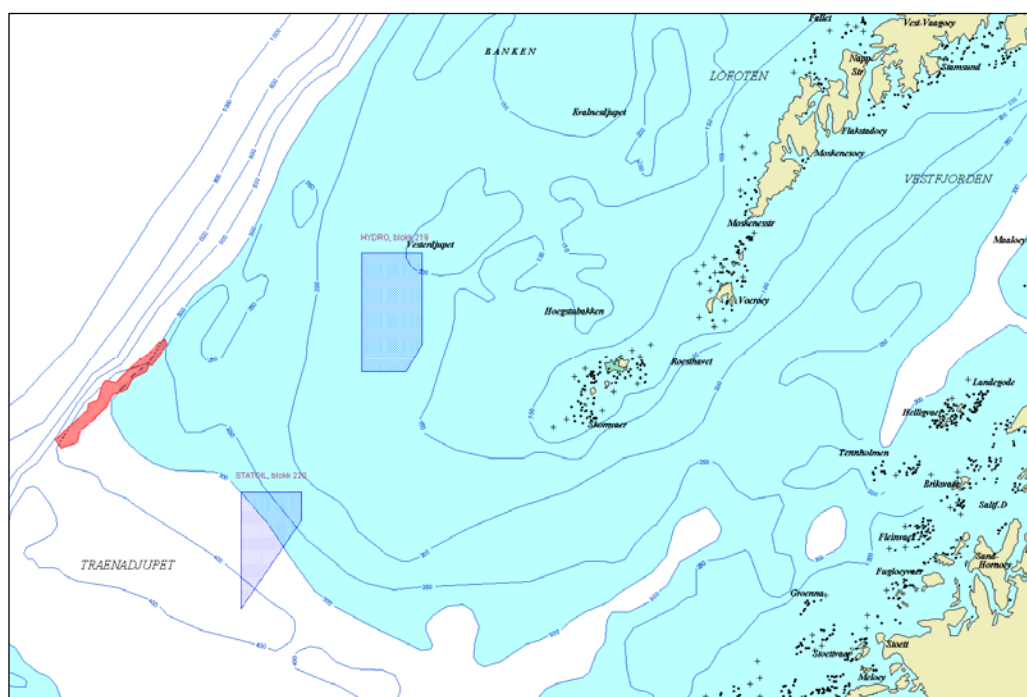


Figure 4.4 A large coral reef on the continental break west of Røst was detected and mapped in 2002 (red area). Two oil licenses (Hydro and Statoil) are shown (blue areas). Map: Institute of Marine Research, Bergen.

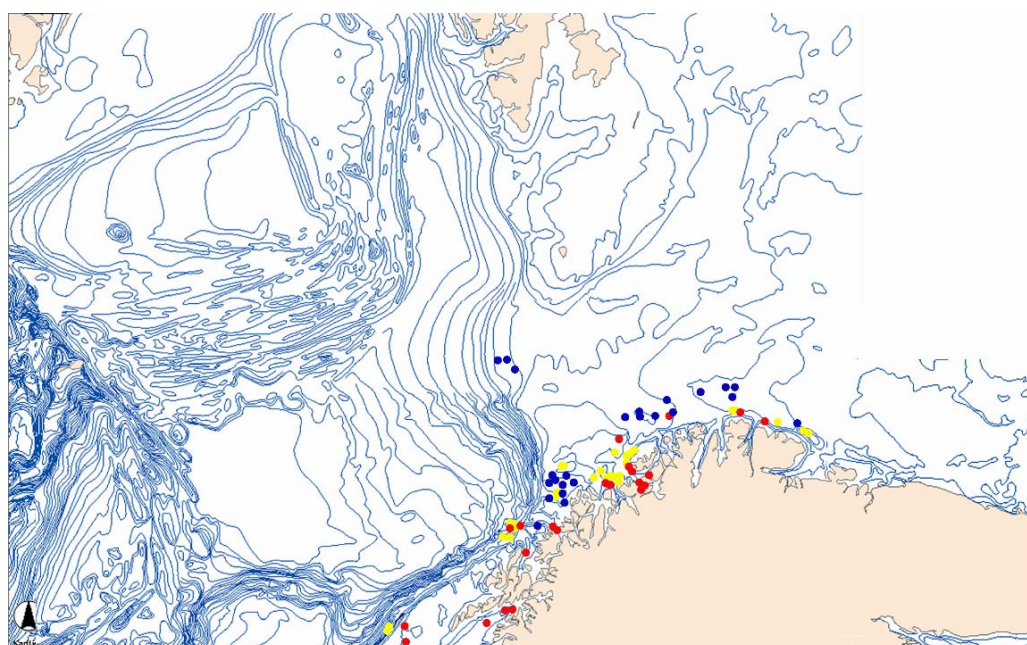


Figure 4.5 The distribution of corals in the Barents Sea. Red dots: verified occurrences of *Lophelia pertusa* as reported in scientific literature. Yellow dots: occurrences of *Lophelia pertusa* as reported by fishermen. Blue dots: occurrences of corals as indicated by Russian fishing maps (Kingfisher Chart [KE 70-23, 1990]). Map: Mortensen (2004).

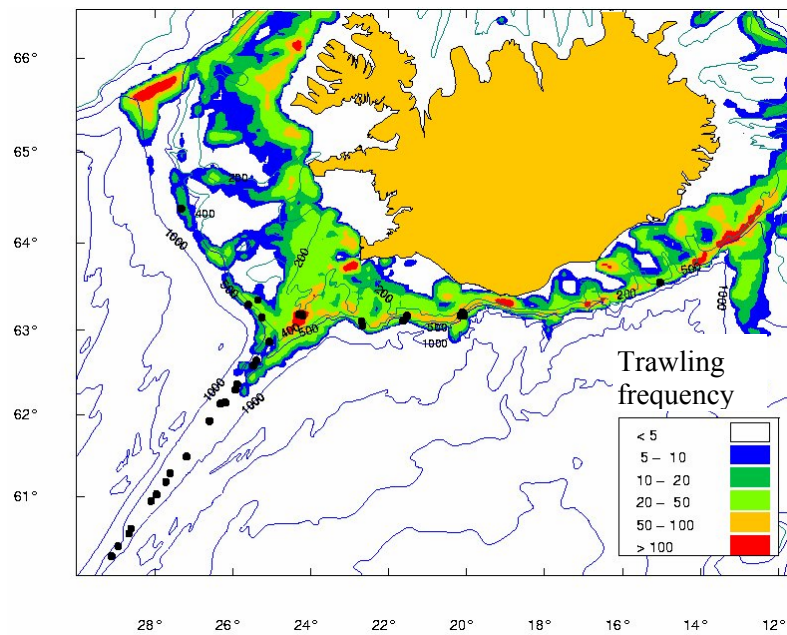


Figure 4.6 Occurrence of *Lophelia pertusa* off Iceland, based on information from the literature and from the BIOICE database, in relation to otter trawling effort (trawling frequency*nm⁻² per year). Map: S.A. Steingrímsson.

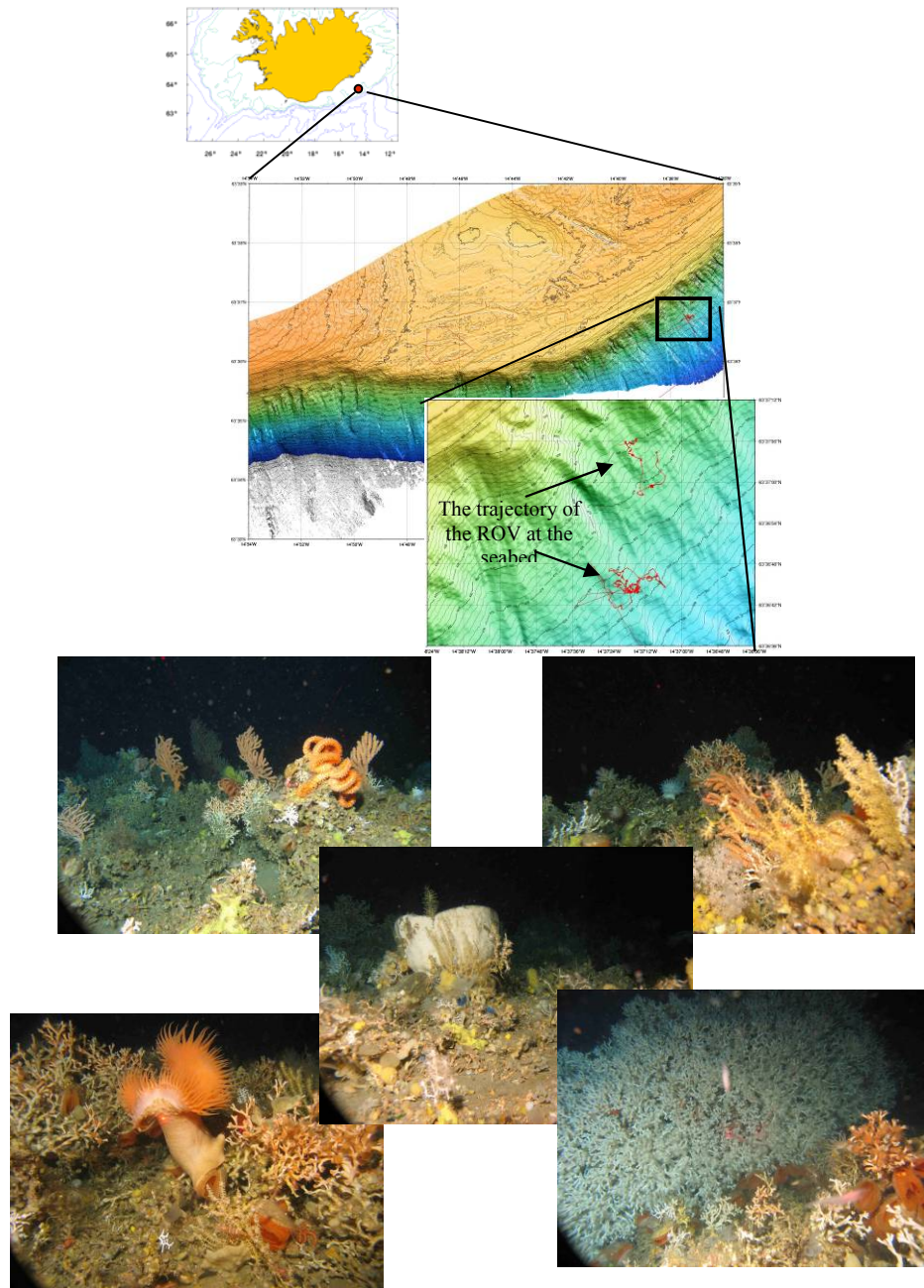


Figure 4.7 Lophelia reefs on the slope area off the Hornafjarðardjúp Deep, SE Iceland (approx. 500m depth). ROV survey indicated diverse biota, including good coverage of *Lophelia pertusa* and various species of octocorals.

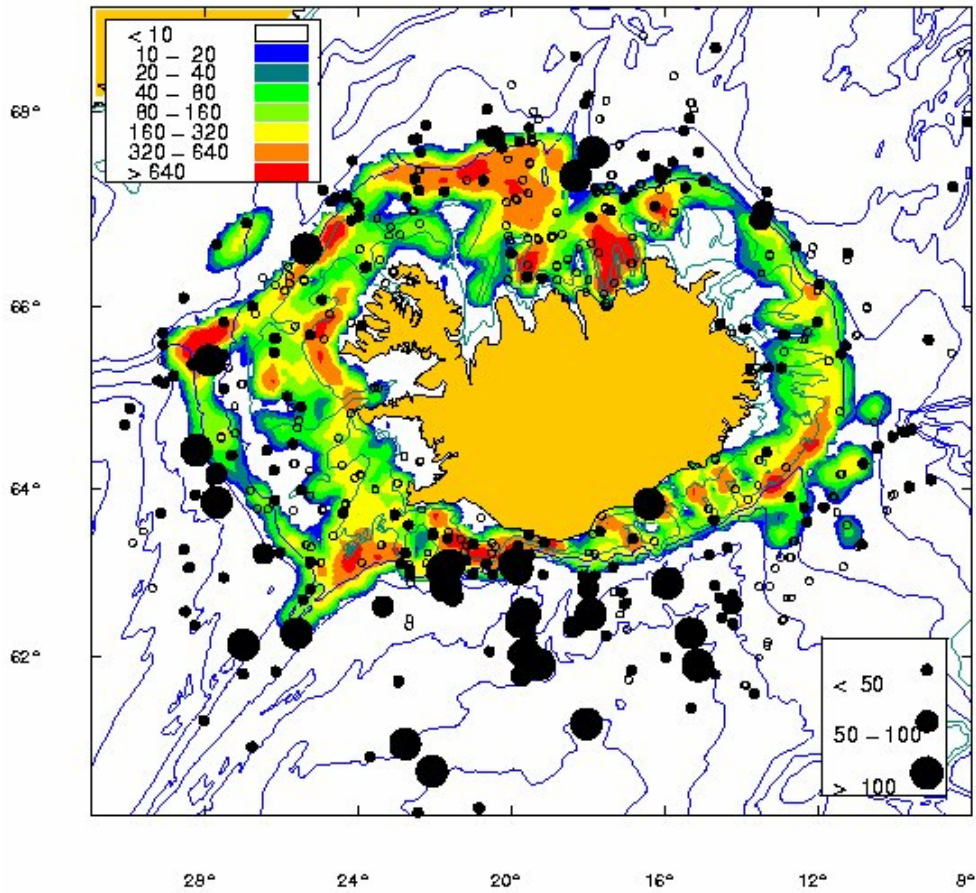


Figure 4.8 Distribution of Gorgonacea corals (number of colonies in a sample) off Iceland in relation to bottom trawling effort (total trawling hours 2003 [combined ground-fish, shrimp and Nephrops fisheries]). Data from the BIOICE database. Map: S.A. Steingrímsson.

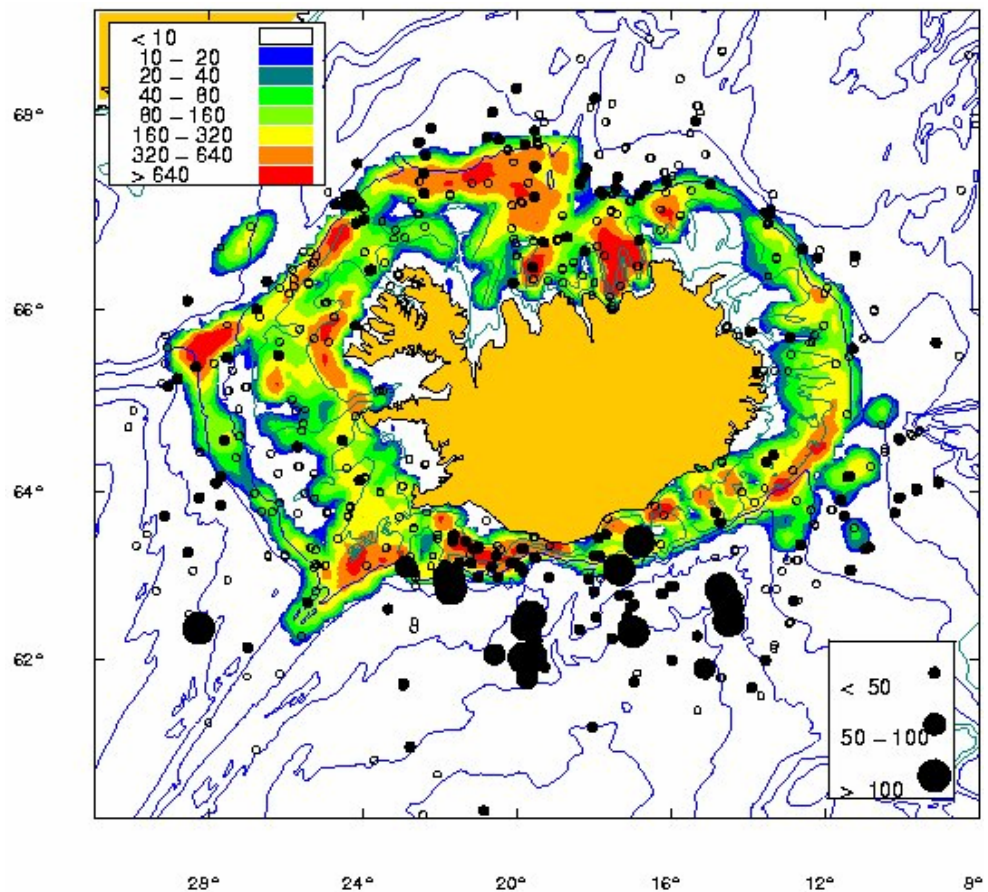


Figure 4.9 Distribution of Pennatulacea corals (number of colonies in a sample) off Iceland in relation to bottom trawling effort (total trawling hours 2003 [combined groundfish, shrimp and Nephrops fisheries]). Data from the BIOICE-database. Map: S.A. Steingrímsson.

4.1.2 Ecological importance

Corals are often a dominant taxon in deep-water hard substrate communities and enhance the number and density of associated species. Studies have shown that the deep-water corals provide habitats for very diverse faunal assemblages (Jensen and Frederiksen 1992; Mortensen et al. 1995; Heifetz 2002; Husebø et al. 2002; Krieger and Wing 2002). However, the ecological importance of corals as habitat for fish species and other forms of marine life has not been adequately studied. Corals may provide habitats for shelter-seeking fish and enhance food availability for suspension feeders that are attached to the coral (Heifetz 2002; Krieger and Wing 2002) but the actual level of their importance for fish populations has not been demonstrated yet.

The *Lophelia* reefs are complex three-dimensional structures that form a habitat for a range of other marine organisms. There are now 614 registered species of animals living on or in association with the coral reefs in

Norwegian waters (Mortensen et al. 1995; Mortensen 2000), and more than 1,300 species have been recorded in the whole NE Atlantic, including demersal fish (Jensen and Frederiksen 1992; Rogers 1999). Therefore, coral reefs are important both from a general biodiversity perspective and as a habitat for commercial fish species. Redfish (*Sebastes* sp.) in particular are found in high abundance in reef areas. Other demersal species, such as ling and tusk also seem to be more common on reefs than on the barren grounds outside the reef areas (Husebø et al. 2002). However, in terms of fish aggregation around coral reefs there is no information whether large reefs play a more important role than small reefs, which may be scattered on a relatively large area of the sea floor.

4.1.3 Threats

Bottom trawling is the most important threat to *Lophelia* reefs and soft corals. Deep-water coral habitats are subject to growing human pressure, particularly as a result of the rapid spread of trawl fisheries into deeper waters and new grounds. This expansion has been aided by recent developments in fishing gear technology and navigational and fish-finding systems. The greatest physical impact on deep-water corals is likely to be caused by towed gears, such as dredges and bottom trawls (Collie et al. 2000). Previous studies show that otter trawling has an adverse impact on structural benthic epifauna, such as deep-water corals (Dayton et al. 1995; Engel and Kvitek 1998; Prena et al. 1999; Fosså et al. 2000, 2002). The following physical effects of bottom trawling are believed to be important (ICES 2003):

- Destruction of complex three-dimensional habitats (e.g. coral reefs/burrows/refuge) (Tuck et al. 1998)
- Changes in topography (tracks and grooves) (Krost et al. 1990)
- Resuspension of sediment and increased turbidity (clogging gills and filter feeding animals) (e.g. Krost et al. 1990)
- Refluxing of contaminants and nutrients (Messiah et al. 1991)
- Litter from abandoned and lost gear (ghost fishing)

Deep-water corals typically exhibit slow growth and longevity. Estimates of linear growth rate of various coral species indicate that they grow from 0.5–25mm a year and live for hundreds of years (Rogers 1999; Mortensen and Rapp 1998; Risk et al. 2002). The polyps of *Lophelia pertusa* grow slowly (about 0.5–1.5cm a year) to form complex reef structures. Their reefs can be more than a kilometre long and 30m high and are generally found on elevated features on the sea floor, such as ridges and moraine structures. The oldest coral reefs were formed after the last ice age and can be up to 10,000 years old (Mortensen and Rapp 1998; Rogers 1999). Therefore, based simply on age and growth informa-

tion, corals are sensitive to fishing gear impacts and recovery rates of impacted coral are believed to be slow, maybe even hundreds of years.

Increased mortality is the most obvious effect from mechanical impact by bottom trawling. The corals are crushed and buried. Tissue wounds and possible microbial infection may also reduce the health of the corals (Fosså et al. 2002). If reefs on the shelf are seriously reduced it is not possible to evaluate the impact on individual coral populations. On a scale from intact to extinct there may be a point below which corals will not be able to sustain populations. The effect will also depend on the reproduction potential, but at present very little is known about the sexual reproduction of *Lophelia pertusa* (Rogers 1999). It is reasonable to assume it has a planktonic larvae similar to the closely related *Caryophyllia* and that it is able to travel long distances. Evidence of this is found in the North Sea, where *Lophelia* has colonized submerged components of oil rigs, far away from known locations of other colonies (Bell and Smith 1999).

Bottom trawling also increases resuspension of bottom sediment and the release of nutrients near the bottom (Piskal'n et al. 1998; Watling and Norse 1998). On a worldwide scale siltation is one of the largest sources of degradation of tropical coral reefs (Norse 1993) and may suppress the growth rate of adult colonies (Cortés and Risk 1985). Siltation or sand deposition due to bottom trawling may have a negative effect on *Lophelia* corals. Roberts and Anderson (2000) studied *Lophelia* in an aquarium and suggested that sand deposition can reduce the level of polyp extension. However, Riegl (1995) shows that scleractinian corals actively clean sand from the surface and conclude that the corals are capable of coping with considerable amounts of sand deposition and that declining reef health in areas of accumulation of sediments may rather be due to additional environmental stress.

4.1.4 Documentation of damage

4.1.4.1 Bottom trawling

Moderate damage to corals off the Norwegian coasts probably occurred in the early phase of trawl fishing. The degree of impact most likely increased dramatically with the development of larger vessels with powerful trawls, e.g. rock-hopper gear adapted to operate on rough stony bottoms and coral areas (Fosså et al. 2000, 2002).

Bottom trawling on the banks of the Barents Sea started in the 1930s. The activity increased in the 1960s with the introduction of factory and wet fish trawlers. In the mid-1980s trawling occurred along the shelf break and extended further to the banks on the shelf as a result of lower quotas for the Norwegian Arctic cod. It was at the end of the 1980s that rock-hopper gear was developed, allowing larger vessels to trawl in areas

that were inaccessible before due to the roughness of the bottom, e.g. by presence of coral reefs.

In the early 1990s, longline and gill net fishermen contacted the Institute of Marine Research (IMR) in Norway to express their concerns about the effects of trawling on coral reefs. They claimed that corals had disappeared from trawling grounds, and that their catches in these areas were lowered. Their worries also concerned the potential function of the reefs as nursery areas for fish.

During the first half of the 20th century, the Icelandic fishery changed from hand- and longline fishery, carried out from open boats (rowing boats) and small-decked boats (sailing ships), to motorized cutters and steam trawlers (Magnússon 1998). However, despite the modernization of the fleet the fishery remained in relatively shallow waters (less than 400m). Heavy investment in new trawlers took place in Iceland in the early 1970s. Within a few years a new stern trawler fleet emerged that was more powerful than the side trawlers, which they substituted. With larger and more powerful ships the Icelandic trawler fleet progressed with their fishing into deeper waters and deep-water bottom trawling (>500m) developed rapidly in the 1970s. As a consequence, incidents of encountering coral areas became more common. Furthermore, in recent years a great improvement was made in gear efficiency, e.g. introduction of bigger and stronger trawls and rock hoppers.

Severe reef damages have been documented on the fishing banks and along the shelf break off Norway and it is estimated that 30 to 50% of the coral areas may be damaged or negatively impacted (Fosså et al. 2002). The Marine Research Institute in Iceland has recently interviewed retired fishermen who fished actively prior to 1970, and carried out a questionnaire to fishermen currently working in the fisheries (Steingrímsson and Einarsson 2004). This information was used to assess the current status of coral areas by comparing their historical and present distribution off Iceland (Figure 4.10). It was concluded that during the 1980s and 1990s some relatively large coral grounds vanished, e.g. one on the Reykjanes Ridge (36km²) (Figure 4.11) and two near the Öraefagrunn Bank (68 and 30km², respectively) (Figure 4.12).

Remotely Operated Vehicles (ROVs) have been used to document damage by bottom trawling on *Lophelia* coral reefs off Norway and Iceland. The trawling grounds were visually inspected with the ROV cameras and in some cases side scan sonar has been used to document trawl tracks. Commonly dead coral fragments were found lying on the slopes of reefs, as a part of the natural process of decaying coral reefs. To distinguish this kind of natural decay from impacts by human activities, such as bottom trawling, one should look for broken living colonies, which have been tilted and turned upside down and / or colonies in unexpected / awkward positions on levelled sea bottom. The remains of fishing gear, such as gill nets, anchors, trawl nets among corals and furrows or scars in

the sea bottom are unmistakable evidence of trawling activity (Figure 4.13).

It has not been possible to perform direct quantitative observations of how much of a reef or reef area has been impacted or destroyed. For instance, on the shallowest part of Sørmannsneset (Norway) and south of the Öraefagrunn Bank (Iceland), places known to be common trawling grounds, fragments of dead *Lophelia* were observed without evidence of living colonies in the surroundings. In such cases it is safe to conclude that the colonies have been wiped out as a result of bottom trawling in the area (Figure 4.14).

Up to the mid 1900 it was common for fishermen as well as scientists to catch large *Paragorgia arborea* (up to 4m tall) in bottom gear. This situation has changed and large individual colonies of *Paragorgia arborea* are now rarely reported or seen. The depletion of the populations of *Paragorgia arborea* is of great concern especially because of the disappearance of old individuals that can be more than thousand years old. This is probably an irreversible process. Concern is likewise expressed for *Primnoa*, which is also slow growing – 1m tall specimens being 500 years old (Risk et al. 2002). The lack of detailed information on the distribution of coral species (soft corals and stony corals) emphasizes the urgent need for coherent mapping of species and habitats in all parts of the study area except Iceland.

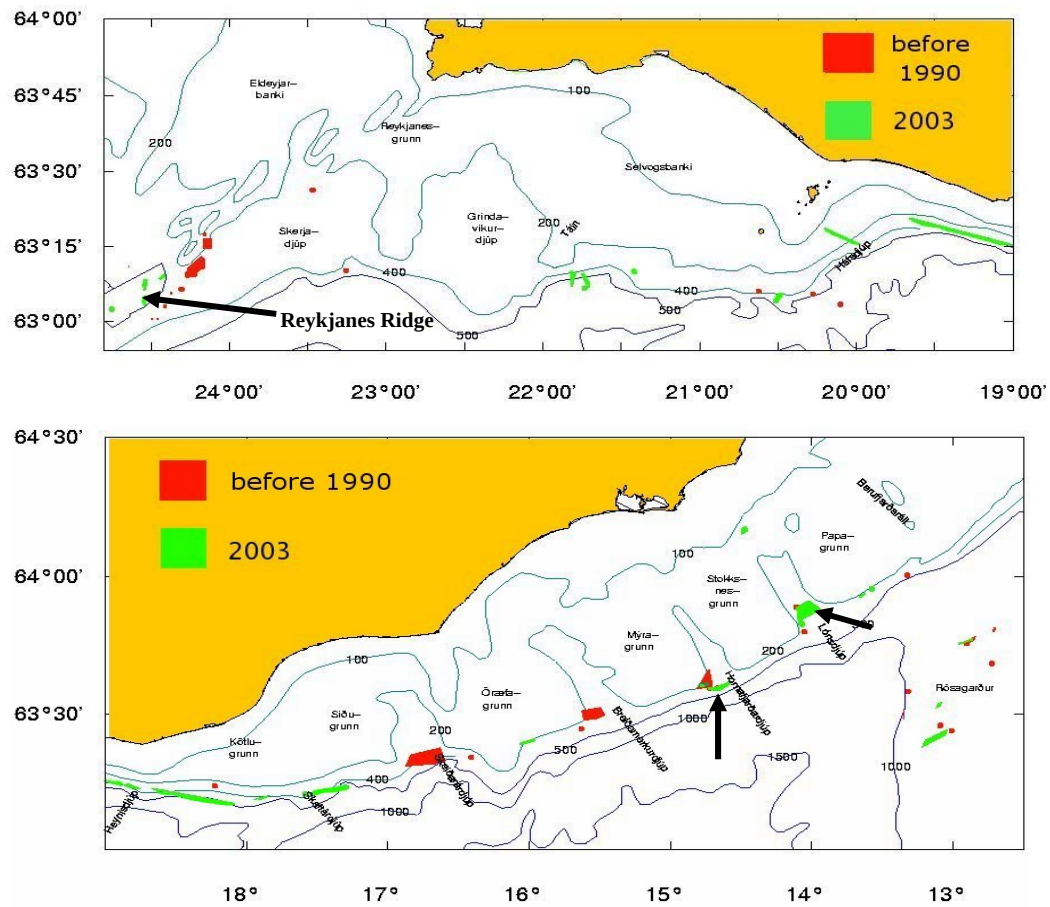


Figure 4.10 Occurrence of coral areas off Iceland, based on information from fishermen. ■ coral areas known to exist prior to 1990 (various sources of information), ■ coral areas existing in 2003 (results from questionnaire). Arrows indicate the largest existing coral areas. Map: S.A. Steingrímsson.

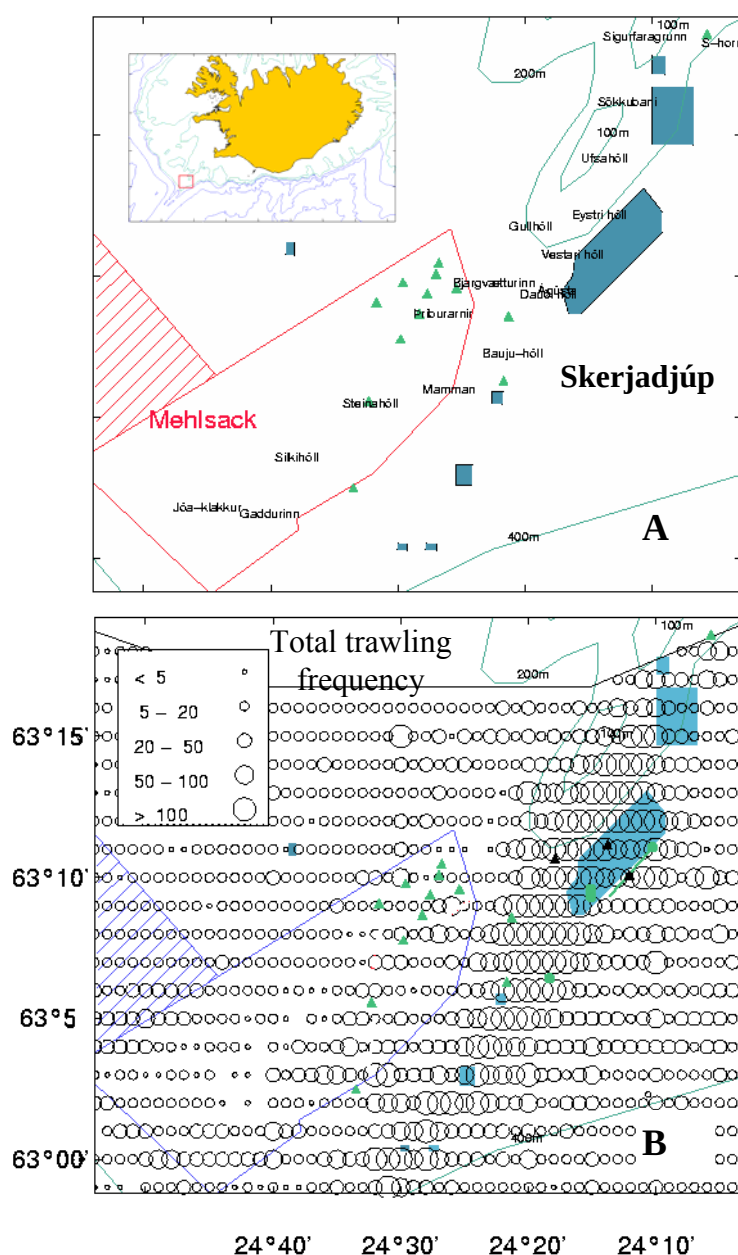


Figure 4.11 Historical distribution of coral in the Skerjadjúp Deep. A) Shaded areas (■, total area 36 km²) indicate coral areas as given on old fishing charts (published 1980–1983), (▲) records on occurrence of coral, based on data from a geological survey on the Reykjanes Ridge (Thors et al. 1992) and (▲) records of *Lophelia pertusa*. Areas closed for otter trawling (since 1995) are outlined with a red line (closed throughout the year) and red hatched area (trawling allowed 1st February – 15th April). B) same area with superimposed total otter trawling effort, during 1991–2002. Size of circles represents different fishing effort (<5, 5–20, 20–50, 50–100 and >100 tows • nm⁻². (trawling frequency • nm⁻², during 1991–2002). Map: S.A. Steingrímsson.

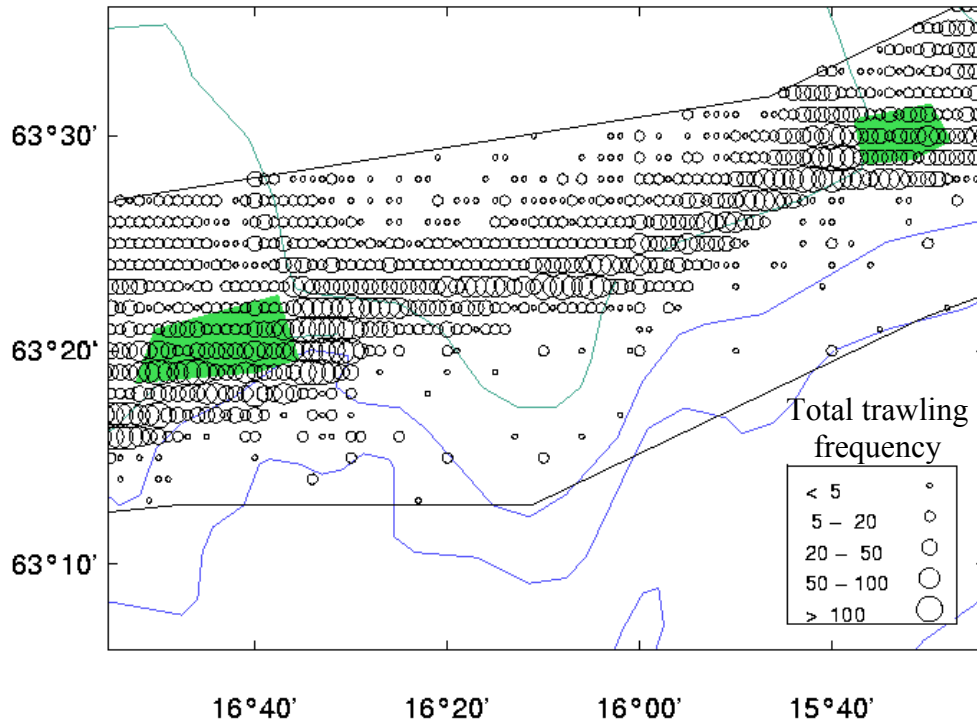


Figure 4.12 Coral areas at the Öræfagrunn Bank existing before 1990 (■) (68 and 30km², left and right, respectively) with superimposed total otter trawling effort, during 1991–2002. Size of circles represents different fishing effort (<5, 5–20, 20–50, 50–100 and >100 tows • nm⁻², during 1991–2002). Map: S.A. Steingrímsson.

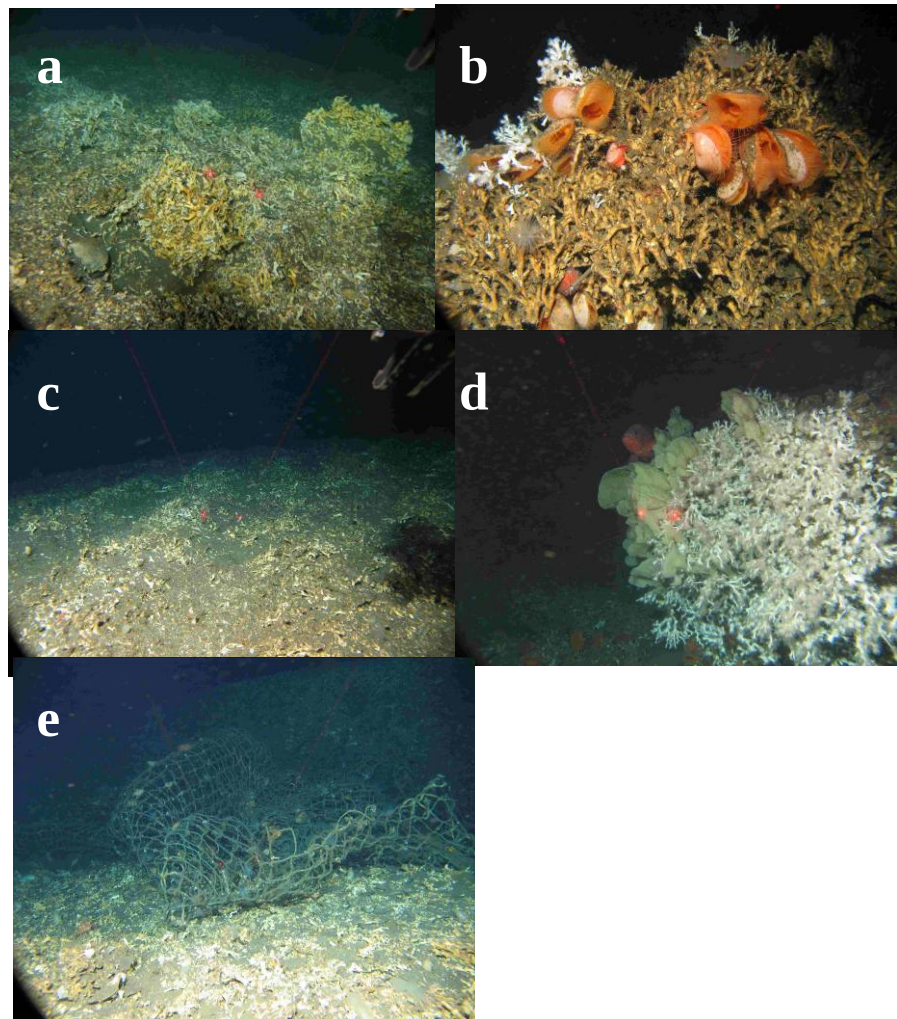


Figure 4.13 Evidence of damaged Lophelia reef. a–b) broken and tilted living colonies, c) furrows in the seabed (trawl door marks), d) pieces of living Lophelia pertusa, e) remains of fishing gear.

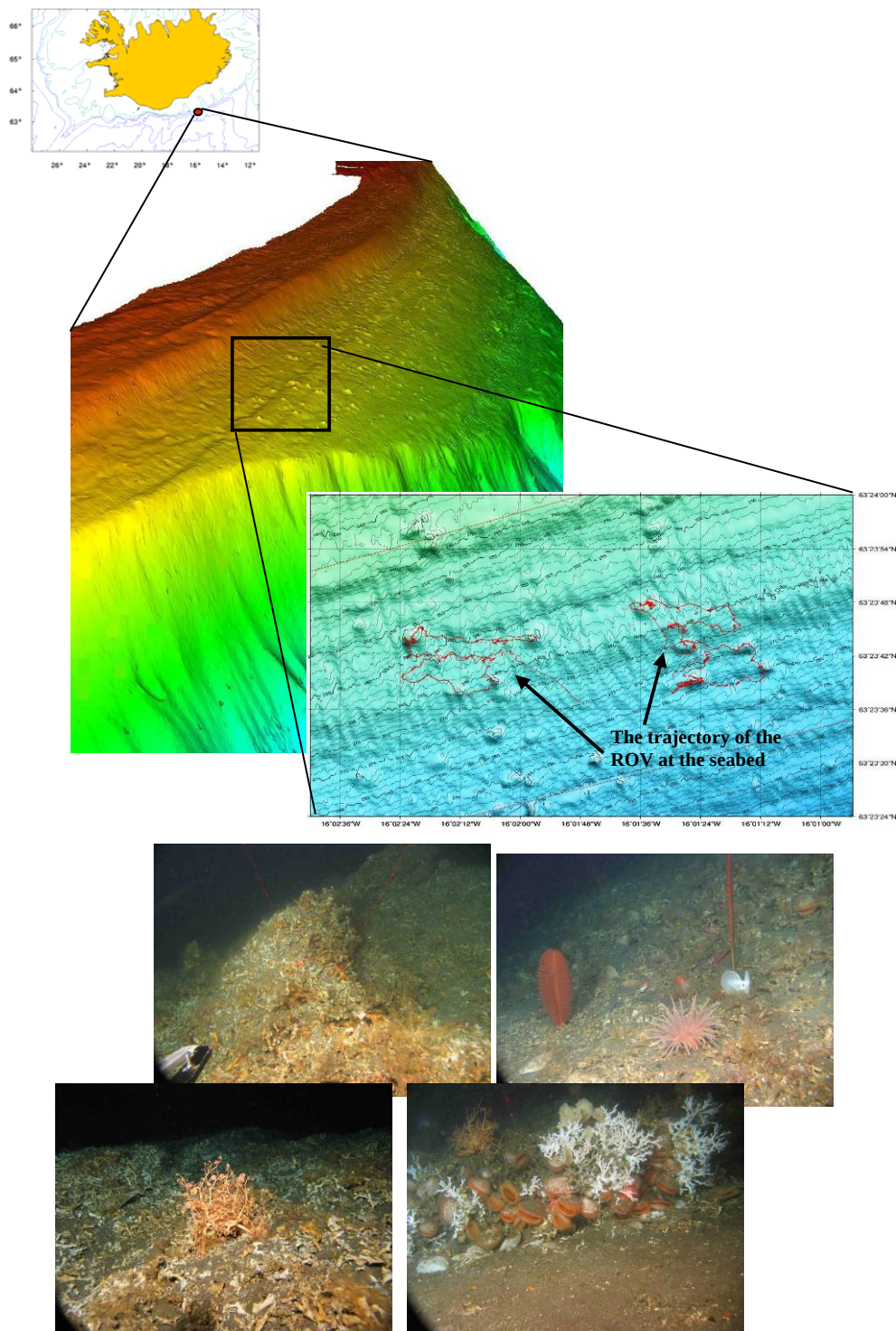


Figure 4.14 Devastated *Lophelia* reefs off the Öræfagrunn Bank, SE Iceland (approx. 250m depth). Multibeam map revealed series of mounds, commonly rising 5–10m high from the bottom. ROV survey documented shattered fragments of dead *Lophelia pertusa* on top of the mounds with muddy sediments, free of *Lophelia*, in between. Live *Lophelia* colonies were rare and normally small when encountered. Evidence of broken trawl wire and pieces of trawl nets was documented.

4.1.4.2 Longline and gill nets

During ROV surveys of reef areas off Norway and Iceland lost longlines, gill nets and other types of fishing equipment have been observed on the seabed. Indeed it is exceptional not to find ropes and nets in the coral beds. Lost nets can be seen ghost fishing and also covering parts of the coral colonies. One direct effect on the corals is breakage, but the effect of the net covering coral colonies is not known.

Although these fishing techniques obviously cause breakage and disturbance of corals, it is assumed that the extent of the damage is limited compared to the effect of bottom trawling. However, a study on gorgonian corals on a Canadian longline fishing ground shows that this fishing practice has a clear impact on corals. Because these organisms are long lived the negative effect of a relatively low disturbance frequency may accumulate over time before it can be detected (Mortensen and Buhl-Mortensen 2004).

4.1.5 Ecological implications of damage

Preliminary work indicates that species diversity is about three times higher on *Lophelia* reefs compared to the surrounding soft-bottom, thus confirming the general positive relation between habitat complexity and species diversity in the marine environment. This implies that the reefs on the shelf and fishing banks represent patches of high diversity in an environment of low diversity. However, we have no examples of species that are obligate reef dwellers.

Longline catches of *Sebastes* spp. have been reported to be six times larger on reefs compared to non-reef areas and two to three times higher for ling and tusk (Husebø et al. 2002). Video inspections off the Norwegian coasts have shown dense aggregations of redfish (*Sebastes* spp.) on the reefs, which in May–June were dominated by gravid females with distended bellies. *Sebastes* sp. was observed swimming a couple of metres above the substrate, lying on the substrate or in caves between the coral colonies. Tusk was also observed, but it was not as abundant as redfish. Stomach analyses indicate that tusk use the coral habitat as a feeding ground.

The reef habitat also plays an important role for invertebrate species, such as *Munidopsis serricornis*, *Ophiacantha* spp. and *Eunice* spp., which all exhibit high abundances on the reefs, but are seldom found in other Norwegian waters. If the reefs containing core populations of such species disappear, the species may have difficulties in either spreading or sustaining their own populations (Fosså et al. 2000). This means that anthropogenic degradation of a significant part of the *Lophelia* reefs may thus dramatically change the distribution of species diversity along the whole shelf and slope.

The *Lophelia* corallites grow about 5–15mm per year and the growth rate of a *Lophelia* reef is estimated to 1.3mm per year. Consequently, it will take hundreds of years for a colony to reach a diameter of 1.5–2m and it will take thousands of years to build a reef structure 10–30m thick. Thus, it will take a long time for the reefs to recover and for the restoration of their ecological function, if at all.

Similar to *L. pertusa*, deep-water gorgonian corals can offer various microhabitats for other organisms to utilize. Information on the distribution and abundance of deep-water gorgonians is scarce, as it is the knowledge on their biology and ecology. Consequently, little is known about the significance of gorgonian corals as habitat for other species in deep-water ecosystems, and how they may be linked to ecosystems in shallower waters.

4.1.6 Management

Norway was the first country to implement protection measures for cold-water corals in European waters. IMR documented the damage to *Lophelia* reefs on trawl grounds in 1998 (Fosså et al. 2000, 2002) and 1999. Norwegian fisheries authorities established a regulation for the protection of deep-water coral reefs against damage due to fisheries through the Sea-water Fisheries Act and the Act related to Norway's exclusive economic zone (EEZ). This national regulation prohibits intentional destruction of coral reefs and requires caution when fishing in the vicinity of known reefs. Furthermore, the regulation gives special protection to specified coral reefs by totally banning the use of bottom trawls that may come in contact with the reefs.

So far, five reefs have received special protection: the Sula Reef, Iverryggen Reef, Røst Reef, Tisler Reef and Fjellknausene Reef. In addition, the environmental authorities have temporarily conserved the Selligrunden Reef through the Norwegian Nature Conservation Act (Table 4.1). Three of them are on the offshore shelf and three in fjords. The northernmost reef, which has received special protection, is situated in Lofoten at about 67° 30' N. None of the northernmost Norwegian reefs in the Barents Sea region have special protection neither through the Fisheries legislation nor through the Nature Conservation Act.

The Government's Report No 12 to the Parliament 'Protecting the Riches of the Seas' (2001–2002), outlines further measures to protect the cold-water coral reefs, including a proposal to protect a selection of reefs against all threats as part of a national representative network of marine protected areas (MPAs). The abovementioned reefs will probably be amongst the reefs that are permanently protected. The process of establishing a network of MPAs started in 2001 and is due to end in 2006–2007. A list and map of the proposed areas can be found at www.dirnat.no/wbch3.exe?d=3719.

In 2003 the Norwegian government established a working group to advise on further measures needed to protect deep-water coral reefs. The working group concluded that the ecological importance of the reefs seems to be higher than earlier anticipated (Fiskeridirektoratet 2003), and argued that the present level of mapping and research is too low and should be increased. The working group also recognized that many different activities may be potentially harmful to coral reefs and suggested, as a principle of precautionary approach, that the legal basis for the protection of coral reefs should be broadened to include all sorts of activities. In that way, the competent authority will be given the necessary legal instruments to prohibit any activity that may have harmful effects on coral reefs in one (or more) specific area. Protection of deep-water coral reefs will also be considered in the preparations that have recently started in Norway for revising legislation on fisheries and the marine environment.

The primary aim of the present legislation for closed areas off Iceland is to minimize the impact of fishing on commercial fish species. The legislation still does not include management tools for other components of the marine ecosystem, such as protection of vulnerable habitats. The current management system is now (February 2005) being reviewed by an expert group under the auspices of the Ministry of Fisheries. The work is specifically aimed at integrating criteria for selecting vulnerable habitats into the present legislation to facilitate protection of vulnerable habitats, such as *Lophelia* reefs.

Table 4.1 Present coral protection areas in Norway

Reef site	Implementation date	Offshore - inshore	Size (km ²)	Restrictions
Sula Reef	March 1999	Offshore	978	Bottom trawling
Iverryggen Reef	January 2000	Offshore	620	Bottom trawling
Selligrunnen Reef	June 2000	Inshore, fjord	0.6	Human activities
Røst Reef	January 2003	Offshore	303	Bottom trawling
Tisler Reef	December 2003	Inshore, fjord	1.8	Trawling (crustaceans)
Fjellknausene Reef	December 2003	Inshore, fjord	1.9	Trawling (crustaceans)

From Fosså et al. 2004.

4.2 Sponge communities

4.2.1 Distribution

Sponges (Porifera) are found on all types of sea bottom, in all marine geographic and bathymetric regions and under very diverse ecological conditions. Some species are encrusting and never grow thicker than 1mm, others are lumpy or barrel-shaped, up to 2m in height. Most species

are in the 2–40cm size range. All larger forms have a skeleton of silicious needles (spicules) or horny fibers (spongine) or a combination of these.

A number of North Atlantic sponge species are well-known by fishermen, as they are often dredged or trawled as by-catch. They have got common names according to smell, texture, size, colour or form, such as “elephant dung”, “mermaids glove”, “abelort” (Danish, meaning “monkey shit”), “elephant ear”, “ost” or “ostur” or “osti” (Faroese, Icelandic, meaning “cheese”), or “sopp” (Norwegian, meaning “mushroom”).

Mass occurrences of large sponges around the Faroes are called ‘ostur’, meaning “cheese bottom”, among the fishermen. This phenomenon was first treated in detail during the BIOFAR investigation (Klitgaard et al. 1997; Klitgaard and Tendal 2001), although it had been previously mentioned in the literature from various parts of the NE Atlantic and the Arctic.

4.2.2 Sponge-dominated biotopes and their distribution in the Arctic waters

In the geographic region discussed here, mass occurrences of sponges have been found off East Greenland, around Iceland, off northern Norway, in the Barents Sea and off Svalbard (Klitgaard and Tendal 2004). “Mass occurrence” is not an unambiguous term, and definitions are by nature vague. We find the following terminology useful to clarify our ideas about some of the features involved:

- **Ostur:** A restricted area where large sponges are strikingly common. We use as a practical guideline that the dominating taxon in a given catch must be sponges, estimated on deck to comprise more than 90% of the biomass, excluding benthic fish (Figure 4.15). The main part of such catches is constituted by several large-sized sponge species (>5cm maximum diameter), and in many cases the group also shows high diversity of smaller species. A conservative estimate based on catches from different types of gear and some underwater photographs suggests that on the bottom there is at least one large sponge per 10–50m². The bottom type is often gravelly with more or less sand.
- **Sponge ground:** Area dominated by large sponges and their skeletons. In practice, the catch is heavily loaded with spicules of dead sponges, either as scattered spicules, as spicule balls or as mat-like formations. A few large-sized sponge species and the spicule-masses constitute more than 90% of the volume of the catch. The diversity of other sponge species is relatively low. The dominating sponges are numerous and can hang more or less together, supported by the underlying masses of spicules. The bottom type is often mud, with some sand.

For the time being we consider the sponge ground a deep-water, soft-bottom kind of *ostur*. Work is ongoing to better clarify differences between sponge-dominated biotopes.

Ostur have not been reported from West Greenland, probably owing to lack of investigation. From East Greenland there are indications in the literature that mass occurrences are found around 1000m depth in the Fram Strait (78°N) (Koltun 1964), and on the seamount Vesterisbanken (73°30'N) there are sponge grounds at about 130–260m (Henrich et al. 1992). Further, we have unpublished sponge ground samples from about 75°N at 750–800m, and *ostur* from a number of localities in the Denmark Strait, generally between 200 and 500m depth.

From North of Iceland we have *ostur* in a number of localities, at depths of 300–750m, some of them to be classified as sponge grounds. From South of Iceland, especially around the Reykjanes Ridge, we have information indicating the presence of comprehensive *ostur*, and also some sponge grounds (Figure 4.16).

From off northern Norway and the western Barents Sea mass occurrences of sponges, seemingly mainly as *ostur* but also some sponge grounds have been repeatedly mentioned in the literature (Klitgaard and Tendal 2004) (Figure 4.17). Fishermen have reported that several tons of “white sponges” up to about 1m in diameter have been regularly caught in some areas.

According to the literature large sponges are common south and west of Svalbard (Blacker 1957, 1965; Dyer et al. 1984), seemingly as *ostur*. We tried to confirm these records during a cruise in 1990, but results were ambiguous, probably because the gear was too small. However, sponge spicules were a very prominent constituent in many sediment samples from around Bjørnøya and West Svalbard, originating in some cases from sponges not yet recorded in the area (Barthel et al. 1991).



Figure 4.15 Catch of ostur (*Geodia* sp.) during the BIOICE 2003 survey.

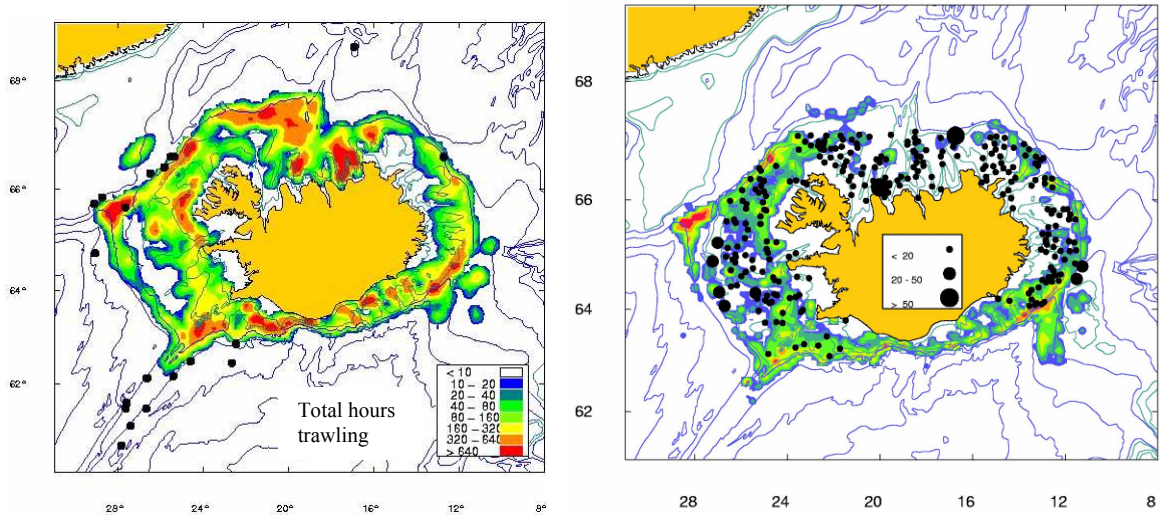


Figure 4.16 a) Geographic distribution of “ostur” (mass occurrence of large-sized demosponges, based on Klitgaard and Tendal 2004) around Iceland in relation to bottom trawling effort (total trawling hours 2003 [combined groundfish, shrimp and *Nephrops* fisheries]). b) Geographic distribution of biomass ($\text{kg} \times \text{h}^{-1}$) of sponges during the MRI (Iceland) groundfish survey (2002) in relation to groundfish otter trawling effort (trawling frequency 2002). Maps: S.A. Steingrímsson.

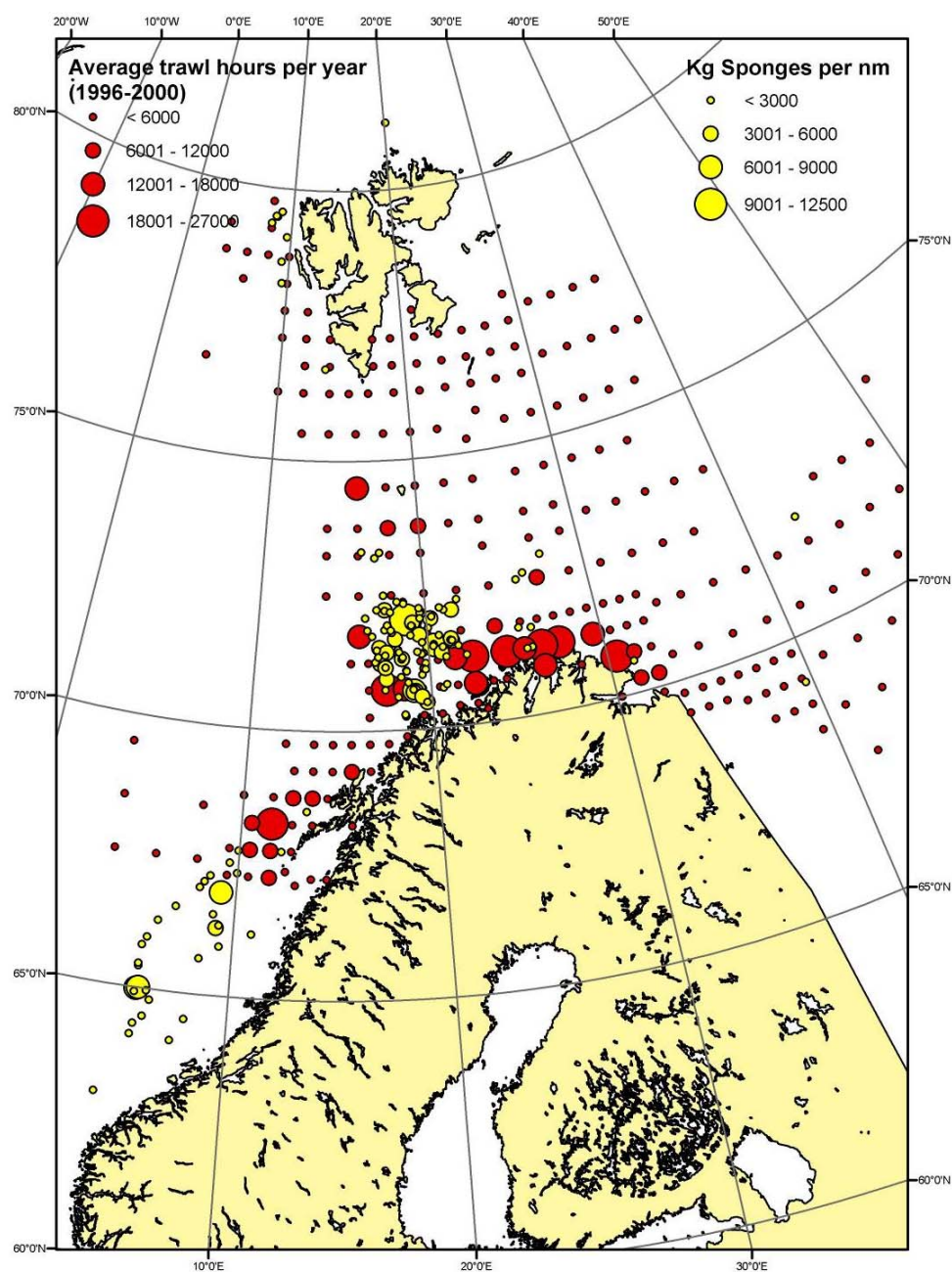


Figure 4.17 Sponge by-catch (in kg/nautical mile trawled) in IMR (Norway) trawl surveys during 1981–2001. Map: Institute of Marine Research, Bergen.

4.2.3 Ecological importance

The presence of the large sponges adds a low three-dimensional structure to the bottom, thus increasing habitat complexity and attracting a large number of other smaller species from many phylae. The associated fauna has not been investigated in the area treated here, but in the Faroes it has been found that the ostur houses about 250 species of invertebrates (Klit-

gaard 1995). Since only very few species utilize the sponges as a food source the interactions should be found in the provision of hard substrate, provision of refuges from predation or physical strain, and access to enhanced food supply directly or indirectly from the surrounding water. Even if the sponges themselves also do not offer food for fish, the numerous and abundant fauna must represent a good feeding ground to particular life history stages. We have regularly observed both in samples and in photographs young redfish (*Sebastes*), sometimes even inside the cavities of large sponges. In the catches there are also often several species of groundfish represented; stomach content samples have been taken but await analysis.

4.2.4 Documentation of damage

Time and again it has been photographically documented that the epifauna of dredged and trawled gravel-, pebble- and rock-bottoms is unmistakably impoverished (~ both species diversity and abundance significantly lowered) as compared to undisturbed nearby areas at the same depth (e.g., Auster et al. 1996; Collie et al. 1997; Collie et al. 2000; Auster 1998; Watling and Norse 1998; Koslow et al. 2000). Investigations on trawling effects show that between 15 and 89% of large-sized benthos is destroyed through a single pass, the variation between results probably being due to differences in construction of the gear used (Moran and Stephenson 2000; Wassenberg et al. 2002). Observations on trawl impact on sponge individuals and sponge populations indicate that differences between species, such as size, form, flexibility and attachment to the ground results in different survival chances (Van Dolah et al. 1987; Wassenberg et al. 2002). It appears that the most sensitive category is lumpy, non-flexible sponges larger than 50cm, exactly the morphological type constituting *ostur*.

There are no reported investigations on the effect of trawling on sponge-dominated bottoms within the area treated here. Faroese fishermen have told us about trawl-damaged sponge bottoms first giving good catches, then decreasing progressively. We investigated the areas where this should have happened some years earlier, and found only few sponges. There are no studies of recovery in sponge areas, and we cannot say if the few we found was the first step in such a process.

We have seen single half-rotten sponges coming up seemingly crushed and dead, and also specimens that obviously recovered, having scars after partial damage. Although we were in trawled area, we cannot, however, say for sure that this damage was effected by towed gear.

We know, both from the studies performed elsewhere and from our own participation in studies in the Gulf of Maine on gravelly bottoms, much like those found in the NE Atlantic, that trawling has the following effects:

- 1) damages sponges physically. The possibility of regeneration, multiplication from fragments or death of the animals depends on the ability each species,
- 2) overturns substrate like stones and boulders with a devastating effect, killing all epifauna,
- 3) creates a cloud of sediment of varying thickness and duration that clogs the filters of suspension feeders. In this last respect sponges are especially sensitive as they cannot sort particles but must use energy to filter all kinds of particles from the water in their canal system and send them through the digestive processes.

During investigations in the Faroes we have seen large-sized ostur sponges (20–40cm in maximum dimension) that had their incurrent channel system absolutely filled with sediment particles. We assume that something happened in the surroundings that stirred up large quantities of sediment into the water. We cannot say for sure that it was trawling, but at a depth of 350m it was hardly a storm effect. Since the sponges otherwise gave the impression of being healthy, they are obviously able to recover by slowly cleaning their system after the incident. However, if this happened often the sponges would be severely stressed, and for some species it is probably lethal.

4.2.5 Ecological implications

The fauna associated with ostur and sponge grounds is, by experience, estimated to be at least twice as rich in species as the surrounding gravel or soft bottoms, and many species are much more abundant within ostur and sponge grounds than outside them (Bett and Rice 1992). All associated species are facultative sponge dwellers, meaning that they are found also in other habitats. The only near-obligate species reported are the isopod *Gnathia abyssorum* and the chitonid mollusc *Hanleya nagelfar* (Klitgaard 1995; Warén and Klitgaard 1991).

The structurally dominating species of the ostur and sponge grounds are large and provided with proportionally very voluminous and heavy skeletons. Aquarium experiments show that damages can be healed relatively fast (Hoffmann et al. 2003), but all observations point to very slow somatic growth, probably only in the productive time of the year. The size structure within the population indicates slow reproduction and recruitment, and high age of the large specimens. No exact aging has so far been done but both size structure and comparable investigations in Antarctica point to decades if not centuries (Dayton 1979; Gatti 2002). Accordingly, it will take a long time for a sponge-dominated area to recover even after partial destruction, and repeated disturbance may lead to permanent extirpation of the species in the area.

4.2.6 Management

Although mass occurrences of sponges have been known for a long time in certain areas no management efforts have so far been made in Norway, Iceland or Greenland. The ecological implications of the presence of ostur and the consequences of severe damages in these areas would seem to make it necessary to consider regulations in the use of towed gear in a foreseeable future.

4.2.7 Taxonomic considerations

The phylum Porifera (sponges) comprises three classes: Calcarea (calcareous sponges), Hexactinellida (glass sponges) and Demospongiae (silicious sponges); only members of the two last-mentioned classes reach a body size and abundance rendering them species potentially building up ostur and sponge grounds.

The habitat-forming species are important units of the ecosystem, and proper identification is necessary in order to know what species are present, to apply newly gained as well as already existing knowledge, and to monitor changes over time, manmade or natural. One could choose to aim at a higher level of taxonomy, that of genus or family, because mistakes will be fewer than at lower levels, and stay with that. However, much knowledge would be lost or unavailable, for instance concerning the species composition and its changes in accordance with variations in ecological parameters. It is, therefore, a most regrettable fact that sponge taxonomy is complicated, unstable and difficult to practice.

A very valuable step towards the solution of some of the problems has recently been taken with the publication of *Systema Porifera: A Guide to the Classification of Sponges* (Hooper and Van Soest 2002; Tendal 2004). The book is a guide (general characteristics, diagnoses, keys, descriptions of type species) to widely accepted genera and families. To take things a step further one must rely on local or regional keys of varying age, and on recently published species lists, such as:

- European Register of Marine Species (soton.ac.uk)
- Distribution of marine, benthic macro-organisms in Norway (Brattegard and Holthe 1997; <http://www.dirnat.no> (look under Publications))
- Distribution of marine, benthic macro-organisms at Svalbard (including Bjørnøya) and Jan Mayen (Gulliksen et al. 1999; <http://www.dirnat.no> (look under Publications))
- Greenland marine benthic animals, diversity and geographic distribution (Tendal and Schiøtte (In prep., send enquiries to: ostendal@zmuc.ku.dk))

4.3 Other vulnerable habitats

4.3.1 Maerl

Maerl consists of loose-lying coralline red algae belonging to the family Corallinaceae. Maerl beds are composed of living and dead algae that accumulate into beds or banks. The living part of the algae is found at the upper sediment layers, while dead coralline algae accumulate underneath. In Arctic waters, maerl species have been reported from Norway (Adey 1971; Freiwald and Heinrich 1994; Foster 2001) and Iceland (Adey 1968; Gunnarsson 1977; Thors and Helgadóttir 1980). The only published accounts of maerl in Greenland is from the Ikka Fjord in West Greenland, where *Lithothamnion* and *Clathromorphum* encrust the lower part of the ikaite columns on the bed of Ikka Fjord and may thereby stabilize these delicate column structures (Buchardt et al. 1997). We found no published accounts on maerl from Svalbard waters.

Adey (1971) investigated the distribution of maerl species along the coast of Norway and in Icelandic waters (Adey 1968), and showed that the geographical distribution of coralline algal species was defined by temperature. The dominant maerl species in the northern part of Norway was *Lithothamnium glaciale* (Adey 1971). In Iceland, Adey (1968) found maerl belonging to the genus *Lithothamnium* widely distributed, but was not able to identify these further to species. Other maerl species that he recorded were *Phymatolithon rugulosum*, *Phymatolithon laevigutum* and *Phymatolithon lenormadi*. In another study carried out in Húnaflói, *L. tophiforme* and *L. glaciale* dominated (Thors and Helgadóttir 1980). The known distribution of maerl in Icelandic waters is shown in Figure 4.18.

The three-dimensional structure of maerl thalli forms an interlocking lattice that provides a wide range of niches for infaunal and epifaunal invertebrates (Kamenos et al. 2004). Studies carried out in UK and Mediterranean waters have shown that due to the high structural complexity the diversity of fauna and flora can be high. Less is known about biota in maerl beds in the Arctic. Freiwald and Heinrich (1994) described the benthic community in maerl beds in northern Norway (70°N). They showed that the maerl bed fauna was dominated by filter feeding organisms (polychaetes, crustaceans and bivalves), and the species composition was similar to that in maerl beds from western Ireland (Bosence 1979).

Maerl is widely harvested in the Atlantic, such as around the UK and France, where it is mainly used as calcium/magnesium soil additive in animal fodder (Blunden et al. 1975; Guiry and Blunden 1981). There are now initiatives to harvest maerl at two locations in Icelandic waters – in Húnaflói Bay (Thors and Helgadóttir 1980) and in Arnarfjörður (Thors 2002). Within both locations, thick beds of maerl (coralline) sediments have been located

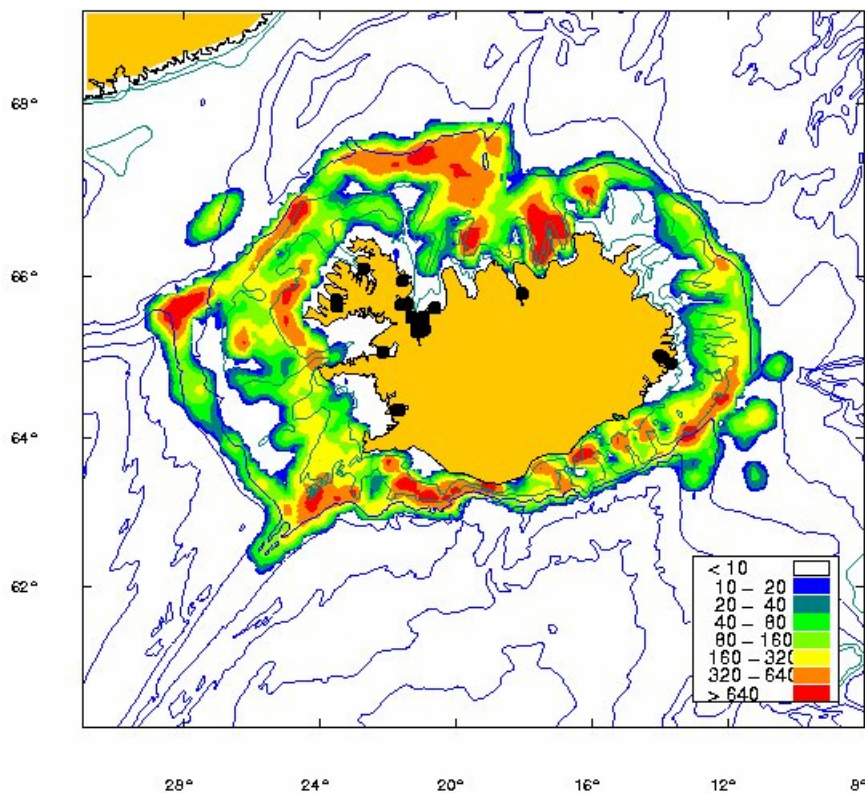


Figure 4.18 Known distribution of maerl in Icelandic waters in relation to bottom trawling effort (total trawling hours 2003 [combined groundfish, shrimp and *Nephrops* fisheries]). Map: S.A. Steingrímsson.

Direct harvesting and fishing activities in areas where maerl occurs is likely to have a detrimental impact on the fauna found within these habitats. A study carried out in Scotland showed scallop dredges to have a large impact on the fauna within maerl habitats (Spencer and Moore 2000). Other threats include sediment extraction, suction dredging and pollution in near shore waters (Birkett et al. 1998).

In Icelandic waters, harvesting of maerl with suction dredging is likely to result in considerable suspension of sediments and impact on benthic communities. We have limited information on fishing activities in Icelandic maerl beds. In 1970, a survey was carried out in Húnaflói Bay to locate scallop fishing grounds (Eiríksson 1970). In the inner part of the Bay, at depths between 10–40m, a large proportion of the catch of the scallop dredge was maerl. Scallops from these areas were covered with maerl and were generally smaller compared to areas where maerl was absent. In a similar survey carried out in 1971, maerl was commonly caught during scallop dredging in Jökulfjörður, NW Iceland (Eiríksson 1971). These surveys were carried out before any scallop fishery took place in these areas. In recent years, maerl is rare as a by-catch on scallop grounds in Húnaflói Bay (H. Eiríksson, pers. comm.). Apart from such anecdotal information, the effects of fishing gear on maerl habitats have not been investigated in Arctic waters.

4.3.2 Hydrothermal vents and cold seeps

Hydrothermal vents occur in areas of tectonic activity. Other types of geographical features involving emission of gases (mainly methane) from the ground are “cold seeps”. Benthic communities around hydrothermal vents and cold seeps are dependent upon the energy derived from sulphur-containing inorganic compounds (hydrothermal vents) or methane (cold seeps). These faunal assemblages are often unique and highly confined to areas of underwater geothermal activity. Furthermore, many of the species found in such habitats are endemic.

Areas of hydrothermal activity probably occur widely in Icelandic waters but they can be difficult to locate, especially in deeper waters. Benjamínsson (1988) reported 53 sites, but most of them were found in shallow coastal waters and in the intertidal zone. Hydrothermal vents have been found off the islands Grimsey and Kolbeinsey (N Iceland), on the Reykjanes Ridge and in Eyjafjörður (also in N Iceland) (Figure 4.19).

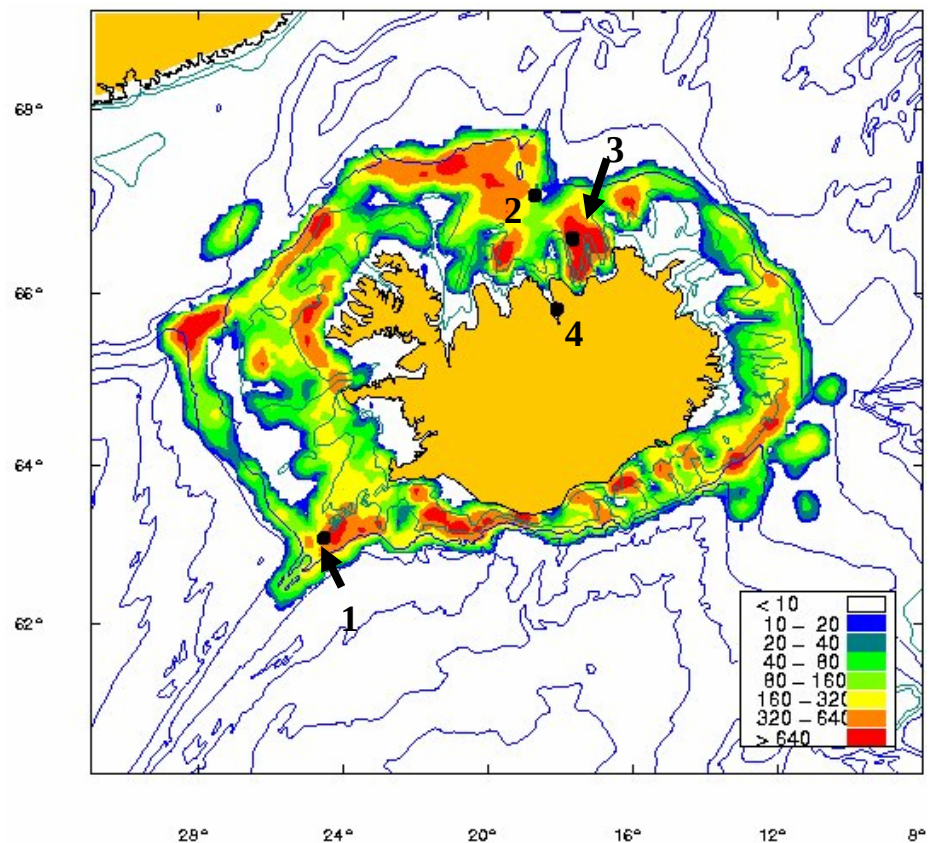


Figure 4.19 Location of areas of hydrothermal activity in Icelandic waters in relation to bottom trawling effort (total trawling hours 2003 [combined groundfish, shrimp and *Nephrops* fisheries]). (1) Steinahóll on the Reykjanes Ridge (2) Kolbeinsey vent fields, (3) Grimsey vent fields and (4) in Eyjafjörður. Map: S.A. Steingrímsson.

In 1988, a number of hydrothermal vents were found at 100–106m depth on the Jan Mayen Ridge, close to Kolbeinsey (Fricke et al. 1989; Ólafsson et al. 1989). Three types of hydrothermal effluents were described: (1) fissures, (2) small chimneys and (3) crater-like dips. Filamentous bacterial mats were found on the vent sites, growing at temperatures ranging between 70–110°C. In contrast to hydrothermal deep-water vent areas found in many other areas, the macrofaunal species found among the Kolbeinsey vents were the same as in the surrounding non-hydrothermal areas in boreal Atlantic and adjacent polar seas. The chemical contents of the effluent gases in the Kolbeinsey and Grímsey hydrothermal fields were investigated one decade after their discovery (Botz et al. 1999). Hannington et al. (2001) found high-temperature (250°C) hydrothermal vents in the Tjörnes fracture zone close to Grímsey. Several types of vents were described, such as solitary anhydrite chimneys, large coalesced mounds and active mounds. In some places, mounds have coalesced into a ridge. Individual mounds are in general low-relief structures, up to 10m across and 3–5m high. The majority of vents occurred on 400m depth, but isolated chimneys and mounds were found down to 700m depth.

Hydrothermal activity has been located at one site on the Reykjanes Ridge during a survey that aimed to map sites of hydrothermal activity along the 600km of the ridge axis (57°45'N to 63°09'N) (German et al. 1994; German and Parson 1998). The only vent found was later named the Steinahóll vent field (63° 06'N), and it is at 250–350m depth.

In 1997, three geothermal silicate cone structures rising 25, 33 and 45m above the sea floor were found in Eyjafjörður (65°49.73'N and 18°06.69'W), North Iceland, at 65m depth (Figure 4.20). The hydrothermal activity is greatest in the highest cone. The temperature of fluids emerging through the fissures and small chimneys on the cone ranges between 60–72°C. The cones increase their size by precipitation of the minerals dissolved in the geothermal water when it mixes with seawater (Marteinsson et al. 2001; Bogason et al. 2004). The hydrothermal vents in Eyjafjörður were protected as a natural monument in 2001 (see chapter 6.7.2). In 2004 and 2005, more areas of hydrothermal activity were found, many of which were characterized by low-relief cones (Bogason, pers. comm.). Exceptional vents have been found in the Ikka Fjord and the Gakkel Ridge in Greenland waters.

The Ikka Fjord, in Southwest Greenland, contains over 700 submarine columns in the innermost part of the fjord. These columns are formed when the cold-water mineral ikaite precipitates due to mixing of the calcium in the seawater and the carbonate and bicarbonate ions in the seep water from the column. These columns are up to 20m high, they have an annual growth of more than 50cm and support a diverse marine life (Burchardt et al. 1997). The Ikka Fjord was protected by law in 2000 (see chapter 6.7.2).

Some of the most exciting hydrothermal vents found in the Arctic are located on the 1100-kilometre-long Gakkel Ridge, stretching from North Greenland towards Siberia. A total of nine vent sites were discovered by two ice breakers while carrying out a geophysical survey along the ridge. Although the fauna in the area was not investigated, a photographic survey revealed considerable biological activity (Edmonds et al. 2003).

An active cold seep, later known as the Haakon Mosby mud volcano, was discovered in 1987 during a side scan sonar survey close to the continental margin in the western part of the Barents Sea (72°N) at 1250m depth (Vogt et al. 1997). It is only 1m high but about 1km in diameter. The mud volcano was investigated in 1995 and 1996 by a team of Norwegian, American and Russian scientists, and with the Mir submersible in 1998 (Bogdanov 1999). The megafaunal benthic community was dominated by two pogonophorans, *Sclerolinum contortum* and *Oligobrachia haakonmosbiensis*. *S. contortum* was very abundant, sometimes covering between 80–90% of the sea floor. A wide range of organisms were found to be highly associated with both of these pogonophoran species. The fish *Lycodes squamiventer* was found commonly throughout the crater, especially in the central part (Gerbruk et al. 2003). The crater was covered with extensive bacterial mats, consisting predominantly of filamentous colourless sulphur bacteria (Lein et al. 2000). The benthic community in areas away from the mud volcano was found to be markedly different (Gerbruk et al. 2003).



Figure 4.20 Hydrothermal vents in Eyjafjörður.

Trawling in areas where hydrothermal vents and cold seeps occur can cause long-lasting or irreversible damage of these geological features and the associated fauna. These habitats are therefore of high conservation importance. Due to lack of data on their distribution, it is difficult to assess whether hydrothermal vents and cold seeps are under threat from

trawling activities in Arctic waters. Some of the vents and seeps are likely to be located below the depth where most fishing activities take place.

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5. Cultural heritage in Arctic waters

D. Nævestad

5.1 Introduction: The process of wrecking in the drift-ice

Ship wrecking in Arctic waters, given the ice conditions, results in wrecking processes different from those taking place on a coastline. Ships wrecking on a rocky coastline are to a great extent broken up in the process. A “wrecking scenario” here may stretch over several sea miles, where parts of the hull, rigging, cargo and equipment are smashed and spread. The scenario is different in open waters, and in wrecking by ice pressure. In open waters, ships usually founder by springing a leak, having the hatches stove in by waves or capsize. The vessel sinks in one piece, the hull and cargo, etc. being deposited on the sea bottom within a limited area. This also occurs when a ship sinks by ice pressure. The term “crushed by the ice,” used in these situations, does not actually mean that the ship breaks into several parts. The pressure of the ice will usually cause the planking and the strakes in the water line, or somewhat under this, to be stove in. The ship springs a massive leak and fills with water. When the ice pressure decreases, the ship will sink in one piece, with the rigging still attached (Figure 5.1).



Figure 5.1 The “Drivis”, sinking in 1928; in a classic situation of wrecking in the drift-ice. Only a few barrels and the lifeboat were left on the surface when she sank, according to the crew (Ottesen 1999, Reprinted by permission of Johan Ottesen, Fotoarkivet).

It is thus in open waters, along the ice edge, and in waters with drift-ice, where the highest potential for finds of whole vessels deposited in the sea bottom exists. These wrecks may also be found in deeper fjords in in-shore waters, where the conditions for preservation may be exceptionally good, due to the low temperatures and abundance of fine sediments. The “closed find” of a vessel, represents a time capsule where little is added or destroyed by later actions, as is often the case on shore.

5.1.1 The special conditions of preservation in Arctic waters

Arctic waters can offer environments specially suited for the preservation of wood and other organic materials. Temperatures and salinity are important factors for the organisms that attack wood and other organic materials in seawater. *Teredo navalis* and other tree-boring species can devour a wreck in a short time in a temperate zone. However, the temperature in Arctic waters is too low for these species to breed and even establish themselves at all.

North of Canada, at the entrance to the Northwest Passage and close to Beechey Island, lays the sunken bark Breadalbane, one of the supply ships in the search of the Franklin expedition. The ship was crushed by the ice, and sank in 100m of water on August 2, 1853 in a very short time. It was discovered by a National Geographic Expedition, led by Joseph MacInnis, in August of 1980 and surveyed by special underwater crafts in 1983 (MacInnis 1985).

The wreck sits on an even keel on the bottom with its masts still standing after 150 years (Figure 5.2). The ship sides, decking and superstructure are still mainly intact, and one can inspect the navigational instruments on the shelf of the deck-housing just abaft the wheel. The latter was recovered by the expedition, almost intact. The wreck of the Breadalbane is almost a parallel to the state of preservation one can find in the Baltic, and the ship can be said to be in the same condition as the *Wasa*. It is possible that the waters East and North of Svalbard by and large match these conditions. In parts of the Barents Sea it will probably be possible to locate wrecks exceptionally well-preserved.

Other special areas where organic material will be well-preserved are, among others, the threshold fjords of Svalbard, where conditions for the preservation of shipwrecks and other organic cultural artefacts are very good. First, the bottom water of these fjords has extremely low temperatures. In these freezing conditions, very few wood boring organisms like *T. navalis* can survive (Gulliksen, pers. comm.). Secondly, the sedimentation is very heavy, with fine grain material from the glaciers and glacial rivers. This enhances the conditions for preservation to a great extent. The environment 60cm below the surface of relatively fine-grained mate-

rial is virtually free of bacteria (Nævestad 1991:106, 112-114). This is a true “cooler” for shipwrecks and organic material, of unique quality.

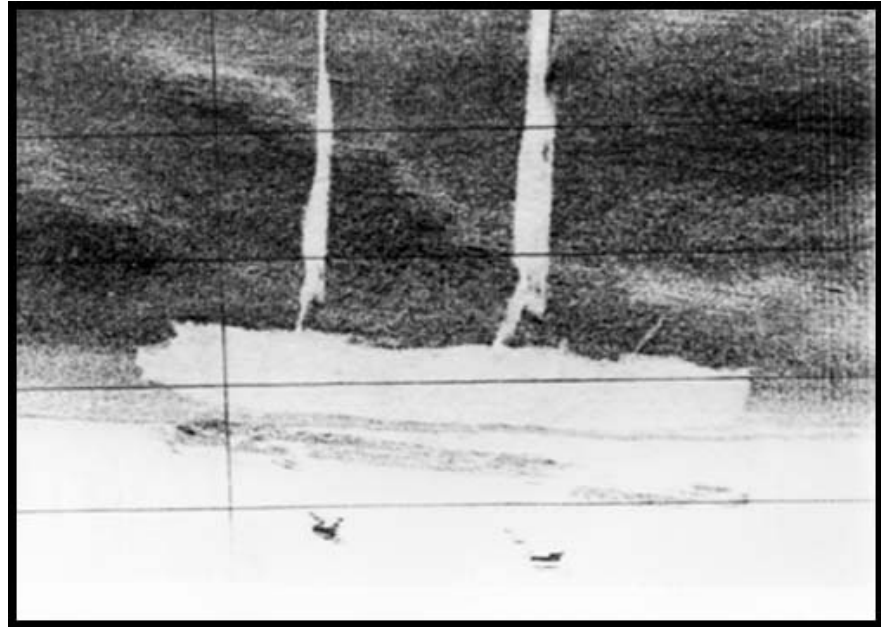


Figure 5.2 One-hundred forty years on the sea-bottom in the Arctic: Side-scan sonar image of the Breadalbane, masts still standing with furling sails (Side-scan image by permission from L3 Klein Associates, Inc.).

5.2 The impact of the fisheries on cultural remains on the seabed

As demonstrated above, conditions in Arctic waters favour the survival of cultural remains. However, a scallop dredge like those used on Spitsbergen, 6m wide and 1m high, with ground chain and steel bag, go partly into the bottom, and crush even artefacts buried in the seabed. Multiple passings, as has been the tradition in these fisheries, will crush, displace and deplete wreck sites over a period of time. The scallop dredgers and shrimp trawlers of Spitsbergen have brought up with their gear anchors, black oak timbers from ships and pottery (Figure 5.3a). To what extent this happens is not known, as only a few incidents have been reported. However, information from different sources points to a vast underreporting of these incidents (Anonymous, interviews scallop dredging crew, pers. comm.). As for trawlers, the impact on the sea bottom is well-known; trawling lanes can easily be seen on side scan sonars and on cameras. The impact on wooden wrecks and artefacts on the sea bottom will of course be substantial, and likewise crush, displace and deplete the sites on each passage. Trawlers tend to get bigger, and new triple trawls requires the use of several weights of up to a tonne (to keep the gear on the

bottom), plus the trawling doors, inflicting a large impact on the sea bottom.

To give an example of the impact of trawling on cultural material on the sea bottom, the following incident shall be related: On the 15th of April 1999, the diving vessel Seaway Kingfisher was doing maintenance work on the H-4 wellhead at the oil platform Troll B in the North Sea. The structure is quite large, with a steel frame to ward off trawls and fishing equipment, measuring 21mx17m at the base, 11.5x9m at the top, standing 7.5m above the seabed; roughly the size of a medium to large house.

On this structure, an 11-metre-long, 40-centimetre-broad piece of a keel made of oak from a large sailing vessel was found. The keel was somewhat entangled in net. It appeared that the keel had been dragged along by a trawl, and torn off at the roof of the H-4 manifold on the seabed. The keel, weighing more than two tonnes, with copper keelbolts, was raised by Seaway Kingfisher, and brought to the Mongstad oil terminal near Bergen in Norway. Here, the find was examined by Bergens Sjøfartsmuseum, and documented. It appears to have been a part of the keel of a vessel of about 350–400 tonnes (Figure 5.3b).



Figure 5.3 a) A Bartmann ceramic vessel fabricated in the Ruhr district in Germany and widely used for wines and spirits from the end of the medieval ages, and into the beginning of the 18th century. One like this, together with oak fragments, came up with the scallop dredge on the North coast of Spitsbergen and was plucked out of the stone-sorter, crushed, by one of the crew members.

b) From Norsk Hydro magazine, 30 June 1999: The keel, 11m long, found entangled in the H4 production well of the Troll B oilrig, had been caught in a trawl, and torn off at the roof of the installation on the seabed. It was obviously torn off a longer piece by the trawl.

5.3 Assessment of wrecks and cultural remains in the Barents Sea and waters off Spitsbergen, Greenland and Iceland

Systematic registrations of submerged cultural remains are not conducted in these areas. Overall, there are not many registered or positioned finds, but there are available sources of knowledge of shipwrecking, and other cultural activity, that indicates a large abundance of unknown cultural material in and on the sea bottom.

Identification and mapping of areas and regions of specific interest concerning cultural remains has been done by evaluation of sources that indicate the existence of such heritage, and an educated evaluation of the value of the material (Figures 5.4 and 5.5). The areas are also evaluated according to the way the material has been deposited and the environmental characteristics, which regulate the terms of preservation.

There are short descriptions of the reasoning behind each chosen area, the cultural historic framework and the value of the expected remains. As the evaluation is based on rather few pillars of existing knowledge, it is important that they may be changed or extended as new knowledge is brought to light.

The waters along the coast of Finnmark, Troms and the Kola Peninsula, and the maritime cultural history of the region, which forms the basis of the potential finds of cultural remains under water in the region, will be discussed. The navigation in the Bjørnøya and Svalbard regions will then be described in the same manner. Finally, some special conditions concerning cultural remains on the seabed in the Arctic zones of these regions will be described. The same framework will be used for the description of Icelandic and Greenland waters.

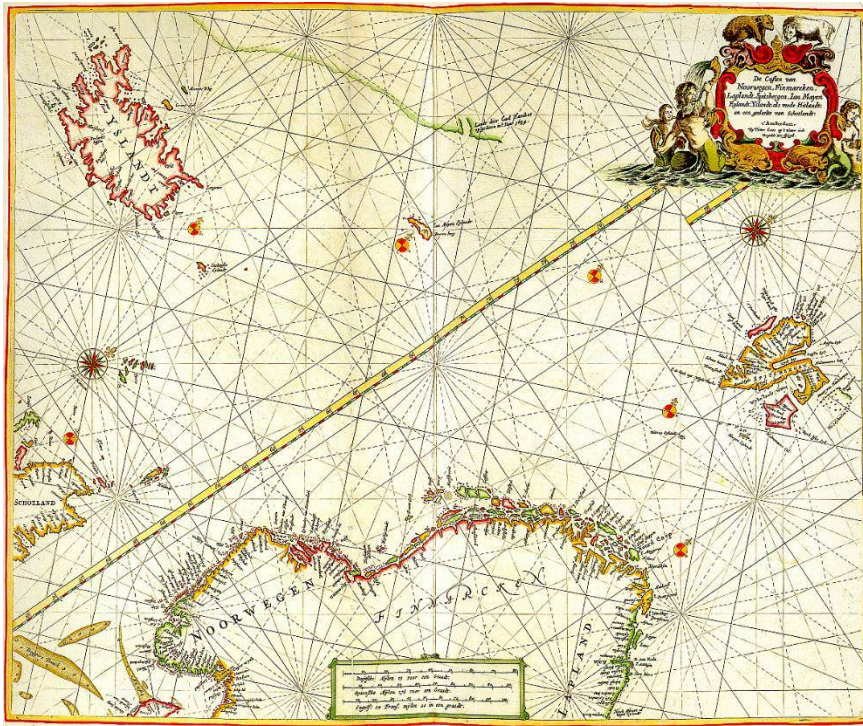


Figure 5.4 An early map of the North Atlantic, useful for navigation in The Barents Sea region. Iceland, Norway and Spitsbergen are well-defined, while little is known of the Greenland coast, only the mouth of a fjord is defined.

Pieter Goos: *De custen van Noorwegen, Finmarcken, Laplandt, Spitsbergen, Ian Mayen Eylandt, Yslandt, als mede Hitlandt, en een gedeelte van Schotlandt.* Amsterdam 1666 (445 x 545). From: *The Northern Lights Route*, University Library of Tromsø. (<http://www.ub.uit.no/northernlights/eng/map08.htm>)



Figure 5.5 In Greenland, and later Spitsbergen, walrus have been hunted for their ivory tusks, and their hides, which were considered to give the strongest ropes known in medieval times. The cathedral of Köln, and other great medieval buildings, were dependent on the walrus-hide ropes to raise the slabs of stone. The Bishop of Gardar in Greenland shipwrecked in Iceland in the year 1266, losing a whole cargo of walrus tusks (Nörlund 1936).

5.3.1 The borders of the Barents Sea, the coastal waters of Troms and Finnmark, Norway

Along the Troms coast, there is a special potential for finds of Stone Age habitats. In the Mesolithic period, people often located their villages close to the sea, or on the beach itself. Transgressions have led to changes in the landscape and the sea level; on the coast of Troms County, in the Lofoten and Vesterålen area, the prehistoric coastline is now situated at 20m depth in the sea. In these regions Stone Age tools have been brought up by trawls and other fishing gear (Figure 5.6).



Figure 5.6 Stone Age tools, brought up from the sea bottom by fishing gear, close to Senja Island in Troms, Norway. The one on the left is defined as a knife being useful in the skinning and preparation of animal hides. The tool on the right is a saw, with a toothed ridge. Both are made of slate. The tools are partly covered by marine organisms, showing that they have been exposed on the sea bottom, not buried in it (Photo: Tromsø Museum. Artefact ref. number TS9470b and TS9470c).

A great number of now submarine habitats from the Stone Age may be found along this coastline. Such sites have yet to be excavated in Norway. The wet environment in such locations gives high hope of sensational finds of organic material. In Denmark, where 2,500 such sites are registered (and the total number is expected to be 25,000), there are cultural layers of organic material of up to 60cm, containing skeletons, textiles, harpoons, log boats, decorated paddles, etc., all in a fine state of preservation thanks to the wet environment.

The earliest written sources from these waters is the tale of the Viking chief Ottar, from around 890 AD, in which he tells King Alfred of England about his country. It is conceivable that the whalers mentioned by Ottar, and other hunting and trading expeditions, had navigated the coast of Troms and Finnmark before his days. Remains of ships, cargo and tools from these times may be found at wreck locations and in harbours that were frequented at the time. In the Lofoten Islands, a great Viking hall was found at Borg, together with numerous boathouses. The largest boatshed is 26m long, and may have sheltered a vessel the size of the Gokstad ship, which is an oceangoing craft. This indicates a society with capable maritime experience in transport, trade and fisheries.

During the Middle Ages, the settlements expanded, and trade increased. A multitude of small communities, farms and fishing villages were established. In the harbour of the trading port Vågan in the Lofoten Islands, submarine cultural layers have been found containing textiles, leather and implements of wood and bone, all well-preserved.

During the great seasonal fisheries, fishing vessels and traders came both from the north and the south, to Lofoten and Vesterålen. There was a significant trade of dried fish, with local vessels, to Trondheim and Bergen. A number of ships from this period have been found on the coast, and in the adjacent sea. The trade with Russia through the Baltic was dominated by the German Hansa, who had established a trading situation there close to monopoly. However, from the 1550s, a new trade route along the Arctic coast to the White Sea was established, which both the Dutch and the English strove to dominate (Figure 5.7).

Archangel was established as a trading port in 1583, on the order of the Tsar. Up to the construction of St. Petersburg around 1700, this was the most important port of trade in Russia (Figure 5.8). This led to a considerable increase in traffic along the coast of Troms and Finnmark in Norway (Figure 5.9), and along the Kola Peninsula. The trading vessels from Western Europe brought gold and silver goods, golden threads, textiles, and dyes like carmine and indigo, wine and spirits. Furs, lumber, tar, hemp and rope work were some of the goods brought back. The number of foreign ships visiting Archangel amounts to ca. 400 a year. The sailing directions describe a course close to the North coast of Norway, and shipwrecking was frequent (Figure 5.10).



Figure 5.7 The Dutch merchant Linscoten made this map of Vardø Island on his passage to the White Sea during Barents' first voyage in 1594. The anchorages are shown, and the ferry place facing the mainland, where several small boats are drawn up on the beach. In: *Voyasie, ofte Schip-vaert ...* from 1601 From: *The Northern Lights Route*, University Library of Tromsø. (<http://www.ub.uit.no/northernlights/eng/linschoten04.htm>)

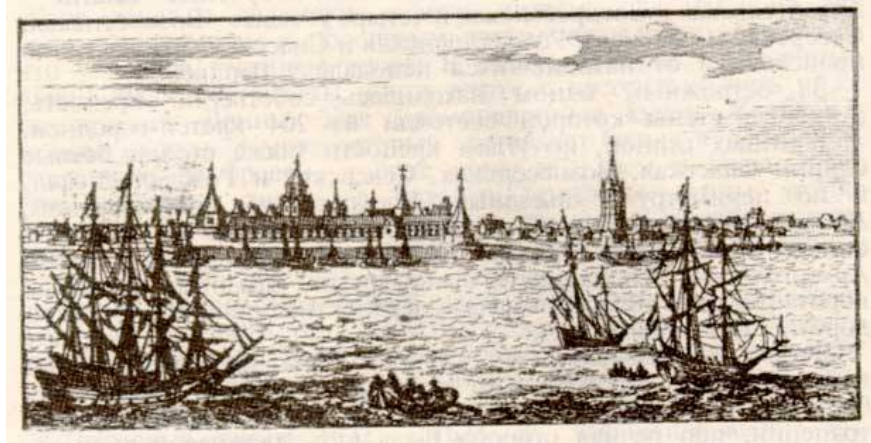


Figure 5.8 The town of Archangel, 1613. This was the only “Gate to Russia” for the traders before St. Petersburg was built, in the 18th century. Up to 400 ships from Western Europe frequented the port each year. After 1750, the port became the centre of the Pomor trade (Figure from: The Northern Lights Route, University Library of Tromsø. <http://www.ub.uit.no/northernlights/eng/arkhangelsk.htm>).



Figure 5.9 The building of Vardøhus Fort, at the island of Vardø, was essential for the Danish king, who thus both made his presence known, and established a military garrison, however small, in the north regions. Russia, Sweden and Norway claimed mastery of Finnmark for a period, the Sámi people being taxed by all three governments.

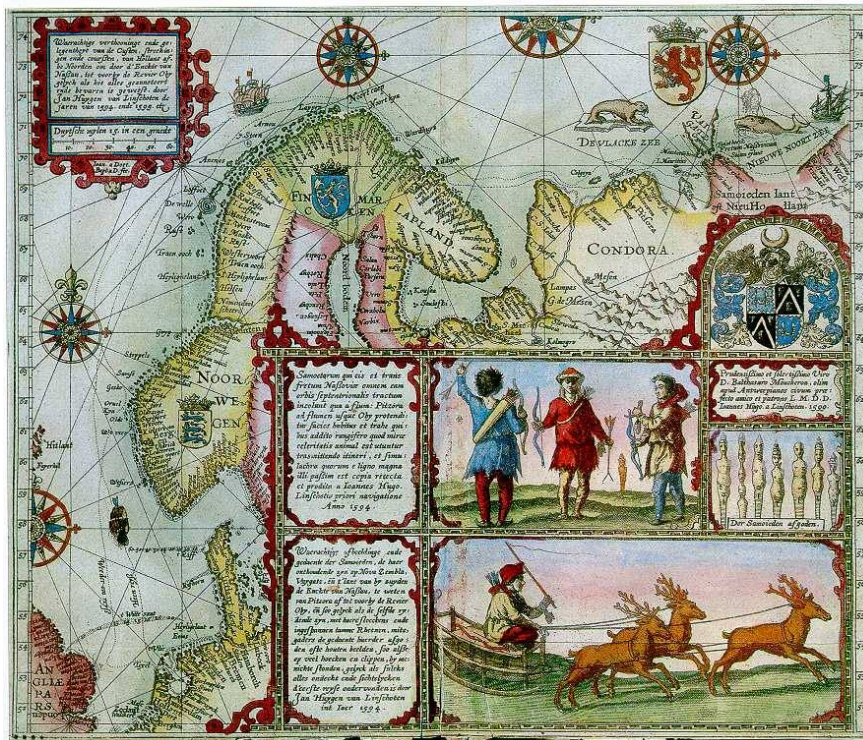


Figure 5.10 Map of Scandinavia and the White Sea area by Jan Huyghens van Linschoten. Made after the first Barents voyage of 1594 (From *Voyasie ofte Schip-vaert...* (1601)). On this map we can actually follow their way of navigation, and trace their sea-lane. The course is marked from Texel by the Zuider Sea, giving South Norway a wide berth. When they reached the latitude of Lofoten, they steered eastwards, to get in touch with the coast. They then kept the coast in sight, which is also possible all night long due to the midnight sun, until they reached the island of Kildin, the trading port in Russia, on the Kola coast. On their way south, they mainly retraced their course.
 From: *The Northern Lights Route*, University Library of Tromsø.
<http://www.ub.uit.no/northernlights/eng/map05.htm>

The Pomors, farmers of the White Sea region, had already in the early years of the 1500s, before the Dutch and English ventured east, navigated the waters east of Novaja Zemlja. From the end of 1600, the Pomors established trade on the Finnmark coast, and some time later also in Troms (Figure 5.11). From the 1750s, a large quantity of Pomor vessels frequented the coastline of Finnmark and Troms, bringing with them mainly grain and lumber, but also ropes, leather, coarse textiles and ironmongery.

From the 1850s, approximately 300 Pomor vessels from the White Sea area frequented North Norway. However World War I reduced the traffic considerably, and the Russian Revolution put a rather sudden end to the 200-year-old trade (Arlov 1996:97).

We do not know the figure of ships lost along the coast at all times, but calculations based on ships sinking at sea during the 19th century, showed that between 10 and 20% of the Norwegian sailing ships foun-

dered at sea (estimates calculated by D. Nævestad, based on the Malmstein register at Norsk Sjøfartsmuseum). This indicates that a considerable number of wrecks lie undetected in this area.

The number of wrecks in the region has also increased in more recent years. During World War II the waters of the Barents Sea saw severe acts of war, resulting in a large amount of shipwrecks and downed aircraft on the sea bottom. Local fishermen call parts of the Varanger Fjord “the airfield”. Shipwrecking still occurs every year in these waters.

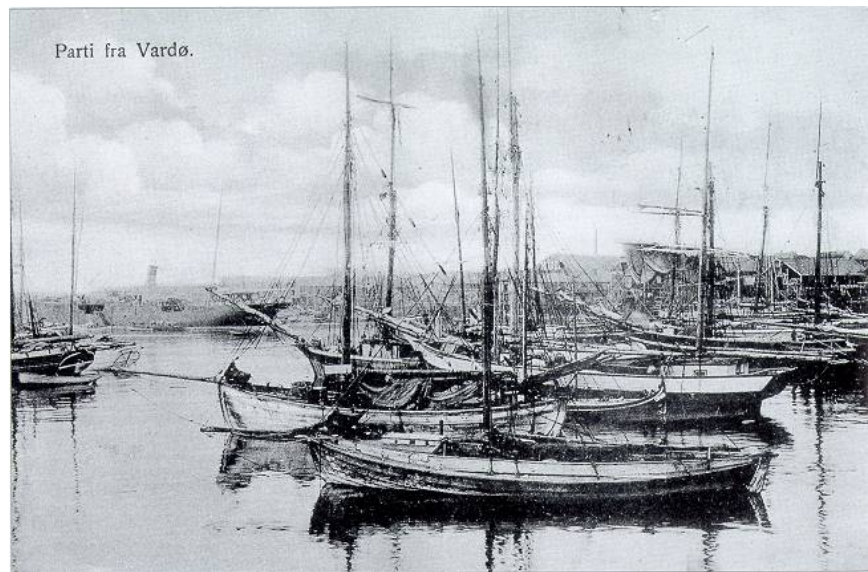


Figure 5.11 The harbour of Vardø, at around 1900, with Norwegian and Pomor ships.
From: *The Northern Lights Route*, University Library of Tromsø.
(<http://www.ub.uit.no/northernlights/eng/pomor01.htm>)

5.3.2 Svalbard and Bjørnøya: coastal waters and sea-lanes

One of the reasons for the 16th century Western European navigation in the north, was the wish to establish a sea-lane to China and the Spice Islands of Indonesia. Rich trading companies and merchants fitted out trading expeditions for this quest (Figure 5.12). One Dutch expedition led by Willem Barents in 1596 discovered Bjørnøya and Spitsbergen (Svalbard). The discovery led to an extensive exploitation of sea mammals in the area for centuries to come (Figure 5.13).

Whale hunting inside the fjords dominated the first whaling period at Svalbard. This period lasted to the 1640s, with a whaling fleet counting 30 to 40 vessels. This “fjord-catching” made use of shore stations, where the blubber was boiled to extract the oil. The ships were anchored close inshore, and the potential for finding single objects and cultural layers in the sea bottom must be considered high. Anchorages can thus yield a wealth of objects, which can date the period of use of the harbours in

different parts of the Svalbard archipelago, by identification and dating of ceramics and clay pipes.

After the 1640s, the number of whales that entered the fjords declined, and the period of whaling in the open sea around Svalbard, and along the ice edge of the Greenland Sea started. This period of pelagic whaling lasted up to ca. 1800. From the 1670s, between 200 to 300 whaling and sealing vessels, mainly Dutch, but also German, British, Danish and Norwegian vessels concentrated in these waters. Even large ships of the line, raiders, operated here (Arlov 1996:85).

The whalers sailed to Svalbard in the spring, and from the islands they sailed southwestward along the ice to meet the migrating whales. If whales were not found, they sailed back to Svalbard to start a new sweep (Figure 5.14). The whaling vessels thus frequented Svalbard several times during the season. This pattern of sailing is illustrated by the large graveyards in the northwest area of Svalbard, mainly because deceased members of the crews as a rule were given decent burials on shore if possible (Figure 5.15). There was thus a considerable traffic on the West coast, and also along the North coast of Svalbard during the period of pelagic whaling. When the whales went east along the edge of the ice, past the northwest corner of Svalbard, the whaling fleet followed. Here the risk of shipwrecking increases. The drift-ice comes quickly upon the shore, and substantial amounts of drift-ice often come out of the Hinlopen Strait (Figure 5.16). Source materials tell of numerous catchers and expedition vessels being surprised by ice and wrecked in these waters. The number of vessels, and their area of action, increases significantly after 1650, and one can expect finds of wrecked vessels dating from the 1660s and onwards nearly all around the archipelago.

In exceptionally bad years, the hunters met the ice far to the south. In a number of seasons, the vessels are reported to have met the ice at Forlandet (Prins Karls Forland), or even further south. In extreme cases, the ice came as far south as Bjørnøya (Bear Island). The whaling fleet often had great losses under such conditions, as they strove to get a full cargo in spite of the ice, and took too great risks (Conway 1906:208).

The different nations struggled for the resources, which resulted in naval operations and piracy in the Barents Sea and at Svalbard. On several occasions fleets of men-of-war were sent to the Svalbard waters to ruin or take enemy whaling ships as prizes. There is evidence of more than 30 vessels being sunk by such actions from the beginning of the 17th century to the end of the Napoleonic Wars (Conway 1906:218–222). Several diving expeditions, the earliest taking place during the 1960s, have been searching for these vessels but so far no wreck has been confirmed found.



Figure 5.12 Willem Barents and his crew abandon ship, caught in the ice at the north end of Novaja Zemlja in the 1596 voyage to reach China. They wintered in a house they built from parts of the ship, and driftwood. In spring they ventured south along the coast in small boats. Barents died on this journey, but most of the crew survived to tell the story. Several expeditions have searched for the wreck of the ship, but so far it has not been found.

Source: Gerrit de Veer. From: The Northern Lights Route, University Library of Tromsø. (<http://www.ub.uit.no/northernlights/eng/wbarentsz02.htm>)

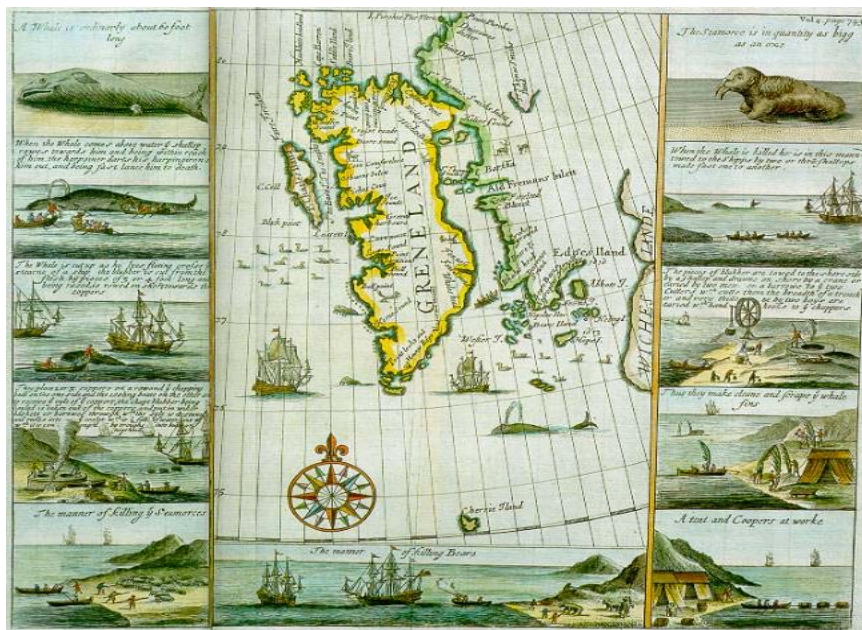


Figure 5.13 Map by Samuel Purchas (1624) from the Muscovy Company in London. This was a fellowship of merchants, first meant to find the passage to China through the Northeast Passage, but heavily involved in the northern trade in Russia, and whaling in Spitsbergen. Spitsbergen is named “Grenland” on the map, due to the belief that this land geographically was connected to Greenland, which was also the claim of the Danish king. The map also shows scenes from the shore stations on Spitsbergen, where the blubber was processed to whale oil. Most of the ports used for this industry have been documented, and a number of shore stations have been archaeologically surveyed (Figure from The Northern Lights Route, University Library of Tromsø. <http://www.ub.uit.no/northernlights/eng/svalbard01.htm>)



Figure 5.14 A view of the Danskegattet, between Amsterdamøya (foreground) and Danskeøya (right). The largest whaling station in Spitsbergen, Smeerenburg, is situated on the sandy hook to the left. Eight double ovens for cooking the blubber were built here; Virgo harbour, left, has four. The whales were caught mostly inshore, in the Smeerenburg fjord (background). The mouth of the fjord, in spite of being inside the National Park, has been dredged for scallops illegally in the 1980s, bringing up an anchor, probably from a 17th century whale.



Figure 5.15 On the Northwest point of Spitsbergen, there are large graveyards, from the time of the whaling in the 17th and 18th century. Some of these graves have been threatened by coastal erosion, and have been excavated by archaeologists. These graves have given us an unique insight into the life, health, and clothing of these sailors, as the graves on the permafrost have kept the clothing mainly intact. In the grave at the left, the sailor has been wrapped in a blanket. His head is resting on a pillow stuffed with feathers. He has a red silken scarf around his neck. The sailor on the right has a finely knitted cap on his head. He is lying on a layer of sawdust in his coffin.



Figure 5.16 From the north end of the Hinlopen Straits, looking towards Waldenøya. The drift-ice in the background has suddenly appeared, coming out of the Straits with the current and wind. This is a known wrecking area, both in the old days and in the present. Both oak planking and other wooden ship parts, together with 17th century Bartmannkrug stoneware vessels from the Rhein district, have come up with the scallop dredges. A shrimp trawler recently sank here, and traffic through the Straits, and trawling, is now restricted by the Sysselmann of Svalbard.

5.3.2.1 The Russian Pomor hunting and trapping expeditions

The time of the Russian presence at Svalbard is rather heavily debated. The point of views span from Russian presence as early as 1400, to the start of Russian trapping late in the 17th century. The whaling skipper Zorgdrager's account puts the presence of Russian vessels in the Recherche Fjord by Bellsund in 1697 (Conway 1906:225–226).

The Russian wintering and trapping stations are mainly located on the Vest-Svalbard (West Spitsbergen) but there are also stations on the west side of Edgeøya (Edge Island) and on the west side of Nordaustlandet. At a number of them, and elsewhere along the shoreline, considerable amounts of ship constructions and planking from sewn Russian "lodjas" have been found (Figure 5.17). Some of these materials are certainly driftwood, but a large part of the constructions comes obviously from ships wrecked on, or close to, Svalbard. Several Russian documents also confirm this. There is thus a potential for finding Russian vessels in Svalbard waters. However, very little is known of the routes the Russians sailed from the White Sea to Svalbard. From ca. 1800, the Pomor trapping and hunting on Svalbard declined, and by about 1850 it was all over (Arlov 1996:114).

In the Svalbard waters there are, as in other coastal waters, some areas and locations with a higher frequency of shipwrecking, due to the amount of navigation, submarine rocks, wind, currents and ice conditions.

How many vessels shipwrecked in the area? It is not possible to give a definite answer to this question. The most exact sources concerning the number of wrecks are found in Dutch records. De Jong, who has looked into abundant material concerning Dutch whaling, mentions a loss of 480 wrecked ships at "East-Greenland" (Svalbard) in the period 1661 to 1819. This amounts to a loss of ca. 3% of the fleet (de Jong 1978:103). The number of losses from before 1661 must be added, as well as the losses of the two other large operators, the British and the Germans. In addition there are the losses of the minor operators, such as Denmark and Norway. Overall these minor operators fitted out one-fourth of the total whaling fleet. If their losses are to be considered the same as the Dutch, the ships lost will amount to ca. 120. In the 18th and 19th centuries, besides the whaling vessels, there was also the smaller sealing fleet, which also sustained quite large losses in some periods.

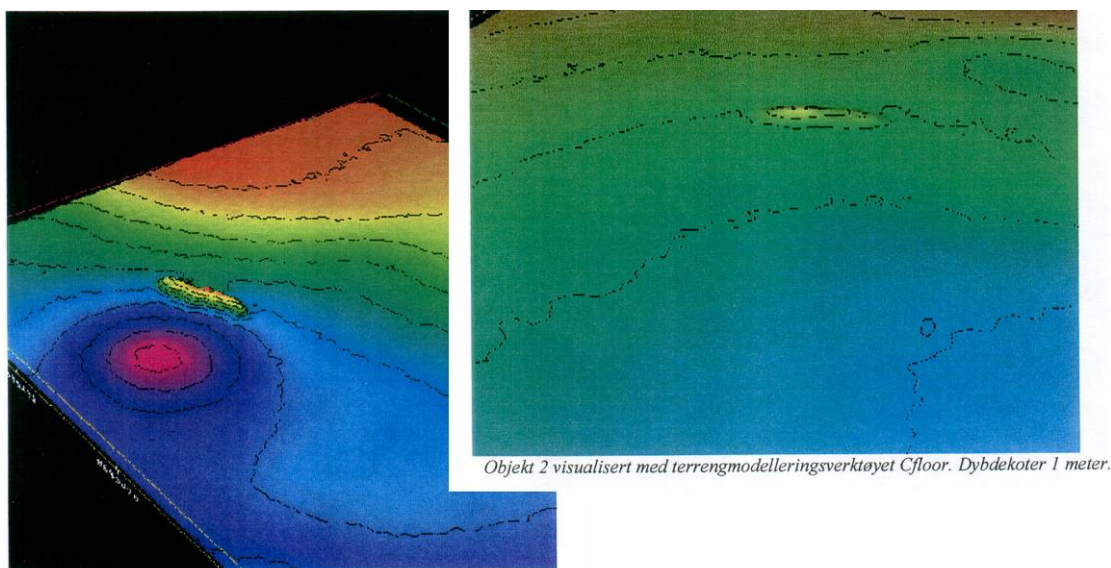
The combined figures of lost whaling, sealing and Pomor vessels suggest that the total number of shipwrecks in the Svalbard archipelago will probably exceed a thousand by far.

The 20th century has also left a considerable amount of cultural remains in the waters of Bjørnøya and Svalbard. The battles of the Murmansk convoys during World War II, has left close to 100 wrecks. Within the 24-nautical-mile zone, these wrecks, aircraft and other cultural remains from 1945 or earlier, are protected by the law.

Two wrecks from the Second World War have been located in the Grønfjorden, a branch of the Isfjorden at Spitsbergen. The Isbjørn, a small icebreaking tug, and the sealer Selis were part of a military operation to man and supply the garrison in Barentsburg. They were surprised by German planes, and sunk by depth charges and cannon fire. The Selis caught fire. Both vessels sank almost immediately. They have now been located, by multibeam echo sounder, at a depth of ca. 100m in the fjord (Figure 5.18). The state they are in is interesting in view of what preservation conditions one can expect in a fjord like this.



Figure 5.17 Part of a wrecked Pomor lodja, at Coles Bay in the Isfjorden, Spitsbergen. The lodjas were sewn vessels, varied in size, but capable of carrying gear, provisions and men for winter hunting expeditions to Svalbard. Lodja parts and wreckage are found all around the shores of Spitsbergen.



Objekt 1 visualisert med terrengmodelleringsverktøyet Cfloor. Dybdekoter 1 meter.

Figure 5.18 The wrecks of the *Isbjørn* (left, Object one) and *Selis* (right, Object 2) at the bottom of the Grøn fjorden. The wrecks seem fairly intact, judging from the sonar pictures. *Isbjørn* is a steel ship, and stands several meters above the seabed. The hole next to her may be a crater from the depth charges used to sink her. The *Selis* burned, but there still seems to be larger parts of her standing at least 2m above the bottom of the fjord (Sonar-grams and illustrations by Kystvakten. Archive of the Sysselmannen, Svalbard).

5.3.2.2 Spitsbergen: harbours and history of navigation

All traffic to Svalbard had to go by sea, and sea transport has been used as far as possible on the archipelago at all times. Heavy transport overland has been avoided, if possible. The available shipping technology at any given time and place has set the basis for which sailing routes and harbours were to be used, as different vessel types have different navigational abilities and constraints. With this total dependency of transport by sea, and lack of navigable rivers or other inland transport lanes in summer, Svalbard gives real meaning to the term “maritime cultural landscape”. The choice of location for buildings and constructions rests basically on the location of the exploitable resources and the seaway transport to this location. Registrations and mapping of cultural remains on Svalbard reflect this “maritime cultural landscape”, where the location of buildings and constructions on land points to the harbours and sea-lanes used (Figure 5.19).

All ports and small harbours used in any larger time span contain a cultural reservoir of objects thrown, or lost overboard from vessels in the harbour (Figure 5.20). In Norway, a series of investigations conducted in old harbours have brought substantial cultural material to light. The finding and registration of such material can identify old harbours, and reveal their time of use, trading lanes, fishing and hunting activities. Wrecks of small and large vessels are also found in the harbours. These are both old boats out of service and ships damaged by storms and accidents that were



Figure 5.21 A figurehead in the form of a lion from a large vessel was found on the Forlandet, Spitsbergen. Other wooden sculptures and details from ships of the 17th century have been found on the beaches. There are most certainly more to be found, buried in the sediments below the waterline in the harbours and anchorages.

Layout 1	NAVN	Trygghamna	Datering	1612
26	STED	Svalbard Oscar II land Isfjorden Trygghamna (Behouden haven (Van Muyen 1612))	Kartblad	B9
Poster 196	BESKR	Trygghamn is the small fiord that was probably named Behouden (Safe) haven by Van Muyen when he took refuge there in 1612, or by Poole in 1610; it is the Nickes cove or Poopy bay of Baffin (1613) subsequently rendered Portnic (Heley, 1617) and Niches cove (Muscovy Company's map, 1625), ... " ...the best position in which to anchor is off the inner corner of the hanging glacier, in depths of from 5 to 8 fathoms (9m1 to 14m6), soft clay, quite close inshore."		
Usortert	KILDE	Arctic Pilot. Vol. II. Fourth Edition 1934. Published for the Hydrographic Department, Admiralty. London 1934. p 258		
	ANM	" Trygghamna... I den innerste delen av bukta er det langgrunt område fra breen og ca. 1n mil utover, mens det forøvrig er nærdypt og med dybder avtagende fra 180m i munningen til ca. 20m lengre inne, god holdebunn. Vær oppmerksom på en 1m grunne ca. 3 kbl av NE land ca 2 n mil inn i fjorden. Det kan bli sterke utfallende vinder, men da det er grunt vann inn mot breen, skulle en ikke være særlig plaget med kalvis. Trygghamna ble i sin til meget benyttet av hvalfangere som betraktet den som en sikker havn, fordi drifisen i fjorden utenfor som regel ikke kommer inn her, derav navnet." Den norske los, bind 7, første utgave 1988. s. 239-240.		

Figure 5.22 The layout of the databases of the ancient ports and anchorages of Spitsbergen, at the Sysselmannen, Svalbard. This record describes Trygghavna, or Safe Harbour. It is known that there are wrecks in this harbour (Author: D. Nævestad).

5.3.2.3 Closing remarks, wrecks and cultural remains under water in the Barents Sea region and in Spitsbergen waters

This short nautical history of the Barents Sea region and Spitsbergen has pointed out that the potential for finding cultural remains, wrecks and even Stone Age habitats is substantial (Figure 5.23). There is also recent evidence that trawling and scallop dredging have severely affected wrecks in these waters. North of Spitsbergen the scallop dredgers have brought up with the dredges wood, ceramics and even anchors.

The marked areas on the map of the Barents Sea do not represent absolute regions but regions with the maximum probability of finding archaeological remains. Obviously there are wrecks and other submerged cultural features outside the defined areas. The traffic to the trading ports in the White Sea and beyond is passing quite close to the Norwegian

coast. Incidentally, this also seems to be the areas most heavily trawled. Besides, there are the passages to Bjørnøya and Spitsbergen; here the general sea-lanes will likely represent the areas of wrecking or foundering at sea. As for the Spitsbergen area, there is greater danger of wrecking in the ice. Moreover, the pelagic whaling in these areas was exposed to this risk because whales follow the edges of the sea ice.

Trawling and scallop dredging will affect cultural remains only in the areas where they overlap. Scallop dredging may take place between 20–200m. Generally, trawling will go down to 500m in these waters (Figure 5.24).

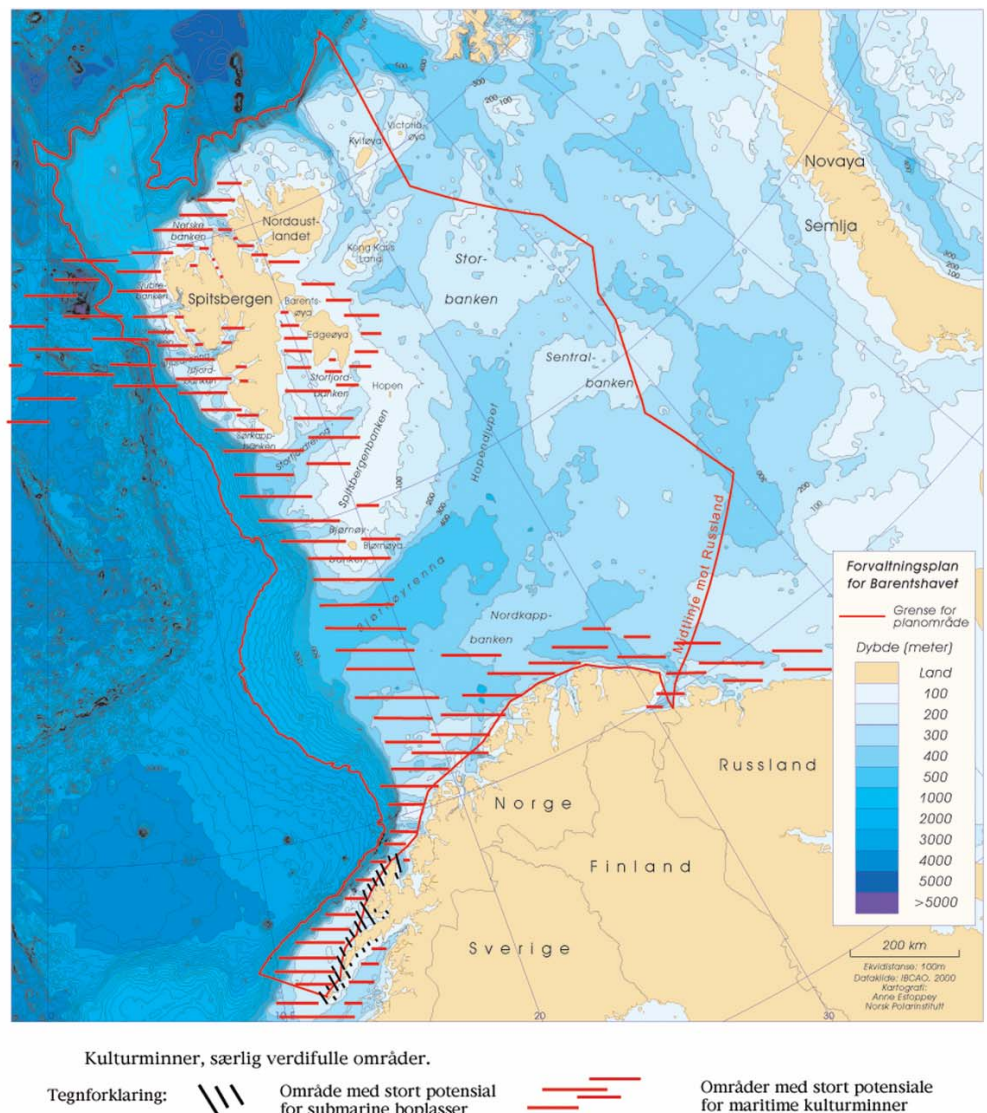


Figure 5.23 Sketch map of areas of high potential regarding cultural remains on the sea bottom. The black markings represent areas of transgressions, with a high potential for finding submarine Stone Age habitats. The red areas represent the most frequented sea-lanes, and areas of high potential for wrecking because of ice conditions (Map by Norsk Polarinstitutt, marked areas by D. Nævestad, Norsk Sjøfartsmuseum).

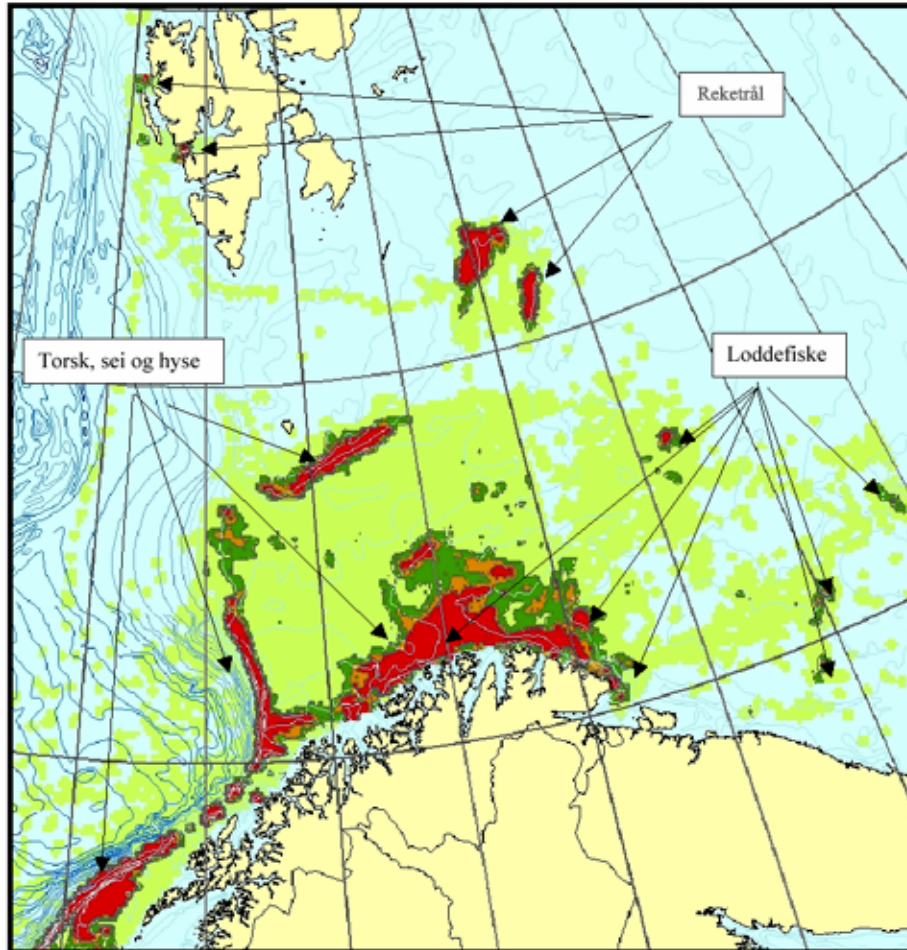


Figure 5.24 The picture of threat? This illustration shows a compilation of satellite tracking of ships over 24m, sailing at less than 4,5 knots during January, February and March 2001. Fishing effort in the Barents Sea is not evenly distributed, and impact of fishing is more intense in those areas where fishing effort concentrates (From Fiskeridirektoratet 2003, "Utredning av konsekvenser av fiskeri i området Lofoten Barentshavet.").

5.3.2.4 The environment and the state of the wrecks. How much is left?

There are great variations in the marine environment in the Barents Sea region. The conditions on the Norwegian coast are known, and are not particularly good concerning the preservation of wrecks. However, there are transgression areas, where certain zones of the sea bottom are expected to contain well-preserved archaeological organic artefacts of great age. In the Svalbard area there are normal Atlantic conditions along the West coast, but in the East coast the cold Siberian current may create conditions very favourable for the preservation of wrecks. The best preservation conditions are located within threshold fjords, where marine biologists have measured year-round temperatures of -2°C , and very heavy sedimentation (Gulliksen, pers. comm.). These fjords can be consi-

dered as cultural heritage refrigerators. Wrecks and other cultural material of organic matter will survive here in good condition for centuries.

5.3.3 Greenland waters, assessment of areas of wrecking and cultural remains under water

The vessels known at Greenland before the Europeans arrived, the kayak and umiak, “woman’s boat”, are boats that are difficult to trace in archaeological situations. They are lightly built, and covered with sealskin that disintegrates rapidly compared to wood (Figure 5.25). Unique deposition situations are required to obtain finds of these crafts in the sea. The probability of finding such vessels is therefore very slight. Other kinds of submarine cultural remains in these waters to be taken into consideration are Inuit habitats, boatsheds and other constructions from the Norse settlers. They are all to be found in transgression areas, or areas where the sea has submerged these remains, which may be now at several metres depth off the coastline. These areas may, however, have, been eroded by wave and ice action.



Figure 5.25 Umiak exhibited at Grønlands Nationalmuseum in Nuuk. Kayaks and umiak's are light constructions, covered with seal hides. These kinds of crafts are seldom found in archaeological material..

5.3.3.1 The Norse settlers, and their seafaring

The Norsemen in Greenland obviously were dependent on their ships. Despite searches, no shipwreck from this period has yet been found. However there have been several finds of ship timbers at archaeological excavations. At a Norse farm, “The farm beneath the sand”, which was

buried under sand from a river, several ship timbers and other artefacts of wood have been found in good condition (Albrethsen, pers. comm.). At the excavations of the sauna at the Sandnes farm, ship parts made of Siberian larch were found (Rousell 1936).

The Nationalmuseet in Denmark has, in cooperation with Grønlandscenter SILA, initiated a project under the title: ‘Skib, naust og maritime aktiviteter i det norrøne Grønland’ (Ships, boatsheds and maritime activities in the Norse Greenland). The project is founded on the idea that the Norsemen’s living conditions have been decisively dependent on ships and navigation, and that the maritime activities must have left significant traces at the archaeological sites in Greenland (Figure 5.26). The aim of the investigations is to identify and date boatsheds in the Norse settlements, and examine the ship timbers found in Greenland to identify types of vessels and their loading capacity (Rieck 2001). The results from these investigations will be of interest as it will reveal information on ships, ship capacity and navigation in these waters. Further results from the Nationalmuseet / SILA project should be welcomed, as they will provide new information on the possibilities of ship findings in Greenland waters.

The written sources tell of ship losses due to wrecking and other accidents. It is, however, difficult to assess the number of wrecked ships. From the first emigration, we learn that 25 ships in all sailed from Iceland. Fourteen ships arrived in Greenland, the rest either drifted back or foundered at sea, but the number of ships that sank is not stated (Figure 5.27).

The sagas tell about shipwrecking on the Greenland coast, where vessels disappeared without known cause. One reason must be the ice conditions, but several sagas tell about wrecking on the coast:

“... in Flateyrbók where it says that the trapper Sigurd Njálsson, found a shipwreck at the East coast of Greenland, and in a cabin close by, the bodies of the deceased. When it proved difficult to transport the bodies the long way to the settlement, they were boiled in kettles till they came apart, after which their bones were taken to the church” (Halldórsson 1978:3–116, translated by author).

Leiv the Lucky salvaged shipwrecked men from a skerry in Greenland: “They set out to sea and had good wind until they saw Greenland and the mountains under the glaciers (...) Leiv had better sight than the others, because he saw that there were men on the skerry (...) Now they put up under the skerry, lowered the sail and anchored, and put out another boat which they carried. (...) ‘I will now,’ says Leiv, ‘invite you all on board my ship, and so much of the cargo as the ship can carry’. They accepted his offer, and sailed from there to Eiríksfjörður with the whole cargo, until they came to Brattalid. They carried the cargo up from the ship. (...) Leiv then said to Torvald: ‘You can go in my ship, brother, if you want to go to Vinland, but first I want the ship to sail out for the wood that Tore had

on the skerry.’ And this was done” (Ingstad 1996:271–277, translated by author).

The Norsemen went far beyond the waters of the East and West Settlements on hunting voyages. Archaeological finds, such as rune stones, parts of chain mail and other artefacts indicate that the Norsemen navigated most of Baffin Bay (Figure 5.28). It is not possible, however, to assess the number of sailings and shipwrecks in this period; the sources are far too vague. We know, however, that the contact with Iceland and Norway ceased around 1400. The Norse settlements in Greenland consisted of 375 farms, 20 churches, two cloisters and the bishop’s farm in the East Settlement; and 80 farms and three churches in the West Settlement. When the community was at its peak, probably in the 13th century, the number of inhabitants probably counted 400. When Ivar Bårdsson, priest at the bishop’s farm at the East Settlement, sailed to the West Settlement around 1350 he found no one there, only the cattle roaming around. The last reliable information from Greenland tells of a ship that on a voyage from Norway to Iceland ended up there. The crew stayed in Greenland for four years, up to 1410 (Ingstad 1996:99).

In short, the Norse seafaring to Greenland and within Greenland waters must have been substantial in the heyday of the colony. There is little doubt that quite a number of the ships wrecked, and that there is a potential of finding such wrecks on the coastline and in the sea-lanes to and from Greenland.

Among other early European voyages to the Greenland waters, it is known that the Portuguese and the Basque were whaling in the waters just south of Greenland. At Red Bay in Labrador, marine archaeologists have excavated several vessels, among them the whaler *San Juan* which sank there in a storm in 1565. This wreck is probably the most intact example of the type of vessels the Europeans used in the colonization of America.

Parts of a wooden ship, which are supposed to be the wreck of a Basque whaler, came up with a trawl in Greenland waters. Details of this find are still unknown. Registering and assessing such information from fishermen and trawlers in a central register would be a start for management of these sites. A step in this direction would be to make the reporting of such findings mandatory.



Figure 5.26 Photo of a frame from a clinker-built vessel, found in Greenland, exhibited at Grønlands Nationalmuseum, Nuuk, 2004.

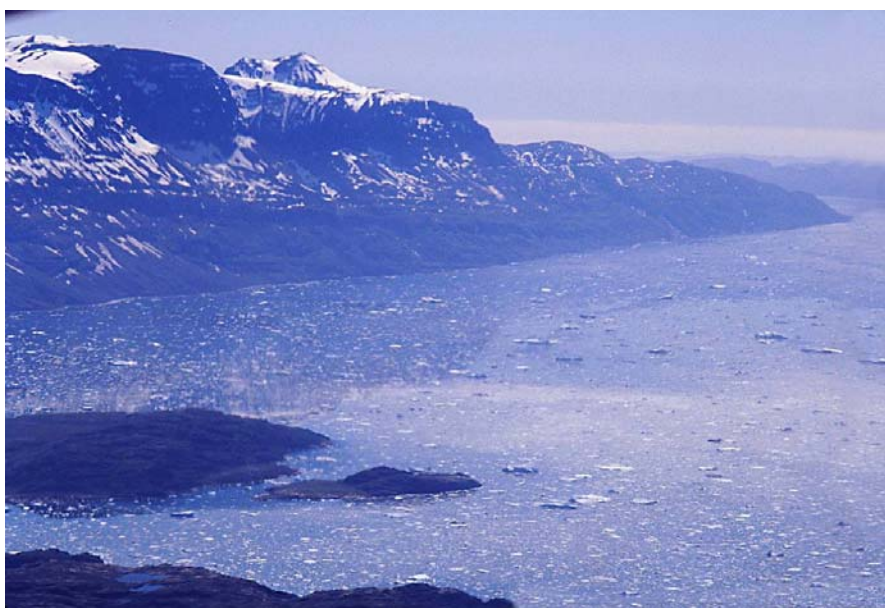


Figure 5.27 Ice conditions in Breifjord (N. Sermilik fjord), in the Norse East settlement, Greenland, June 2004. There were ca. 25 farms in this fjord. The navigational hazards are obvious.



Figure 5.28 Rune stone, found at Kingigtorsuaq island, off the coast of West Greenland, at 72 degrees 57 minutes N. "Erling Sigvatsson, Bjarne Tordsson and Eindride Oddsson raised these cairns Saturday before gongdag (25 April) and runed them well" (Ingstad 1996:84. Photo: Nationalmuseet, København).

5.3.3.2 Navigation in Greenland waters from the 17th century

The hunt for new sea-lanes to China and the East Indies, among them the Northwest Passage, brought explorers to these waters (Figure 5.29). John Davis sailed northwards along the West coast of Greenland in 1585–87; William Baffin navigated the Baffin Bay in 1616; Henry Hudson and Jens Monk explored Hudson Bay early in the 17th century; often with fatal consequences for their crews and themselves.



Figure 5.29 On Ortelius's map of the North Atlantic, Greenland is correctly placed northwest of Iceland (Ortelius 1570, *Septentrionalium Regionum descriptio*). However, Ortelius fills the northern ocean with islands mentioned in old travel accounts, most of which were imaginary (Spies 1997, from *The Northern Lights Route*, University Library of Tromsø. <http://www.ub.uit.no/northernlights/eng/map02.htm>).

It was, however, towards the end of the 17th century that the traffic increased in volume, in connection to the European whaling in the Davis Straits

and into Baffin Bay. Most of the whalers came from English ports, but other nations participated too, and from 1764 also a substantial number of whalers from New England (Figure 5.30). The whalers congregated in spring at the edge of the ice in Davis Straits, waiting to follow the migrating herds of Greenland whales that gathered along the ice to feed in Baffin Bay when the ice there broke up. In peak years, as many as 200 whalers engaged in the fisheries, in average years there would be around 50 whaling vessels. The whales often congregated in the Straits at 65–66°N, and then halted again at the second ice barrier, which normally occurred at 71°N. The ships followed the whales into Baffin Bay, and many shipwrecked due to ice conditions and other causes. Gordon Jackson writes: “By contrast, vessels engaged in the Davis Straits fishery sailed westwards in late February, battling their way through Atlantic storms to arrive in April or May in the darkness, fog, and icy sea off Labrador. Here they waited, or moved slowly northward until the ice barrier, usually around 66°–68°N, opened to allow an abundance of whales through in their progress to their feeding grounds in and beyond Baffin Bay”. And further: “The great advantage of the Straits fishery in the early days lay in the fact that whales tended to congregate or rest in specific areas of open water where they were easily found, around 65°–66°N, 68°–69°N, and again around a second ice barrier usually located at 71°N. Thereafter, as the ice receded the whales moved northwards at a leisurely pace, with the whalers in pursuit, until they disappeared in the impenetrable icy wastes of the north and west Baffin Bay” (Jackson 1978:78).

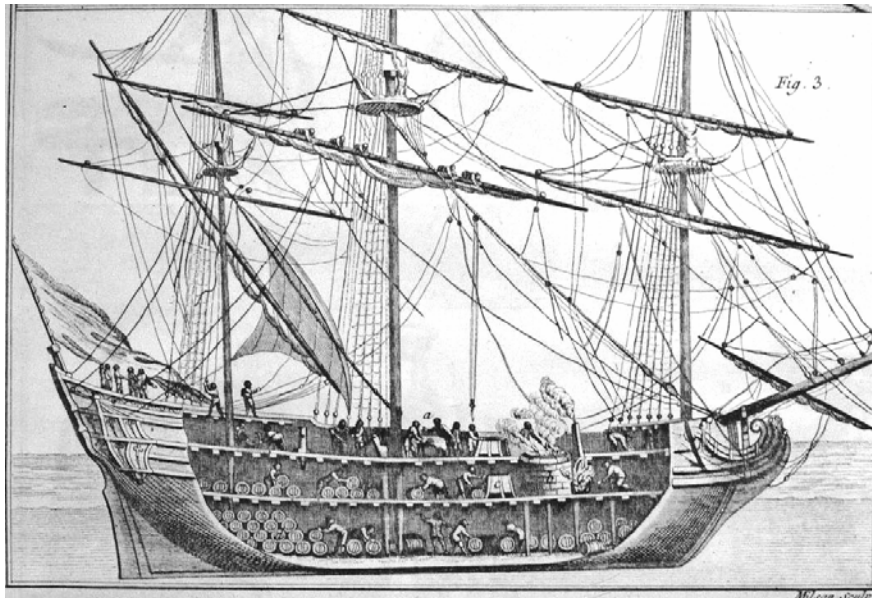


Figure 5.30 The days of the shore stations for whaling were over by the 1650s. The whalers now followed the migrating whales along the edges of the ice. This vessel is rigged for whaling, an even has cooking facilities on board, a practice that was soon abandoned because of the fire risk. The blubber was usually stripped off, and put in barrels, to be processed back in Europe -even if this meant a reduction of the quality of the oil produced. 15th century engraving (From Norsk Sjøfartsmuseum).

A number of different written sources from this period give information on the whaling here. The waters are described as dangerous, with much ice, that led to heavy losses (Figure 5.31). "...it was unwise to spend too long in Baffin Bay, for the ice closed quickly and often without warning, as many overzealous vessels found to their infinite cost" (Jackson 1978:80). The whalers did not process the blubber on shore, as in earlier days, but put it in barrels on board. Shore stations, as we know them from the first whaling period on Spitsbergen, were not common. Thus there are not as many archaeological traces in Greenland as in Svalbard from these activities, but nevertheless graves are found on islands in Disko Bay and other places, which can be connected to the whaling. Other features are ruins of storehouses that can be related to the whalers from this period (Malm, pers. comm.).

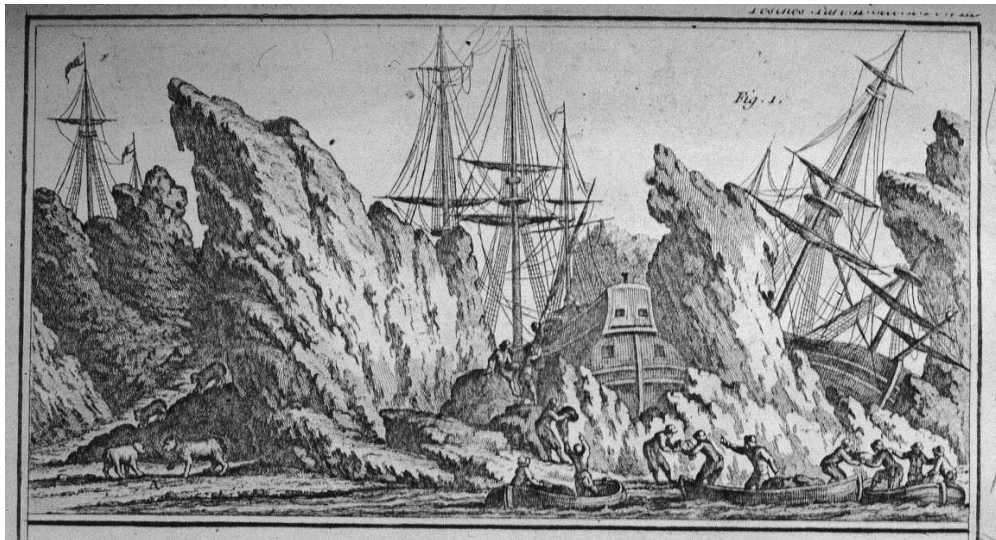


Figure 5.31 Whaling vessels caught in the ice, the crews are evacuating onto the ice, with the whaleboats. The ship planking and frames are bended but not crushed. The ship will fill with water and sink in one piece once the ice pressure decreases. The ships are deposited on the sea bottom, more or less in one piece (18th century print, Hvalfangstmuseet, Sandefjord).

Very few vessels frequented the East coast of Greenland in the 17th century. The traffic increased in the 18th and 19th centuries when the exploitation of seals in the West Ice, and later the smaller species of whales, like the bottlenose and the beluga, began. There were considerable risks of being crushed by the ice in these waters, and many ships were lost in the waters east of Greenland. One of the larger catastrophes of pelagic whaling occurred in these waters in 1777; a great number of whaling ships were caught in the West Ice (Figures 5.32).



Figure 5.32 Detail from the map of skipper Hidde Kat, from the disaster in 1777. The ships are caught in the ice (Detail from Oesau 1955).

The crushing of 15 ships is well-documented, but there were certainly more casualties. The tragedy started north of Jan Mayen, where a whaling fleet said to count 100 vessels was operating. They ventured too far into the drift-ice when a sudden storm hit them and they became locked in the ice. Ship after ship sank, while drifting southwards with the East Greenland current. The first ship sank between Spitsbergen and Greenland on the 3rd of June, the last one sank by Kapp Farvel on the 11th of October. Some of the crew members escaped to other vessels, as their own ships were crushed, or they tried to reach the coast of Greenland in the whale-boats (Figure 5.33). At the time there were 284 men on board one vessel, all starving (Mulvad 2002:57). A number of crews disappeared in the ice, or starved to death, but a large number reached the mainland, where the Inuit took care of them. Most of the 15 sunken ships documented were from Rømø, Hamburg and Holland (Mulvad 2002:127) (Figure 5.34).

Inshore, at the East Greenland coast, there were also several accidents, as the vessels caught in the ice tried to get out by going south in the sometimes open waters along the shores. This was, however, dangerous, and a number of ships have wrecked when the ice is pressed up against the coast by wind and current. The so-called “Liverpool coast” is a well-known shipwreck area. Concerning the inner fjords on the east coast, few ships are known to have frequented them, and it is expected that there will be fewer wrecks there. However, inside the fjords, there might be areas of exceptional conditions, where wrecks may have been preserved in mint condition.

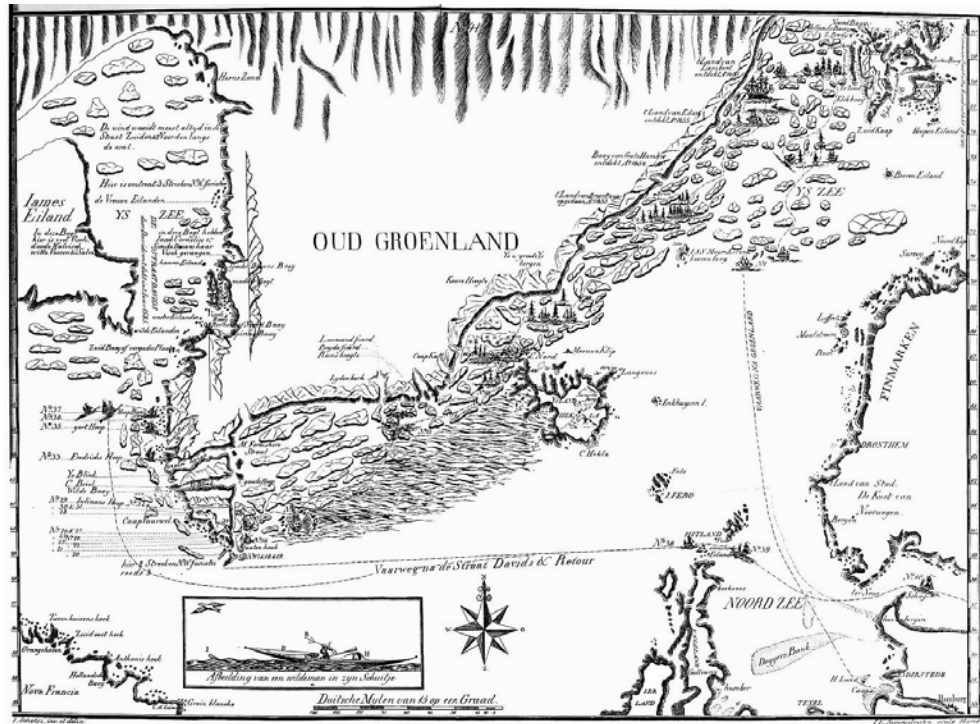


Figure 5.33 Map from the diary of the whaling skipper Hidde Kat, of the catastrophe in the West Ice in 1777. The ships crews congregate in the surviving ships, along the ice-drift. They are often in sight of land, and some escape in the boats, and on reaching the shore are rescued by Inuits. Ice navigation on East Greenland is a tricky business, even today. The waters of the West Ice may contain thousands of wrecks (Oesau 1955).



Figure 5.34 The approximate positions of 12 of the 15 vessels sunk off the coast of East Greenland, with the ship names and the dates of sinking (Map by D. Nævestad).

5.3.3.3 Icebergs in Greenland water as the cause of many ship losses

The abundance of icebergs of all sizes in the Greenland waters has led to a series of ship losses. The frequency of ships lost to collisions with ice is largest by the Newfoundland Banks, and in the Strait of Belle Isle. This is due to the trans-Atlantic traffic, and the many ships passing through these waters. Brian T. Hill has established a database based on collisions with icebergs, and in the diagram enclosed, a number of events, old and modern, from Greenland waters, have been extracted from this database (Hill 2001) (Figure 5.35). Obviously the icebergs have led to a higher frequency of shipwrecks in Greenland waters. Even smaller pieces of ice, so-called “growlers”, will cause such leaks in wooden ships, both from the Norse period and recent sailing vessels, that they will sink.

Date	Position	Description of Incident	Lives Lost/Injured	Damage
10 Jul 1686	30 leagues within Hudson Strait, 62°N 75°W?	HAPPY RETURN struck ice on way to Hudson Bay for North West Fur Co.	Unknown	Sank
21 Apr 1704	About 50 leagues off Newfoundland coast from Lisbon	Ship ANNE struck underwater tail of a huge island of ice and started to leak. Bore off and very soon after hit same or another island of ice	Crew took to open boat and made St. John's in 7 days. 5 men perished in boat, 6 soon after arrival. 3 survivors of which one had both legs amputated.	Sank
26 Apr 1832	58°N 42°W from Hull to Davis Strait	SHANNON hit a berg	Crew taken off	Presumed sank
18 Jul 1875	61°N [?] 51°W from Londonderry to Quebec	HENRY PALMER hit an immense berg in very thick fog	Unknown	Lost 6 stanchions, rail, bulwarks, anchor stock, etc. Put into Sydney for repairs
Oct 1896	Near Cape Farwell, Greenland, Greenland-Denmark ferry service	CASTOR disappeared, thought to have hit iceberg	25 lost	Lost
30 Jan 1959	59°30'N 43°00'W from Godthab to Copenhagen	M/V HANS HEDTOFT hit a berg on return portion of maiden voyage	95 lives lost	Sank
29 Apr 1963	Off S.E. Greenland	M/V VALOI hit a berg	?	Sank
3 Aug 1963	Hudson Strait for UK	Yugoslav freighter KASTELA hit a berg	No record of survivors	Sank
22 Apr 1969	Near Greenland	German vessel	?	Hole in bow
9 Aug 1988	Off Greenland coast, 67°47'N 29°48'W	M passenger/cargo AQALUK ITTUK hit a large piece of ice	None known	4 x 40cm hole; leaking towed to Angmassik for repairs
8 Apr 1988	North of Jan Mayen Island	M/fv VESLEMARI hit a berg	None known	Sprang a leak and sank
3 Oct 1990	Melville Bay, Greenland, 73°48'N 78°04'W or near Arctic Bay, Canada	TERRA NOVA struck iceberg while following USCG Polar Star	?	Constructive total loss
11 Aug 1991	72°N 59°58'W off Greenland, chartered to Canarctic to carry zinc ore from Nanisivik mines.	Cargo ship FINNPOLARIS with scrap iron struck an iceberg	Crew rescued	Listed and sank 12th.
11 Sep 1993	Kangerlussuaq Fiord, Greenland	CSS HUDSON hit a berg	None known	Holed
19 Jul 1995	63°05'N 67°42'W, Daniel's Harbour, Frobisher Bay, Arctic	Russian M/pass. ferry ALLA TARASOVA sustained ice damage	None known	Vessel holed but no help requested

Figure 5.35 Extract of database by: Hill, Brian T. 2001: "Database of ship collision with icebergs." <http://researchers.iot.nrc.ca/~hillb/icedb/ice/> (National Research Council Canada – Institute For Ocean Technology).

5.3.3.4 Closing remarks, wrecks and cultural remains on the seabed in Greenland waters

The shipwreck areas of Greenland are mainly the waters of the West coast, which has the longest history of navigation, and along which the greatest number of ships have passed. The oldest and most numerous sea voyages took place in the coastal waters around Kapp Farvel, along and between the East and West Settlements, and the fjords in these areas. Other wrecking areas were the West Ice, the sea-lanes from Iceland to Greenland and the areas of the Davis Straits and Baffin Bay, where the whaling took place at the edge of the ice. As mentioned, there are three main areas of wrecking here; by the ice edge at 65–66°N, the ice edge at 68–69°N, and the ice edge at 71°N (Figure 5.36). In these areas, the whalers have been in danger of being crushed during the whaling operation, chasing the whales closely to the ice edge. The wrecking areas east of Greenland, the West Ice, are expected to have abundant wrecks from around 1700 onwards, and on the Liverpool coast there are probably wrecks from more recent years.

In all waters around Greenland, ships will be endangered by collisions with icebergs, increasing the frequency of shipwrecks considerably.

Transgressions may have submerged Inuit habitats, Norse boatsheds and other structures that now would be at several metres depth along the coast of Greenland. However, these shallow waters are not be affected by trawling and scallop dredging.



Figure 5.36 Map of the most navigated sea-lanes and whaling-areas of Greenland, from the time of the Norse settlements, and into the 19th century. Shipwrecks have occurred on the coast, and as a result of ice conditions, or in the open sea from other causes, such as collisions with icebergs and smaller pieces of ice or “growlers” (Map by D. Nævestad).

5.3.3.5 The environment and the state of the wrecks. How much is left?

The conditions for the preservation of organic material are generally good in Greenland waters; judging by the wreck of the *Breadalbane*, they are excellent. The *Breadalbane* was, however, rather distant from West Greenland, and there are considerable differences in the marine environment in different parts of Greenland. There is reason to believe that the abundance of tree-boring organisms is very limited because of the low temperatures of the waters. Furthermore, Greenland has a number of threshold fjords, where conditions for the preservation of organic material may be very good. The areas with very low bottom temperature and abundant sediments have a great potential. A compilation of data on such phenomena, together with an evaluation of the sea-lanes and Norse settlements, can lead to an assessment of the areas of greatest potential concerning submerged cultural remains (Figure 5.37).



Figure 5.37 Nuuk Fjord. Most of the fjords of Greenland have situations of heavy sedimentation. In addition, the cold water in these regions will create environments where organic material, such as shipwrecks, will be in very good condition over a long period of time.

The findings of the whaling ships from the second half of the 14th century in exceptionally good conditions in Red Bay, Labrador, was, according to professor Robert Grenier, due to ice conditions. The ice had, according to Grenier, split the ships apart and caused the timbers to be covered with sediments in a short time (Grenier, pers. comm.). Excavations of the vessels started in 1978, and so far three whaling galleons, and specially built whaling boats, “chalupas”, have been found. These conditions may very well be found in harbours on the coast of Greenland, thus similar situations in the harbours frequented by whalers and other ships may be expected.

5.3.4 Iceland

Immigration to Iceland started in the beginning of the 9th century, and since then there have been regular sailings through the medieval times and into the modern age. The sea-lanes to and from Iceland, and onwards to Greenland, are known from medieval sources, which give good descriptions of the preferred routes (Figure 5.38).

In Hauksbók it says this about the navigation on Greenland: “So says learned men, that from Stad in Norway, there is 7 dægr (days at sea) to Horn on the east coast of Iceland, but from Snæfellsnes there is four dægr sailing to Hvarf in Greenland (close to the southern point). From Bergen in Norway, one should sail straight west, towards Hvarf in Greenland, and then one sails north of Hetland (Shetland Islands), so that one barely can see the land in clear weather, but south of the Fair Isles, and then in such a manner that one only sees half of the height of the land, and so far

south of Iceland, that the sea-birds and whales of this land can be seen...” (Ingstad 1996:79).

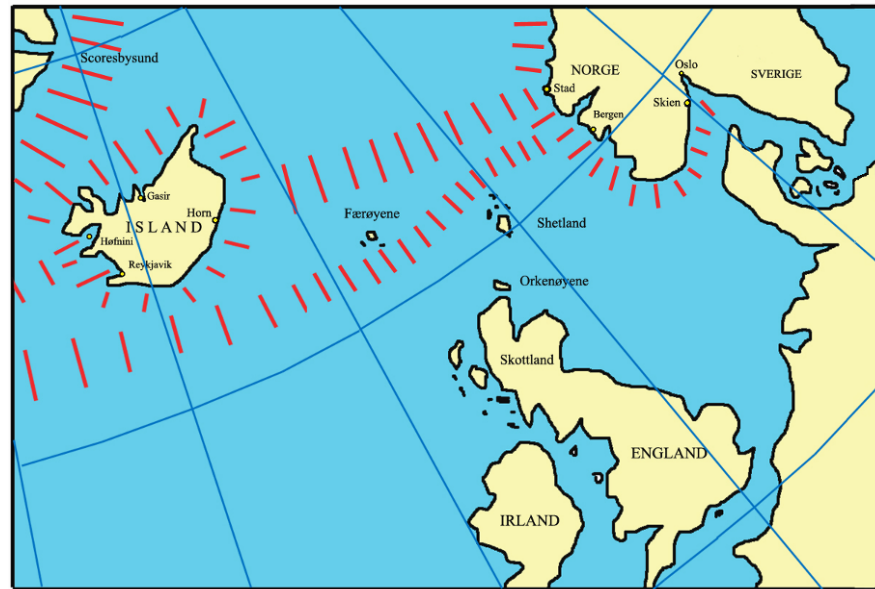


Figure 5.38 Sea-lanes from Norway to Iceland, as described in *Hauksbók*. The southern route to Greenland passes between Shetland and the Fair Isles so far off Iceland that the land is not sighted, surely to avoid wrecking on the coast. The areas of coastal traffic and the areas of wrecking in the Strait of Denmark are marked. The traffic to other European countries, as Germany and England, passed most likely between the Orkneys and the Shetlands, south of the Fair Isles. The ships to and from Europe driven off course by bad weather went into Icelandic waters. There is thus a potential for finding wrecks of ships also outside the sea-lanes, including ships not destined to Iceland (Sea lane map by D. Nævestad).

From Norway, most of the shipping traffic on Iceland up to 1300 had its origin in the Trøndelag district. From then onwards Bergen took over as the main port for the traffic on Iceland. The ship traffic from Norway reached its peak around 1340, with 11–12 trading vessels a year. In the winter of 1346–47 no fewer than 18 seagoing vessels stayed at Iceland, apart from two others, which had wrecked that summer (Bugge 1923:260).

Icelandic sagas also relate other ship losses. A brief search of these sources came up with about 30 references to ships wrecked in Iceland before the year 1500. Among others, the Bishop of Gardar in Greenland was shipwrecked in Iceland twice, in 1262 and in 1266. On the last occasion he lost 12 men, and a large cargo of walrus tusks (Nörlund 1936, <http://www.personal.utulsa.edu/~marc-carlson/history/grontime.html>). In the year 1428 no fewer than 18 vessels wrecked at Akranes. Furthermore information is given about the ship *Kanabátinn*, wrecked at the *Sydlandet* in the year 1400, and the *Svalskipit*, which foundered in 1412. The ships that sailed to Iceland were quite large seagoing vessels (Figure 5.39). The *Svalskipit* is said to have carried 160 men (Bugge 1923:260).

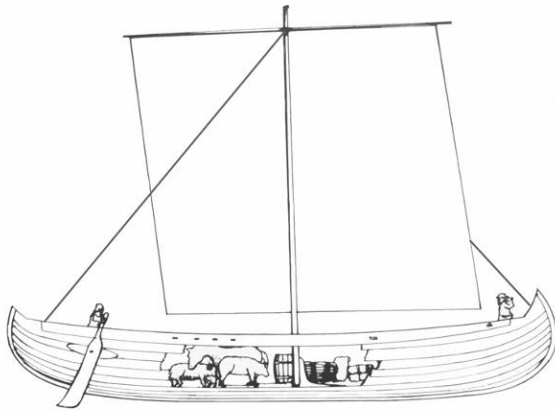


Figure 5.39 Ships of the type *knarr* are known from the sagas and from the ship-finds at Skudelev in the Roskilde fjord, Denmark. Ships of this kind were ocean-going vessels, quite broad and with high sides, well suited for transport and trade. A similar type trading vessel, *busse*, is also often mentioned in connection to trade in Iceland (Illustration from Pettersen 1997:58).

Medieval shipping on Iceland is also illustrated through other written sources, and archaeological finds on shore, such as the trading port at Gásir in Eyjafjörður. These sources show that also the North coast of Iceland has potential for finding medieval trading and fishing vessels (Figure 5.40). Gásir is first mentioned in written sources dating from 1163, and is mentioned in connection with trade and transport in various sagas and annals regarding the 12th to 14th centuries. Trading goods have been found, among others traces of the Icelandic export item, sulphur, and imported ceramics. Finds from recent excavations indicate that the location might have been in operation into the 15th century (<http://www.instarch.is/gasir/gashistory.htm>). Ships also seem to have been wintering in the port; in the saga *Guðmundar saga dýra* it says of the year 1191: “Þann vetr váru skip at Gásu. Ok um sumarit var kaupstefna mikil.” (<http://www.gasir.is/background.htm>) meaning “This winter there were ship(s) at Gásir, and a large trading fair in the summer” (Translation from the Author).

5.3.4.1 Medieval trade on Iceland; the finding of the Darsser cog

No medieval shipwreck has, as far as we know, been located in Icelandic waters. Such finds are, however, to be expected. A wreck, not found in Iceland but in the Baltic, can shed some light on medieval trade on Iceland, and what one can expect to find. The Darsser cog was found near the island of Rügen in the Baltic (Figure 5.41). Investigations show that the cog probably carried Icelandic goods in the cargo, namely barrels of sulphur. This cargo was carried together with whetstones from Eidsborg in Telemark, Norway. The vessel is probably of German origin (MOSS Project, www.nba.fi/INTERNAT/MoSS/eng/darsser_1.html).

It cannot be verified whether the ship had been in Iceland, or if it had taken on the cargo of sulphur and whetstones in Skien, South Norway,

the export harbour for the whetstones from Eidsborg. We know, however, that Skien at this time was trading with Iceland and that vessels designed for this trade were built in Skien. The governor Gunne Lange built two ships in Skien in 1206 that were registered as “islandsbusser” (Bugge 1925:Vol2:107). (“Busse”: Oceangoing merchant ship.)

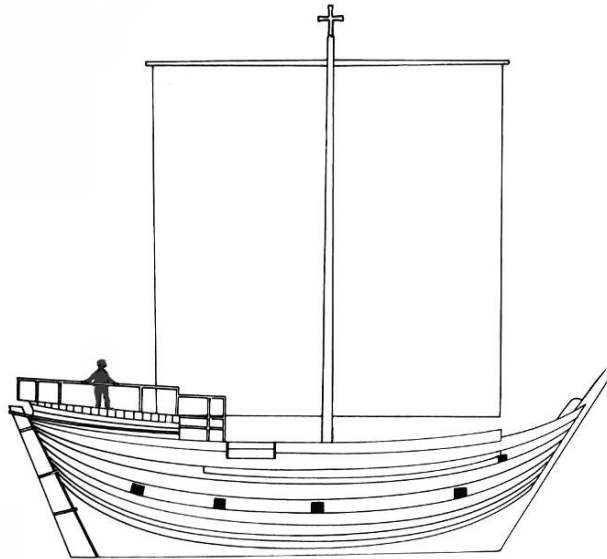


Figure 5.40 The main transport-vessel of medieval Europe was the cog. These vessels originated in North Germany, and were the preferred ships of the Hansa towns. These ships are ocean-going, strongly built ships, with planking of oak up to 60cm broad (Illustration from Pettersen 1997:62).



Figure 5.41 From the wreck of the Darsser cog. Photo of the cargo: antler, barrels of sulphur, and whetstones from Eidsborg in Telemark. It can not be verified whether the ship has been in Iceland, or if it has taken on the cargo of sulphur and whetstones in Skien, Norway, the export harbour for the whetstones from Eidsborg. A whetstone is seen directly above the sulphur barrel, under the reindeer antler (Photo: The Darsser Cog project, Credit: Archäologie und Denkmalpflege, Mecklenburg-Vorpommern).

In addition to the shipping that originated in Scandinavia, the Scots and the English also traded with Iceland. In the beginning of the 14th century the English increased their dried fish trade trips to Iceland (Bugge 1923:271). From the year 1468 onwards, King Kristian of Denmark allowed German merchants to sail to Iceland. The Hansa cities took over part of the trade, followed by the Dutch. The English started their own fisheries at Iceland, which culminated in the 1520s. In the year 1528 the British coastal cities sent a fleet of 149 ships to fish in Icelandic waters. The Germans, mainly from Hamburg, took over much of the merchant shipping on Iceland, leading to several complaints; the Germans sent six to ten ships to bring the fish back to Hamburg. Fredrik II tried to regain control, and made, among other regulations, the trade with sulphur a royal monopoly (Bugge 1923:304–307).

The frequency of shipwrecking of the Icelandic trade in this period is not known; however, the sources above show a quite large traffic, both from merchantmen and fishing vessels.

5.3.4.2 Shipping in Icelandic waters in modern times

From around 1600, merchant shipping and fisheries increased, as well as the number of ships passing the area, on their way to other destinations (Figure 5.42). This is to some degree related to the trans-Atlantic trade, but mainly due to the whaling and sealing fleets in transit to the catching areas in Greenland, Vestisen and Spitsbergen. A substantial number of ships participated in these fisheries, with a corresponding number of casualties. The common sea-lanes used by the vessels are indicators of wreck locations, but wind and current may lead to large deviations from these for sailing vessels. Thus a ship bound for Scotland shipwrecked on the east side of Iceland in the year 1337 (Bugge 1923:259). Another example of a vessel off course is the wrecking of the ship *Wapen van Amsterdam*.

This vessel was quite large, constructed in 1653, and belonged to the Dutch East India Company (VOC). The ship was on its way home from Batavia in the East Indies, carrying a cargo of porcelains, tin, and jewels (diamonds), when it wrecked at Skeiðarársandur in Iceland, the 19th of September 1667. One-hundred forty men died, says the records, while 60 were saved (Bruijn et al. 1979, http://www.vocshipwrecks.nl/home_voyages/wapen_adam1667.html). There have been searches for this wreck for 40 years.

Archaeological investigations of shipwreck locations in Iceland have been limited. Only two wreck sites at Höfnin by Flatey in Breiðafjörður have been surveyed (Figure 5.43). It is not mandatory to report old wreck sites found by fishing activities. Nor have positions of wreck sites been registered when found in connection with marine biological surveys. The wrecks at Höfnin are interesting also in their context to harbour-related questions and coastal navigation. The wrecks here have been identified as

the Dutch ship *Melckmeyt*, dating from 1659. She was ready to sail but sank in the harbour because of a sudden storm. Deposited over this wreck is the wreck of the Danish schooner *Charlotte*, from 1882. From the wreck of the *Melckmeyt*, more than 30 kilos of Dutch pottery have been recovered (Einarsson et al. 1993:135).

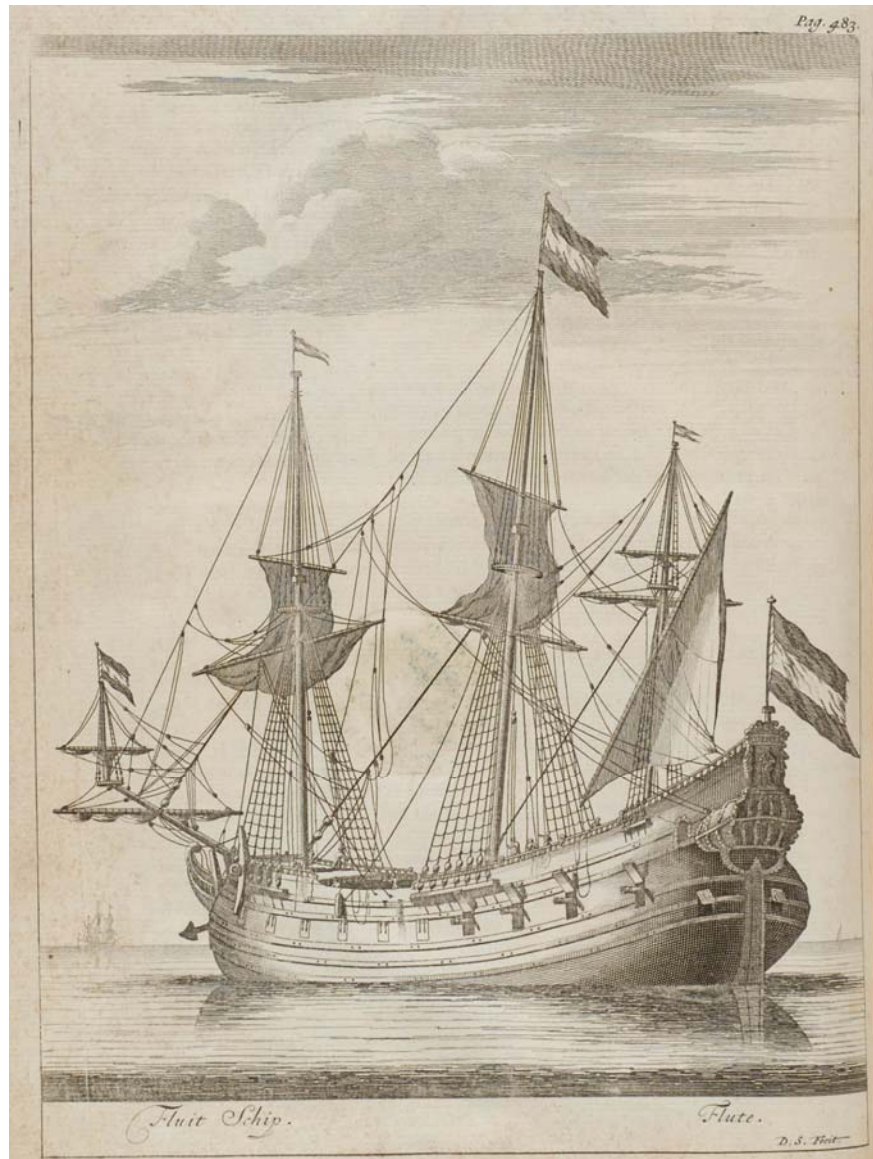


Figure 5.42 The fluit ship was developed in the Netherlands around 1600. The type was very common in the 17th and 18th centuries. It had a broad belly and a high stern. The ship could be managed by 15 men, and was a popular merchantman, also in Icelandic waters. 18. century engraving (Norsk Sjøfartsmuseum).

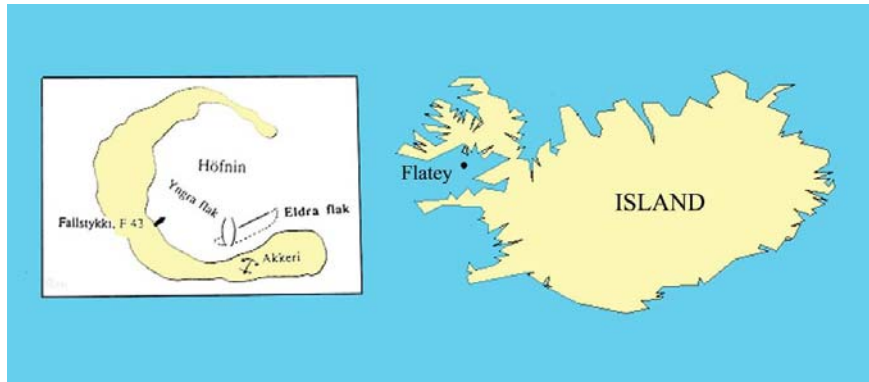


Figure 5.43 The wrecks of the *Melckmeyt* and the *Charlotte* in the Höfnin by Flatey in Breiðaffjörður, Iceland. The wreck of the *Charlotte* sank in 1882, covers parts of the *Melckmeyt*, which sank in 1659. The ship was carrying a cargo of fish, ready to set sail, but sank in the harbour during a storm. The wrecks were surveyed by Bjarni F. Einarsson et al. in 1993 (Einarsson et al. 1993, map by D. Nævestad, inset map by B.F. Einarsson).

5.3.4.3 Closing remarks on wrecks in Icelandic waters

The wreck locations described here, and diverse written sources concerning navigation in Icelandic waters, illustrate a substantial potential for wrecks, both in- and offshore. Unlike the Spitsbergen waters, where the main traffic first starts around 1600, and mainly consists of whaling and hunting expeditions, the waters around Iceland are navigated by merchant shipping, migration ships, fishing ships and men-of-war for 1200 years. In addition there is the transit traffic to Greenland, and also to North America. The wrecking of *Wapen van Amsterdam* shows that ships, very much off course, may also be found. A certain concentration of wrecks will be found along the most frequented sea-lanes, and along the drift-ice areas of the Strait of Denmark (Figure 5.44).

Mapping of recent wrecks in Icelandic waters shows a concentration around Reykjanes; probably due to the concentration of traffic, and a concentration of wrecks on the banks northwest of Iceland, and probably due to the fishing activities here. Scattered south of Iceland, several WWII merchant ships and submarines are found.

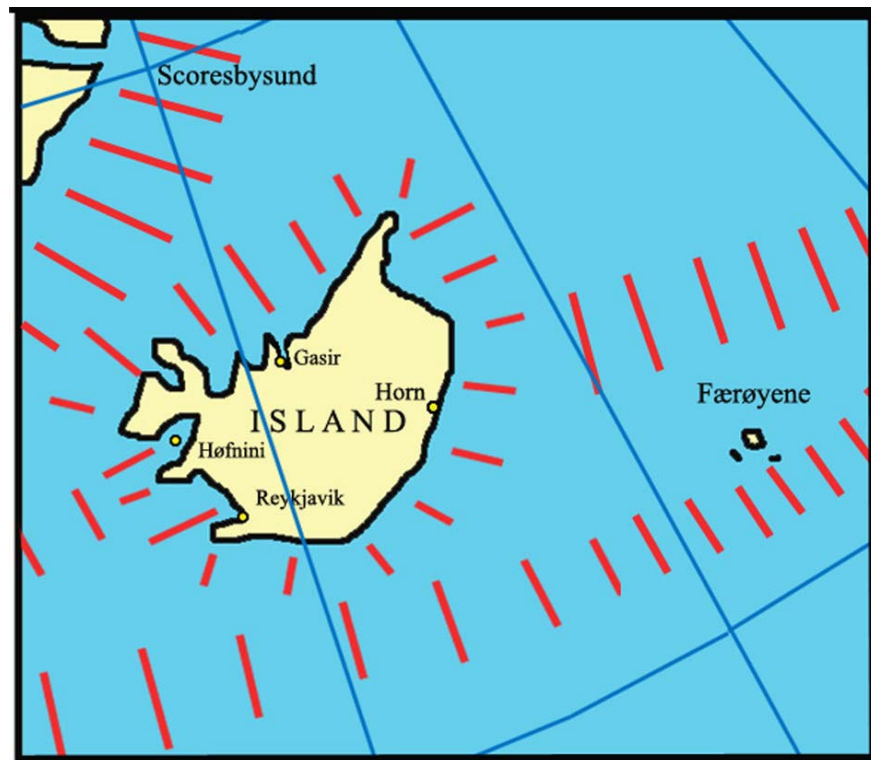


Figure 5.44 Sea-lanes and probable areas of wrecking in Icelandic waters. There are of course also wrecks outside these areas, but probably more scattered (Sea lane map by D. Nævestad).

5.3.4.4 The environment and the state of the wrecks. How much is left?

The marine environment in Iceland will probably not display conditions different from those of the Norwegian coast, which are not favourable to organic material. However, local conditions, such as high sedimentation, areas of low oxygen inside fjords, and other parameters will create favourable conditions for wrecks and artefacts. Tree borers belonging to the class *Bivalvia* seem not to be abundant in Icelandic waters, which is positive concerning the preservation of wood.

5.4 Mapping and registering of cultural heritage on the seabed

The previous assessment of areas of wrecking and cultural heritage under water in the Arctic is, as stated, based on a large-scale evaluation. A protection plan should be founded on a basis of knowledge according to precise information. However, as the written sources on wrecks in Arctic waters vary greatly in accuracy and reliability, the information at hand is inconsistent.

The reports on actual finds may also be approximate, as far as positioning is concerned, but usually of a far better precision. It is therefore

important to enforce the legislation that states that it is mandatory to report wrecks in all the Nordic countries. This has never, or seldom, been enforced concerning the fishing fleet, according to this research. Nor has it been normal procedure on survey vessels, or in connection with other marine research. There are, however, several records and compiled data available from a number of different sources, which may be exploited for the purpose of bringing the information to light. This, and a policy of informing on and enforcing the legislation at hand, may provide the management with an accumulating base of knowledge.

The measures to be taken to achieve this will include the establishment of databases, compiling known sources, and a system of recording and updating information, locally and regionally. The dataset should of course be integrated and seen in a holistic view in which non-renewable cultural resources are considered along with coral reefs, sponge fields, hot vents and other vulnerable habitats. The information on these natural phenomena is limited, concerning spatial distribution, and as for the understanding of their nature and function in the ecosystem, much is left to discover in the field of natural sciences. On integrating the mapping of natural and cultural phenomena one must bear in mind, however, that maritime archaeology is a very recent branch of science, and has had very limited time and few resources to record and consolidate a base of knowledge. The evaluation of an area might thus change radically by the reporting of a wreck or other cultural phenomena on the sea bottom. This underlines the importance of enforcing the reporting of such occurrences. Research on the distribution of coral reefs, as illustrated in this report, uses much of the same systems of information and methods of investigation as would a survey for shipwrecks, namely information from fishermen on the occurrence of corals, and mapping and investigation by sonic surveys like multibeam or side scan, and visual observations by ROVs (remote operated vehicles).

5.4.1 Methods for mapping of cultural heritage

Apart from mapping wrecks by means of reports, surveys of different kinds may reveal the presence of wrecks. Digital data obtained by seabed surveys by multibeam echo sounders may be analysed and interpreted to reveal the presence of wrecks. As the Arctic environment seems to offer exceptionally good conditions for the preservation of wrecks, the multibeam sonar surveys will be able to detect wrecks, coral reefs and other phenomena that will be represented by a different height and respond signature of the sonar beams. In Svalbard, the wrecks of two vessels in Grønfjorden have been surveyed and mapped by multibeam. One, the wreck of *Selis*, a wooden ship, is distinguishable, standing about two metres above the seabed. The *Isbjørn* next to her, the steel wreck of a small tug and icebreaker, stands several metres above the ocean floor

(Figure 5.45). Both vessels were sunk during World War II, by German airplanes. The survey, executed by the Norwegian coast guard, shows that the signature of such objects are identifiable by this method once one knows what to look for.

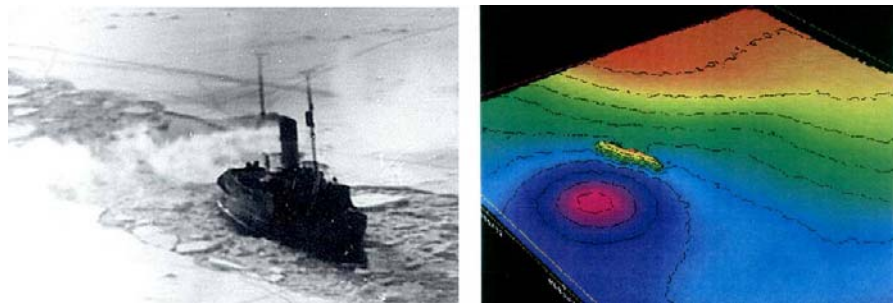


Figure 5.45 Left: The icebreaker SS Isbjørn, photographed from the German Focke Wulf Kondor airplanes that sunk her in Grønfjorden, Svalbard, in 1942. Right: the sonic signature of the wreck, in 136m of water. The red colour through in the seabed next to the wreck has been interpreted as a result of the depth charges used to sink the vessel. Multi-beam sonogram recorded by the coast guard vessel KV Lance, visualized by the software terrain modelling tool Cfloor. Depth intervals: 1m (From the Sysselmennen, Svalbard).

Side scan sonar surveys, using towed “fish” recording the sea bottom, are able to pick up trawling trenches in the sea bottom and other anomalies, as well as wrecks. Signatures of “mould and score” being elevated areas of a wreck, together with the trough created by current scoring the wreck site, is an established method of recognizing shipwreck sites, even if the wreck itself is buried in the bottom sediments (Nævestad 1991:208–220).

Multibeam mapping, and side scan sonar surveys, are methods used by marine naturalists mapping features from submarine sediment avalanches to coral reefs. Recent developments of multibeam methods have shown several advantages compared to side scan sonar. The interpretation of such surveys, when analysed for an archaeological purpose, may give results of great detail. It is thus of importance to give attention to the possibilities of joint venture surveys, where archaeological parameters may be introduced to the survey goals.

There are, at the moment, a number of projects looking into the spatial management of marine resources and phenomena. The Norwegian MAREANO project (Marine spatial database for Norwegian coast and sea areas) is one example (<http://www.mareano.no/>) (Figure 5.4). This project aims to establish a detailed topographical mapping of the seabed, incorporating seabed morphology, geological resources, contaminations and environment, biological diversity, natural environment, cultural heritage and marine resources. The Barents Sea, and the sea areas close to the Lofoten Islands, has been given priority, and work will be in progress from 2005. The basis for the survey in this area has been the “Integrated Management Plan for the Barents Sea” (Helhetlig forvaltningsplan for Barentshavet og havområdene utenfor Lofoten). The plan aims to initiate

a coordination of the management of the different human activities within the concept of sustainable development. The non-renewable cultural heritage sites on the seabed are one of the parameters to be mapped and considered inside this holistic concept.



Figure 5.46 Wreck of a merchant ship in the harbour of Narvik recently recorded by the Norwegian Government Seabed Mapping Agency (Statens Kartverk, Sjøkartverket (SKSK)). The sonargram has high detail resolution; still higher resolution is available, depending on the hardware used, and software processing programs. This picture was recorded with a EM300 echo sounder, and modelled on a 0,25m grid. (Illustration by SKSK, <http://www.mareano.no/>).

Based on the databases of the different MAREANO partners, a user-friendly Internet information system is to be established with central record-keeping and upgrading. The system aims to cover the whole Norwegian coastline and all sea territories.

Concerning the Arctic areas, a management system like MAREANO will imply a series of questions and concerns to work on at national and international levels. The implementations on a national basis should thus also aim to be in accordance with, and encourage, international cooperation in building such a management plan.

5.4.2 Registers of cultural heritage on the seabed in Arctic waters

In several earlier studies by the Norwegian Maritime Museum, and on this project, databases on cultural heritage on the seabed in Arctic waters have been compiled from a number of sources. The status for these databases is at the moment the registration of several hundred positions. Few of these are located wrecks with confirmed positions. The data will provide the management with approximate positions on where to expect wrecks, and a possible key to the identification of vessels. The datasets also contain information on shipping lanes, harbours and other informa-

tion on navigation and use of the maritime cultural landscape. There is, however, a need to look into several other databases, and link the information on a larger scale. There is a register on wrecks and known “catches” (heft), primarily on the North Sea region, but also with some information on the Barents Sea. There is also quite a number of registrations in military sources; if any of these could be de-classified is not known. Information from the fisheries would also be of great importance, and given the precise positioning possibilities of today, probably of good quality.

The linking of these data with multibeam surveys, and other mapping methods, would be of interest in order to be able to process data from a known wrecking position to a resolution suitable for an archaeological purpose of identification and positioning. Future work on this subject should be performed along these lines to establish better management of these non-renewable resources.

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6. Protection of natural and cultural heritage and natural resources in the Arctic

H.P. Haraldsson, S.Á. Ragnarsson and D. Nævestad

6.1 Introduction

Marine and coastal protected areas (MPAs) in the Arctic are essentially set up to serve either of these two purposes: resource management or preservation of natural and cultural heritage (Salm et al. 2000). MPAs are considered to be an important tool for managing the marine environment. However, only about 4,000 MPAs exist today worldwide, covering about 0.5% of the ocean surface according to the World Conservation Monitoring Centre. Most of them are small, located in waters close to shore and many are poorly managed (Belfiore et al. 2004).

Protection in order to preserve natural and cultural heritage means exclusion of any exploitation that has a lasting effect. Legal frameworks were originally established to protect land areas. However, in many cases the same criterion serves for protection in both land and sea. Areas in the sea are protected for example for science, for wilderness protection, to preserve seascapes, ecological and geological features or merely for recreation (Salm et al. 2000).

The use of marine protected areas as a tool in fishery management to alleviate depletion of target stocks has been gaining increasing interest. There is augmenting evidence that fish populations benefit from the establishment of MPAs. Integrating large-scale networks of marine reserves into fishery management has been suggested as a useful approach to protect marine species and their habitats (Gell and Roberts 2003). The benefits of marine protected areas are most obvious in the case for organisms that are sedentary or have limited movements, such as habitat-forming species. Murawski et al. (2000) showed that biomass of scallops was up to 14 times greater after four years of area closure. Restricting fishing activities within marine protected areas to allow for build up of stocks can also benefit benthic habitats that have been disturbed by fishing activities (Gell and Roberts 2003).

Advances in fishing-gear technology have made it possible to fish in areas where it was not possible before (Roberts 2002). This trend is of concern as the fauna found in deeper waters is often vulnerable to gear

impacts. Currently there is evidence for detrimental impacts of deep sea fisheries on geological features, such as seamounts (Clark et al. 2004), deep-water fish species (Koslow et al. 2000) and vulnerable habitat-forming species (Fosså et al. 2002). Growing understanding on the high ecological value of many benthic habitats has called for the need to protect these.

In Arctic waters, most marine protected areas have been established in order to protect nursery and spawning grounds of fish and some target invertebrate species, such as scallop and shrimp. Very few marine protected areas have been established in the Arctic with the aim of protecting vulnerable marine seabed habitats. However, there are protected areas on land bounded by a coastline, which extends to varying extents into the sea. Many of these areas are of limited economic importance to humans. This includes for example the largest protected area in Europe, which is located in Greenland and it is mostly a glacier. On the other hand, temporary closure of areas to protect spawning and nursery grounds as a fishery management tool is widely used in the Arctic. These closures prohibit the use of one or more fishing-gear types and therefore do not offer a complete protection against all human activity, but may nevertheless provide important protection for marine benthic habitats. Closures to protect archaeological remains are currently non-existent.

The Nordic Council of Ministers stressed in Nord (1999) the need to preserve our cultural and natural heritage as a most important legacy to understand the evolution of our society, its traditions and relations with other cultures or countries. There is increasing effort and resources invested to preserve singular habitats or landscapes and archaeological remains – on land. Traditionally, very few funds have been devoted to the protection of submarine landscapes and archaeological findings and there are no areas in Arctic waters that have been established to protect archaeological remains. UNESCO has very recently stressed the importance of marine archaeological remains in the Convention on the Protection of the Underwater Cultural Heritage.

6.2 Review on nature protection in Arctic waters

Haukur Þór Haraldsson

Nature conservation schemes are designed at local levels and adopted in national legislation. Legislation is often based on the six IUCN categories (Box 6.1). All the IUCN categories can refer to marine areas. In Greenland, Iceland and Svalbard the Ministries for the Environment and the conservation agencies are responsible for the administration of protected areas. They have a statutory responsibility for developing conser-

vation objectives and advice on any activities that may cause deterioration to protected features and sites.

The extensive work carried out by the fisheries authorities to control and maintain the fish stocks and to protect certain areas has something in common with the nature conservation schemes. For example, closures as regulated by the fisheries law can be comparable to category VI protection according to the IUCN definitions (Salm et al. 2000). The World Commission on Protected Areas has designed conservation categories that can incorporate all principles of protection and management (IUCN 1994).

Protected area systems are designed locally and at national levels. These are often based on the six IUCN categories. All categories can refer to marine areas. The theory and practice of protected area management has undergone several changes throughout the years. Protection has developed to become more flexible in terms of aims, definitions and approaches to management. Thus biological processes and traditional human lifestyles are as suitable for protection as endangered species or unique landscapes (Dudley and Stolton 1998). Nevertheless, discrepancies among countries, i.e. regarding rules of public access for different categories of protection, lead to confusion on the purpose of protected areas. The World Commission on Protected Areas suggested a modified set of six IUCN Protected Area Management Categories, adopted by IUCN in 1994 (Box 6.1).

Box 6.1 Marine protected area management based on IUCN Categories**Category Ia**

Strict nature reserve/wilderness protection area managed mainly for science or wilderness protection – an area of land and/or sea possessing some outstanding or representative ecosystems, geological or physiological features and/or species, available primarily for scientific research and/or environmental monitoring.

Category Ib

Wilderness area: protected area managed mainly for wilderness protection. A large area of unmodified or slightly modified land and/or sea is protected and managed to preserve its natural condition, retaining its natural characteristics and influence, without permanent or significant habitation.

Category II

National park: protected area managed mainly for ecosystem protection and recreation – natural area of land and/or sea designated to (a) protect the ecological integrity of one or more ecosystems for present and future generations, (b) exclude exploitation or occupation inimical to the purposes of designation of the area and (c) provide a foundation for spiritual, scientific, educational, recreational and visitor opportunities, all of which must be environmentally and culturally compatible.

Category III

Natural monument: protected area managed mainly for conservation of specific natural features – area containing specific natural or natural/cultural feature(s) of outstanding or unique value because of their inherent rarity, representativeness or aesthetic qualities or cultural significance.

Category IV

Habitat/Species Management Area: protected area managed mainly for conservation through management intervention – area of land and/or sea subject to active intervention for management purposes so as to ensure the maintenance of habitats to meet the requirements of specific species.

Category V

Protected Landscape/Seascape: protected area managed mainly for landscape/seascape conservation or recreation – area of land, with coast or sea as appropriate, where the interaction of people and nature over time has produced an area of distinct character with significant aesthetic, ecological and/or cultural value, and often with high biological diversity. Safeguarding the integrity of this traditional interaction is vital to the protection, maintenance and evolution of such an area.

Category VI

Managed Resource Protected Area: protected area managed mainly for the sustainable use of natural resources – area containing predominantly unmodified natural systems, managed to ensure long-term protection and maintenance of biological diversity, while also providing a sustainable flow of natural products and services to meet community needs.

6.2.1 Greenland

The law on nature protection in Greenland (Nature Conservation Act nr. 29/2000) (Table 6.1) has the main objective of protecting biodiversity and ecosystems. The law applies to areas on land and in the sea within the fisheries territory. However, it does not apply to management of marine and freshwater resources.

Greenland's protected area program is based primarily on species needs, sustainable use of living resources and the uniqueness of the areas. The system uses a combination of traditional area protection and regulations on hunting, fishing and harvesting.

In Greenland, there is no right to private ownership of land, and all land use requires permission from the municipality authorities or the Home Rule Authorities. Local communities can set their local rules and regulations, some of which have some protective functions, resulting in a variety of different regulations. However, most protected areas in Greenland are uninhabited. Fishing and hunting traditions are based on long travel distances and this has to be taken into consideration when planning nature protection in Greenland.

Table 6.1 Review on nature conservation legislation in Iceland, Greenland and Svalbard maritime area

	New	Aim	Marine protection
Iceland			
Nature Conservation Act nr. 44/1999	Conservation measures strengthened. CPAN principles and guidelines and EC Habitat Directive taken into account.	Protection of natural landscapes and to ensure the course of natural processes.	Enables protection of marine areas in cooperation with the minister of fisheries (paragraph 54).
Greenland			
Nature Conservation Act nr. 29/2003	Enables wider protection for different kind of habitats than before.	To protect biodiversity and ecosystems.	Enables wider protection of marine habitats including protection of foraging areas for birds and marine animals.
Svalbard			
The Svalbard Environmental Protection Act nr.79/2001	All environmental regulations collected in one act for the first time.	To protect the pristine environment in Svalbard.	The act is a legal base for designation of new MPAs or their potential conservation efforts within twelve nautical miles.

6.2.2 Iceland

According to the Nature Conservation Act from 1999, paragraph 54, the minister for the environment can designate an MPA within the territorial limit. Cooperation with the minister of fisheries is needed. Protection of areas and sites can be declared; firstly, if they are important for their natural processes, geological formations, scientific interest or beauty;

secondly, for areas and sites important for their biological value, special or endangered species, habitats and ecosystems; and finally for areas important for recreational use (Table 6.1). The aim is to protect Iceland's natural landscapes and seascapes to ensure the course of natural processes. The categories of different types of area protection are described in the act. The categories listed below (Náttúruverndarráð 1996) belong to the IUCN categories IB, III, VI and II respectively.

Nature reserves

Nature reserves may be established in areas considered important for their landscape, flora or fauna. Common to all the reserves is protection of their wildlife and landscape and a restriction on development and public access. The degree of restriction may vary, as the following examples show: Surtsey Nature Reserve off South Iceland is closed to all public traffic whereas Hornstrandir, in Northwest Iceland is closed to development, such as construction of houses and roads, farming, grazing and horse riding but is open to the public with restrictions.

Natural monuments

Natural monuments are natural phenomena or landscape features that are of outstanding beauty, are unique or are interesting for special scientific interest. These include waterfalls, volcanoes, hot springs, rock pillars, fossils and minerals.

Country parks

Country parks are protected areas upon request of local government and mandated by them. The parks are primarily intended to be for recreational purposes and are open to the general public. The parks may vary in size and restrictions but prohibition of unnecessary construction works is a common rule.

National parks

National parks are established in areas considered outstanding in landscape, flora or fauna, or to have special historic significance. They are established on state-owned land with occasional exceptions where there is an agreement between the landowner and the minister of the environment. National parks are mandated by the Environment and Food Agency, which facilitates public access by making trails and provides visitor facilities and information on the natural and cultural heritage that is to be found in the park.

6.2.3 Svalbard

Svalbard is part of Norway and Norwegian law was implemented through the Svalbard contract 1920 (Governor of Svalbard 2002). With the law on

Svalbard from 1925 (Svalbardsloven 17 July nr. 11) the king of Norway was given the power to implement regulations in order to protect plants, animals and cultural remains. In response to growing interest in industrial activities, exploitation of coal, gas, oil and minerals and uncontrolled hunting of whales and walruses, Norwegian authorities realized the need to protect Svalbard's nature. Coastal waters up to four nautical miles were protected since 1973, as well as the coastline. The larger protected areas in Svalbard were located by the coast and all included the waters around them out to four nautical miles (Governor of Svalbard 2002).

The Norwegian government suggested an evaluation on nature conservation in Svalbard in 1995. Marine conservation sites were of special interest. It was concluded that the national parks were not representing Svalbard's natural and cultural heritage sufficiently and the most productive areas were still under threat. Subsequently a new legislation was adopted in 2001, Act of 15 June 2001 nr.79 on the protection of the environment in Svalbard (Table 6.1). It recruited the existing regulations under one law. The aim of the law is to protect unspoiled wilderness in Svalbard: landscapes, flora, fauna and cultural remains. With this initiative Svalbard is now amongst the best managed wilderness areas in the world. Within the marine protected area, bottom trawling in waters less than 100 metres of depth as well as mining, oil and gas exploration or other infrastructure development is prohibited. The marine protected area is now 40,000km² (Governor of Svalbard 2002).

The Svalbard environmental protection law applies three types of protection (Act of 15 June 2001 nr.79 on the protection of the environment in Svalbard).

National parks

This category is applied to bigger unspoiled areas and less spoiled areas considered to be important for science, recreation and education. No activity that has a lasting effect on the natural environment or cultural heritage is permitted in a national park. The landscape and, if applicable, the seabed with plants, animal life and geological formations is protected against development, construction, pollution and other activities. This includes limitations to access and traffic that may affect or disturb the natural environment. The national parks are open to basic, non-motorized outdoor recreation. In special cases, for example for scientific purposes, the governor allows limited use of snowmobiles, airplanes or helicopters.

Nature reserve

This category is applied to areas that represent fragile or rare ecosystems. It also includes geological formations with importance for flora and fauna of scientific value. Untouched areas or largely untouched areas may be designated nature reserves if they contain distinctive or vulnerable eco-

systems, comprise a special type of habitat or special geological formations.

The nature reserves have higher level of protection than national parks. A nature reserve may be given absolute protection. The regulations can contain provisions regarding the protection of the cultural heritage in the reserve. All traffic (including non-motorized) can be forbidden if necessary to protect the nature. The nature reserves were established to protect large tracts of undisturbed Arctic wilderness where natural ecological processes can proceed unhindered by man, as much as possible.

Biotopes and geotopes

Areas of particular importance to the flora or fauna or that contain important or distinctive geological formations may be given protected status as biotopes or geotopes.

In such areas, activities that may affect or disturb the flora or fauna or damage geological formations contrary to the purpose of the protection measure shall be avoided. The regulations may contain provisions regarding the protection of the cultural heritage in the protected area.

6.3 Nature conservation plans

Svalbard

A plan for nature protection has been available since 2003–2004. It extended the territorial limit out to 12 nautical miles. The boundaries around the protected areas in Svalbard will enlarge to the same extent (with the exception of Bear Island, which is being treated separately). Proposals for new protected areas are suggested including some marine zones, i.e. the protection of habitat types, in particular in the inner fjord zones (Governor of Svalbard 2002).

Iceland

A conservation plan was published in 2003, in which it was suggested to protect four marine areas, Álfanes-Skerjafjörður (mostly the tidal zone), Álfanes-Akrar-Löngufjörur (covering mainly the tidal zone), Vestmannaeyjar (2km around the island) and Látrabjarg (a marine protected zone extending between 0.1km and 2km from the coast depending on location) (Umhverfisstofnun 2004).

Greenland

There is no conservation plan for Greenland.

6.4 Review of conservation measures and actions in the Arctic

In order to sustain international cooperation, establish a legal framework to work toward sustainable use of the coasts and oceans and secure common interests, international schemes have been established. Greenland, Svalbard and Iceland take an active part in the circumpolar initiatives in protecting the Arctic (see also Box 6.2).

There are five working groups of the Arctic Council working on the subject of the coasts and oceans. These are devoted to the following topics:

Arctic Monitoring and Assessment Program (AMAP)

AMAP's current objective is to provide reliable and sufficient information on the status of, and threats to, the Arctic environment and to provide scientific advice on actions to be taken in order to support Arctic governments in their efforts to take preventive actions relating to contaminants.

Conservation of the Arctic Flora and Fauna (CAFF)

CAFF has the status of working group in the Arctic Council. Its primary role is to advise the Arctic governments on conservation and sustainability matters. It is a forum to discuss and address circumpolar Arctic conservation issues. Participants are Arctic professionals, indigenous people's representatives and observer countries and organizations.

Emergency, Prevention, Preparedness and Response (EPPR)

EPPR is a framework for future cooperation in responding to the threat of environmental emergencies. The mandate is to deal with the prevention, preparedness and response to environmental emergencies in the Arctic that are the result of human activities.

The program for the Protection of the Arctic Marine Environment (PAME)

PAME has the mandate to address policy and non-emergency pollution prevention and control measures related to the protection of the Arctic marine environment from both land- and sea-based activities. These include coordinated action programs and guidelines complementing existing legal arrangements.

Circumpolar Protected Areas Network (CPAN)

Projects under development and implementation include: a compendium of ecologically important marine areas in the circumpolar region; an assessment of the full value of Arctic protected areas; an assessment of the Conservation Value of Sacred Sites of Indigenous Peoples in Northern

Russia, together with the Russian Association for Indigenous Peoples of the North (RAIPON) and the Indigenous Peoples Secretariat (CAFF 2004).

Box 6.2 Review of international cooperation conservation measures and actions

MPAs were at first designated as a result of national initiatives, often on the basis of usefulness or economical interest to governments. However, it has slowly become the subject of international agreements and negotiations to ensure the conservation of marine and coastal resources. These are sometimes non-binding treaties with no obligations to the nations involved and sometimes more restrictive, as for example the Ramsar treaty (Salm et al. 2000).

The Rio agreement

The Rio agreement is about the balance between environmental protection and continuing economic growth and well-being. The outcome has been called sustainable development. The main criteria for sustainable development were adopted at the world summit in Rio De Janeiro in 1992.

Agenda 21

Agenda 21 is an action plan adopted by communities to fulfil the goals set in Rio 1992. Agenda 21 (chapter 17) describes the ocean's living resources in an international context as a potential to meet the rising need for food and to meet the economic and social goals for the future. The key is to strengthen international cooperation (Anonymous 1992).

United Nations Convention on the Law of the Sea

It is the first, very wide ranging international agreement from 1982. Its purpose is to protect the ecology of the oceans, to sustain international cooperation on the subject and establish a legal framework to work toward sustainable use of the oceans and thus secure common interest for all mankind.

The EU nations are obligated to protect marine areas according to the bird protection directive and the habitat directive. The same applies to the states that have signed the RAMSAR convention, Helsinki convention (HELCOM) and Oslo–Paris convention (OSPAR).

RAMSAR

The Ramsar convention is an international agreement on protection of wetlands, which have international importance for birds. All member states have the obligation to initiate some actions to achieve the goal.

The Habitat Directive – Directive 92/43

The aim of the directive (dir 92/43) is to secure the existence of biological diversity. The network of protected areas, that includes marine areas and wetlands, was established based on this directive.

The Habitat Directive is a major contribution by the European Community to the biodiversity convention agreed upon by more than 150 countries at the 1992 Rio Earth Summit. The EC Habitats Directive gives governments the opportunity to designate and protect important areas within the marine environment. The main objective of the Habitats Directive is to ensure that biodiversity is maintained through conservation of important, rare or threatened

Habitats and the habitats of certain species. The goal is also to make a contribution to sustainable development of the sites. In order to achieve the objectives of the EC Habitats and Birds Directives the Natura 2000 was established (Anonymous 1997).

The Bird Protection Directive –Directive 79/409

The objective is to establish or recreate protected areas for all bird species that have their habitat in Europe. Like the Habitat Directive it also applies to areas within maritime areas. The Bird Protection Directive and the Habitat Directive obligate member states to point out all marine areas that meet the criteria in the directives. The OSPAR, HELCOM and RAMSAR recommend their states to do the same. The objective of all five categories is the same – to protect diversity.

UNESCO

The United Nations Educational, Scientific and Cultural Organization (UNESCO) seeks to encourage the identification, protection and preservation of cultural and natural heritage around the world that is considered to be of outstanding value to humanity. This is embodied in an international treaty called the Convention concerning the Protection of the World Cultural and Natural Heritage, adopted by UNESCO in 1972.

Cultural heritage refers to monuments, groups of buildings and properties with historical, aesthetic, archaeological, scientific, ethnological or anthropological value.

Natural heritage refers to outstanding physical, biological and geological formations, habitats of threatened species of animals and plants and areas with scientific, conservation or aesthetic value (www.unesco.org).

OSPAR

The Convention for the Protection of the Marine Environment of the Northeast Atlantic ("OSPAR Convention") was opened for signature at the Ministerial Meeting of the Oslo and Paris Commissions in Paris on 22 September 1992.

The Convention has been signed and ratified by all of the Contracting Parties to the Oslo or Paris Conventions (Belgium, Denmark, the Commission of the European Communities, Finland, France, Germany, Iceland, Ireland, the Netherlands, Norway, Portugal, Spain, Sweden and the United Kingdom of Great Britain and Northern Ireland) and by Luxembourg and Switzerland.

The OSPAR Convention entered into force on 25 March 1998. It replaces the Oslo and Paris Conventions, but decisions, recommendations and all other agreements adopted under those conventions will continue to be applicable, unaltered in their legal nature.

OSPAR does not have a role in the fisheries management. OSPAR, however, gathers information, analyses the problems and makes suggestions on solutions to national governments or other responsible institutions. It has a bigger role in pollution control. In Annex 5 of the agreement it is especially stated that fisheries management is not its primary role.

The OSPAR Commission adopted a strategy on the conservation of biological diversity of marine ecosystems in 1998. It promotes the establishment of a network of marine protected areas to ensure sustainable use. The aim is to establish an ecologically coherent network of well-managed marine protected areas by 2010 (OSPAR 2003).

6.5 National legislation and international conventions concerning cultural heritage on the seabed

D. Nævestad

This overview of international agreements and legislations in the Nordic countries was made in order to address what kind of juridical protection of underwater cultural heritage is in effect in the Arctic regions covered by this report. These legislations differ in many ways, such as in the geographical area they cover, and what they aim to protect. An overview of the national legislation has been compiled, and is presented here. In addition, it is of value to review the common practice of the enforcement of the laws in each country, and pinpoint deviations with a view of describing areas of conflict, and to sketch out solutions for better integration and enforcement on a holistic basis. As it appears from the description of the regulations of fishing activities, MPAs are often strongly recommended, both for monitoring of fished areas and protection of marine habitats, but these can be difficult to implement. Joint efforts, and coordination of ecological and cultural legislation, may have a synergetic effect in the protection of natural and cultural phenomena on the seabed.

Concerning international waters, the Convention on the Protection of the Underwater Cultural Heritage has been put forward by UNESCO. The work was initiated in 1997, and the final draft was presented in 2001. It states that there is a growing awareness that underwater cultural heritage is threatened by unauthorized activities, and that there also is a need to respond appropriately to the possible negative impact by human activities, such as fisheries and the oil industry on underwater cultural heritage. The convention seeks to strengthen the protection of cultural heritage on the sea bottom *in situ*, by improving the effectiveness of measures at international, regional and national levels. The convention has not been signed by all countries concerned, and it is not likely to be ratified by all. However, the Annex of the Convention, containing rules and principles, where *in situ* protection of the cultural heritage is the first choice, is supported by a vast majority of countries.

The Law of the Sea, (UNCLOS, United Nations Convention Law of the Sea) has, however, been signed by most nations. Two articles, nrs. 149 and 303, focus especially on archaeological and historical objects. Article 149 states that: "All objects of an archaeological and historical nature found in the Area shall be preserved or disposed of for the benefit of mankind as a whole, with particular regard being paid to the preferential rights of the State or country of origin, or the State of cultural origin, or the State of historical and archaeological origin." This represents a change from earlier international law, which stated that the finder of such objects could dispose of them as they wished.

Article 303 concerns the right to archaeological and historical objects, and must be seen in connection with article 149. Article 303-1 says:

“States have the duty to protect objects of an archaeological and historical nature found at sea and shall cooperate for this purpose.”

The Law of the Sea is important in view of trawling and bottom dredging, as it states that the states concerned have an obligation to cooperate to protect the wrecks, and that a permit has to be obtained to remove objects, and that violation of this would result in an infringement within its territory or territorial sea of the laws and regulations referred to in that article. Denmark and Sweden have changed their respective laws on archaeological and historical matters to bring them in line with the UNCLOS convention. Denmark has made the most radical change, in an addendum to the “Museumsloven” (The Museum Law), §28a, made operative as of June 1, 2003. Here, an age limit of 100 years for the protection of wrecks, found by Danish citizens and Danish ships “in the deep sea” (“på den dybe havbund”) outside the territorial waters, is stated. Further, there is to be a mandatory reporting of such finds, and a declaration that states that one cannot, without permission, “change the state of underwater cultural heritage”. This last paragraph concerns, related to this report, the direct impact of trawling and bottom dredging on cultural remains under water, and also secondary effects like the disturbance or removal of the bottom sediments protecting the sites. The Danish law thus seems to be regulating such activities as trawling and bottom dredging on the seabed by Danish vessels in international waters.

6.5.1 National legislation: the national cultural heritage acts

A limited study has been made on the legislation and the state of the situation concerning reporting of finds to the management for each of the Nordic countries. The study is mainly based on telephone interviews with the executive branch of the management responsible for cultural heritage under water. The aim of the study has been to point to common areas of conflict, and possible measures concerning these. A framework on the following points has been applied to the study:

- What geographical area does the legislation cover?
- Is there a time limit concerning the protection of cultural remains under water; and if so, what is the time frame?
- Is there an obligation, according to the jurisdiction, to report finds of cultural remains under water? Is this legislation enforced?
- Prior to construction work, dredging, landfills, trawling, scallop dredging and other activities with impact to the seabed, are there any investigations concerning cultural remains to be made, according to the legislation?

It seems that the jurisdiction on cultural heritage under water in the Nordic countries is quite uniform, with the same focus and purpose, as can be seen from the table 6.2. As for the geographical limit, most of the countries have a limit of jurisdiction out to 12 or 24 nautical miles from the baseline. Greenland, however, has a territorial water of only three nautical miles.

Concerning the time span the different acts cover, i.e. how old a wreck has to be to be considered protected, most Nordic countries have an upper limit of 100 years. However, some countries set the age limit from the year of sinking, not the year of construction. At Svalbard, the time span goes from 1945 and back, protecting a number of WWII wrecks and aircraft inside the territorial waters. Here, the law also states that a security zone of 100 metres from the objects perimeter, in which no disturbances are tolerated. This means that trawling is not allowed closer to the wreck of the "Isbjørn", sunk by German planes in Grønfjorden during the war, than 100 metres. In effect, the area cannot be fished with bottom gear within a diameter of 200 metres. This will also apply to all other wreck sites on Svalbard, inside 12 nautical miles from the baseline. In addition, there is a general trawling ban in waters shallower than 100 metres of depth, quite large national parks and nature reserves, where no fishing with bottom gear is allowed, giving wrecks in these waters a unique legislative protection.

The legislation of all the Nordic countries makes it mandatory to report wrecks. This is to a great extent done when sport-divers locate such cultural heritage, but only sporadically by the fishing fleet. The reasons for this can be both traditional and because there has been too little information distributed on the subject. The environmental management also needs time to adjust to new situations and new threats. Registering and managing underwater cultural heritage is a new responsibility, emerging from the start of sport-diving in the mid-1950s, which gave sudden access to, and threatened, cultural heritage earlier protected by the sea itself. As new phenomenon the management and museums have not been allocated economic means to inform about and enforce the law, or survey and document the cultural heritage under water adequately.

Table 6.2 The legislation concerning cultural remains under water in the Nordic countries, a short overview

Cultural heritage act; name	Law protects	Time frame	Geographical area	Mandatory to: - report finds - investigate seabed
Denmark				
Lov nr. 473 af 7. juni 2001	“Cultural heritage, among these wrecked ships, ships cargoes and parts”	Older than 100 years/or objects of special protection	Territorial waters to 24 nautical miles.	-Yes
Museumslov			International waters: Danish subjects/vessels may not change the state of underwater cultural heritage	-Yes
Finland				
Lag om fornminnen 17.6.1963/295	Ships, parts from ships and other objects	For ships:	Territorial waters to 4 nautical miles	-Yes
		Older than 100 years	(if not otherwise defined)	-Yes
Greenland				
Landstings-forordning nr. 6 af 20. oktober 1998 om museums-væsen	“Objects that have been, or are lying in the sea-territory”	Without time limit; “remains from the past”	The sea territory 3 nautical miles	-Yes -“The museum shall cooperate with the plan authorities”
Iceland				
The National Heritage Act Nr. 88 of 29 May 1989 with later amendments	Wrecks of ships or pieces from them	Older than 100 years/or objects of special protection	Territorial waters to 12 nautical miles.	-Yes
				-Yes.
Norway				
Lov om kulturminner av 9. juni 1978 nr 50	Wrecks, parts of wrecks and other objects that have been on board	Older than 100 years, (year of ship construction)	Territorial waters to 24 nautical miles.	-Yes
Petroleums loven av 29.11.1996 nr 72			For oil-industry related activities, the Petroleum Act is in effect also on the continental shelf.	-Yes
Svalbard (Spitsbergen)				
LOV 2001-06-15 nr 79:Lov om miljøvern på Svalbard	Wrecks, parts of wrecks and other objects that have been on board	From 1945 or earlier/objects of special protection younger than 1945	Territorial waters to 12 nautical miles.	Mandatory to provide information
Petroleums loven av 29.11. 1996 nr 72			Security zone of 100m in all directions from the visible or known perimeter of the cultural remains.	-Yes
			The Petroleum Act: the continental shelf from 12n.miles onwards.	
Sweden				
Lag (1988: 950) om kulturminnen	Shipwrecks, if more than 100 years have passed since the wrecking	Older than 100 years (from the day of wrecking)	Territorial waters to 12 nautical miles.	-Yes
			International waters: wrecks from international waters brought to Sweden, or salvaged by a Swedish ship, belong to the state.	-Yes

The conclusion on national legislation in the Nordic countries, inside each nation's territorial waters, is that in general the legislation offers adequate legal protection of cultural heritage on the seabed. The laws are, however, not always enforced. The practice of the legislation concerning the fisheries generally lacks enforcement of the obligation to report finds. Likewise, demands for preliminary investigations of the seabed prior to exploitation are not presented. Both these practices should be looked into with the view to change this situation. As for the protection of sites, only the Environment Act of Svalbard offers protection of sites, from trawling and dredging, in a 100m radius from the objects. However, as of today, this is not enforced.

6.5.2 Conventions concerning cultural heritage in international waters; conclusions

The UNESCO proposal for a Convention on the Protection of the Underwater Cultural Heritage has, as mentioned, not been signed by all parties. Concerning trawling and bottom dredging, the proposal addresses this problem and points to the "need to respond appropriately to the possible negative impact on underwater cultural heritage of legitimate activities that may incidentally affect it". Furthermore, the proposal includes acts dealing with the mandatory reporting of finds; this must of course include finds made by the fishing industry. The convention has not been signed by all countries concerned, and it is not likely to be ratified by all. However, the Annex of the Convention, containing rules and principles, where in situ protection of the cultural heritage is the first choice, is supported by a vast majority of countries.

UNCLOS, United Nations Convention Law of the Sea, is signed by a large number of nations. The convention's article 149 deals with the preservation of objects:

"All objects of an archaeological and historical nature found in the Area shall be preserved or disposed of for the benefit of mankind as a whole".

According to article 303, the "States have the duty to protect objects of an archaeological and historical nature found at sea".

In consequence, the practice of trawling and scallop dredging should be liable to prosecution if in any way damaging archaeological or historical sites, or if failing to report the findings of objects. This will only happen if national legislation is brought into compliance with the intentions of the international agreement, as the agreement itself merely states an intention.

As mentioned, one of the Nordic nations, Denmark, has recently (2003), to comply with the UNCLOS convention, added a paragraph on international waters to their legislation on cultural heritage, concerning Danish vessels and subjects. According to this, one may not inflict changes in the state of the cultural heritage objects under water. Such changes could be

physical damage or exposure by trawling and dredging. The conclusion on the part of international waters is that the national legislation of the countries involved in trawling and bottom dredging in Arctic waters, should be brought into compliance with the international conventions, as illustrated in the example of Denmark. The wording in the Danish text, stating that “one may not inflict changes” should be noted, as it protects wrecks *in situ*, as well as objects being removed from them.

6.6 Review on marine protected areas as a fishery management tool in Arctic waters

S.Á. Ragnarsson

6.6.1 Iceland

6.6.1.1 History of fishing limits within Icelandic waters

In 1859, the Danish government implemented four nautical mile fishing limits in Icelandic waters. Other nations were opposed to these limits and in 1901, the Danish and the British government declared a fishing limit with an exclusive zone of three nautical miles, which was applicable to both Icelandic and foreign trawlers (Figure 6.1). In 1952, the fishing limit was further extended to four nautical miles. Within the exclusion zone (now including Faxaflói Bay), all fishing with otter trawls and Danish seine was prohibited, both by Icelandic and foreign vessels. In 1958, the Icelandic government decided to extend their fishing limits further to 12 nautical miles. This decision met much opposition by several nations, especially Great Britain, which continued to fish within the 12 nautical mile exclusion zone. For the next three years, British warships protected their fishing vessels during fishing. The conflict was resolved in 1961 when Great Britain accepted the new limits. Icelandic vessels, however, were permitted to fish with otter trawl and Danish seine within certain areas and at certain times (Ólafsson 1999).

In 1972 Iceland proclaimed a fishing zone of 50 nautical miles and the dispute with the Great Britain was renewed. This conflict was concluded with an agreement between the two countries that limited British vessels to fish within certain areas. In 1975, the Icelandic government extended their fishing limits (Economic Exclusion Zone) to 200 nautical miles. This action was again opposed by the British government and that year there were numerous conflicts between the Icelandic coast guard vessels and British trawlers and frigates. In 1976, an agreement between the Icelandic and the British governments was reached where almost all fishing by foreign vessels was prohibited within the 200 nautical mile fishing limits (Agnarsson 2000).



Fig 6.1 Fishing limits in Icelandic waters until 1972. Three nautical mile limits between 1901–1952 (dark blue), four nautical miles 1952–1958 (medium blue) from the most distal land, islands and skerries and 12 nautical miles in 1972 (Ólafsson 1999)

6.6.1.2 Types of closures

Real-time closures

Real-time closures are imposed when the proportion of undersized fish in the catch exceeds a pre-defined reference level. This reference level varies according to species. For example, real-time closures are imposed when more than 25% of cod in the catch (by number) is smaller than 55cm. These types of closures were first enacted in 1976 to minimize discarding and the catch of undersized fish. Fisheries inspectors from the Directorate of Fisheries regularly measure fish onboard vessels or at markets and monitor fishing. If the proportion of undersized fish exceeds the quoted reference level, the area is closed to fishing. All decision making concerning closure of areas is based on advice from fisheries scientists. The closure is confined to the area where the proportion of undersized fish is highest and for that reason, these closures are generally of small size (Fig 6.2).

The duration of real-time closures is generally about 14 days but can be extended further for seven days if considered necessary. Depending on the number of real-time closures and the percentage of small fish within the same fishing ground, a committee consisting of delegates from the Marine Research Institute, the Directorate of Fisheries and the Ministry

of Fisheries decides on further actions concerning management of fisheries in the area. This could involve delineation of those areas where the frequency of real-time closures is sufficiently high to allow the establishment of protected areas that are closed for longer period of time or permanently (Kristinsson et al. 2005).

Over the period 1977–2003, a total of 1,975 real-time closures have been imposed (Kristinsson et al. 2005). The majority of these have been located off Northwest Iceland (or 627 in total). From 2000 onwards, the number of real-time closures imposed annually ranged from 113 to 152. The main reason for imposing real-time closures was to protect stocks of undersized cod (63%) (Kristinsson et al. 2005).

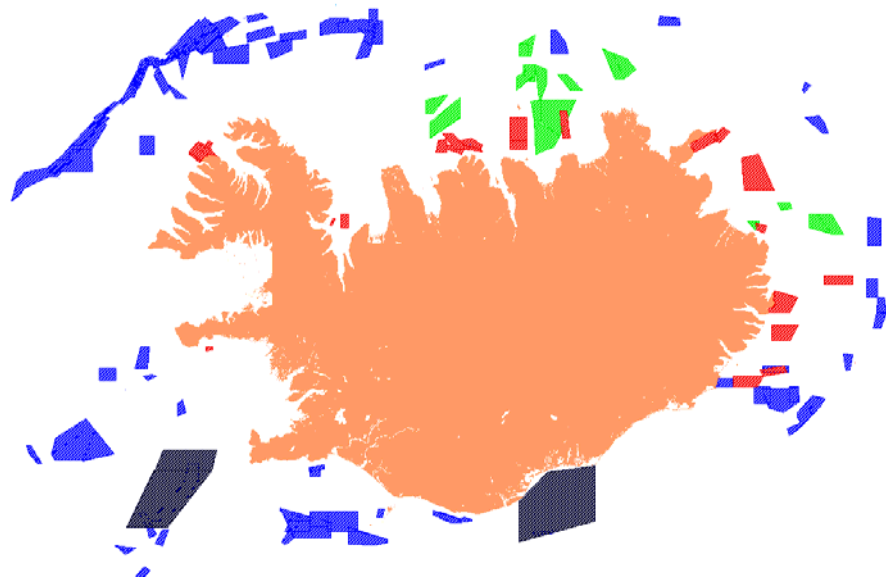


Figure 6.2 The spatial distribution of real-time closures in 2000. Areas closed to shrimp trawls (green), longline (red), all gear except shrimp trawl (blue) and other closures (black)

Regulatory fisheries closures

The Ministry of Fisheries in Iceland is responsible for the implementation of legislation and regulations regarding closed areas, following advice from the Marine Research Institute. The primary aim of these closures is to alleviate detrimental impacts of fishing that can reduce the future yield of target stocks. The types of closures that are implemented vary greatly depending on their purpose. Some areas are closed to fishing seasonally in order to protect nursery and spawning grounds. During spawning of cod and plaice, the closure takes place in April and the length of the closure varies from one week to one month. Other areas are closed between one to six months according to known temporal migrations and spawning of various species. Some areas are closed to fishing during the night, such as in the coastal shrimp fishery or during the day as in the fishery target-

ting redfish. For some areas it is considered necessary to close these permanently for the whole year. In most closed areas, the use of one or two gear types is regulated. This includes for example areas where fishing with otter trawl is restricted but not longline and vice versa (Figures 6.3 and 6.4). Some areas are closed to trawls unless they are fitted with sorting grids that are very efficient to reduce by-catch (Figure 6.3). Sorting grid design varies depending on the species the fishery is targeting. In the shrimp fishery, the use of grid with bar spacing of 22mm used to sort out fish is mandatory. Additional devices or sorting grids are mandatory in some shrimp fishing grounds to reduce the catch of undersized shrimp. On otter trawls targeting fish, grids with bar spacing of 55mm are used to sort out undersized fish.

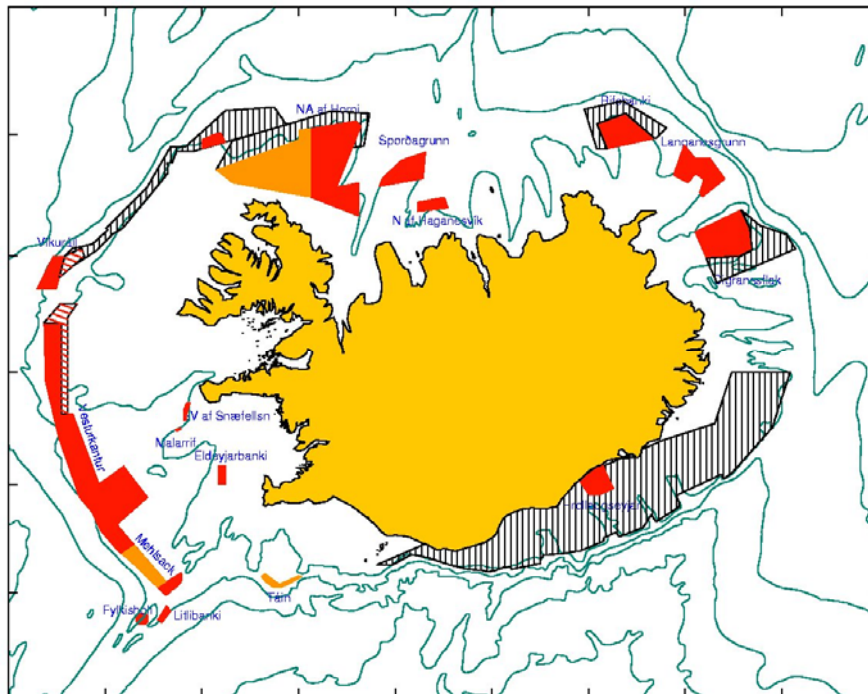


Figure 6.3 Areas closed to fishing with otter trawl in 2004.

- Areas permanently closed all year
- Areas closed 12 hours a day all year long
- Areas closed part of the year
- Trawling banned except with trawls fitted with sorting grids

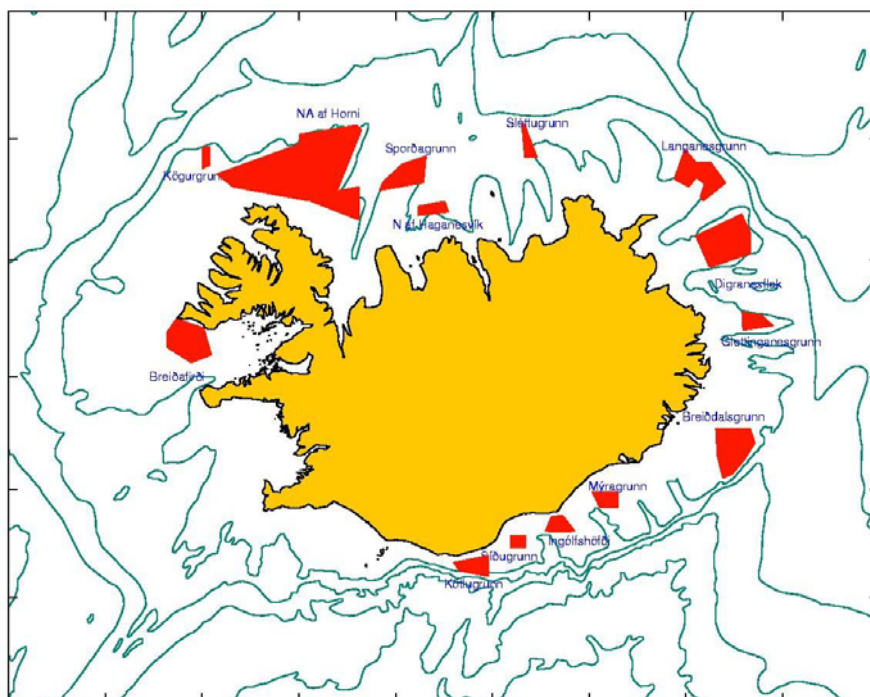


Figure 6.4 Areas permanently closed to long lining in 2004.

The first regulatory closed areas were established in 1972. For the period 1972–1993, there have been considerable changes in the number, the location and the size of closed areas. Some areas are now much smaller compared to when they were first established. From 1993 onwards there have been minor changes in the size and boundaries of closed areas (Figures 6.3 and 6.4). The total surface area of closed areas in Icelandic territorial waters was 48,600km² in 2004. The total surface area of each closure type is shown in table 6.3 (The text in this section was partly based on unpublished information from Sigfús Schopka, MRI).

Table 6.3 Overview of the total surface area of each of the main type of regulatory closed areas in Icelandic waters in October 2004.

Gear	Type of closures	Total surface area (km ²)
Otter trawl	Permanent closures	15,700
	Diurnal closures	1,100
	Seasonal closures	3,700
	Sorting grids	28,000
Longline	Permanently closed areas	12,700

Areas closed for otter trawls and longline are shown separately. 6.6.2

6.6.2 Norway

In 1976, Norway established a 200 nautical mile Exclusive Economic Zone (EEZ). The EEZ was supplemented by a fisheries protection zone around Svalbard and a fisheries zone around Jan Mayen (Figure 6.5). Svalbard currently has territorial limits of 12 nautical miles. In the Ba-

rents Sea, the loophole (“smutthullet”) is open for fishing by international fleets while the grey zone (“gråsonen”) has been partly divided up between Russia and Norway. There is an ongoing dispute between Russia and Norway concerning fishing rights in part of the grey zone.

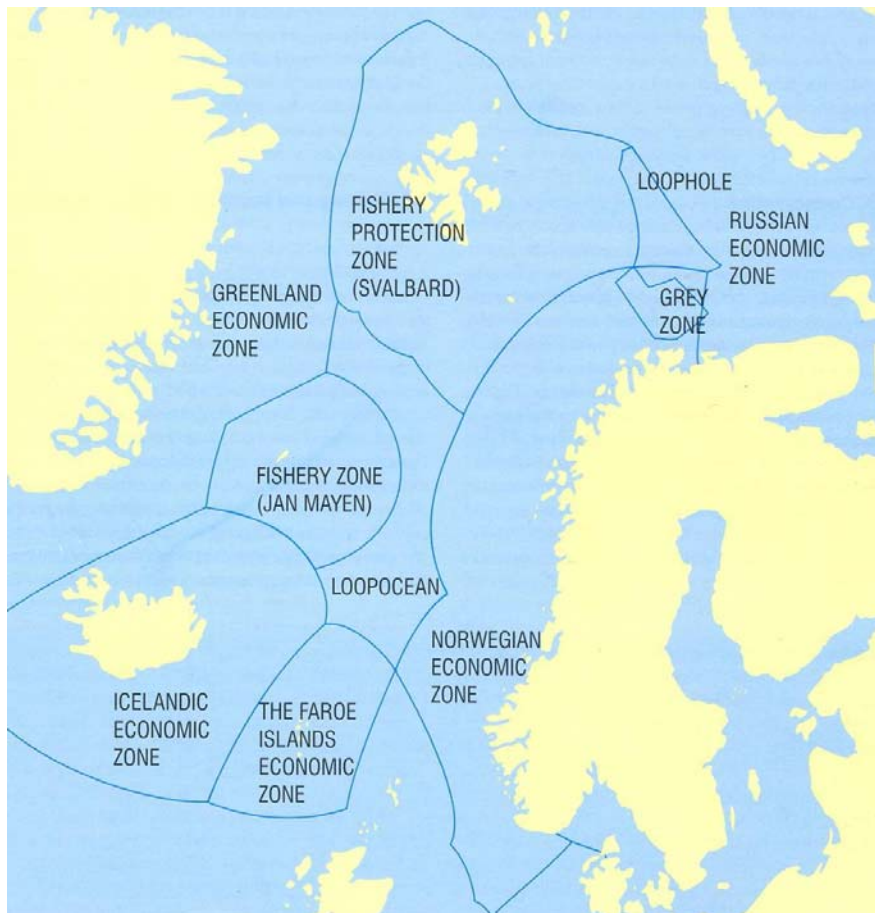


Figure 6.5 Fishery protected areas in the North Atlantic and the Barents Sea (OSPAR 2000)

The main purposes of closures in Norwegian waters are first to protect nursery and spawning grounds, and second to minimize conflict between vessels with different gear types. Closures are implemented by the Norwegian Directorate of Fisheries. The coast guard is responsible for ensuring that these closures are respected by monitoring the distribution of the fleet and the size and composition of the catch. The coast guard also inspects foreign vessels that are fishing in Norwegian waters.

The real-time closure system is implemented when the proportion of undersized fish in the catch exceeds some pre-defined reference levels (Figure 6.6). Real-time closures are for example frequently implemented in the shrimp and the cod fishery north of 62°N and around Svalbard. These areas are regularly monitored by the coast guard, which reports if the incidence of juvenile fish in the catch is too high. Temporarily closed

areas are monitored as well, and if the proportion of undersized fish in the catch is no longer above set limits the area is reopened for fishing.

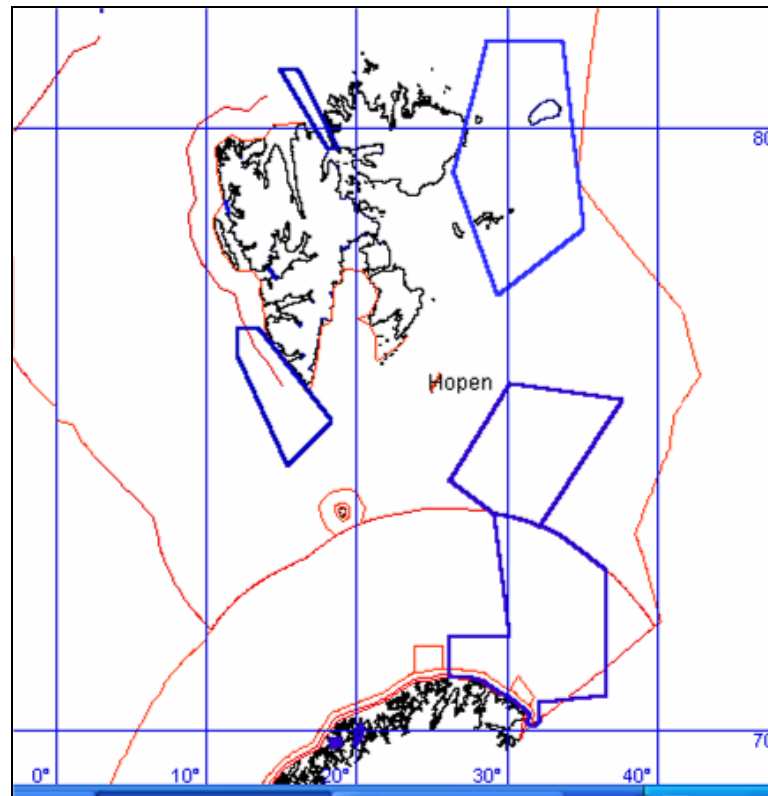


Figure 6.6 Example of the application of real-times closures. Location of real-time closures within the Svalbard Fishery Protection Zone on the 31st of January 2005 (Jens-Petter Hansen, Directorate of Fisheries)

Permanent closures have been implemented in some areas. This includes areas around Bjørnøya and NW of Svalbard that are closed to all fisheries except for shrimp and shellfish. Along the coast of North Norway there are two areas (Röst and Senja) permanently closed to trawling (Figure 6.7). In addition, there are several areas closed for part of the year to protect spawning fish (Figures 6.7 and 6.8). Multi-gear closures (“flexibelt område”) consist of areas that are closed for certain gears at certain times of the year. To fish within these areas, the skipper is obliged to report to the coast guard on the type of gear they are using. The reason for the establishment of multi-gear closures is to minimize conflicts between vessels using different gear. Some closures are applicable to vessels above certain size.

Norwegian trawlers are not allowed to fish within six nautical miles from the baseline. In some areas (Sørøya in Finnmark and Fugløybanken in Trøms), all trawling is banned between eight to 12 nautical miles from the baseline. Foreign vessels are not allowed to fish within the 12 nautical mile territorial limits (This text was mainly based on Anonymous 2002

and on personal communication with personnel at the Directorate of Fisheries, Bergen).

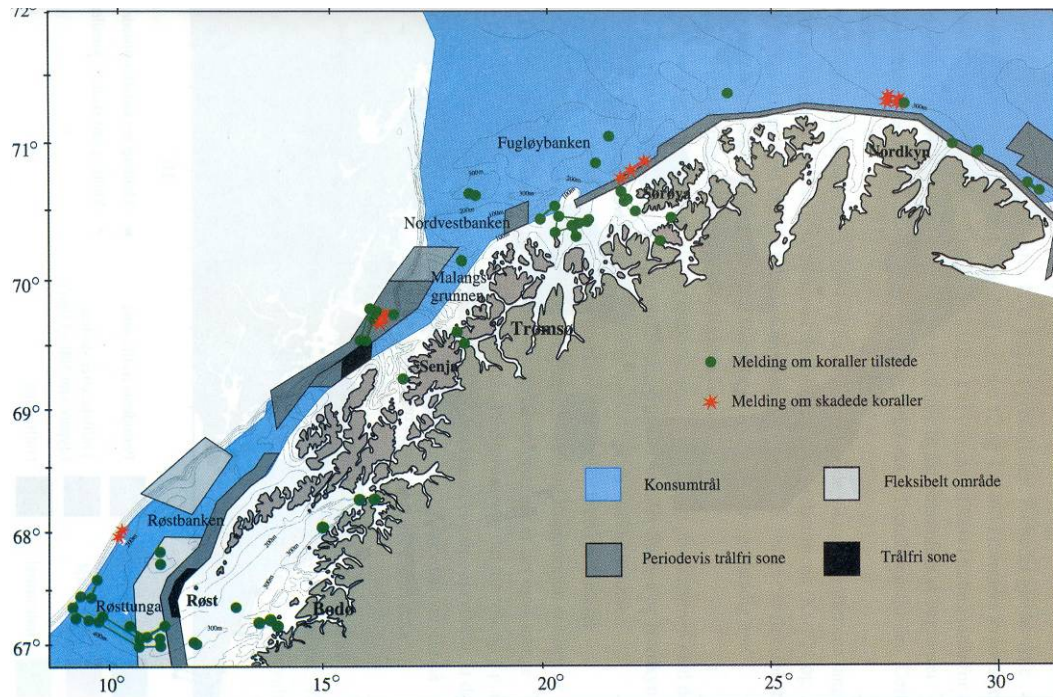


Figure 6.7 Closed areas and fishing grounds off North Norway. Distribution of areas closed permanently (black) or part of the year (dark grey) to trawling, multi-gear closures (light grey) and open to demersal trawl fishery targeting whitefish (blue) (Fosså et al. 2000). The points denote distribution of corals.

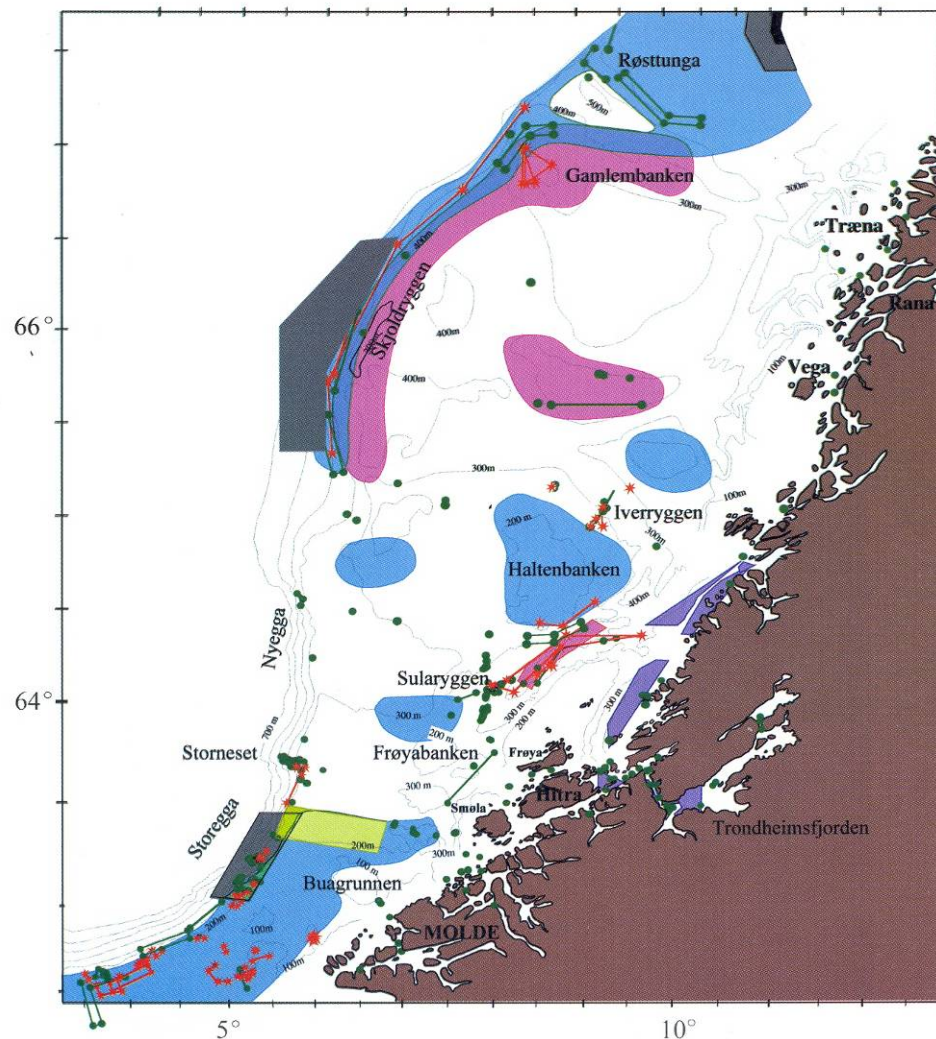


Figure 6.8 Closed areas and fishing grounds off mid-Norway. Distribution of areas closed permanently (black) or part of the year (dark grey) to trawling and open to demersal trawling targeting whitefish (blue), Greater Silver Smelt, *Argentinus silus* (pink), *Macrouriid* species in waters between 300–350m (purple) and industry trawling (light green). The points denote distribution of corals (Modified from Fosså et al. 2000).

6.6.3 Greenland

Fishery regulated areas in Greenland

The main fisheries law in Greenland is the "Landstingslov nr.18 af 31 oktober 1996 om fiskeri". The Greenland Home Rule has legislative power and is responsible for laws and regulations concerning the fishery. The aim of these laws (described in §2 of the law) is to protect the sustainable use of fish stocks. The coast guard and the police are responsible for surveillance and control (§27). The main regulations issued by the Home Rule of Greenland were fishery closures imposed from 2001 to 2002. Regulation number 39 from 6 December 2001 deals with technical protection measures. In §9, it is stated that fishery using trawls and Da-

nish seine is prohibited within the three nautical mile fishing limits for cod, redfish, halibut, Greenland halibut and catfish while harvesting of shellfish is allowed within the three nautical mile fishing limits. Some area closures are limited to fisheries targeting only certain fish species. According to §11, the use of explosives, poison and guns for fishing practices is prohibited. Electric fishing is not allowed without a special licence. In addition, fishing for Greenland halibut is not permitted between 64°30'N and 68°N° (Landstingslov nr.18 af 31 oktober 1996 om fiskeri).

Regulation number 23 from 29 August 2002 deals specifically with the shrimp fishery. In §5, the geographical positions of five closed areas on the West coast of Greenland are given. These areas are the “Hareo-kassen”, the “Disko-kassen”, the “Sisumit-kassen”, the “Qaqortoq-kassen” and the “Banan-kassen” (Figure 6.9). In the coastal shrimp fishery, management of fishing inside these closed areas is managed with area-based licensing (§6). Vessels are coded with a radio call signal specific to each vessel. Vessels with a certain type of signal have license to fish only within certain areas. In the offshore shrimp fishery (§8), vessels with licence to fish in offshore waters and process the catch onboard are not allowed to fish within the three nautical mile limits or within the five abovementioned areas. Exceptions to this regulation are several. For example, between 1 November and 31 March, fishing is allowed within the three nautical mile limit between the 61°N to 65°N. Foreign vessels targeting shrimp are never allowed to fish within the 12 nautical mile fishing limits and failure to follow this rule can mean imposition of penalties (§10).

In 1981, the ICES Demersal Fish Committee (Anonymous 1981) recommended closure of a large area along the East coast of Greenland and the geographical boundaries of this area (later known as the “redfish box”) were defined (Figure 6.10). The reason for closure was the high prevalence of juvenile redfish in the catch in the area. In Greenland Home Rule departmental order Nr. 20 from 20 August 2000, the geographical boundaries of the redfish box were redefined again.

In October 2000, the Greenland Home Rule introduced the mandatory use of 22mm sorting grids within the full geographical range of the shrimp fishery to minimize by-catch of fish. In May 2001, the North-western working group concluded that there was no justification to maintain the redfish box, on the basis of new information that showed that the distribution of juvenile redfish had changed and that the sorting grids were highly efficient to reduce fish by-catch. They suggested instead a combination of flexible and temporary closures (Anonymous 2001).

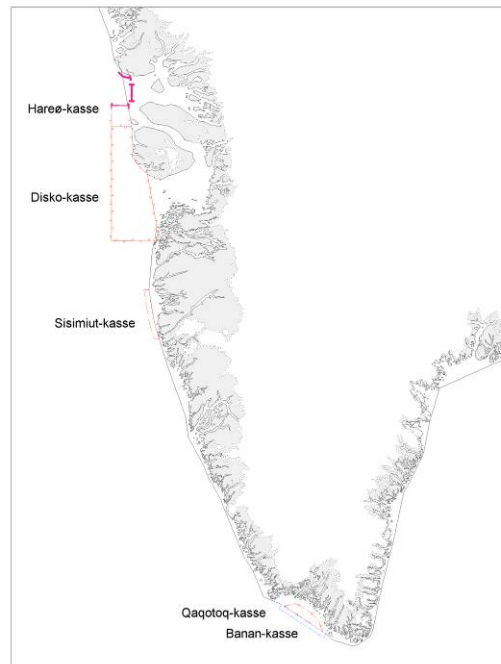


Figure 6.9 Management of the shrimp fishery in Greenlandic waters. The figure shows the location of the three nautical mile fishing limit and the location of the protected areas designated to manage the West Greenland shrimp fishery.

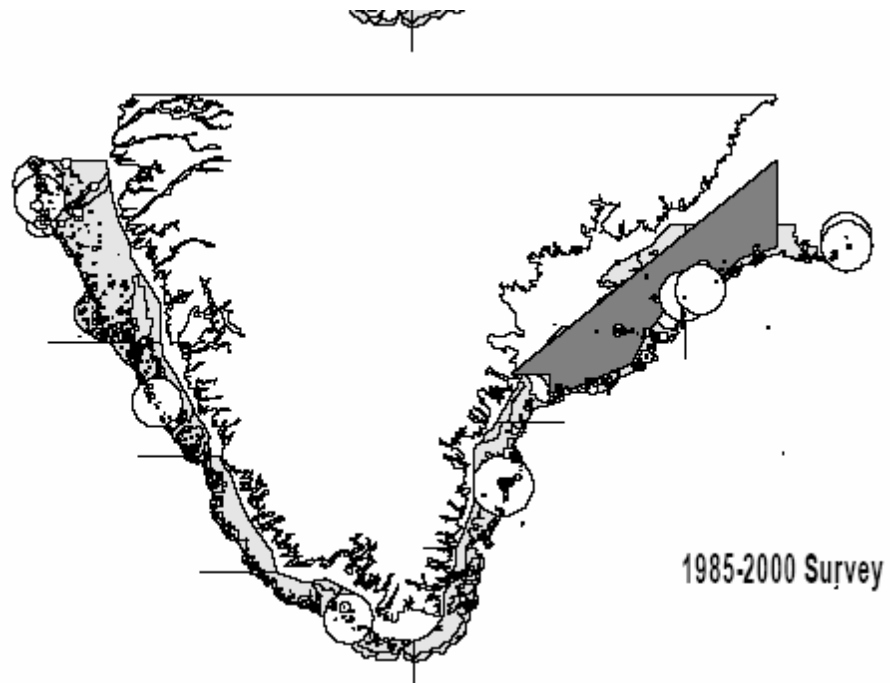


Figure 6.10 Location of the redfish box on the East coast of Greenland and the catch of redfish smaller than 17cm over the period 1985–2000 (Anonymous 2001)

6.7 Review of marine protected areas in Arctic waters

H. Haraldsson

A number of marine and coastal areas have been protected in the study area on the basis of environmental legislation (Table 6.4). The table shows for each IUCN category, the total size of protected areas and the proportion of protected areas relative to the total size of terrestrial and territorial waters.

Table 6.4 Overview of protected areas in Iceland, Greenland, Svalbard and Jan Mayen based on the IUCN categories at the end of 2004.

IUCN Categories	Number of Protected Areas	Area Protected (Ha)	Protected area on land as a proportion of total terrestrial and territorial waters	Protected area on land and in sea as a proportion of total terrestrial and territorial waters
Greenland. Terrestrial area 341,700km². Territorial sea area (12nm limit)				
Ia				
Ib	5	1,064,038	Nd	Nd
II	1	97,200,000	Nd	Nd
III				
IV				
V	1	207	Nd	Nd
VI				
Total	7	98,264,245	Nd	Nd
Iceland. Terrestrial area 103,000km². Territorial sea area (12nm limit) 73,037km². Total area 176,037km²				
Ia	2	272	0%	0%
Ib				
II	3	177,000	1.72%	1.01%
III	32	29,100	0.28%	0.17%
IV	21	78,050	0.76%	0.44%
V	21	696,228	6.76%	3.96%
VI				
Total	79	980,650	9.52%	5.57%
Svalbard and Jan Mayen Islands. Terrestrial area 62,010km². Territorial sea area not available				
Ia	14	4,914,298	79.25%	79.25%
Ib				
II	3	1,735,711	27.99%	27.99%
III				
IV	1	1,140	0.02%	0.02%
V				
VI				
Total	24	6,651,149	107.26%	107.26%

Information obtained from the world database of protected areas (CAFF 2004) and <http://sea.unep-wcmc.org/wdbpa/>.
ND=No data

6.7.1 Greenland

The Greenland National Park

The Greenland National Park in the northeast of the country belongs to IUCN category II. It is the world's largest nature protection area (alpine tundra). The National Park was established in 1974. It forms a wildlife sanctuary and a gene bank. The Park now has an area of 972,000km² together with the Greenlandic territorial waters off to the three nautical mile border (Figure 6.11).

Remoteness and the relative absence of human activity are the prime characteristics of the region. The park is characterized by inland ice, islands, peninsulas and deep fjords blocked by the sea ice eight months a year, which characterizes the coasts. The coast provides important sites for a range of Arctic mammals, such as bearded and ringed seal, polar bear, narwhal and walrus. The park is open to the public, but access is only allowed with the permission of Greenland Home Rule authorities (CAFF 2002).

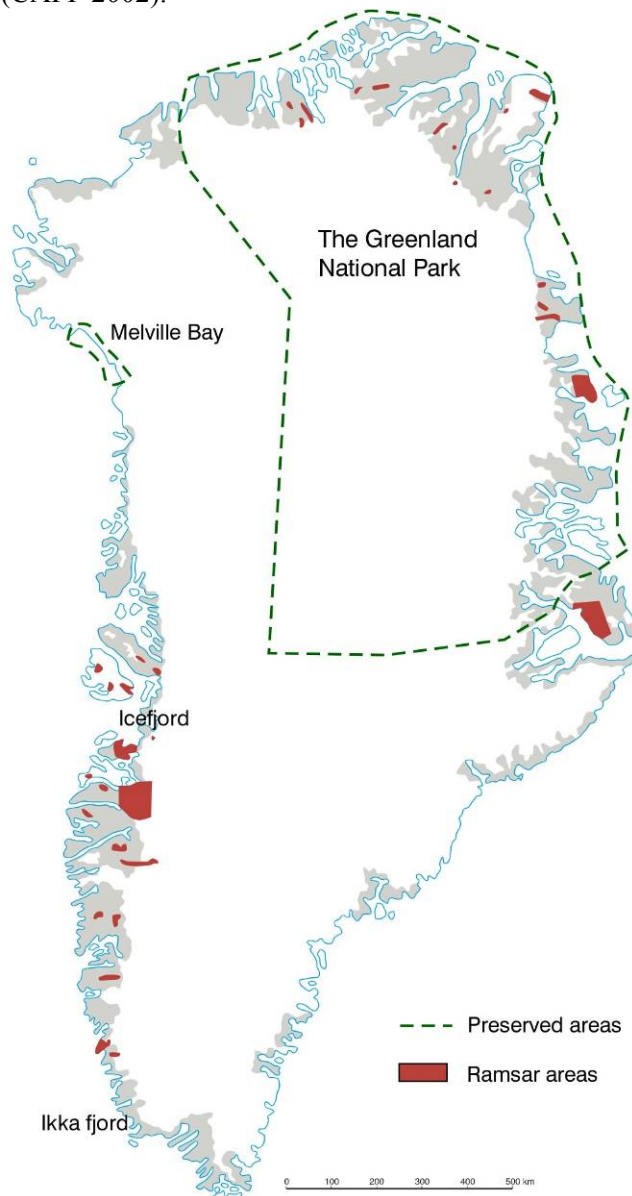


Figure 6.11 Distribution of marine and coastal protected areas in Greenland

Melville Bay (Qimusseriarsuaq)

Melville Bay belongs to IUCN category I. The protection was established in 1977 but already in 1946, regulations were stipulated for the protection of the exceptional wildlife in Melville Bay. The nature reserve is situated on the east shore of the bay Qimusseriarsuaq, also known as Melville Bay. It stretches along the ice-bound coast in the northernmost part of West Greenland. Most of the coastline consists of extensive glaciers separated by promontories of land with occasional islands.

The purpose of this nature reserve is to protect a breeding population of polar bears, a summer population of belugas and a breeding population of narwhal. Furthermore, the region is an important breeding area for ringed seal and Sabines gull (*Larus sabini*), which is a rare breeding bird in Greenland. Traditional hunting may to a certain degree still be carried out in the outer area (Nord 1999).

Icefjord

Icefjord, Ilulissat (40,240 hectares) is located on the West coast of Greenland. Icefjord is where Sermeq Kujalleq reaches the sea. Sermeq Kujalleq is one of the fastest and most active glaciers in the world. It has been estimated that this glacier calves over 35 cubic kilometres of ice annually. It was added to the UNESCO World Heritage List in 2004 (Nord 1999).

The Ikka Fjord

The Ikka Fjord was protected by law in 2000 and belongs to IUCN category I (see also section 4.3.2). The Ikka Fjord contains submarine rock formations, which rise up to 20m above the seabed and can be seen from the surface. They can grow with a speed of 50cm per year. They are formed by the mineral ikaite ($\text{CaCo}_3 \cdot 6\text{H}_2\text{O}$), which precipitates when the seep water mixes with sea water, which is high in calcium content. It is considered most likely that the formation of the columns has taken place since the end of the Ice Age, 10,000 years ago. Ikaite pillars are unique even though similar formations have been found in California and minerals with the same chemical composition exist.

The hollow columns are habitat for a rich and flora and fauna, some new to science. Most significant is the large number of sea urchins (*Strongylocentrotus* spp). Locals use the fjord for recreational purposes and tourists visit the fjord, but only in small numbers. Only small non-motorized boats are allowed and any activity that could damage the columns is forbidden (Nord 1999).

6.7.2 Iceland

6.7.2.1 Islands and coastal areas

Protection for several islands includes the marine area around them. Examples are Eldey and Surtsey, both with 2km of surrounding waters (Figure 6.12). These are protected under the IUCN category IA. Skróður, off the East coast of Iceland is also protected with 500m of surrounding waters. Other islands protected by the Nature Conservation Act together with surrounding waters are a part of Flatey and Hrisey in Breiðafjörður, Melrakkay and Skróður. Several protected areas also include the tidal zone, such as Grunnaþfjörður, Blautós og Innstavogsnes, the coast at Arnarstapi and Hellnar Spákonufellshöfði and Dyrhólaey (Náttúruverndarráð 1996).

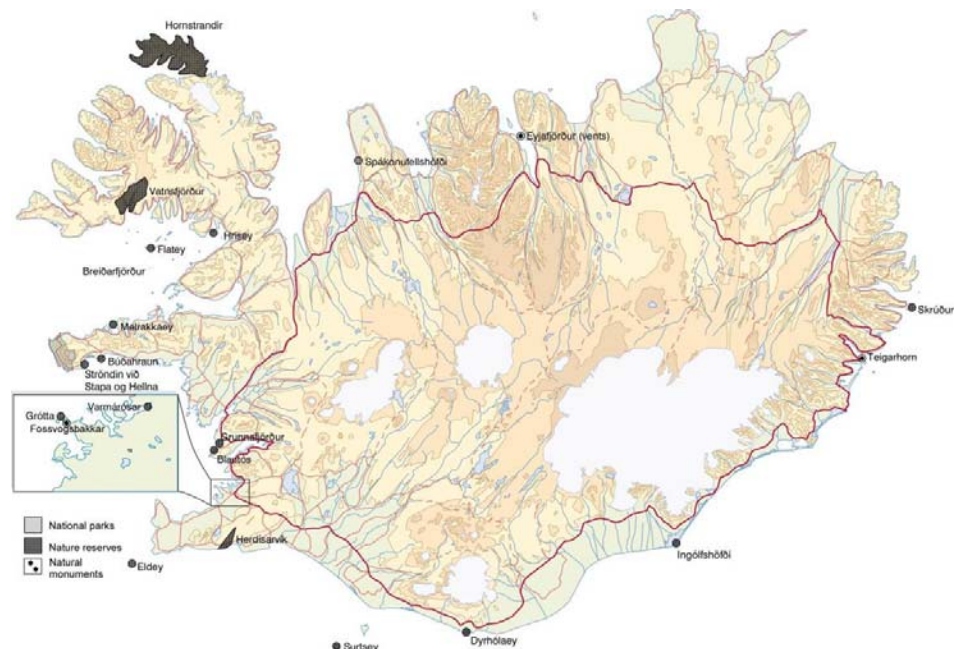


Figure 6.12 Distribution of marine and coastal protected areas in Iceland

Breiðafjörður

Breiðafjörður is the largest fjord in Iceland, situated in West Iceland. It was declared a conservation area in 1995 by special legislation. The management objectives are to conserve the many ecological and cultural features and to accommodate sustainable use, such as fisheries, tourism and algal extraction and maintain traditional uses of natural resources (Petersen et al. 1998).

The regulatory regime imposes some restrictions that affect also the fisheries in the area. Local communities have been directly involved since the outset and are represented in a steering committee for the project that assesses development proposals and makes recommendations to the Minister for the Environment. To date, impacts of designation seem posi-

tive. It has facilitated scientific research, raised awareness of the biological, geological and economic values of the area, increased the interest in the cultural heritage and is motivating development of tourism, including whale watching. One reason is that the local communities aim for a balance between the needs of the natural environment and the needs of Icelanders for sustainable use of natural resources (CAFF 2002).

Hydrothermal vents in Eyjafjörður

The hydrothermal vents in Eyjafjörður were protected in 2001 as a natural monument and fishing is not allowed within 200m radius (Bogason et al. 2004). Geothermal marine areas (or hydrothermal vents) were relatively recently discovered and have attracted great attention. Those that are known are already protected by law in Arctic waters. They were first discovered in Galapagos in 1977 but now there are more than 40 such areas known worldwide, eight of them in the Atlantic Ocean. They are probably quite abundant, but investigating them is difficult and expensive as they occur in deep waters (Corliss et al. 1979). It is possible to dive down to the hydrothermal vent in Eyjafjörður in regular sports-dive equipment, which makes it unique (Bogason et al. 2004).

6.7.3 Svalbard

Northwest Spitsbergen National Park

The Northwest Spitsbergen National Park covers the Northwestern corner of Spitsbergen and some smaller islands. There are numerous seabird colonies in this park. Sites for walrus are found within the park and it contains several historic sites of cultural value (Figure 6.13) (Nord 1999).

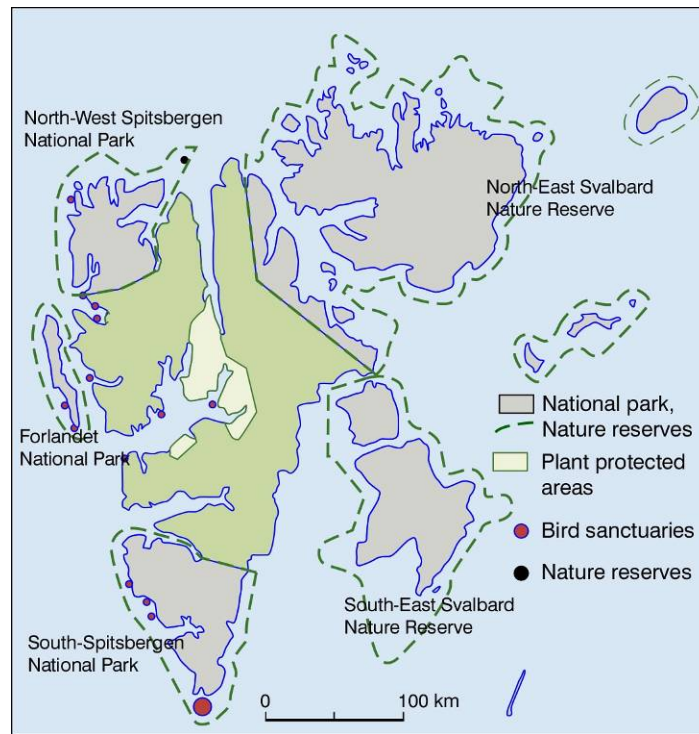


Figure 6.13 Distribution of marine and coastal protected areas in Svalbard

Forlandet National Park

Forlandet is a long and narrow island with long tidal flats, high mountain peaks and many smaller glaciers. It is an important nesting ground for eider duck (*Somateria mollissima*) and geese. The island meets the most northerly arm of the Gulf Stream, which creates a relatively mild oceanic climate. The world's northernmost population of harbour seal (*Phoca vitulina*) is found on Forlandet (CAFF 2002).

South Spitsbergen National Park

South Spitsbergen National Park is the southernmost part of Spitsbergen. Glaciers or permanent snow and ice cover about 65% of the area.

Moffen Nature Reserve

The Moffen Nature Reserve is a little gravel island within Northwest Spitsbergen National Park. Moffen is a resting area for walrus and an important nesting site for birds.

Northeast Svalbard Nature Reserve

The Northeast Svalbard Nature Reserve is the largest of Svalbard's protected areas. The reserve includes the islands Kvitøya, Kong Karls Land and Nordaustlandet. The small archipelago Kong Karls Land is the most important denning and cub-rearing area for polar bears in this part of the Arctic. For this reason a strict year-round ban on traffic is imposed.

Southeast Svalbard Nature Reserve

The nature reserve covers two large islands, Edgeøya and Barentsøya, and several smaller nearby islands and islets. A large population of Svalbard reindeer lives within this reserve. Polar bears are also common, especially during the winter. The walrus population is increasing in the surrounding waters. In addition important nesting grounds for several bird species are found within the reserve boundaries (Nord 1999).

Bird reserves and plant protection areas

There are 15 special bird reserves in Svalbard, all of which are found along the West coast of Spitsbergen. Almost all of these reserves are small islands or islets. Such ice-free islands are rare in Svalbard. The concentration of nesting birds can therefore be quite high in the bird reserves. Two plant protection areas were established as early as 1932 in Svalbard (Governor of Svalbard 2002).

6.7.4 Ramsar sites

Below are listed the marine and coastal environments that have been designated as Ramsar sites within the study area. This information was extracted from www.wetlands.org.

*6.7.4.1 Greenland**Kitsissunnguit*

Coastal (mostly marine) islands in the southern part of Disko Bay are characterized by rocky shorelines and salt-water lagoons. The importance of the islands is due to their wetlands, the large number of staging shorebirds during migration, high diversity of birdlife and the large breeding populations of Arctic terns (*Sterna paradisaea*). It is a popular hunting and fishing ground reflecting its biological importance. It has a cultural value as it is located close to a major settlement and on a major sailing route.

Kitsissut Avalliit

This is mostly a marine area: a group of rocky islands and skerries off the Southwest coast of Greenland. This area is important for seabirds and is the largest breeding area for Brünnich Guillemot (*Uria lomvia*) in Greenland. There is no information provided on the human uses of this area.

*6.7.4.2 Iceland**Grunnafjörður*

Grunnafjörður is an intertidal and partly subtidal estuary located 10km north of the town Akranes with extensive mudflats rich in invertebrates.

This is an important staging area for wading birds, such as the barnacle goose (*Branta bernicla*). Grunnafjörður is a privately owned land. Current land use consists mostly of collection of eider down and mining on a small scale.

6.7.4.3 Svalbard

Kongsfjorden

Kongsfjorden is a bird sanctuary located in the Northwest of Spitsbergen. It hosts a large breeding population of barnacle goose and eider. No human activities threaten the sanctuary except growing tourism.

Gåseøjen

Gåseøjen is a bird sanctuary in Western Spitsbergen featuring mostly rocky coast and islands. It serves as a large breeding ground for barnacle goose, eider and Arctic tern. No disturbances or threats are recorded.

6.8 Conclusions

Iceland, Svalbard and Greenland are dependent on the ocean resources for income and welfare to a great extent. Growing exploitation has resulted in decline in fisheries, destruction of coral reefs and periodic decline in sea mammal and bird populations. Marine protected areas (MPAs) are a practical way to maintain ocean productivity and biodiversity. One of the ways forward should be to protect and manage in an ecologically sustainable way a system of representative examples of marine areas. Fragile benthic communities (like corals) should however be protected altogether and immediately.

In Arctic waters, several MPAs have been established in order to protect nursery and spawning grounds of commercial fish species and some of them have been permanently closed for several decades. For that reason, these closures may have benefited benthic communities and habitats. Some studies have shown that several species and habitats that are sensitive to trawling, such as sponges are more common in areas that are closed to trawling (Burridge et al. 2003). Protection of benthic habitats may not only be important for benthic organisms but also for fish that depend heavily on these for a number of reasons, such as by providing refuge from predation or as spawning ground.

For closures to benefit benthic organisms and their habitats, these need to be of reasonable duration and preferably involve permanent closures. In Icelandic waters, a considerably large proportion of the fishing ground is closed permanently to fishing gear, or around 16,000 km². In Greenlandic waters there are no permanently closed areas and in Norwegian waters, most of the very few permanently closed areas are of small size. Establishment of closures in areas where fishing effort is high would

clearly meet strong opposition by stakeholders within the fishing industry. For that reason, many of the closed areas are located on fishing grounds where fishing effort tends to be low. Information on the fishing effort on high spatial resolution is therefore a requisite in order to evaluate the importance of closures for benthic communities.

The conclusion on national legislation in the Nordic countries, inside each nation's territorial waters, is that in general the legislation offers adequate legal protection of cultural heritage on the seabed. The laws are, however, not always enforced. The practice of the legislation concerning the fisheries generally lacks enforcement of the obligation to report finds. Likewise, demands for preliminary investigations of the seabed prior to exploitation are not presented. Both these practices should be looked into with a view to change this situation. As for the protection of sites, only the Environment Act of Svalbard offers protection of sites from trawling and dredging within a 100m radius from the objects. However, as of today, this is not enforced.

The conclusion on the part of international waters is that the national legislation of the countries involved in trawling and bottom dredging in Arctic waters should be brought into compliance with the international conventions, as illustrated in the example of Denmark. The wording in the Danish text stating that "one may not inflict changes" should be noted, as it protects wrecks *in situ*, as well as objects being removed from them.

In general, to strengthen the protection of the cultural heritage and the natural environment on the seabed one should aim to improve the effectiveness of juridical measures at international, regional and national levels. Much of this could be achieved simply by enforcement of the national laws and international agreements already in effect, as shown by this study. The questions are rather how, and to what extent, should measures like area closure, mandatory survey of seabed prior to trawling in new areas, mandatory reporting, etc. be enforced. There are obvious consequences to be considered, also on the side of NOT enforcing regulations, endangering non-renewable resources.

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Illustrations 6.11, 6.12 and 6.13 by Sigurgeir Skúlason

Front cover

The Drivis wrecked on the drift ice (Ottesen, 1999)
Healthy coral community (Sigmar A. Steingrímsson)
Bycatch from a shrimp trawl (Elena Guijarro Garcia)
Gorgoniacean on a destroyed coral reef (Sigmar A. Steingrímsson)

Back cover

Detail of a scallop roller dredge (Elena Guijarro Garcia)
Sailor buried in Spitsbergen in the 17th or 18th century (Dag Nævestad)
Iceland scallops (Elena Guijarro Garcia)
Northern shrimp (Elena Guijarro Garcia)