SOUTH GREENLAND

A Strategic Environmental Impact Assessment of hydrocarbon activities in the Greenland sector of the Labrador Sea and the southeast Davis Strait

Scientific Report from DCE – Danish Centre for Environment and Energy No. 23 2012

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Abstract: This report is a strategic environmental impact assessment of activities related to exploration, development and exploitation of oil in the Greenland sector of the Labrador Sea and the southeast Davis Strait.

Keywords: Strategic environmental impact assessment, SEIA, oil exploration, oil exploitation, oil spill, Labrador Sea, Davis Strait, South Greenland

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Preface

The Bureau of Minerals and Petroleum (BMP) is planning for further exclusive licenses for exploration and exploitation of hydrocarbons in the Greenland offshore areas of the Labrador Sea and Davis Strait. To support the decision process, the BMP has asked the Danish Centre for Environment and Energy (DCE) at Aarhus University and the Greenland Institute of Natural Resources (GINR) to prepare this Strategic Environmental Impact Assessment (SEIA) for the Greenland sectors of the Labrador Sea and the southeastern Davis Strait, south of 62° and west of 42° 30′ W.

If more licences are granted, it is planned that an environmental background study program will be initiated to fill in identified data gaps and information needs to support environmental planning and regulation of the oil activities. The new information will be included in an updated SEIA, which will be a reference document for future management decisions and replace this version.

Acknowledgments

Jørgen Bojesen-Koefoed from GEUS provided useful information on the likely characteristics of oil in the assessment area.

Summary and conclusions

This document is a Strategic Environmental Impact Assessment (SEIA) of activities related to exploration, development and exploitation of hydrocarbons in the Greenland sector of the Labrador Sea and the south-eastern Davis Strait, south of 62° and west of 42° 30′ W.

The SEIA was prepared by the Danish Centre for Environment and Energy (DCE) at Aarhus University and the Greenland Institute of Natural Resources (GINR) for the Bureau of Minerals and Petroleum (BMP) to support the decision process for further exclusive licenses for exploration of hydrocarbons in the Greenland offshore areas of the Labrador Sea and Davis Strait. The SEIA uses existing published and unpublished sources, supplemented with dedicated field studies of seals and seabirds, to describe the physical and biological environment, including protected areas and threatened species, background contaminant levels as well as natural resource use. Based on this description of the existing situation, the potential impacts of oil activities are assessed.

If more licences are granted, it is planned that an environmental background study program will be initiated to fill in identified data gaps and information needs to support environmental planning and regulation of the oil activities. The new information will be included in an updated SEIA, which will be a reference document for future management decisions and replace this version.

The assessment area is shown in Fig. 1.1. This is the region that potentially could be impacted by a large oil spill deriving from activities within the expected licence areas, although spilled oil may drift beyond the borders of this area, most lkely northwestwards along the Greenland coast.

The environment

Physical environment

The assessment area is situated in the sub-Arctic sector of the Northwest Atlantic and constitutes the north-eastern part of the Labrador Sea and the south-eastern part of the Davis Strait, and includes the South Greenland coastline from just east of Cape Farewell to Paamiut. The continental shelf (depth < 200 m) is relatively narrow (60-80 km), with a well-defined shelf break. The major part of the assessment area consists of deep water (> 2,000 m), with a maximum depth of ~3,700 m. The coastal topography is complex, with many archipelagos and fjords, and most shorelines are rocky with a relatively large tidal range.

The major current systems in the area are the cold East Greenland Current and the warm Irminger Current, which meet around Cape Farewell and flow north-westwards along the coast of Greenland. The relative strength of these two currents determines annual fluctuations in particularly the nearshore part of the assessment area. Compared to the rest of Greenland, sea ice is relatively sparse in the assessment area. However, the East Greenland Current carries large (but variable) amounts of drift ice and icebergs around Cape Farewell, and this ice often restricts ship access to the coast in late winter, spring and early summer.

The pelagic ecosystem

Very few oceanographic studies have been carried out in the assessment area, and as a consequence little is known about the location of particularly important areas with high productivity. As in other northern seas without ice cover, productivity peaks in spring when the water column stabilises, and declines during summer due to lack of nutrients. The highest productivity is likely to occur where upwelling or hydrographic fronts bring nutrient-rich water to the surface, e.g. along the shelf break and where currents meet. The spring phytoplankton bloom is dominated by diatoms, which to a large extent are grazed by zooplankton, mainly copepods. The most abundant copepod species is *Calanus finmarchicus*, which is a very important food source for small pelagic fish and juvenile stages of larger demersal fish. The deep part of the Labrador Sea is one of the most important overwintering areas for *C. finmarchicus*, and copepods originating from this area are likely to support commercial fisheries in Greenland and Canada.

Benthic flora and fauna

Benthic macrofauna (molluscs, crustaceans, echinoderms and polychaetes) consume a large part of the primary production that is left ungrazed by zooplankton. These animals also provide an important food source for demersal fish, marine mammals and sea ducks. Few studies of benthic fauna exist from the assessment area, and the geographical variation in community composition is largely unknown.

The tidal and subtidal zones often possess dense macroalgal vegetation, which provides food, substrate and shelter for many invertebrates and fish. The tidal vegetation is dominated by fucoid species. At shorelines highly exposed to waves and ice scouring, the characteristic macroalgal vegetation may not be able to establish due to the mechanical stress. Recent studies indicate that subtidal kelp forests may extend down to a depth of 50 m in the assessment area.

Columns of ikaite (a rare form of calcium carbonate) are found in Ikka Fjord. Besides being unique geological structures on a world scale, these columns house a highly diverse flora and fauna, including several species of microorganisms known only from this site. The conservation value of Ikka Fjord is extremely high.

Fish and shellfish

Most of the commercially important species in the assessment area are demersal, i.e. they occur near the sea floor. Northern shrimp and snow crab are widely distributed and common. Greenland halibut are less numerous than further north in Greenland, while the largest populations of Atlantic cod in West Greenland occur in the assessment area. Redfish occur in the deep offshore areas. The coastal zone is particularly important for spawning capelin and lumpsucker. The ecologically most important species are bentho-pelagic schooling fish (e.g. capelin and sandeel), which are key prey for many larger predators, including large fish, marine mammals and seabirds.

Seabirds

Populations of breeding seabirds in the assessment area are relatively small, but highly diverse. The most important colony is Ydre Kitsissut, which has the largest population in Greenland of the common murre (red-listed as Endangered in Greenland) and the largest population in the assessment area of thick-billed murre and razorbill. A detailed study of the foraging ecology and migration of these species has been carried out there (see Box 1).

Large populations of non-breeding seabirds occur in the assessment area. The area is particularly important for moulting harlequin ducks and wintering common eiders (both occurring near the coast), and for migrating and wintering thick-billed murres, black-legged kittiwakes, Atlantic puffins and ivory gulls (occurring further offshore). Non-breeding great shearwaters from colonies in the South Atlantic also occur offshore in large numbers during the northern summer. Very few data exist on seabird distribution and abundance in the deep parts of the assessment area.

Marine mammals

Among the seals, the assessment area is particularly important for the harbour seal (red-listed as Critically endangered in Greenland). An important haul-out site was discovered near Cape Farewell during fieldwork related to this SEIA, and the space use and behaviour of this and other seal species was studied in detail (see Box 2). In addition, a recently discovered whelping area of harp seal is located in the drift ice off the South Greenland coast, and very large numbers of hooded seals migrate through the area between their breeding and moulting sites.

The continental shelf and shelf break is a very important summer foraging area for baleen whales, particularly humpback, minke and fin whales. Sperm whales and other toothed whales also occur commonly, although few data exist. In addition, it is possible that individuals of the tiny remnant population of the northern right whale (red-listed as Critically endangered worldwide) pass through the area.

Human use

Commercial fisheries in the assessment area are relatively small, particularly in recent years. The most important species are northern shrimp, snow crab, lumpsucker and Atlantic cod. The most important areas for the fishery are Julianehåb Bugt and the continental shelf break. It is expected that the cod fishery will increase in the near future, if a local spawning stock is re-established.

Subsistence and recreational fisheries and hunting take place around all settlements, but particularly the number of birds taken has decreased since 2000. The most commonly taken birds are thick-billed murre and common eider, while harp seal and ringed seal are most important for seal hunters. Around a quarter of the Greenland catch of minke whales is taken in the assessment area (48 whales in 2010), and harbour porpoises are also important for local hunters.

Contaminants

Contaminant levels are reasonably well studied due to the AMAP programme. Results show that levels of organochlorines (particularly PCBs and DDT) are highest in the marine organisms belonging to the top trophic level (e.g. whales). AMAP activities have also shown a decrease in the levels of some ‘legacy’ POPs (e.g. PCBs and DDT), as a result of the introduction of bans and restrictions relating to their use in other parts of the world. At the same time, however, new persistent pollutants, such as brominated flame retardants are increasing, also in animals from Greenland. Levels of petroleum compounds, including PAHs, are relatively low in the Greenland environment and are regarded as background concentrations. Past mining activities have resulted in local contamination; most importantly, lead concentrations in mussels around the former cryolite mine at Ivittuut are still too high for human consumption, although they have decreased considerably since the mine closed.

Climate change

Climate change has a large potential to modify marine ecosystems, particular in high latitude regions. Alterations in the distribution and abundance of keystone species at various trophic levels could have significant and rapid consequences for the structure of the ecosystems in which they currently occur. Implications for fisheries and hunting are likely. For some populations, climate change may act as an additional stressor in line with e.g. hunting, leading to higher sensitivity towards oil spill accidents. Other populations may become more abundant and robust as a consequence of climate change. Finally, the species composition may change, with some disappearing or moving north and other species moving in from the south.

Assessment of impacts

The assessments presented here are based on our present knowledge concerning the distribution of species and their tolerance and threshold levels toward human activities in relation to oil exploration. However, the Arctic is changing due to climate change, and this process seems to accelerate, so conclusions and assessments may not apply under future conditions. Furthermore, a large part of assessment area is poorly studied, and improved knowledge may also lead to adjusted assessments and conclusions.

Normal operations – exploration

The main environmental impacts of exploration activities derive from noise generated either by seismic surveys or by the drilling platforms, and from the drilling process if cuttings and drilling mud are released to the sea.

The species most sensitive to noise from seismic surveys in the assessment area are the baleen whales (minke, fin, sei and humpback) and toothed whales such as sperm and bottlenose whales. These may be in risk of being displaced from parts of their critical summer habitats. A displacement will also impact the availability (for hunters) of whales if the areas affected include traditionally hunting grounds.

As seismic surveys are temporary, the risk for long-term population impacts of single surveys is low. However, long-term impacts have to be assessed if several surveys are carried out simultaneously or in the same potentially critical habitats during consecutive years (cumulative effect). 3D seismic surveys, which are typically conducted in small areas, may cause more severe temporary impacts.

Commercial fisheries in the assessment area (mainly for northern shrimp and snow crab) will probably not be affected.

Noise from drilling rigs will also be temporary, but locally more long-lasting than seismic surveys. The most vulnerable species in the assessment area are cetaceans (whales and harbour porpoise). If alternative habitats are available to the whales no effects are expected, but if several rigs operate in the same region there is a risk for cumulative effects and displacement even from alternative habitats.

Drilling mud and cuttings that are released on the seabed will cause local impacts on the benthic fauna. Within the assessment area only very local effects on the benthos are expected from discharging water-based muds with non-toxic additives from the drilling of an exploration well. Any drillings should be avoided in the most vulnerable areas. Baseline studies at drill sites must be conducted prior to drillings to document if unique communities or species such as cold-water corals and sponge gardens are at risk of being harmed by increased sedimentation. Post-drilling studies should document that activities did not cause any specific effects.

Exploration drilling is an energy-demanding process emitting large amounts of greenhouse gasses, so even a single drilling will increase the Greenland CO_2 emissions significantly.

Finally, there will be a risk for oil spills during exploration drilling (see below).

Unacceptable environmental impacts from exploration activities are best mitigated by careful planning based on thorough environmental background studies, BEP, BAT and application of the Precautionary Principle and international standards (OSPAR); for example, by avoiding activities in the most sensitive areas and periods.

Normal operations – development and production

Development and production activities are difficult to evaluate when their location and the level of activity are unknown. Overall, impacts will depend on the number of activities, how widely they are scattered in the areas in question, and also on their duration. In this context cumulative impacts will be important to consider. Drilling activities in the assessment area may take place at great depth, and this raises specific issues (see below).

The activities during development, production and transport are long-lasting, and there are several activities which have the potential to cause severe environmental impacts.

Emissions and discharges

Drilling will continue during the development and production phases, and drilling mud and cuttings will be produced in much larger quantities than during exploration. Discharges should be limited as much as possible by recycling and reinjection, and only environmentally safe substances (such as “green” and “yellow” chemicals), tested for toxicity and degradability under Arctic conditions, should be allowed discharged. In Greenland the use of “black” chemicals is not allowed, and the use of “red” chemicals requires specific permission. Even non-toxic discharges will alter the sediment substrate, and if these substances are released to the seabed impacts must be expected on the benthic communities near the release sites.

However, the release giving most reason for environmental concern is residues of oil in produced water. Recent studies have indicated that the small amounts of oil can impact birds, fish and primary production, and there is also concern for the long-term effects if radionuclides and hormone-disruptive chemicals are discharged.

Discharge of ballast water is also of concern, as there is a risk of introducing non-native and invasive species. Ballast water should therefore be treated and discharged according to specific regulations. This is currently not a severe problem in the Arctic, but the risk will increase with climate change and the intensive tanker traffic associated with a producing oil field.

Development of an oil field and production of oil are energy-consuming activities, which will contribute significantly to the Greenland emission of greenhouse gases. A single large Norwegian production field emits more than twice the total current (2010) Greenland CO_2 emission.

Noise

Noise from drilling and the positioning of machinery, which will continue during the development and production phases, may potentially lead to permanent loss or displacement of important summer habitats for cetaceans, especially if several production fields are active at the same time. Noise from ships and helicopters, now more frequent than during the exploratory phase, can affect both marine mammals and seabirds. The most sensitive species within the assessment area are colonial seabirds, minke whales, fin whales and harbour porpoise – species that may associate noise with negative experiences (hunting). Traditional hunting grounds may also be affected. Introducing fixed flying lanes and altitudes will reduce impacts from helicopter noise.

Placement of structures

Placement of offshore structures and infrastructure may locally impact seabed communities and there is a risk of spoiling important feeding grounds. Inland structures may locally impact breeding birds, obstruct rivers with implications for anadromous Arctic char, damage coastal flora and fauna, as well as having an aesthetic impact on the pristine landscape, which again may impact the local tourism industry.

A specific impact on fisheries is the exclusion/safety zones (typically 500 m), which will be established around both temporary and permanent offshore installations. These may affect some of the important fishing areas for northern shrimp.

Illuminated structures and flares may attract seabirds at night, and there is a risk of mass mortality for especially eiders and perhaps little auks.

Cumulative impacts

Cumulative impacts of several oil fields (including other human impacts and climate change) are difficult to evaluate when the level of activity is unknown, and the impacts will depend on the scale of activities, the density of operation sites and the duration of the activities. A complete assessment must await such information.

The best way of mitigating impacts from development and production activities is to combine a detailed background study of the environment (in order to locate sensitive ecosystem components) with careful planning of structure placement and transport corridors. Then BEP, BAT and the application of international standards such as OSPAR and HOCNF can do much to reduce emissions to air and sea.

Oil spills

The environmentally most severe potential accident from hydrocarbon activities is a large oil spill. Accidental oil spills may occur either during drilling (blowouts), or from accidents when storing or transporting oil. Large oil spills are relatively rare events today due to ever-improving technical solutions and HSE policies. However, the risk of an accident cannot be eliminated. The potential consequences of oil spills at depth are described below.

Drift modelling shows that oil from a surface spill in the assessment area is most likely to spread north-westwards along the Greenland coast. Much of the oil is likely to end up on the shoreline, both in the assessment area and further north. Due to persistent ocean currents, areas east of Cape Farewell will not be affected.

Large oil spills have the potential to affect all levels in the marine ecosystem, from primary producers to top predators. A large oil spill represents a threat at population and maybe even species level, and the impacts may last for decades as documented after the *Exxon Valdez* spill in Prince William Sound in Alaska in 1989. For some populations, oil spill mortality can to some extent be compensatory (be partly compensated by reduced natural mortality due to less competition), while for others it will be largely additive to natural mortality. Some populations may recover quickly, while others will recover very slowly to pre-spill conditions, depending on their life history and population status. For species which are vulnerable to oil spills and are also harvested, oil spill impacts could be mitigated by managing the harvest wisely and sustainably. The lack of efficient response methods in partly ice-covered waters and the remoteness will add to the severity of an oil spill, and therefore exploration drilling is not allowed when ice is present.

For this impact assessment, the offshore part of the assessment area has been divided into six subareas, which have been classified according to their sensitivity to oil spills, taking into account the relative abundance of species/species groups, species- or population-specific oil sensitivity values, oil residency and human use. During all seasons, the subareas on the continental shelf are the most sensitive. These areas are especially important for migrating/wintering seabirds, human use of northern shrimp and snow crab and as foraging areas for baleen whales. Areas further from the shore are ranked as less sensitive, mainly because seabirds and marine mammals occur at lower densities.

A comparison of seasons, based on absolute sensitivity values and averaged across all offshore areas, shows that autumn and summer are most sensitive to oil spills, while winter and spring are least sensitive. The main reason for this difference is the large number of moulting and migrating seabirds during summer and autumn, which are very sensitive to oil.

The coastal zone of the assessment area is even more sensitive to oil spills, due to a higher biodiversity and related to the fact that oil may be trapped in bays and fjords where high and toxic concentrations can build up in the water. There will be a risk of negative impacts on spawning concentrations of fish such as capelin and lumpsucker in spring, Arctic char assembling outside their spawning rivers and on many seabird populations both in summer, during migration periods and in winter. Long-term impacts may occur in the coastal zone if oil is buried in sediments, among boulders, in mussel beds or is imbedded in crevices in rocks, where it may persist for decades. In Prince William Sound in Alaska, such preserved oil has caused negative long-term effects e.g. on birds utilising the polluted coasts, and some populations have still not recovered after more than 20 years. The coastal zone is also of crucial importance for local hunters and fishermen, and in case of an oil spill, these activities may be adversely affected by closure zones and/or by changed distribution patterns of targeted species. The tourist industry in the assessment area will probably also be impacted negatively by oil exposure in the coastal area.

In general, accidents are best mitigated by careful planning, strict Health, Safety and Environment (HSE) procedures and application of the Precautionary Principle in combination with BEP, BAT and international standards (OSPAR).

Primary production and zooplankton

The impact of a surface oil spill in the assessment area on primary producers and zooplankton in open waters is likely to be low, because these organisms occur over very large areas. There is, however, a risk of impacts (reduced production) on localised primary production areas, and the spring bloom will be the most sensitive period. Copepods overwintering at great depth may be exposed in the case of a subsea blowout, and their sensitivity to such exposure is essentially unknown.

Fish and crustacean larvae

In general, eggs and larvae of fish and crustaceans are more sensitive to oil than adults, and may theoretically be impacted by reduced annual recruitment strength with some effect on subsequent populations and fisheries for a number of years. Atlantic cod is especially sensitive because their eggs and larvae are concentrated in the upper 10 m of the water column, whereas larvae of shrimp and Greenland halibut, for instance, are found deeper and would therefore be less exposed to harmful oil concentrations from an oil spill at the surface. However, a large subsea blowout may expose eggs and larvae over much larger areas and depth ranges, and may potentially also impact the recruitment and stock size of other species, such as northern shrimp, snow crab and sandeel.

Benthos

Bottom-living organisms such as bivalves and crustaceans are vulnerable to oil spills; however, no effects are expected in the open water unless oil sinks to the seabed. In shallow waters (< 10-15 m), highly toxic concentrations of hydrocarbons can reach the seafloor with potentially severe consequences for local benthos and thus also for species utilising the benthos – especially common eider, harlequin duck, long-tailed duck and bearded seal. A large subsea spill may have the potential to impact seabed communities in deep waters too.

Tidal and subtidal macroalgae and the associated invertebrate fauna are sensitive to smothering and toxic effects of oil hitting the shore. The unique ikaite columns and their associated flora and fauna in Ikka Fjord are likely to be very sensitive to toxic effects of oil, but it is probably unlikely that they will be exposed even in the case of a major spill.

Adult fish

Impacts from a surface spill on adult fish stocks in the open sea are not expected. The situation is different in coastal areas, where high and toxic oil concentrations can build up in sheltered bays and fjords resulting in high fish mortality. Spawning capelin and lumpsucker are particularly vulnerable in the coastal zone.

Fisheries

An oil spill in the open sea will affect fisheries mainly by means of temporary closures in order to avoid tainting of catches. The duration of a closure will depend on the duration of the oil spill, weather, etc. The assessment area is an important fishing ground for northern shrimp and snow crab, and closure zones may have significant economic consequences for this section of the fishing industry.

Oiled coastal areas would also be closed for fisheries for a period – the duration of the closure would depend on the behaviour of the oil. There are examples of closures lasting many months due to oil spills, particularly if oil is caught in sediments or on beaches. The commercial inshore fishery targets primarily lumpsucker and local populations of Atlantic cod, while capelin are taken in the subsistence and recreational fishery.

Seabirds

Seabirds are extremely vulnerable to oil spills in the marine environment because they usually spend much time at the surface where most oil spills occur. Their plumage is highly sensitive to oil, as only small amounts will destroy its insulation and buoyancy properties. Exposed birds usually die from hypothermia, starvation, drowning or intoxication. In the assessment area, the coastal zone is particularly sensitive because high concentrations of seabirds are found year-round. A substantial part of these birds, including breeding birds, moulting birds and wintering birds, are associated with habitats along the highly exposed outer coastline. In such areas, oil spill response is hampered by remoteness, the complex coastal morphology and often harsh weather conditions. The seabird species most vulnerable to mortality from oil spills are those with low reproductive capacity (low population turnover), a trait especially found among auks, fulmars and many sea ducks.

During autumn and winter, a number of species are also at risk further offshore in the assessment area, including the shelf areas, although birds tend to be more dispersed in the open water compared to coastal habitats. Some of the important species include northern fulmar, black-legged kittiwake, Atlantic puffin, little auk and thick-billed murre.

Marine mammals

Whales and seals are vulnerable to surface oil spills. Baleen whales may get their baleens smothered with oil and ingest oil. This may affect filtration capability, or lead to toxic effects and injuries in the gastrointestinal tract if oil is ingested. There is also a risk of inhalation of oil vapours and direct contact with eye tissues. The extent to which marine mammals actively will avoid an oil slick and also how harmful the oil will be to fouled individuals is uncertain. However, observations indicate that at least some species do not perceive oil as a danger and have repeatedly been reported to swim directly into oil slicks.

Seal pups are highly vulnerable to direct oiling, and even short exposures can be lethal, as the oil will affect the isolation properties of the fur. Whelping of harp seal occurs in the assessment area.

Marine mammals species affected by an oil spill during winter in the assessment area could include bearded seal, hooded seal, ringed seal, harbour seal, harbour porpoise, bottlenose whale and sperm whale. Harbour seals are especially vulnerable because they are rare and endangered in Greenland, and the most important concentration occurs in the assessment area. Marine mammals that use the area as feeding grounds during summer include harp seal, hooded seal, ringed seal, harbour seal, fin whale, humpback whale, minke whale, sei whale, harbour porpoise, white-beaked dolphin, bottlenose whale, sperm whale, and pilot whale. Blue whales occur only rarely in the assessment area, but are vulnerable due to a very small population. The globally highly endangered northern right whale may also occur in the area.

Mitigation

The risk of accidents and their environmental impacts can be minimized with extremely high safety levels, planning to avoid the most sensitive areas and periods and efficient contingency plans with access to adequate equipment. Oil spill sensitivity maps, where the most sensitive areas have been identified, can assist in the planning phase.

Risk, fate and consequences of a large deep-water oil spill

Because much of the assessment consists of very deep water, where the experience of drilling (and response to spills) is very limited, it is important to consider carefully the attendant risks. The risk of blowouts is in general very low (estimated as 1 in 13,000 wells), but is likely to be somewhat elevated when drilling takes place in deep water, as may be the case in the assessment area. Drilling in oil reservoirs at high temperature and pressure is considered more risky, and such conditions are more likely to be encountered at great depth. The best way of reducing the risk is to apply high safety standards and careful planning.

Should a subsea blowout occur in the deep part of the assessment area, the general pattern of horizontal dispersal will be similar to a surface spill, implying that oil is expected to drift northwestwards and a large fraction will reach the coast. However, expected drift rates are lower due to lower current speeds at depth. At present, it is very difficult to predict whether a fraction of the oil is likely to remain dispersed at depth following such a spill, instead of rising to the surface. This is because the oil type in the assessment area is unknown, and the processes determining the behaviour of spilled oil under high pressure and low temperature are poorly understood.

The experience from the *Deepwater Horizon* blowout in the Gulf of Mexico in 2010 – the largest peacetime oil spill in history – shows that under some conditions large amounts of oil may remain dispersed at depth and form extensive subsea plumes. It is unclear to what extent this was due to the unprecedented large-scale application of dispersants directly at the wellhead, and what the role of gas hydrate formation and dissolution was.

At the time of writing, the picture of the ecological consequences of the *Deepwater Horizon* spill is still incomplete. However, it appears that much of the oil dispersed at depth was metabolized by microorganisms within a few weeks of the spill. While this is likely to have limited the toxic effects on other biota, oxygen depletion may have occurred as a consequence. As far as is known, impacts on fish and other vertebrates have also been limited, although some mortality of seabirds, marine mammals and sea turtles was observed following the spill. Potential long-term effects have still to be assessed.

Knowledge gaps and new studies

There is a general lack of knowledge on many of the ecological components and processes in the South Greenland area, as well as on the likely fate of spilled oil. A preliminary identification of information needs and knowledge gaps for environmental management and regulation of future oil activities in South Greenland can be found in chapter 11. To manage future oil activities, more information is needed to a) assess, plan and regulate activities so the risk of impacts are minimized; b) identify the most sensitive areas and update the oil spill sensitivity mapping of coastline and offshore areas, and c) establish a baseline to use in 'before and after' studies in case of impacts from large oil spills.

1 Introduction

This document comprises a preliminary strategic environmental impact assessment (SEIA) of expected hydrocarbon activities in the Greenland sector of the Labrador Sea and the south-eastern Davis Strait (south of 62° N and west of 42° 30′ W, Fig. 1.1). It has been developed by the Danish Centre for Environment and Energy at Aarhus University (AU), in cooperation with the Bureau of Minerals and Petroleum (BMP) and the Greenland Institute of Natural Resources (GINR).

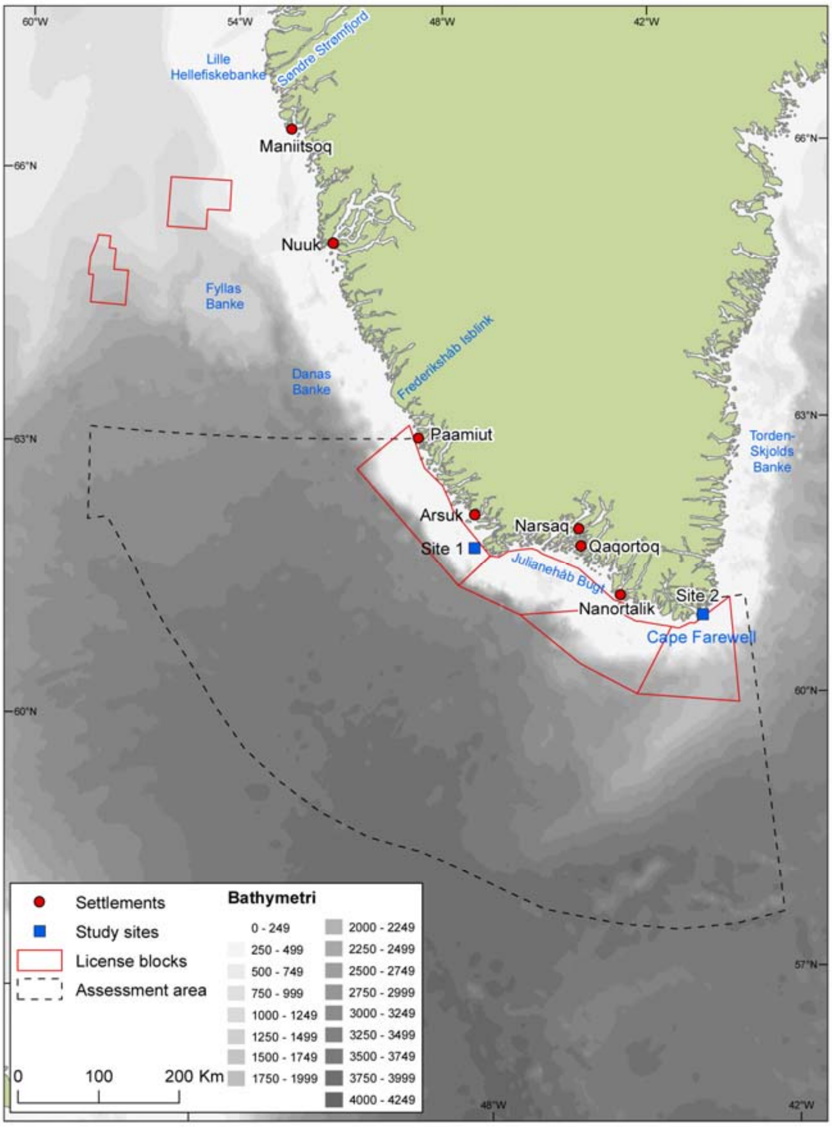

Figure 1.1. Map of the South Greenland assessment area, showing existing license areas, towns and other important features. Also shown are the study sites for the two dedicated field studies: Site 1 is Ydre Kitsissut, where a detailed study of the ecology of breeding seabirds was carried out (see Box 1). Site 2 is Qeqertat, where habitat use of several seal species was studied (see Box 2).

The present SEIA is based on existing published and unpublished sources. These include previous environmental impact notes for the waters off South Greenland (Boertmann 2007a, Boertmann & Mosbech 2010), existing environmental oil spill sensitivity mapping (Mosbech et al. 2004a), and similar impact assessments of oil activities in the Disko West area and Baffin Bay region (Mosbech et al. 2007, Boertmann et al. 2009). The recent assessment from the Lofoten-Barents Sea area in Norway (Anon 2003) has also been consulted for comparison of potential impacts, because the environment in a number of respects is comparable to West Greenland waters. Another important source of information is the Arctic Council working group's AMAP Oil and Gas Assessment from 2007/8 (Skjoldal et al. 2007). In addition, the extensive literature from the *Exxon Valdez* oil spill in 1989 has been a valuable source of information. Information from the large subsea *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010 has also been drawn upon, although the scientific information available on effects is still limited at this point.

In addition, several dedicated studies have been carried out as part of the SEIA process for the South Greenland area, and the most important results of these studies are summarised in this report and included in the assessment. These studies are:

A field study by AU of the year-round habitat use and foraging behaviour of breeding seabirds in the archipelago Ydre Kitsissut, the most important seabird colony in the assessment area. Results are summarised in Box 1.

A field study by GINR and AU of important habitats for seals in the Cape Farewell area, with special focus on the harbour seal (red-listed as Critically endangered in Greenland). Results are summarised in Box 2 and Appendix 1.

An evaluation of the risk and potential size of a blowout in connection with hydrocarbon exploration and production in the Greenland part of the Labrador. This evaluation was carried out by Acona for the BMP, and results are presented in Appendix 2 and summarised in section 10.1.1.

Two modelling studies of the likely distribution and fate of oil from potential spills in the assessment area, including surface spills as well as a subsea blowout. These studies were carried out by the Danish Meteorological Institute (DMI). Results are presented in Appendices 3 and 4 and summarised in section 10.2.

It is important to stress that an SEIA does not replace the need for site-specific Environmental Impact Assessments (EIAs). The SEIA provides an overview of the environment in the licence area and adjacent areas, which may potentially be impacted by the activities. It identifies major potential environmental impacts associated with expected offshore oil and gas activities. The SEIA also identifies knowledge and data gaps, highlight issues of concern, and make recommendations for mitigation and planning. An SEIA forms part of the basis for relevant authorities' decisions and may identify general restrictive or mitigative measures and monitoring requirements that must be dealt with by the companies applying for hydrocarbon licences.

Finally, an important issue in this context is climate change. This affects both the physical and the biological environment; for example, sea ice cover is expected to be reduced, which will impact the ecology and particularly wildlife dependent on ice, such as polar bears. Most of the data used for this SEIA have been collected over a number of decades, and as oil activities, particularly development and exploitation, may be initiated more than 10 years from now, environmental and ecological conditions may be very different from at present.

1.1 Coverage of the SEIA

This SEIA covers the Greenland EEZ south of 62° N and west of 42° 30′ W in the Labrador Sea and south-eastern Davis Strait (approximately from Paamiut to Cape Farewell, Fig. 1.1), referred to in this report as 'the assessment area'. A preliminary SEIA is concurrently in production for the area north of 62° N.

The present assessment area extends over waters of two municipalities: Sermersooq and Kujalleq. Four towns are located within the area: Nanortalik, Qaqortoq, Narsaq and Paamiut, with roughly 1,500, 3,200, 1,600 and 1,600 inhabitants, respectively. In addition, 12 settlements are found in the area (Aappilattoq, Narsaq Kujalleq, Tasiusaq, Ammasivik, Alluitsup Paa, Saarloq, Eqalugaarsuit, Qassimiut, Igaliku, Narsarsuaq, Ivittuut, Arsuk), with altogether ca. 1,200 inhabitants (Greenland Statistics 2011, www.stat.gl).

1.2 Abbreviations and acronyms

AMAP: Arctic Monitoring and Assessment Programme
AMSR: Advanced Microwave Scanning Radiometer
AU: Aarhus University
BAT: Best Available Technology
BEP: Best Environmental Practice
BIOS: Baffin Island Oil Spill
BMP: Bureau of Minerals and Petroleum
CI: Confidence interval
DCE: Danish Centre for Environment and Energy
DDT: Dichlorodiphenyltrichloroethane
DKK: Danish kroner
DMI: Danish Meteorological Institute
DTU: Technical University of Denmark
EEZ: Exclusive Economic Zone
EIA: Environmental Impact Assessment
GEUS: Geological Survey of Denmark and Greenland
GINR: Greenland Institute of Natural Resources
HBCD: Hexabromocyclododecane
HOCNF: Harmonized Offshore Chemical Notification Format
HSE: Health, Safety and Environment
IBA: Important Bird Area
ICES: International Council for the Exploration of the Seas
IMO: International Maritime Organization
IUCN: International Union for Conservation of Nature
IWC: International Whaling Commission
MARPOL: International Convention for the Prevention of Pollution from Ships
MODIS: Moderate Resolution Imaging Spectroradiometer
NAFO: Northwest Atlantic Fisheries Organization
NAO: North Atlantic Oscillation
NASA: National Aeronautics & Space Administration
NERI: National Environmental Research Institute
NGO: Non-governmental organization
NMFS: National Marine Fisheries Service
OBM: Oil-based drilling mud
OSPAR: Oslo-Paris Convention for the Protection of the Marine Environment of the Northeast Atlantic

PAH: Polycyclic aromatic hydrocarbon
PBDE: Polybrominated diphenyl ether
PCB: Polychlorinated biphenyl
PFC: Perfluorocarbon
PLONOR: Pose Little Or No Risk to the Environment
PNEC: Predicted No Effect Concentration
POP: Persistent organic pollutant
SBM: Synthetic-based drilling mud
SEIA: Strategic Environmental Impact Assessment
SMMR: Scanning Multichannel Microwave Radiometer
TBBPA: Tetrabromobisphenol A
TBT: Tributyltin
UV: Ultraviolet
VEC: Valued Ecosystem Component
VOC: Volatile Organic Compound
WBM: Water-based drilling mud
WSF: Water-soluble fraction
ww: Wet weight

2 Methods

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The following assessment is based on available information compiled from studies published in scientific journals and reports, from previous NERI technical reports (e.g. Mosbech et al. 1996, Boertmann et al. 1998, Mosbech et al. 1998, Mosbech 2002, Mosbech et al. 2007) and information from the oil spill sensitivity atlas prepared for most of West Greenland, including the assessment area (Mosbech et al. 2000, Mosbech et al. 2004b, a). Based on the information needs and knowledge gaps identified in chapter 11, supplementary studies may be carried out subsequent to this SEIA. Results from such studies will contribute to the impact assessment in an updated version of this SEIA.

2.1 Boundaries and scope

The assessment area covers the area described in the introduction (Fig. 1.1). This section of the Greenland EEZ can potentially be impacted by oil-related activities and particularly by a large and long-lasting oil spill deriving from activities in the expected license areas off South Greenland. However, it cannot be excluded that the area affected might be even larger, particularly including coastlines and fishing banks north of the assessment area, and also areas on the Canadian side of the Davis Strait and Labrador Sea.

The assessment covers, as far as possible, all activities associated with an oil field, from exploration to decommissioning. Exploration activities are expected to take place throughout the year.

If decided upon and initiated, production activities will take place throughout the year. How potential production facilities will be constructed is presently not known, but setup is likely to be similar to that described for the Disko West area by the APA (2003) study.

2.2 Impact assessment procedures

The first step of an assessment is to identify potential interactions (overlap/contact) between potential petroleum activities and important ecological components in the assessment area in both time and space. Interactions are then evaluated for their potential to cause impacts.

The assessment of potential environmental impacts is based on the concept of Valuable Ecosystem Components (VECs), as defined by Hansson et al. (1990): 'A VEC is defined as a resource or environmental feature that:

a) is important (not only economically) to a local human population, or
b) has a national or international profile, or
c) if altered from its existing status, will be important for the evaluation of environmental impacts of industrial developments, and the focussing of administrative efforts.'

VECs can be species, populations, biological events or other environmental features that fulfil one or more of these criteria. They can include important flora and fauna, habitats or specific sites, and processes such as the phytoplankton spring bloom. The VECs selected here are species, habitats and events which potentially can be impacted by oil activities in the assessment area, and where changes can be monitored and detected. They are listed in section 4.8.

The potential impact on VECs of activities during the various phases of the life cycle of a hydrocarbon license area are summarised in a series of tables in chapters 9 and 10. The tables are based on a worst-case scenario for impacts, under the assumption that current (2011) guidelines for the various activities as described in the text are applied. For each VEC, examples are given of typical vulnerable organisms (species or larger groups) in relation to specific activities. These examples are non-exhaustive.

Potential impacts are assessed under three headings: displacement, sublethal effects, and direct mortality. Displacement indicates spatial movement of animals away from an impact, and is classified as none, short term, long term or permanent. For sessile or planktonic organisms, displacement is not relevant, and this is indicated with a dash (-). Sublethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. This category thus includes impacts which decrease fertility or cause mortality of juvenile life stages. Sublethal effects and direct mortality are classified as none, insignificant, minor, moderate or major. If no members of a VEC are vulnerable to a given activity, this is indicated by a dash (-) for each impact type.

The scale of potential impact is assessed as local, regional or global. Impacts may be on a higher scale than local either if the activity is widespread, if it impacts populations originating from a larger area (e.g. migratory birds), or if it impacts a large part of a regional population (e.g. a large seabird colony). Global impacts are those which potentially affect a large part of (or the entire) world population of one or more species.

However, quantification of potential impacts on ecosystem components is very difficult and in most cases impossible. The spatial overlap between the expected activities and the presence of one or more VECs can only be assessed to limited degree, as only the location of initial license areas are known at this point. Furthermore, the physical properties of potentially spilled oil are not known at present. In addition, there is still a lack of knowledge concerning important ecosystem components and how they interact. Finally, ecosystem functioning may be altered in the near future due to climate change.

Relevant research on toxicology, ecotoxicology and sensitivity to disturbance has been used, and conclusions from various relevant sources have been drawn upon. Among the most important sources are: the Arctic Council Oil and Gas Assessment (Skjoldal et al. 2007), the extensive literature concerning the *Exxon Valdez* oil spill in Alaska in 1989, the so far limited literature concerning the *Deepwater Horizon* spill in the Gulf of Mexico in 2010, and the Norwegian EIA of hydrocarbon activities in the Lofoten-Barents Sea (Anon 2003)

Many uncertainties still remain, and expert judgement or general conclusions from research and EIAs carried out in other sub-Arctic or Arctic areas have been applied in order to evaluate risks and to assess the impacts. Much uncertainty in the assessment is inevitable and is conveyed with phrases such as ‘most likely’ or ‘most probably’.

3 Physical environment

Michael Dünweber & Morten Frederiksen (AU)

The assessment area is part of the northern Atlantic Ocean located within the sub-Arctic climate zone, which means the air temperature in July averages more than 10° C. The northern parts of the Atlantic consist of the Labrador Basin, the Irminger Basin and the Iceland Basin, which are all semi-enclosed. The offshore part of the study region (56º 30′ - 62º N and west of 42º 30′ W) includes the south-eastern Davis Strait and north-eastern Labrador Sea. The continental shelf with waters less than 200 m deep is rather narrow (< 80 km) compared to further north in West Greenland. On the shelf there are several fishing banks with water depths less than 100 m. Beyond the continental slope south and west of Greenland, the assessment area includes large deep-water areas, up to 3700 m (Fig. 1.1) (Mosbech et al. 2004a).

In terms of hydrography, the area is characterised by sub-Arctic waters from the North Atlantic with average July temperature above 5° C. On a large scale, the meteorological and oceanographic conditions of the northern Atlantic (i. e. the Cape Farewell area) are quite well known. Recent descriptions involving South Greenland are found in Buch et al. (2004) and Myers et al. (2009). More detailed descriptions of the hydrography of offshore areas can be found in publications by the Danish Meteorological Institute and the Bureau of Mineral and Petroleum (Nazareth & Steensboe 1998, Buch 2000a, 2002, Hansen et al. 2004, Ribergaard 2010). Furthermore, an oil sensitivity atlas for the coastal zones of South Greenland was collated by Mosbech et al. (2004a).

3.1 Weather and climate

The weather in this region is to a large extent determined by the dominant atmospheric circulation pattern over the North Atlantic Ocean, namely the North Atlantic Oscillation (NAO) (Hurrell et al. 2001). The NAO exerts a dominant influence on the wintertime surface air and sea temperatures in the Arctic. When the NAO is positive, enhanced westerlies flow across the Atlantic and intensify the North Atlantic Current, which is deflected to the east of Greenland, resulting in low intensities of the cold south-flowing East Greenland Current and the warm, north-flowing Irminger Current (derived from the North Atlantic Current). This results in cold conditions in Greenland. During a negative NAO phase, the conditions are almost opposite, with low inflow of North Atlantic Waters and intensified East Greenland and Irminger Currents, giving high temperatures in Greenland (Buch 2002, Ribergaard 2010). However, the Greenland Ice Sheet and the steep coasts of Greenland also have a fundamental impact on the local weather. Many Atlantic depressions develop and pass near the southern tip of Greenland and frequently cause very strong winds off West Greenland. More local phenomena such as fog or polar lows are also common features near the West Greenland shores. The probability of strong winds increases close to the Greenland coast and towards the Atlantic Ocean. Detailed descriptions on local wind patterns can be found in the sensitivity atlas of the South Greenland region (Mosbech et al. 2004a).

3.2 Oceanography

3.2.1 Currents

The surface waters off South Greenland are primarily composed of two major currents. Closest to the shore, the surface layer (0-150 m) is the East Greenland Current (cold low-saline Polar Sea water), which flows from the East Coast of Greenland, rounding Cape Farewell to reach the West Coast. The Irminger Current flows below and west of the Polar Water and originates from the North Atlantic Current. The Irminger Current is relatively warm and salty and flows on the offshore edge of and parallel to the East Greenland Current and rounds Cape Farewell (Buch 2000a) (Fig. 3.1). It is the strength of these two currents that determines the hydrographical conditions around Southeast and West Greenland. As they round Cape Farewell, the Irminger Current subducts under the Polar Water forming the West Greenland Current. The Irminger Current can be traced up to the northern parts of the Baffin Bay (Buch 2000a). However, a third water mass proposed by Buch (1998) as originating from the North Atlantic Current, characterised by relatively warm and high saline properties and referred to as sub-Atlantic Water, enters southeast Greenland, rounding Cape Farewell and entering the Davis Strait. In the deeper layers, two other distinct water masses are found, namely the Western Boundary Undercurrent and the Northeast Atlantic Deep Water.

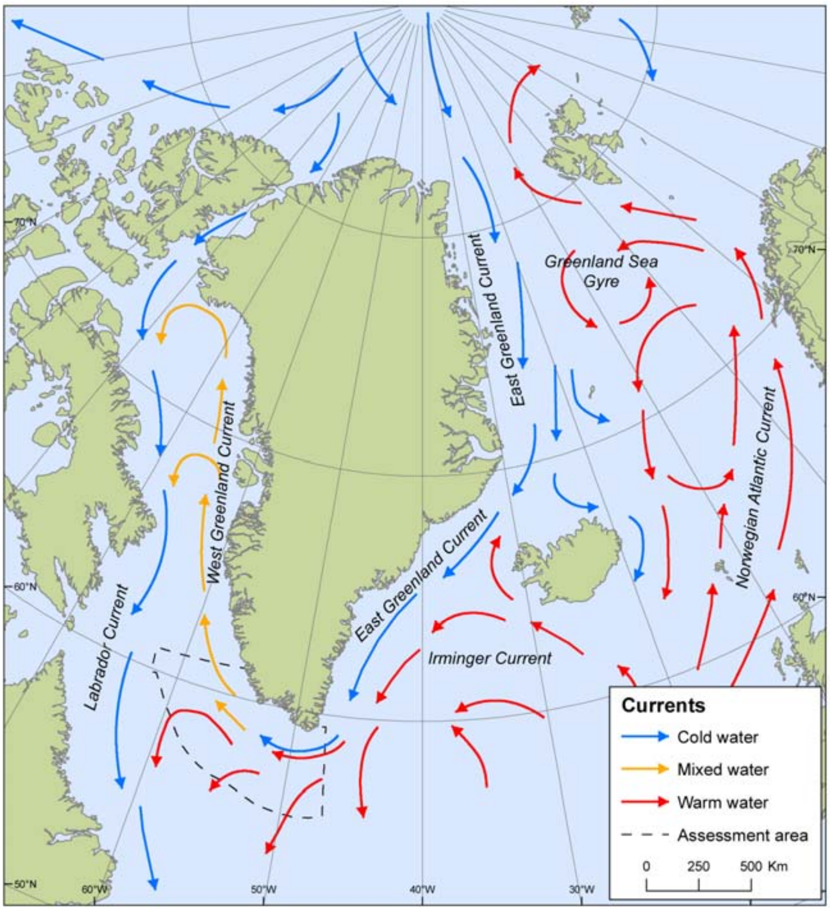

Figure 3.1. Major sea surface currents in the northern Atlantic. The red arrows indicate relatively warm water from the Atlantic, which mixes with relatively cold water (blue arrows) from the East Greenland Current. The cold water moving southwards in the Baffin Bay is the Baffin Current (or Baffin Island Current), which further south becomes the Labrador Current. Along the West Greenland coast, mixed water (orange arrows) forms the West Greenland Current.

Along the west Greenland coast, the current patterns tend to follow the bathymetry along the coast (Nazareth & Steensboe 1998). North of the assessment area (south of the Fyllas Banke area), the current patterns are influenced by the steep continental slope, and the complex topography of several shallow banks that deflect the coastal currents and generate instabilities in the current flow.

The West Greenland Current component loses its momentum on the way northward, and at the latitude of Fyllas Banke (64° N) there is no longer a strong and solid current. A large proportion of the mass branches westward towards Canada, where it joins the south-flowing Baffin Island Current. It follows the Canadian Coast, and continues into the Labrador Current. Further north along the west Greenland coast, the deflection towards west continues resulting in a further weakening of the current (Nazareth & Steensboe 1998). Further south, the Labrador Current mixes with the North Atlantic Current and later with the Irminger Current in the Irminger Sea and returns to the area of Cape Farewell. The current system in the southern area of the North Atlantic is regarded as a great cyclonic gyre with relatively low current velocities (Buch 2000a, 2002). Off Southwest Greenland (61.5° N), high current instabilities are found with high eddy motion causing the current flow of the Irminger and Polar water to extend much further offshore over deep waters off West Greenland (Ribergaard 2004, and references therein).

The Polar water inflow is strongest during spring and early summer (May-July). The inflow of relatively warm Atlantic water masses of the West Greenland Current is strongest during autumn and winter, explaining why the waters between 58° N and 67° N are usually ice free during the winter. Mixing and heat diffusion of the two layers (The Polar and Irminger Currents) are important factors determining temperature conditions in the assessment area. Years where the East Greenland and Irminger Current are strong will often be warm years (Nazareth & Steensboe 1998, Buch 2000a, 2002, Hansen et al. 2004).

A fifty-year long time-series (1950-2000) of temperature and salinity measurements from West Greenland oceanographic observation points at Fyllas Banke has revealed strong inter-annual variability in the oceanographic conditions off West Greenland. This climatic variability can be related to a shift in the NAO index from negative to positive values during the period 1970-2000, resulting in a colder climate (Buch et al. 2004). However, during the past two decades there has been a tendency towards increased water temperatures and reduced ice cover during the Arctic winters (Rothrock et al. 1999, Parkinson 2000, Hansen et al. 2006, Comiso et al. 2008). The warmer climate during the last decade in the Arctic may partly be a result of the change in the NAO index from positive to negative, but there is also clear evidence of an increase of 0.4° C per decade of Arctic surface air temperature during 1966-2003, which exceeds natural expected variation (McBean et al. 2005).

3.2.2 Fronts

Fronts are inclined boundaries between water masses with different characteristics. Thus, fronts separate water of different density along the inclined boundaries. Along the west coast of Greenland, a front is formed between the low saline Polar Water and the saline water of Atlantic origin. Temperature and salinity observations on the west coast of Greenland show that the front between the two water masses is weak in the winter and spring months from January to May. The weak stratification is a combined effect of the upper layer being homogenised by vertical overturning due to atmospheric cooling, and relatively low inflow of Polar Water at this time of the year. During the rest of the year, the front is relatively strong with maximum strength in the autumn months of September and October. At Cape Farewell, the front between the Polar Water and the Atlantic Water is clear and sharp, whereas it is much more diffuse further north (Buch 2002).

At the Canadian east coast, the Labrador Current is of very low salinity and separated from the warmer, saltier Labrador Sea by an intense shelf break front. East of this front there is a cyclonic circulation bordered by the North Atlantic Current in the south. The North Atlantic Current reaches the Labrador Sea as the relatively warm Irminger Current. Thus, a front separates the warm Irminger Current and the cold West Greenland Current approximately 100 km off West Greenland.

From the perspective of biological productivity, the vertical velocities across the front can transport nutrient-rich water from greater depth to the surface layer, enabling elevated plankton production (Frajka-Williams et al. 2009, Yebra et al. 2009).

3.2.3 The coasts

Mosbech et al. (2004a) provided an overview of the coastal topography of the assessment area. The coastal zone between 60 and 62° N is dominated by rocky coasts, archipelagos and occurrences of glacier coasts at the intertidal zone. In terms of shoreline length, rocky coast is the dominant shore type (64.8 %). 'Rock' is the dominant substrate (87.6 %). 'Inclined' is the dominant slope (50.5 %) and 'semi-protected' is the dominant exposure type (50.4 %). The majority of the coasts within the 'archipelago' shore type are rocky coasts. Together, the 'archipelago' and 'rocky coast' shore types by length constitute 88.9 % of the total investigated shoreline. Rocky coasts are found near Cape Farewell, on Nunarsuit and near Aappilattoq. Areas of archipelagos are found in Kobberminebugten, and glacier coast at the head of Bredefjord (Mosbech et al. 2004a).

3.3 Ice conditions

Sea ice primarily occurs in the Cape Farewell area as multi-year drift ice (locally known as 'Storis'), mainly of polar origin carried to southwest Greenland by the East Greenland Current. Another sea ice type which rarely occurs in the assessment area is the 'West ice', mainly first-year drift ice formed in the Baffin Bay and Davis Strait. However, the waters south of Nuuk are normally free of sea ice, occasionally covered for a short period of time in late winter. The annual variability in distribution of the first-year sea ice is primarily determined by the North Atlantic Oscillation (NAO), as explained above. The annual NAO variability determines the current pattern of the Davis Strait, which influences the north-south extent of sea ice and the position of the sea ice edge. Multi-year ice is normally present most of the year off the entire east coast of Greenland (Buch 2000a, 2002, Heide-Jørgensen et al. 2007) (Fig. 3.2).

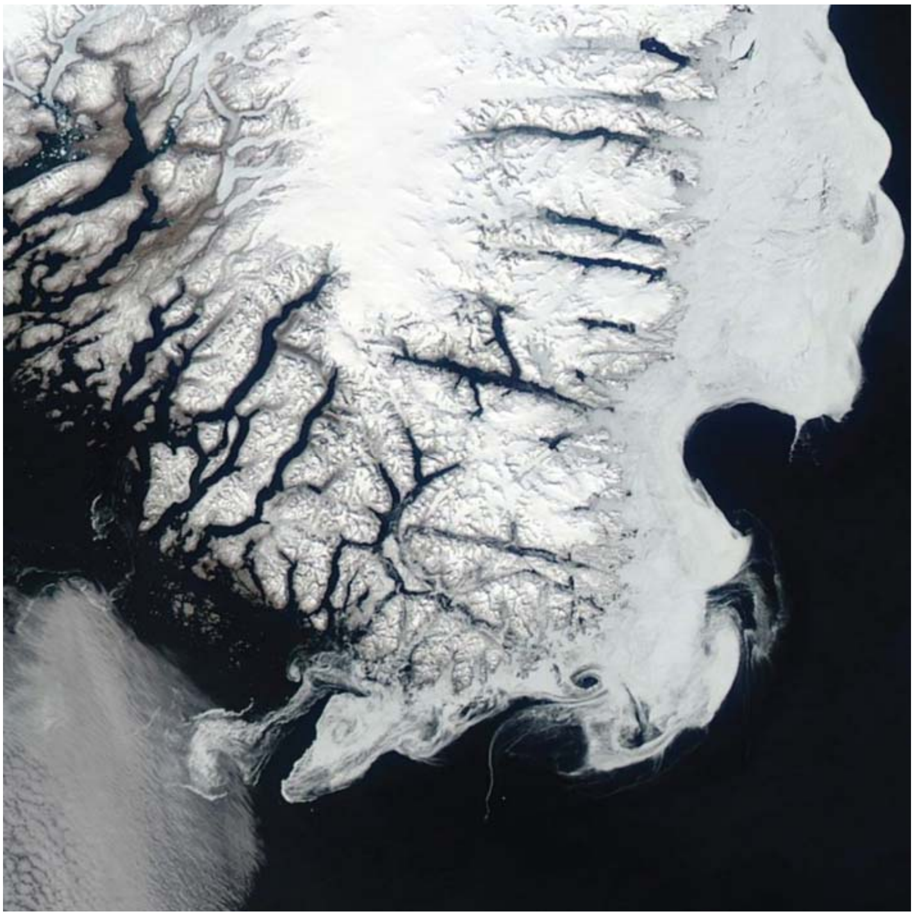

Figure 3.2. MODIS Aqua image from 9 May 2011, 20:00 UTC of the Nanortalik area, showing the distribution of sea ice cover at the East Greenland coast and off Cape Farewell. Data source: The satellite picture is processed by DMI with support from the Greenland Climate Research Center and the European Space Agency's PolarView project.

Sea ice cover has decreased in the Arctic during the past 20 years (Parkinson 2000), in both thickness and extent (Rothrock et al. 1999). This has occurred much faster than would be expected from natural climate variability (Vinnikov et al. 1999). Observations based on satellite data from 1979-2007 showed a reduction in sea ice cover of 11.4 % per decade. This rate is expected to increase due to a reduction in the albedo effect as multi-year ice disappears (Comiso et al. 2008 and references therein).

Recently, two East Greenland outlet glaciers (Kangerdlugssuaq and Helheim) have begun to thin, and the calving front has retreated (Luckman et al. 2006). A time series of 6 years (2000-2006) has been recorded for 32 glaciers in East Greenland, where nearly all the observed glaciers show simultaneously net retreat, thinning and acceleration. The retreat and thinning rates were explained by high coastal air and sea-surface temperatures, mainly in 2003 (Howat et al. 2008). Also, evidence exists of increased amounts of melt water in the fjord systems from the Greenland Ice Sheet as it loses mass (Velicogna & Wahr 2006, Velicogna 2009), including increased melt water from the inner parts of the Godthåbsfjord (Rignot & Kanagaratnam 2006). To what extent the increased fresh water input from the fjord systems affects the characteristics of the West Greenland Current is currently unknown.

3.3.1 The multi-year ice and drift patterns

The first year sea ice (West Ice) conditions between 60° and 71° N are primarily determined by the north- or northwest-flowing West Greenland Current bringing in relatively warm water and the cold south-flowing Baffin Island Current. South of 65° N, sea-ice free areas dominate, and the ice edge is normally located towards Hudson Strait or the Labrador Coast.

The multi-year ice reaches the Cape Farewell area in December-January, depending on the intensity of the East Greenland Current and the amount of ice in it. The track and intensity of low pressure systems in the North Atlantic Ocean also influence the distribution of sea ice near Cape Farewell. The amount of multi-year ice in South Greenland waters peaks in early summer. The intensity of the lows normally decreases in spring and summer and may cause the multi-year ice to drift north-westward along the Southwest Greenland coast in the West Greenland Current. The multi-year ice dominates in the southern part of West Greenland and is present 4-5 months per year in the Julianehåb Bugt from Cape Farewell to about 61-62° N (Fig. 3.3).

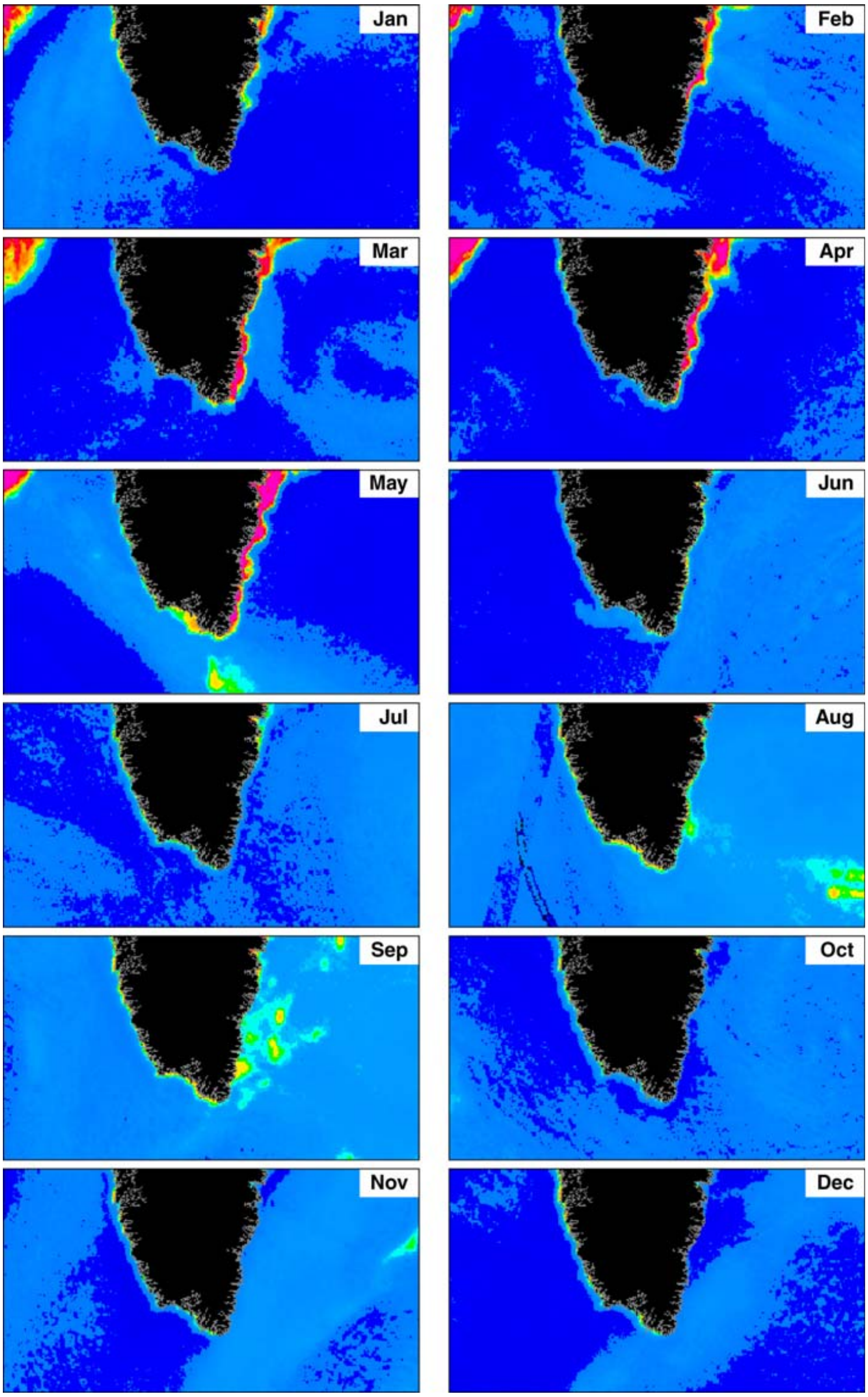

Figure 3.3. Monthly sea ice cover in 2010. Red and magenta in the maps indicate very dense ice (8-10/10), while yellow indicates less dense ice. The loosest ice (1-3/10) is not recorded. Some artefacts occur in offshore areas south and east of Cape Farewell in the summer months. Images based on Multichannel Microwave Radiometer (AMSR and SMMR). Based on data from DTU, DMI and the Canadian Ice Service – Environment Canada.

The width, concentration and position of this ice belt vary from year to year. Some years the ice never passes Nunarsuit, while in other years it reaches Nuuk and the Fyllas Banke area. On average, the northernmost position of the multi-year ice on the west coast is situated around Paamiut at 62° N, although the ice has rarely reached so far north since 2000 (Fig. 3.4). The assessment area is normally free of sea ice from early August. The diameter of the multi-year ice floes is always less than 100 m and normally about 5 to 20 meters. When multi-year ice occurs off Southwest Greenland, it is usually characterised by low or medium concentrations when averaged over large areas, however long narrow belts of high concentrations are also common. The variability of the sea ice distribution in the South Greenland waters is due to strong ocean currents and severe weather, which characterise the area.

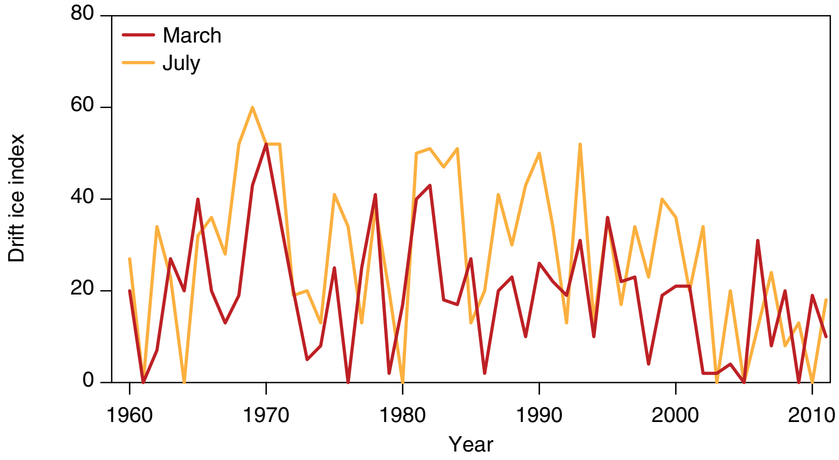

Figure 3.4. Annual variation (1960-2011) in the northern extent of the drift ice along the West Greenland coast in March and July. The index increases northwestwards from Cape Farewell (0) to the limit of the assessment area at Paamiut (34, shown by horizontal dashed line). Sources: Fabricius et al. (1995), Rosing-Asvid (2006, updated).

The drift pattern of the sea ice off South West Greenland is not very well known. On average, multi-year ice drifts into Cape Farewell area in December/January dependent on low pressure systems over the North Atlantic Ocean. During this period, sea ice only passes Cape Farewell for short periods. In spring and summer, belts of multi-year ice drift into the Cape Farewell area and normally drifts northwards into north-eastern Labrador Sea or along the West Greenland Coast. The interannual variability in the occurrence and extent of multi-year ice to the north from Cape Farewell is primarily driven by wind and current patterns, and low winter temperatures (Nazareth & Steensboe 1998, Buch 2000a, 2002, Hansen et al. 2004). Except for 1982, multi-year sea ice was never observed north of 63º N earlier than late February during 1958-2003 (Hansen et al. 2004).

The amount of multi-year ice entering Southwest Greenland shows great interannual variation on multi-decadal timescales. The interannual variation is controlled by several factors such as the outflow of sea ice from the Arctic Ocean, the formation of sea ice along the east coast of Greenland and in the Greenland Sea, and prevailing wind conditions. Eight yearly events of extreme amounts of multi-year sea ice entering West Greenland waters were observed during1968-1993 (Ribergaard 2004, and references therein).

3.4 Icebergs, drift and distribution

Icebergs differ from sea ice in many ways:

- they originate from land
- they produce fresh water on melting
- they are deep-drafted and with appreciable heights above sea level
- they are always considered as an intense local hazard to navigation and offshore activity

The process of calving from the front of a glacier produces an infinite variety of icebergs, bergy bits and growlers. Icebergs are described by their size according to the following classification:

Type	Height (m, above sea level)	Length (m)
Growler	less than 1	up to 5
Bergy bit	1 to 5	5 to 15
Small iceberg	5 to 15	15 to 60
Medium iceberg	16 to 45	61 to 120
Large iceberg	46 to 75	121 to 200
Very large iceberg	Over 75	Over 200

The production of icebergs on a volumetric basis varies only slightly from year to year. Once calving is accomplished, meteorological and oceanographic factors begin to affect the icebergs. Icebergs are carried by sea currents directed by the integrated average of the water motion over the whole draft of the iceberg. However, wind also plays an important role, either directly or indirectly.

Iceberg sources

Glaciers are numerous in West Greenland, but most of these are situated well north of the assessment area. The assessment area is mainly affected by the drift of iceberg originating from glaciers in East Greenland. The distribution and density of icebergs is also controlled by the presence of multi-year sea ice, and variability of the current pattern along the East Greenland coast (see above). Icebergs drifting within the multi-year ice are prone to lower melting rates and less deterioration from wear and swell action (Karlsen et al. 2001, Hansen et al. 2004). During summer, at the end of the peak occurrence of multi-year ice in the assessment area, it is expected that iceberg density off Southwest Greenland is at the highest level. Occasionally, under the effect of wind and when the Irminger Current is weak, icebergs may continue south-westwards instead of northwards along the West Greenland coast, reaching as far as 150 – 300 km offshore. Some of these icebergs drift across the southern Davis Strait and reach the coast of Labrador and Baffin Island, where they join the Baffin Island Current/Labrador Current drifting southwards (Nazareth & Steensboe 1998, Karlsen et al. 2001) (Fig. 3.5).

There is a large annual variation in the number and size of icebergs rounding Cape Farewell and transported north with the West Greenland current (Nazareth & Steensboe 1998, Buch 2000a, Karlsen et al. 2001). In addition, many small icebergs and bergy bits are calved in the southwest Greenland fjords; however, these have a short life span due to melting, and rarely affect offshore areas (Nazareth & Steensboe 1998).

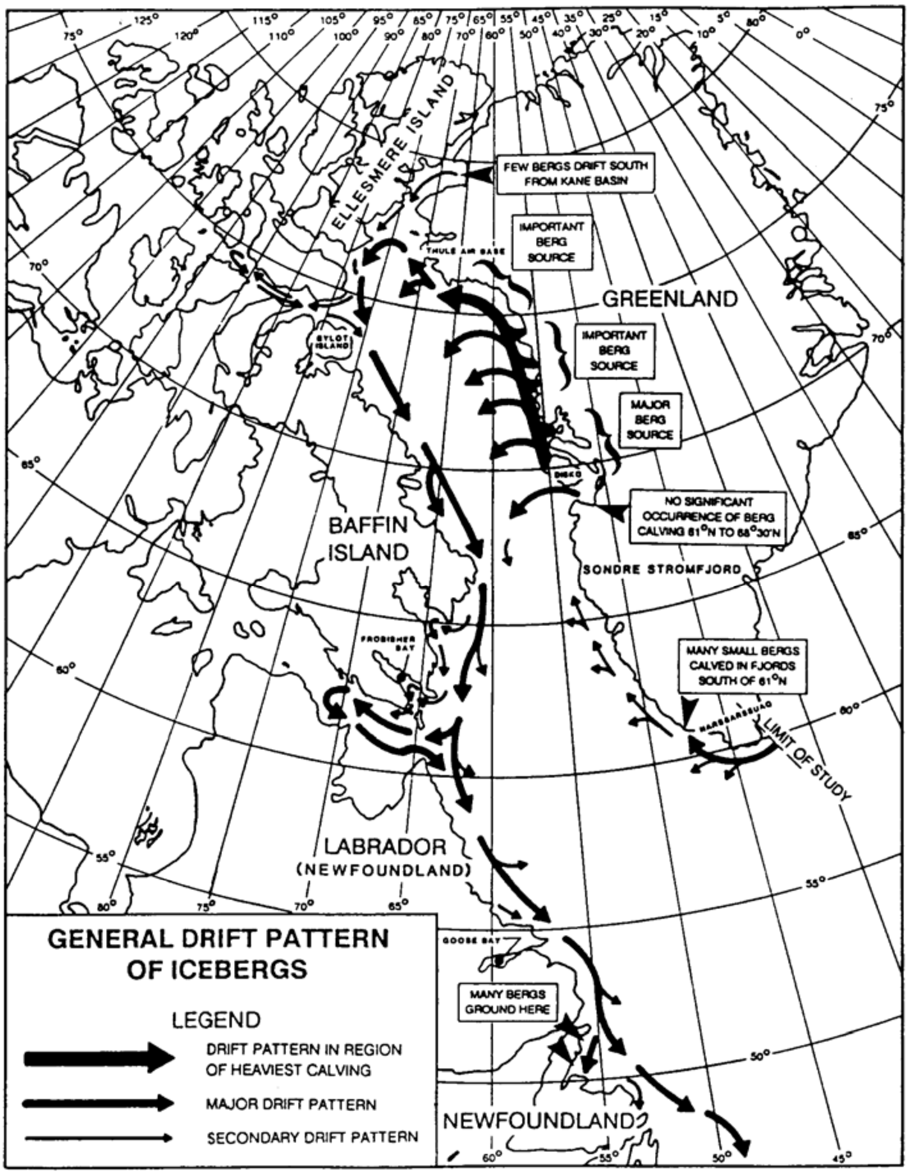

Figure 3.5. Major iceberg sources and general drift pattern in West Greenland Waters. Data source: US National Ice Center.

Iceberg dimensions

The characteristics of iceberg masses and dimensions off the west coast of Greenland are poorly investigated, and the following is mainly based on a Danish study in the late 1970s (Nazareth & Steensboe 1998 and references therein).

In the eastern Davis Strait, the largest icebergs were most frequently found south of 64° N and north of 66° N. South of 64° N, the average mass of an iceberg near the 200 m depth contour varied between 1.4 and 4.1 million t, with a maximum mass of 8.0 million t. Average draft was 60-80 m and maximum draft was 138 m. It is worth noting that many icebergs are deeply drafted and, due to the bathymetry, large icebergs will not drift into shallow water regions (Nazareth & Steensboe 1998, Karlsen et al. 2001).

Maximum draft can be evaluated by studying factors which limit the dimension: glacier thickness, topographic factors which cause icebergs to be calved in 'small' pieces, and sills at the mouths of the glacier fjords. The measurements of iceberg drafts north of 62°N indicate that an upper limit of 230 m will only be exceeded very rarely; however, no systematic 'maximum draft measurements' exist and the extremes remain unknown. Several crushes or breaks of submarine cables have occurred at water depths of about 150-200 m; the maximum depth recorded was 208 m, southwest of Cape Farewell (Nazareth & Steensboe 1998, Karlsen et al. 2001).

4 Biological environment

4.1 Phytoplankton

Michael Dünweber & Morten Frederiksen (AU)

4.1.1 General context

The waters off West Greenland are characterised by low species diversity whereas the primary production is relatively high. Due to the presence of winter ice in many areas and the marked variation in solar radiation, primary production is often highly seasonal with an intensive phytoplankton bloom in spring.

The Arctic oceans generally have a brief and intense phytoplankton (microscopic algae) bloom immediately after sea ice break-up, characterised by high (transient) biomass and a grazing food web dominated by large copepods (i.e. *Calanus* spp.), but relatively low total primary production integrated over depth and season. However, this general picture is modified by the presence of large polynyas, where early sea ice break-up and availability of nutrients from upwelling leads to locally very high production.

The development of the phytoplankton bloom in spring gives a peak in the primary production in the water column, and it is the single most important event determining the production capacity of Arctic marine food webs. The time of the onset of the spring phytoplankton bloom (i.e. spring bloom) varies between years depending on duration of the winter sea-ice cover, oceanography and meteorological conditions. The spring bloom develops when the water column is stabilised due to the retreat of the sea-ice cover and increasing solar input into the upper parts of the water column. The spring bloom quickly depletes the surface layers (the euphotic zone) of nutrients, thereby inhibiting the primary production until nutrients are replenished.

4.1.2 Productivity at the sea ice edge and marginal ice zone

At ice edges, the spring bloom is often earlier than in ice-free waters due to the stabilising effect of the ice on the water column. Here, the bloom can be very intense and attracts species of seabirds and marine mammals which often occur and congregate along ice edges and in the marginal ice zones (Frederiksen et al. 2008). Ice edges are not stable in time, and their distribution varies according to oceanographic and climatic conditions. However, at sites where nutrients continuously are brought to the uppermost water layers, for example by hydrodynamic discontinuities such as upwelling or fronts, primary production and hot spots may occur throughout the summer. The underside of the sea ice has its own special biological community with algae, invertebrates and fish. In spring when the light increases, this community can be very productive. Due to limited sea ice cover, this community is less important in the assessment area than further north.

4.1.3 The spring phytoplankton bloom in the assessment area

The onset of the spring phytoplankton bloom usually occurs in Southwest Greenland in early April. In ice-covered areas, the time of the onset is determined by the ice melt. When the prevailing winds are north-westerly and advect fresh water towards southwest Greenland, density stratification develops enabling the spring bloom (Head et al. 2000). However, the south-eastern coastal part of the assessment area is covered by multi-year ice from March to July in most years. After the peak sea-ice concentration in April-May, the sea ice normally drifts north-westwards. Thus, the variability of the multi-year sea ice could be considered as a limiting factor for the initiation of the spring bloom in Julianehåb Bugt during years when ice cover is high. Based on remote sensing measurements of surface phytoplankton concentrations in 2010, elevated values occur in April and May in the northern part of the assessment area (Fig. 4.1). Phytoplankton biomass is lower during summer, although a July bloom was observed in the offshore Labrador Sea (Fig. 4.1).

4.1.4 Productivity in open water

A large part of the assessment area is open ocean, with strong gradients in ice cover and water temperatures. Most studies of primary production in the Labrador Sea have focussed on the Canadian sector, where ice cover is higher due to the cold Labrador Current. After the sea ice break-up, high melt-water input stratifies the water column, and the spring phytoplankton bloom usually initiates on the Grand Banks of the Labrador shelf. The area of the bloom spreads during the season, and by the end of April covers the entire northeast Newfoundland Shelf and the Grand Banks (Wu et al. 2007). The progression of the spring phytoplankton bloom with season was investigated by Wu et al. (2008) in the Labrador Sea during a five year period, and they found a south-to-north progression of the bloom. However, the onset of the spring bloom in the northern Labrador Sea occurred early, approximately at the same time as in the southern Labrador Sea. This was related to a shallow mixed layer in the northern Labrador Sea due to input of low salinity water through horizontal advection and mixing of water from the Greenland coast to the northern Labrador Sea. This shallow mixing layer combined with solar input drives the phytoplankton growth in the Northern part of the Labrador Sea, in contrast to the southern Labrador Sea where stabilisation of a seasonal thermocline determines the onset of the spring bloom. Afanasyev et al. (2001) examined the seasonal pattern of phytoplankton chlorophyll in the different current regimes of the Labrador Sea. In the cold Labrador Current zone, a typical bloom event followed an Arctic pattern with one phytoplankton maximum in summer; further south, in the warm Gulf Stream zone, a typical bloom event followed a subtropical pattern (smoothed maximum during winter); and in between these zones, a typical mid-latitude bloom event occurred (two maxima, in spring and autumn).

Head et al. (2000) found that the most intense fluorescence (proxy for primary productivity) was measured in the central and north-central part of the Labrador Sea, on the eastern and western margins of the central basin and on the central Greenland Shelf. They suggested that sea ice covering the entire Labrador shelf prevented bloom development, and that melting in April advects fresh water towards the south-east causing stratification and bloom initiation.

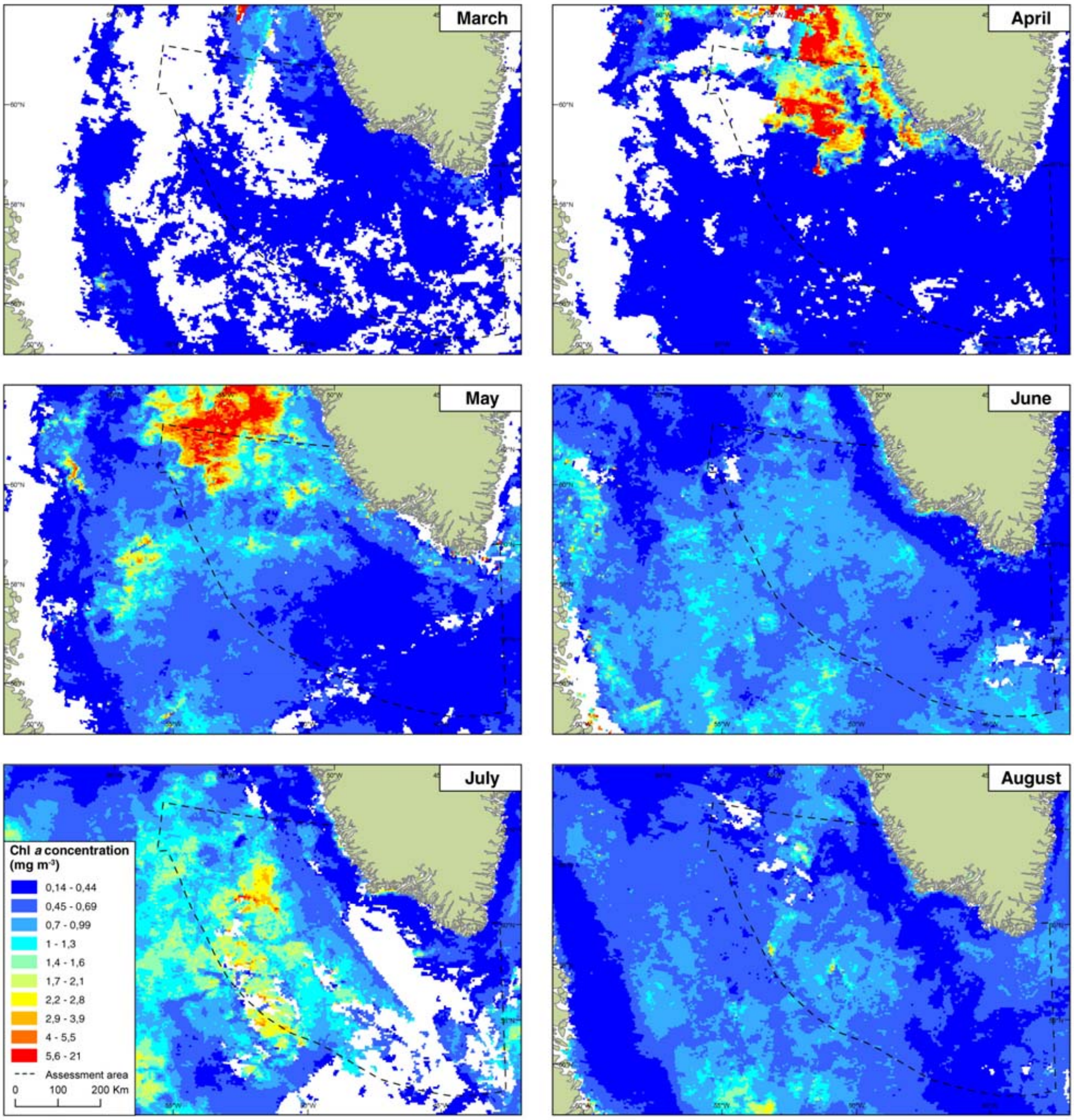

Figure 4.1. Monthly sea surface chlorophyll *a* (chl *a*) concentrations (mg m^{-3}) from March to August 2010. Data are presented as a monthly average from MODIS level 3 Aqua. Chl *a* concentrations are shown by the colour scale, with blue areas indicating very low and red very high chl *a* concentration. White indicates ice or cloud cover. The spring bloom in 2010 occurred in April and May, with high surface chl *a* concentration observed particularly in the northern part of the assessment area. During summer, surface chl *a* concentration were lower. Data from the Oceancolor homepage, NASA.

4.2 Zooplankton

Michael Dünweber (AU)

4.2.1 General context

Zooplankton has an important role in marine food webs, since it provides the principal pathway to transfer energy from primary producers (phytoplankton) to consumers at higher trophic levels, e. g. fish and their larvae, whales, primarily the bowhead whale (*Balaena mysticetus*) (Laidre et al. 2007, Laidre et al. 2010), and seabirds, e. g. the little auk (*Alle alle*) which is a specialised zooplankton feeder on the large copepods of the genus *Calanus* (Karnovsky et al. 2003). Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipids that are accumulated in *Calanus* (Lee et al. 2006, Falk-Petersen et al. 2009). Consequently, a great deal of the biological activity, e.g. spawning and growth of fish, is synchronised with the life cycle of *Calanus.* Zooplankton not only supports the large, highly visible components of the marine food web, but also the microbial community. Regeneration of nitrogen and carbon through excretion by zooplankton is crucial for bacterial and phytoplankton production (Daly et al. 1999, Møller et al. 2003). Zooplankton, mainly *Calanus* copepods, play a key ecological role in supplying the benthic communities with high-quality food through their large and fast-sinking faecal pellets (Juul-Pedersen et al. 2006). Thus, the vertical flux of faecal pellets sustains diverse benthic communities such as bivalves, sponges, echinoderms, anemones, crabs and fish, when sinking down to the seabed (Turner 2002, and references therein, Sejr et al. 2007).

4.2.2 The importance of *Calanus* copepods

Earlier studies on the distribution and functional role of zooplankton in the pelagic food web off Greenland, mainly in relation to fisheries research, have revealed the prominent role of *Calanus*. The species of this genus feed on algae and protozoa in the surface layers and accumulate surplus energy in the form of lipids, which are used for overwintering at depth and to fuel reproduction in the following spring (Lee et al. 2006, Falk-Petersen et al. 2009, Swalethorp et al. submitted). Most of the higher trophic levels rely on the lipids accumulated in *Calanus* mainly as wax esters, which are transferred through the food web and incorporated directly into the lipids of consumers through several trophic levels. For instance, lipids originating from *Calanus* can be found in the blubber of white and sperm whales, which feed on fish, shrimps and squid (Smith & Schnack-Schiel 1990, Dahl et al. 2000), and in the bowhead whale and the northern right whale (*Eubalaena glacialis*), which eat mainly *Calanus* (Hoekstra et al. 2002, Swaim et al. 2009). In larvae of the Greenland halibut (*Reinhardtius hippoglossoides*) and sandeel (*Ammodytes* spp.) from the West Greenland shelf, various copepod species, including *Calanus* were the main prey item during the main productive season (May, June and July). They constituted between 88 % and 99 % of the ingested prey biomass (Simonsen et al. 2006).

The vertical distribution of *Calanus* species is influenced strongly by ontogenetic vertical migrations that occur between the dark winter season and the light summer season when they move into surface waters. During summer and autumn, *Calanus* initiates descent to deep-water layers for winter hibernation, changing the plankton community structure from *Calanus* dominance to smaller copepod and protozooplankton dominance. The grazing impact on phytoplankton by the smaller non-*Calanus* copepod community after *Calanus* has left the upper layer can be considerable higher than in spring. This is a result of shorter generation time and more sustained reproduction and a relaxed food competition and predation by *Calanus* (Hansen et al. 1999, and references therein). The importance of small non-*Calanus* copepods in ecosystem productivity could be greater than implied by their biomass alone (Hopcroft et al. 2005, Madsen et al. 2008).

4.2.3 Zooplankton in the assessment area

Zooplankton knowledge is scarce in the assessment area, and current knowledge is based on studies from the Labrador Sea and North Atlantic (Head et al. 2000, Head et al. 2003, Heath et al. 2004, Yebra et al. 2009, Head & Pepin 2010) and the southwest Greenland coastal zone (Pedersen & Rice 2002, Munk et al. 2003, Pedersen et al. 2005, Bergstrøm & Vilhjalmarsson 2007, Arendt et al. 2010). The coastal studies in southwest Greenland confirm that most of the biological activity in the surface layer is present in spring and early summer in association with the spring bloom and the appearance of the populations of the large copepods *Calanus*. *Calanus* occurs widespread in the West Greenland waters, where high biomasses have been recorded throughout the Labrador Sea in southwest Greenland, almost exclusively dominated by *C. finmarchicus* during spring (Head et al. 2003, Heath et al. 2004), and also north of the assessment area at the important fishery banks (e.g. Pedersen et al. 2005, Arendt et al. 2010). The Labrador Sea is considered to contain the major concentration of the overwintering stock of diapausing *C. finmarchicus*, which descend in late summer and winter to deep water before returning to surface waters in spring. *C. finmarchicus* has its centre of distribution in the Northwest Atlantic in the deep Labrador basin, from where they disperse to the nearby shelves in the Northwest Atlantic and to South Greenland (Head et al. 2000, Head et al. 2003, Heath et al. 2004, Speirs et al. 2006).

In general, copepods in the North Atlantic can be divided into a number of associations, including temperate, sub-Arctic and Arctic species (Beaugrand et al. 2002a). The abundance of the sub-Arctic copepod *C. finmarchicus* increases towards the south along the West Greenland coast and is highest in the Labrador and Irminger Basin. *C. finmarchicus* is most abundant in the surface water during late spring and early summer after the peak spring phytoplankton bloom. In summer, it begins to descend towards depths for winter diapause, until it ascends again to the surface from late winter (Head et al. 2000, Heath et al. 2004). The copepod community distribution and advection is largely influenced by prevailing sea water temperatures in the North Atlantic. Advection of copepod species has been observed in a 40 year period 1960s-1990s and is closely linked to the variability in the North Atlantic Oscillation (NAO) index (Beaugrand et al. 2002b). Variability in current regimes of the North Atlantic Water and advection of *C. finmarchicus* into the assessment area have strong implications for their distribution, life cycle and production, and for the succeeding link to higher trophic levels, e.g. juvenile Atlantic cod (*Gadus morhua*) (Sundby 2000, Pedersen & Rice 2002). Transportation of *C. finmarchicus* from the North Atlantic into the South and West Greenland waters can outnumber the Arctic *C. glacialis* and *C. hyperboreus* by a factor of 3 throughout the year, depending on food availability (Pedersen et al. 2005, and references therein).

Head et al. (2003) found high presence of other zooplankton species than *C. finmarchicus* in the Northern Atlantic such as *Paraeuchaeta norvegica*, *Scolecithrocella minor* and euphausiid species, while *C. glacialis*, *C. hyperboreus* and *Pseudocalanus* spp. played minor roles in southwest Greenland and were more associated with cold Polar Water at the Canadian shelf.

4.2.4 Large zooplankton and fish larvae

Large zooplankton (>1 cm) includes both herbivores like krill (Euphausidae) and copepod predators such as hyperiid amphipods, but few of these species have been studied in any detail in the assessment area. The distribution of the most important krill species (*Meganyctiphanes norvegica*) was examined in September 2005 by Bergstrøm & Vilhjalmarsson (2007). Krill were found in scattered aggregations in most of the area (between 60-70° N), with a pronounced increased prevalence north of the assessment area (62° to 65° N). However, relatively large patches were found in the assessment area (Fig. 4.2).

Larvae of fish and shrimp are important components of the plankton, and movements and behaviour have been studied for some of the commercially utilised species (Pedersen & Smidt 2000, Pedersen et al. 2002). Ribergaard (2004) examined the variability in the cod stock in southwest Greenland waters in relation to the prevailing hydrography and cod larvae transport. Cod larvae mainly feed on *C. finmarchicus*. Moreover, increasing temperature has a positive effect on the growth of cod in the Barents Sea. The transport of *C. finmarchicus* into the Barents Sea increases with the inflow of warm Atlantic Waters (during a phase of high NAO index), thus more food is therefore available for cod. Contrary to the Barents Sea cod, the Canadian cod in the Labrador Sea experience cold water temperatures under a positive NAO index and experience low recruitment under such a scenario (Buch et al. 2004, Ribergaard 2004, and references therein). Thus, the distribution and abundance of *C. finmarchicus* has a large effect on cod recruitment and the food conditions for juvenile cod.

Pedersen & Smidt (2000) analysed fish larvae data sampled along three transects during summer in southwest Greenland waters over 34 years. The peak abundance of fish larvae was observed in the early summer in association with the peak abundance of their plankton prey. They found a large interannual variation in abundance of polar cod larvae. Although planktonic organisms are supposed to move with the currents, there seem to be retention areas over the important fisheries banks in southwest Greenland, where plankton is concentrated and entrapped for periods (Pedersen et al. 2005).

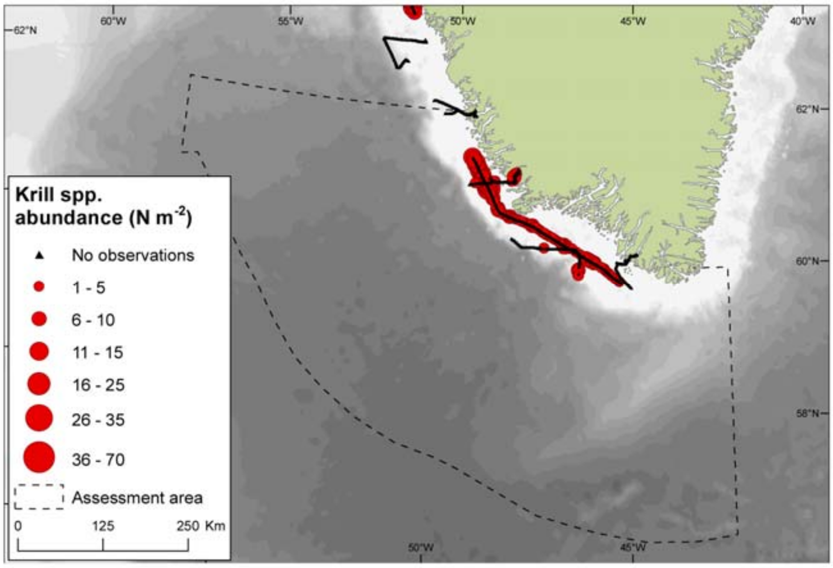

Figure 4.2. Krill abundance (N m^{-2}) from acoustic measurements from September 2005 in the 0-50 m column (Bergstrøm & Vilhjalmarsson 2007). High krill abundance, mostly *Meganyctiphanes norvegica*, is evident near the coastal areas.

Several surveys have investigated the horizontal distribution of fish larvae in relation to oceanography and their potential prey along West Greenland

(Munk 2002, Munk et al. 2003, Simonsen et al. 2006). They document that the important sites for the development of fish larvae are the slopes of the banks and the shelf break where the highest biomass of their copepod prey is also located (Simonsen et al. 2006).

4.2.5 Knowledge gaps

The variability in the physical forcing of the Atlantic inflow and the freshwater runoff from the Greenland Ice Sheet determines the physical gradients and thereby the geographical distribution of the plankton communities. The dynamics between physical environment and fishery resources in West Greenland waters needs to be further addressed. Thus, a better understanding of the recruitment success of fish and shellfish requires comparative studies of zooplankton, fish larvae, hydrography and climate, from inshore to offshore areas. The exact mechanisms determining the plankton community distribution and their specific adaptations to physical/chemical gradients are still unknown. Currently, no annual surveys of primary and zooplankton production relative to hydrography in the assessment area have been conducted (except at the mouth of the Godthåbsfjord, Arendt et al. 2010). Model studies including variability in ocean temperature, seasonal timing of food and production, spawning stock biomass, larval drift and species interactions (cannibalism), should improve the understanding and prediction of the distribution and recruitment of fish and shellfish.

4.2.6 Zooplankton sensitivity to oil

The impact of oil activities on zooplankton is likely to vary depending on season, location and biological activity. High biological activity in the surface waters can be expected in connection with hydrodynamic discontinuities, i.e. spring blooms, fronts, upwelling areas or at the marginal ice zone. In Arctic marine habitats, the most severe ecological consequences of massive anthropogenic impacts (such as oil spills) are to be expected in seasons with high biological activity in the upper 50 m. In late summer, the biomass of grazers in surface water is low after *Calanus* have migrated to their overwintering depths near the bottom (Dünweber et al. 2010). The biological activity is thus lower and concentrated at the pycnocline, and ecological damage from an oil spill on plankton communities could be assumed to be less severe (Söderkvist et al. 2006).

Exposure experiments performed on natural plankton communities (Hjorth et al. 2007, Hjorth et al. 2008) and copepods (Hjorth & Dahllöf 2008, Jensen et al. 2008, Hjorth & Nielsen 2011), with pyrene as a proxy for crude oil, have shown reduction in primary production, copepod grazing and production, and an indirect positive effect on bacterial growth due to substrate release. Effects of pyrene have been studied on a wide range of variables and life stages of the calanoid copepods *Calanus finmarchicus and C. glacialis* held under three different temperatures (0, 5 and 10º C) (Hjorth & Nielsen 2011, Grenvald et al. in prep).

Adult *C. finmarchicus* were affected most by pyrene exposure, and the sensitivity increased at higher temperatures in contrast to *C. glacialis*, which may be partly due to buffering from lipid stores. Pyrene had no effect on the development time of the two first non-feeding nauplius stages, but clearly prolonged the development time from nauplius stage 3, when copepods begin to graze on phytoplankton. This was most pronounced at the lowest temperature (0° C). This suggests that pyrene exposure during a spring phytoplankton bloom (~0° C in the upper 50 m) will have the largest impact, since reduced grazing on the phytoplankton potentially will lead to lower incorporation of phytoplankton into lipids, with more biomass left ungrazed and thus settling to the benthic community. The differential responses of food uptake, production and development time of the two species to pyrene exposure and higher water temperature will not only affect them at the species level, but will affect the entire Arctic food web through a shift to less lipid-rich energy flux to higher trophic levels. Temperature stimulates *C. finmarchicus* more than *C. glacialis*, but this species is also more sensitive to oil.

4.3 Macroalgae

Susse Wegeberg (AU)

Shorelines with a rich primary production are of high ecological significance. The littoral and sublittoral canopy of macroalgae is important for higher trophic levels of the food web by providing substrate for sessile animals, shelter from predation, protection against wave action, currents and desiccation or directly as a food source (Bertness et al. 1999, Lippert et al. 2001). Because of strong biological interactions in rocky intertidal and kelp forest communities, cascades of delayed, indirect impacts of oil contamination (e.g., biogenic habitat loss and changes in prey-predator balances due to species-specific mortality) may be much more severe than direct impacts (Peterson et al. 2003). However, some shorelines are highly impacted by natural phenomena such as wave action and ice scouring, and such shorelines will therefore naturally sustain a relatively lower production or may appear as barren grounds. Thus to identify important or critical areas, a robust baseline knowledge on littoral and sublittoral ecology is essential.

Investigation of the marine benthic flora in the assessment area was limited and included a floristic study in the Cape Farewell area in 1970 (Pedersen 1976). However, studies focusing on kelp forest biomass and ecology has been conducted and initiated. In the Qaqortoq area, the distribution and biomass of kelp species were studied by the Nordic Seaweed Project 2004-2006 (Wegeberg 2007), and during August 2011 the depth distribution of the kelp forest species at Ydre Kitsissut was studied. A more comprehensive investigation of macroalgal diversity as well as littoral and sublittoral macroalgal community structures in the Cape Farewell area took place in September 2011.

4.3.1 General context

Marine macroalgae are found along shorelines with hard and stable substrates, such as stones, boulders and rocky coast. The vegetation is distinctly divided into zones, which are most pronounced in areas with high tidal amplitudes. Some species grow above the high-water mark, the supralittoral zone, where sea water reaches them as dust, spray or by wave action. In the littoral zone, the vegetation is alternately immersed and emersed, and characterised by fucoid species. The majority of the macroalgal species grow, however, below the low-water mark within water depths with sufficient light. In the Arctic, the length of the ice-free period is an important determinant of the light reaching the sea floor, and the depth range of the kelp belt increases from north to south along the Greenland coast in parallel with the increase in length of the ice free period (Krause-Jensen et al. 2011). In North Greenland, a relatively dense macroalgal flora can be found down to about 20 m (Krause-Jensen et al. 2011), while they occur at a depth of 50 m in South Greenland and around Disko (Wegeberg et al. 2005, Hansen et al. 2011).

The assessment area has open water year round, but particularly the outer coasts of the Cape Farewell area are heavily impacted by drift ice. This ice, as well as the marked seasonal changes in light regime and low water temperatures, calls for efficient adaptive strategies. The ability to support a photosynthetic performance comparable to that of macroalgae in temperate regions might be explained by low light compensation points and relatively low respiration rates during periods of poor light conditions, and indicates an adaptation to constant low temperatures and long periods of low light intensities (Borum et al. 2002). Furthermore, a fast response in photosynthetic performance to changing light conditions is considered to be part of a physiological protection strategy in a highly variable environment e.g. in the littoral zone, as well as ensuring optimal harvest of light when available (Krause-Jensen et al. 2007, Becker et al. 2009). No studies elucidating the macroalgal production or photosynthetic strategies have been conducted in the assessment area, though.

The sea ice also causes a profound physical impact on the macroalgal vegetation through ice scouring. The mechanical scouring by floating ice floes prevents especially perennial fucoid species establishing in the littoral, which is the zone most influenced by ice dynamics. Even though the assessment area is an open water region, drift ice from East Greenland may impact exposed coast lines, which thus may be subject to the phenomenon of opportunistic green algae development. As *Fucus* spp. cannot establish due to ice scouring, green, especially filamentous, algal species dominate creating a green belt in the littoral zone. This phenomenon is well-known from several localities in Greenland including in the assessment area.

Perennial species from the littoral zone tolerate temperatures of or close to freezing, and might survive in an ice foot, when this phenomenon occasionally occurs in the fjords of the assessment area, and the ice foot melts without disrupting the vegetation. It was shown for *Fucus evanescens* from Spitsbergen that the species was able to halt the photosynthetic activities at subzero temperatures and resume almost completely when unfrozen (Becker et al. 2009).

Water of low salinity or fresh water may influence the macroalgal vegetation, especially in the littoral zone when it is exposed to rain and snow during low tide and when sea water mixes with fresh and melt water during seasons with high water runoff from land. Low tolerance to hyposaline conditions may result in increased mortality or bleaching (strong loss of pigments), which suggests that hyposalinity may impact on the photosynthetic apparatus, as shown for kelp species at Spitsbergen (Karsten 2007).

Substrate characteristics are also important for the distribution and abundance of macroalgal vegetation, and only hard and stable substrates can serve as base for a rich community of marine benthic macroalgae. However, commonly some macroalgal species are attached to shells, small stones or occur loose-lying in localities with a soft, muddy bottom. Naturally occurring loose-lying macroalgae tend to be depauperate, probably due to poor light and nutrient conditions. When not attached to stable substrates, the algal material drifts and clusters resulting in self-shading and nutrient deficiency within the algal cluster. Furthermore, soft bottom localities, often located in the inner parts of fjords, are created and influenced by resuspended particles in melt water. The light conditions are impacted due to significantly reduced water transparency as well as sedimentation of resuspended particles on the macroalgal tissue resulting in shading. Pedersen (1976) described this phenomenon from the inner fjords in the Cape Farewell area with loose-lying *Desmarestia* and *Chaetomorpha melagonium*.

Sea urchins (*Strongylocentrotus droebachiensis*) are the most important grazers on kelp forests. A high density of sea urchins can result in grazing down of kelp forests leaving 'barren grounds' of stones, boulders and rocks, which may be covered by coralline red algae only. If barren grounds are due to grazing by sea urchins, and not to ice scouring, the barren grounds will be found below the intertidal vegetation as the sea urchins do not tolerate desiccation (Christensen 1981).

Isotope ($\delta^{13}C$) analyses used to trace kelp-derived carbon in Norway suggest that kelp may serve as carbon source for marine animals at several trophic levels (e.g., bivalves, gastropods, crab, fish), and mainly enters the food web as particulate organic material (Fredriksen 2003). Especially during the dark winter period when phytoplankton is absent, an increased dependence on kelp carbon has been measured (Dunton & Schell 1987). A study of fish-macrofauna interactions in a Norwegian kelp forest showed that kelp-associated fauna was important prey for the 21 fish species caught in the kelp forest (Norderhaug et al. 2005). A reduction in kelp forest cover due to harvest thus affected the fish abundance and diminished coastal seabird foraging efficiency (Lorentsen et al. 2010).

Climate change may affect the macroalgal vegetation in the assessment area. A change in northward distribution of species is an expected scenario coupled to oceanic warming (Müller et al. 2009), and less drifting ice may open for macroalgal colonization in otherwise ice-scoured habitats. Furthermore, a study of climate forcing on benthic vegetation in Greenland (Krause-Jensen et al. 2011) suggests that depth range, abundance and growth of sublittoral vegetation belts will expand as temperatures increase, but the study also concluded that those species with the most northern distribution responded negatively to warming. In addition, melting of the Greenland Ice Sheet leads to an increase in freshwater runoff, which may result in lowered salinity and increasing water turbidity (Borum et al. 2002, Rysgaard & Glud 2007), with a negative impact on the local macroalgal vegetation.

There are different reports on the impact of oil contamination on macroalgal vegetations and communities. The macroalgal cover lost in connection with the *Exxon Valdez* oil spill in 1989, as observed for *Fucus gardneri* in Prince William Sound, has taken years to fully re-establish as a result of the grazer-macroalgae dynamics as well as intrinsic changes in plant growth and survival (Driskell et al. 2001), and is still considered recovering (NOAA 2010). In contrast, no major effects on shallow sublittoral macroalgae were observed in a study conducted by Cross et al. (1987). This might be due to a similar lack of impact on the herbivores or to the vegetative mode of reproduction in the dominant macroalgal species. Thus, it has been shown that petroleum hydrocarbons interfere with the sex pheromone reaction in the life history of *Fucus vesiculosus* (Derenbach & Gereck 1980).

4.3.2 The macroalgal vegetation in the assessment area

183 macroalgal species (excl. the blue-green algae, Cyanophyta) are listed for Greenland according to a compiled checklist from 1976 (Pedersen 1976). Due to taxonomic and nomenclatural changes the number presented in the compiled checklist presently equals 137 species; 37 red algal species, 66 brown and 37 green. Within the assessment area now 39 red algae, 55 brown and 34 green have been recorded, which includes new records of red algal species from the Ikka Fjord (Wegeberg et al. submitted) and the Qaqortoq area (Wegeberg et al. 2005).

The brown algae *Laminaria solidungula*, *Punctaria glacialis*, *Platysiphon vertillatus* and the red algae *Haemescharia polygyna*, *Neodilsea integra*, *Devalerea ramentacea*, *Turnerella pennyi* and *Pantoneura fabriciana* are considered as Arctic endemics (Wulff et al. 2009). Of these species *L. solidungula*, *D. ramentacea*, *T. pennyi* and *P. fabriciana* are present in the assessment area.

Pedersen (1976) described the flora in the Cape Farewell area. Sheltered littoral zones were dominated by *Ascophyllum nodosum* and *Fucus vesiculosus*. In the Cape Farewell in-sound area, the main type of shore localities are more exposed to currents than to actual wave action, and may be strongly influenced by ice scouring. The littoral zone may thus be dominated by species of filamentous and smaller leafy green algal genera (*Urospora, Ulothrix, Pseudothrix*). Just above the kelp forest composed mainly by the genera *Agarum*, *Alaria*, *Laminaria* and *Saccharina* in the sublittoral zone, smaller and in particular brown algal species were observed (e.g., *Chordaria flagelliformis, Delamarea attenuata, Dictyosiphon foeniculaceus, Pylaiella littoralis, Scytosiphon lomentaria*) (Pedersen 1976).

In the littoral and sub-littoral investigations of macroalgal biomasses conducted in southern Greenland, the biomass of *Fucus vesiculosus* and *Ascophyllum nodosum* averaged 7-8 kg wet weight m^{-2} of the dominant species at sheltered localities near Qaqortoq. For *F. vesiculosus* it varied between 4 and 7 kg wet weight m^{-2} at two different localities, reaching up to 10 kg wet weight m^{-2} (Wegeberg *et al.* 2005). In the Disko West assessment area, Hansen (1999) found somewhat lower biomasses for *Fucus* spp., in average between 2 and 4 kg wet weight m^{-2} (calculated from fig. 4 in Hansen (1999) using a conversion factor of 5 from dry to wet weight) from two localities close to Udkiggen, Qeqertarsuaq, and maximal values of 6 and 8 kg wet weight m^{-2}. The lower biomasses obtained at Disko may be a result of a higher degree of exposure rather than a more northerly location. In a study on *Fucus* spp. along an exposure gradient (wind, ice) in the littoral zone at Ydre Kitsissut, in the assessment area, a decrease in biomass was found in the range of more than 40 % from the sheltered station to the semi-exposed, and down to about 2 % at the most exposed station (Wegeberg, unpubl. data). In the upper sublittoral zone (≤20 m), biomasses of kelp in the Qaqortoq area averaged 3-8 (13.5) kg m^{-2}, with highest values at sites with relatively high degrees of exposure (Wegeberg 2007).

A study for achieving comparable data from the Cape Farewell area as well as data for macroalgal associated fauna was carried out in September 2011.

In general, the existing knowledge of macroalgal diversity and extent as well as their ecological importance is increasing in the assessment area. As the knowledge is still somewhat sporadic, achieving robust comparable data from more localities along the South Greenland coasts could add information to the existing and hence improve the base for mapping and initiating modelling littoral and sublittoral ecology. At present, important or critical shoreline habitats cannot be identified on the available information, but the results from the up-coming investigation in the Cape Farewell area may add critical information to such an assessment. However, knowledge of the trophic cascades, i.e. macroalgal /-faunal interactions on all trophic levels, including e.g. grazing on macroalgae by sea urchins and bird foraging in the kelp forest, will still be lacking. This knowledge would be highly important for assessing the full ecological impact of a beaching oil spill. Therefore, it is suggested to perform investigations that in particular focus on 1) macroalgae as a food source, including trophic relationships through stable isotope analyses, as well as organisms dependent on macroalgal carbohydrate exudates; 2) kelp forests as nursery grounds for fish species and their importance for the higher trophic levels such as seabirds. Such studies would provide additional information for optimizing advice on prioritizing shoreline protection and clean-up, as well as evaluation of subsequent rehabilitation of an oil impacted coast.

4.4 Benthos

Martin Blicher (GINR) & Mikael Sejr (AU)

The benthic habitat has a central role in the marine ecosystem in the Arctic, both in terms of elemental cycling, ecosystem function, and biodiversity. While the benthic flora is confined to a relatively narrow photic zone extending from the inter-tidal zone to approximately 40 meters depth, the benthic fauna is more widespread and is found at all depths and all types of substrate. The benthic fauna is often very species-rich, and more than 100 species per m^2 are typically found in undisturbed soft sediments (Sejr et al. 2010a, Sejr et al. 2010b). Three benthic species are fished commercially in Greenland waters. The scallop *Chlamys islandica* and the snow crab *Chionoecetes opilio* live directly on the sea floor, whereas the northern shrimp *Pandalus borealis* is found closely associated with the bottom.

The benthic community is affected by a multitude of different biological and physical parameters, with temperature, depth, food input, sediment composition, particle load, disturbance level (e.g. ice scouring) and hydrographical regime being the most prominent (e.g. Gray 2002, Włodarska-Kowalczuk et al. 2004, Piepenburg 2005). Therefore, the benthic community is often extremely heterogeneous on both local and regional scales.

Southwest Greenland is characterised by numerous fjords, but differs from the rest of West Greenland in having a relatively steep continental slope close to the coastline (<100 km). The coastal zone is highly affected by ice, some of which is transported with ocean currents from East Greenland, and some coming from the numerous glaciers in the area, resulting in heavy ice scouring of shallow benthic habitats.

4.4.1 Fauna

Compared to the extremely long coastline of Greenland, the number of benthic surveys is very limited. Still, there have been reports of high standing stocks of macrofauna (>1000 g wet weight m^{-2}) in shallow benthic habitats in Greenland (<100m), and macrobenthos is considered an important food source for fish, seabirds and mammals (Vibe 1939, Ambrose & Renaud 1995, Sejr et al. 2000, Sejr et al. 2002, Born et al. 2003, Sejr & Christensen 2007, Blicher et al. 2009, Blicher et al. 2011). Such rich macrozoobenthic communities are often characterised by many individuals of high age (up to >25 years), which can only be attained in relatively stable environments. Natural sources of disturbance are primarily ice scours and particle sedimentation in areas near glaciers and rivers. The productivity of macrobenthos in the Arctic is often linked to food availability (e.g. Grebmeier & McRoy 1989, Ambrose & Renaud 1995, Piepenburg et al. 1997, Blicher et al. 2009), and consequently high production is expected to be found in areas where sea-ice cover is minimal and does not control primary production, and also at shallow depths where benthic primary production is considerable, and pelagic production is transferred most efficiently to the sea floor. Moreover, it has been suggested that low individual energy requirements at low temperatures contribute to a positive energy budget despite low and/or highly seasonal primary production (Clarke 2003, Blicher et al. 2010).

South Greenland is poorly studied in terms of benthos, and consequently our knowledge is limited.

One specific benthic habitat in South Greenland has been studied in detail. The columns of ikaite tufa found on shallow depths along a 2 km stretch in the Ikka Fjord (61° 11′ N, 48° 02′ W) are described as unique geological structures that have been formed under very specific physical and chemical conditions existing at the head of the fjord. Ikaite crystals forming the tufa columns are chemical precipitates grown from mixing of alkaline submarine spring water and cold seawater (Buchardt et al. 2001, Seaman & Buchardt 2006). The diverse bacterial community associated with the ikaite columns is considered unique and highly specialised to the cold and alkaline environment, and a number of new species of bacteria, algae and fauna have been described from the site (Kristiansen & Kristiansen 1999, Stougaard et al. 2002, Schmidt et al. 2006, Schmidt et al. 2007). A diverse macrofaunal community is associated with the ikaite columns. In a qualitative study a total of 165 epifaunal invertebrate species were registered at five sampling sites extending down to 20 m depth (Thorbjørn & Petersen 2003). The species in the fjord were known from Boreal and Arctic regions. Three species were reported as new to Greenland.

A single benthic survey was conducted in the fjords of Saqqaa and Uunartoq near Nanortalik (*c.* 60ºN). The study was designed to test for environmental impacts of the gold mining in Kirkespirdalen (Glahder et al. 2005). The benthic samples were collected between 200 and 300 m depth in sediment dominated by fine particles. The particle fraction < 63 µm was above 90% at most stations. As is typically found in the deeper parts of Greenland fjords, the benthic fauna was dominated by polychaetes (80% of all specimens). The 5 most abundant species (all polychaetes) found in two fjords near Nanortalik were also common in the Godthåbsfjord system (Sejr et al. 2010a), at several stations in Northwest Greenland (Sejr et al. 2010b), and in Holsteinsborgdybet (MarinID 1978), indicating that several species of polychaetes are abundant along the entire west coast of Greenland.

In May 2010, a benthic sampling campaign was performed in the near-shore area between 64 and 61° N (Batty et al. 2010). Detailed taxonomic data are not available yet, but the study is expected to provide data on benthic biomass, abundance, diversity and species composition as well as the physicochemical characteristics of the sediment. Visual examinations of the seabed using an underwater drop camera down to 250 m depth indicated that the sea floor was very heterogeneous. Several substrate types were recorded, ranging from soft mud and clay, through a mix of stones and shells, to clean rock. The species composition of epifauna was obviously influenced by these different physical conditions, and several different epifaunal communities were identified (Fig. 4.3). To our knowledge, this cruise was the first of its kind in South Greenland, and consequently we cannot present a detailed description of the macrozoobenthic community in the area south of 62° N at the time of writing of this report. However, due to the reported heterogeneity in the area, it can be expected to host several different assemblages of epi- and endobenthic species. In a recent study from the inner Godthåbsfjord to Fylla Bank and the continental slope in Southwest Greenland (64° N), more than 80 different species were observed per 0.1 m^2 sample at some sites (Sejr et al. 2010a). In a pan-Arctic inventory of macro- and megabenthic species including all existing data from Arctic shelf regions, a lack of data from Greenland waters was apparent. Enough data were available from West Greenland (63 to 68° N), however, to make detailed regional comparisons of species composition. This analysis suggested species diversity in West Greenland to be at the high end compared to other ecoregions in the Arctic (Piepenburg et al. 2011). Species richness is generally found to increase with depth from about 200 m to maximum values at 1,500–2,500 m (Etter & Grassle 1992, Gray 2002). Data from Greenland waters, and especially from deep water (>300 m), are too scarce to show such patterns.

A general problem as regards quantitative taxonomical studies of benthos is that the majority of samples have been collected at sites with soft sediment due to the technical difficulties of quantitative sampling on hard or mixed substrates. As a consequence, our knowledge about the benthic communities associated with such heterogeneous habitats is limited, despite the fact that such habitats are widespread in coastal areas in Greenland.

One specific taxon that is receiving increasing attention is cold-water corals. These corals are widespread in large parts of the north Atlantic where they create a unique habitat that is inhabited by a specific fauna (Mortensen & Buhl-Mortensen 2004, Bryan & Metaxas 2006). Cold water corals have been found in the western part of the Davis Strait (Edinger et al. 2007b). In Greenland waters, coral distribution and abundance have not been studied systematically. However, during trawl surveys conducted by the Greenland Institute of Natural Resources corals are frequently found in the trawls (K. Sünksen, *pers comm.*), indicating that corals occur along the continental shelf of Southwest Greenland.

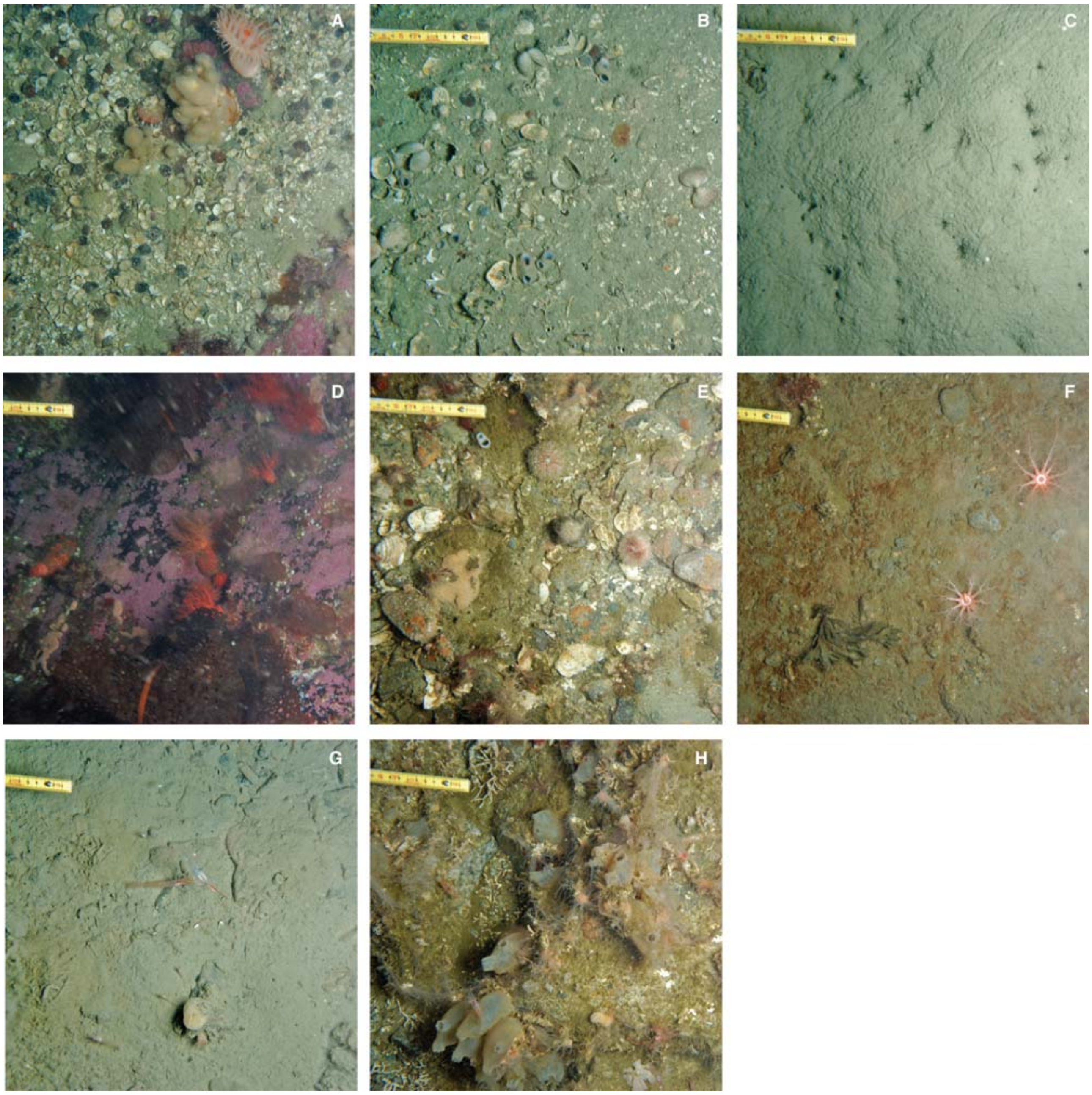

Figure 4.3. Photos of the sea floor at different coastal sites in South Greenland, illustrating variation in the physical and biological structure. A: 43 m depth, B: 90 m, C: 100-170 m, D: 30 m, E: 64 m, F: 37 m, G: 150-180 m, H: 80-85 m. Source: Batty et al. (2010).

4.5 Fish and shellfish

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Many different shellfish and fish species occur commonly in the assessment area. Most are demersal i.e. live near the sea bottom. Important species among shellfish includes cold-water shrimp, snow crab, scallop, blue mussel and among marine vertebrates Greenland halibut, salmon, cod, Atlantic halibut, wolffish, redfish, capelin, lumpsucker and others. The marine shelf is an important fishing ground and is characterised by relatively few dominant species, with strong interactions (Pedersen & Kanneworff 1995). Table 4.1

provides an overview of the most important fish and shellfish species, their habitat requirements and spawning periods.

Table 4.1. Important fish and shellfish species in the assessment area.

Species	Main habitat	Spawning area	Spawning period	Exploitation	Importance of study region to species
Blue mussel	subtidal, rocky coast	subtidal, rocky coast		local	low
Scallop	inshore and on the banks with high current velocity, at 20 -60 m depth	same as main habitat		commercial and local	medium
Deep sea shrimp	mainly offshore, at 100-600 m depth	larvae released at relatively shallow depth (100-200 m)	March-May	commercial	medium
Snow crab	coastal and fjords, at 180-400 depth	same as main habitat	April-May	commercial	medium
Atlantic cod	banks south of 64 ° N	pelagic eggs and larvae in upper water column	March-April	local and commercial	high
Sandeel	on the banks at depths between 10 and 80 m	on the banks, demersal eggs, pelagic larvae	May-August	important prey item	medium
Spotted wolffish	inshore and offshore	hard bottom, demersal eggs	peaks in September	local	medium
Arctic char	coastal waters, fjords	Freshwater rivers	in autumn	local	medium
Capelin	coastal	beach, demersal eggs	April-June	local, important prey item	medium
Atlantic halibut	offshore and inshore, deep water,	pelagic eggs and larvae, deep water	spring	local	low
Greenland halibut	deep water, in fjords and offshore	deep water, pelagic eggs and larvae	winter	local and commercial	medium
Redfish	offshore and in fjords, 150-600 m depth	spawns outside area	-	local	medium
Lumpsucker	pelagic	coastal, demersal eggs	May-June	commercial and local	medium

4.5.1 Selected species

Northern shrimp, *Pandalus borealis*

Biology: The key species northern shrimp dominates in West Greenland waters. The striped pink shrimp (*Pandalus montagui*) is also found in the area, but is much less abundant (Kanneworff 2003). Both shrimp species have a life history called protandric hermaphroditism, which means that individuals grow up as males and then go through a transition to females. Right before the females extrude the eggs, the males attach a spermatophore to the female, followed by extrusion of eggs, which females carry on the legs for approximately 6-9 months.

Distribution: The northern shrimp is a widespread species (Bergström 2000) with a circumpolar occurrence. In West Greenland, shrimps are distributed along the entire coastline at depths ranging from 9 – 1,450 meter, but are most common at 100 – 600 m depth. However the striped pink shrimp is more abundant in shallow and coastal waters (Simpson et al. 1970). In recent years, the range of the northern shrimp has moved northwards (Ziemer et al. 2010), and the main biomass is now concentrated north of 67° N.

Movements: Shrimps are highly mobile both horizontally and vertically, and have a diurnal migration where they forage at the bottom during daytime and in the pelagic food web during the night (Horsted & Smidth 1956).

Breeding distribution: Shrimps migrate horizontally to inshore shallow areas in order to spawn (Hjort & Ruud 1938, Horsted & Smidth 1956, Haynes & Wigley 1969, Bergstrøm 1991), and the northern shrimp spawns in Greenland waters during April (Horsted 1978).

Population size: The northern shrimp stock is assessed as a single population. The total biomass of northern shrimp in West Greenland has increased since the early 1990s, reached its highest level in 2005, and has since decreased. However, total biomass in 2010 appears to be above the level where it can produce its maximum sustainable yield and is above the average for the entire time series (Arboe & Kingsley 2010). Since 2007 the stock has declined in the assessment area, as the distribution of northern shrimp has contracted northwards (Ziemer et al. 2010). Recruitment of northern shrimp has been low since 2006, but the reason for this is uncertain (Ziemer et al. 2010). Pedersen & Storm (2002) and Koeller (2009) suggest that the recruitment of shrimps is dependent on food availability.

Buch et al. (2003) has shown a tight relationship between the occurrence of cod and the disappearance of shrimps. Nevertheless, in recent years the estimated biomass of cod has been very low and there must therefore be other explanations for the decline in shrimp biomass. It would be reasonable to look into a possible mismatch between shrimp egg hatching and the peak of the phytoplankton bloom in order to investigate possible correlations (Wieland & Hovgaard 2009).

Sensitivity and impacts of oil spill: Boertmann et al. (2009) assumed that fish and shrimp larvae are more sensitive to oil than adults, but consequences for survival and impacts on annual recruitment strength, subsequent population size and on the fishery are unknown. Shrimp larvae have a pelagic phase and will be especially sensitive to oil spill during this period.

Knowledge gaps: The early life history of shrimp, including larval drifting between offshore and inshore sites and along the west coast, nursery grounds, settling and occurrence of benthic stages is unknown or poorly understood in the assessment area. Furthermore, there is a need for understanding whether or not there is a link between shrimp recruitment and climate change due to a mismatch in the timing of shrimp larval hatching and the peak of the phytoplankton bloom in West Greenland. The underlying mechanisms for the range shift of the northern shrimp stock, moving south (around 1990) and then north (mid-2000s) in West Greenland waters, are poorly understood. Whether this movement is caused by increased predation affected by the return of cod in southern Greenland, increased bottom temperatures or other factors is unknown. Food web interactions between northern shrimp and their prey and predators are also poorly understood.

Snow crab, *Chionoecetes opilio*

Biology: The snow crab (*Chionoecetes opilio* O. Fabricius; Brachyura, Majidae) has a wide distribution and is considered to be of Arctic-boreal biogeographic affinity, because it does not usually extend north of the Arctic Circle into the High Arctic (Squires 1990), although two exceptions exist (Paul & Paul 1997, Burmeister 2002). Snow crabs mainly inhabits grounds of mud or sand-mud substrate at depths from 30 to 1400 m, where bottom temperature is –1.5 to 4° C year round (e.g., Squires 1990, Dawe & Colbourne 2002). The snow crab may be physiologically constrained to this temperature range, as its energy budget becomes negative beyond it due to reduced feeding and rising metabolic costs (Foyle et al. 1989, Thompson & Hawryluk 1990).

As other brachyuran crabs, the snow crab life cycle features a planktonic larval phase and a benthic phase with separate sexes. The mating system is complex, with a distinct male dominance hierarchy resulting from intense sexual competition favouring larger males (Donaldson & Adams 1989, Elner & Beninger 1995, Sainte-Marie et al. 1999, Sainte-Marie & Sainte-Marie 1999). Females can reproduce several times in their lifetime, may be quite polygamous and have a pair of spermathecae for extended storage of sperm (Elner & Beninger 1995, Sainte-Marie et al. 2000). It is accepted that female snow crab may produce more than one viable brood from spermatophores stored in their spermathecae (Sainte-Marie 1993, Sainte-Marie & Carriere 1995). Eggs are incubated beneath the female's abdomen, and hatching and larval release occur during late spring or early summer just prior to extrusion of the new clutch of eggs, which may or may not be preceded by mating.

The larvae proceed through three planktonic stages (zoeae I – II, megalops) and settle on the bottom during fall, at a carapace width of approximately 3 mm. The snow crab spends the rest of its life on the sea floor, where it preys on fish, clams, polychaetes and other worms, brittle stars, shrimp, other crabs and its own conspecifics (Lefebvre & Brêthes 1991, Sainte-Marie et al. 1997). Crabs grow by moulting, in late winter or spring in the case of larger crabs, and both males and females have a terminal moult to adulthood (i.e. functional sexual maturity), which occur over a wide size interval (Conan & Comeau 1986, Sainte-Marie & Hazel 1992, Sainte-Marie 1993, Sainte-Marie et al. 1999). There is a large sexual size/age dimorphism at adulthood, with males living up to approximately 15–16 years and females up to about 11–12 years after settlement (Sainte-Marie et al. 1995, Alunno-Bruscia & Sainte-Marie 1998, Comeau et al. 1998). The males enter the fishery approximately 8-9 years after settlement to the benthic stage.

Distribution: The most northerly record of snow crabs is from Greenland, where the species is distributed along the west coast between 60° N and 74° N in both offshore and inshore (fjords) locations (Burmeister 2002). Greenland fjord populations are possibly isolated at the benthic stage, as appears to be the case in Canadian fjords (Conan & Comeau 1986, Bernard Sainte-Marie, MLI, Canada, pers. comm.). In Greenland, the snow crab is generally found at depths between 100 and 800 m and at bottom water temperatures ranging from about –1.0° C to about 4.5° C.

Movements: The Greenland coastal system consists of fjords and basins. Fjord populations of snow crab in the benthic phase are partially or completely isolated from one another and from offshore populations by sills (Burmeister, unpubl. data, Burmeister & Sainte-Marie 2010). Genetic analysis showed that snow crabs in West Greenland waters differ significantly from those in western part of the Davis Strait (Atlantic Canada), whereas no difference was found between inshore and offshore subpopulations within the assessment area (Puebla et al. 2008).

Population size: The population occurring in the assessment area has an unfavourable conservation status due to years of high fishing pressure.

Sensitivity and impacts of oil spill: Boertmann et al. (2009) assumed that fish and shrimp larvae are more sensitive to oil than adults. Larvae of snow crabs might be sensitive to an oil spill as well, and consequences for survival and impacts on annual recruitment strength, subsequent population size and on the fishery are unknown. In contrast to pelagic fish and crustaceans, benthic stages of snow crabs are observed not to migrate over larger distance in Greenland, but are believed to be stationary. Change in habitats through chemical pollution is thus of particular interest for snow crab, as they might not be able to avoid contaminated sediment. A laboratory study on habitat preferences for juvenile king crabs (*Paralithodes camtschaticus*) and Tanner crabs (*Chionoecetes bairdi*) exposed to oil led to the suggestion that exposure time is likely to be longer for species intimately associated with sediment, and that pollution might play a larger role in crab population declines (Moles & Stone 2002).

Knowledge gaps: The early life history of snow crabs, including larval drifting between offshore and inshore sites and along the Greenland west coast, nursery grounds, settling and occurrence of benthic stages is unknown or poorly understood in the assessment area.

Greenland halibut, *Reinhardtius hippoglossoides*

Biology: Greenland halibut is a slow growing deep-water flatfish widely distributed in the North Atlantic, including the shelf of the Davis Strait and Labrador Sea and inshore areas along the entire west coast of Greenland. Furthermore it is distributed off East Greenland and around Iceland. The two main spawning grounds are assumed to be located in the central part of the Davis Strait at depths greater than 1500 m, probably around 62° 30′ N - 63° 30′ N, but the precise position has never been located, and at a not very well defined area off Southwest Iceland. Only sporadic spawning has been observed in the inshore areas off Southwest Greenland. Generally eggs and larvae are displaced northward from the spawning ground in the Davis Strait by the West Greenland Current (Smidt 1969, Stenberg 2007), and it is not known to which extent Greenland halibut are recruited to the off- and inshore areas at Southwest Greenland from the spawning ground in the Davis Strait. Tagging experiments (Smidt 1969, Boje 2002) have shown that some Greenland halibut tagged in the Southwest Greenland fjords migrate towards the spawning ground southwest of Iceland, which could indicate an inflow of larvae brought to the assessment area from Iceland by the Irminger Current and the West Greenland Current as it has been observed for cod. This drift pattern has been strongly supported by models simulating the drift of Greenland halibut eggs and larvae at East Greenland and Southwest Greenland (Stenberg 2007). Unpublished studies of larvae in the Southwest Greenland fjords have shown two groups of larvae with different modal length, indicating that the larvae may originate from different areas (J Boje, DTU-Aqua, pers. comm.). Tagging experiments (Boje 2002) and recent unpublished data from Greenland Institute of Natural Resources have shown that Greenland halibut are able to make long distance migrations, and that fish above the larval stage could have migrated into the assessment area from other parts of the Northwest Atlantic. This has, however, never been documented by recapture of fish tagged outside the assessment area, maybe because of the low fishing intensity in the area.

Sensitivity and impacts of oil spill: The assessment area may include (some of) the main spawning grounds of Greenland halibut in the Northwest Atlantic, and the recruitment to important fishing grounds in the Davis Strait, Baffin Bay, eastern Canada and inshore waters in Northwest Greenland and Canada may be dependent on recruitment from this area. Further, eggs and larvae that recruit to the assessment area from the spawning grounds either in the Davis Strait or at Iceland drift slowly through the assessment area at 13-40 m depths (Simonsen et al. 2006) and are very vulnerable to oil if exposed to a large subsurface spill. In such a case, effects on the recruitment to the fishery should be expected. Tainting by oil residues in fish meat is a severe problem related to oil spills. Fish exposed even to very low concentrations of oil in the water, in their food or in the sediment where they live may be tainted, leaving them useless for human consumption (GESAMP 1993). In the case of oil spills, it will be necessary to suspend fishery activities in the affected areas, mainly to avoid the risk of marketing fish that are contaminated or even just tainted by oil (Rice et al. 1996). This may apply to the Greenland halibut fisheries within the assessment area. Large oil spills may cause economic losses due to problems arising in the marketing of the products. Strict regulation and control of the fisheries in contaminated areas is necessary to ensure the quality of the fish available on the market.

Atlantic cod, *Gadus morhua*

Biology: The Atlantic cod is an epibenthic-pelagic species (Coad & Reist 2004) and is distributed in a variety of habitats from the shoreline to the continental shelf. The cod is an omnivorous species, eating anything from invertebrates to fish including younger members of its own species. The Atlantic cod spawns once a year in batches (Murua & Saborido-Rey 2003). Old and large female cod produce more eggs of better quality per female compared to young and small female cod. Eggs from old and large females also have higher probability of surviving (Kjørsvik 1994). In Greenland, the Atlantic cod spawns in spring (April-May). The eggs and later larvae drift with the currents, and the larvae settle in the autumn at a length of 5-7 cm. Temperature has an impact on the abundance as well as the development and survival of the eggs (Buckley et al. 2000).

Distribution and spawning stocks: The Atlantic cod found in Greenland is derived from three separate ‘stocks’ that each is labelled by their spawning areas: I) historical offshore spawning grounds of East and West Greenland; II) spawning grounds in West Greenland fjords and III) Icelandic spawning grounds where the offspring occasionally are transported in significant quantities with the Irminger current to Greenland waters. The Icelandic offspring generally settles off East and South Greenland, whereas the offspring from the Greenland offshore spawning is believed mainly to settle off the

West Greenland coast (Wieland & Hovgaard 2002). The assessment area is therefore a potential nursery area for young cod originating from both the Icelandic and the offshore Greenlandic stocks. Tagging experiments have shown that the offshore stock occasionally migrates to the coastal zone and mixes with the inshore stocks (Storr-Paulsen et al. 2004).

Lumpsucker, *Cyclopterus lumpus*

Biology: Mature lumpsucker adults (3-5 years of age) arrive along the Greenland coastline throughout the assessment area in early spring (Mosbech et al. 2004b) and spawn in the following months in shallow waters (Muus & Nielsen 1998). The male guards and ventilates the approximately 100,000 – 350,000 eggs for a couple of months (Muus & Nielsen 1998, Sunnanå 2005). Based on Norwegian data, the offspring probably spend the first two years in the near shore kelp. The adult fish reside in deeper waters outside the spawning season, but it is unknown if and to where they migrate outside the spawning season. They are however, occasionally caught in near shore shelf areas by bottom trawls (GINR, unpubl. data). The feeding behaviour of Greenland lumpsuckers is unknown, but due to their poor swimming capabilities it is most likely restricted to jellyfish and other slow moving organisms (Muus & Nielsen 1998). Lumpsuckers may constitute a significant prey resource for sperm whales in the area as seen elsewhere (Kapel 1979, Martin & Clarke 1986).

Distribution: The lumpsucker is distributed throughout the assessment area, and also found at both higher and much lower latitudes (i.e. North Sea). Hence, climatic changes will most likely not negatively affect the lumpsucker in the assessment area through direct temperature effects. However, as little is known on lumpsucker migrations and dependency on other ecosystem components, it is unclear how the species would response to climatic changes.

Sensitivity and impacts of oil spill: Given the dependency on shallow waters near coastal areas for spawning, the lumpsucker will be especially sensitive to an oil spill on beaches in the spawning period. Other potentially important areas, such as feeding areas, are not known. The overall sensitivity of lumpsuckers was estimated as moderate in an environmental oil spill sensitivity atlas for the coastal zone in the assessment area (Mosbech et al. 2004b), and similar conclusions should apply in this case.

Salmon, *Salmo salar*

Biology and distribution: Atlantic salmon migrate to Greenland from countries around the North Atlantic. In Greenland, the only known spawning population of Atlantic salmon is located in the Kapisillit river in the inner part of the Nuuk fjord, West Greenland (Nielsen 1961). Other rivers that could potentially hold a salmon population exist, but in general the rivers of Greenland are short, steep and cold (Jonas 1974). Although persistent, the contribution of the small Kapisillit population to the salmon fishery around Greenland, must be regarded as insignificant, compared to other countries around the North Atlantic. Salmon can be found in the waters around Greenland throughout the year, but the abundance seems to peak in the autumn from August to October. In West Greenland the northern distribution limit varies from year to year, but salmon can be found as far north as the Upernavik district around 72° N.

Population size: In recent years, the overall status of the stocks of both North American and European origin contributing to the West Greenland fishery is among the lowest recorded, and as a result the abundance of salmon in Greenland waters is thought to be extremely low compared to historic levels.

Capelin, *Mallotus villosus*

Distribution: The capelin has a circumpolar distribution and in Greenland it is found from the southern tip to 73°N and 70°N on the west and east coast, respectively. Although not thoroughly documented, known differences in maximum length, progressive spawning and well separated fjord systems suggest that individual fjord systems contains separate capelin stocks (Sørensen & Simonsen 1988, Hedeholm et al. 2010).

Capelin distribution in 2005 was studied by Bergstrøm and Vilhjalmarsson (2007). Capelin was absent offshore, but present in the fjords and near-shore areas (between 60-70° N) (Fig. 4.4). The capelin biomass in these fjords and near shore areas was estimated to be between 170-200,000 t. In West Greenland waters, capelin spawn and grow in the many and varied fjords or fjord complexes. Only a small part of the stock usually remains at the deep shrimp grounds and distributed farther north. Bergstrøm and Vilhjalmarsson (2007) covered none of the deep water areas west of the West Greenland shelf break, therefore it can neither be confirmed nor rejected that the adult stock migrates across the shelf to feed in summer/autumn in the deep waters of the eastern Davis Strait.

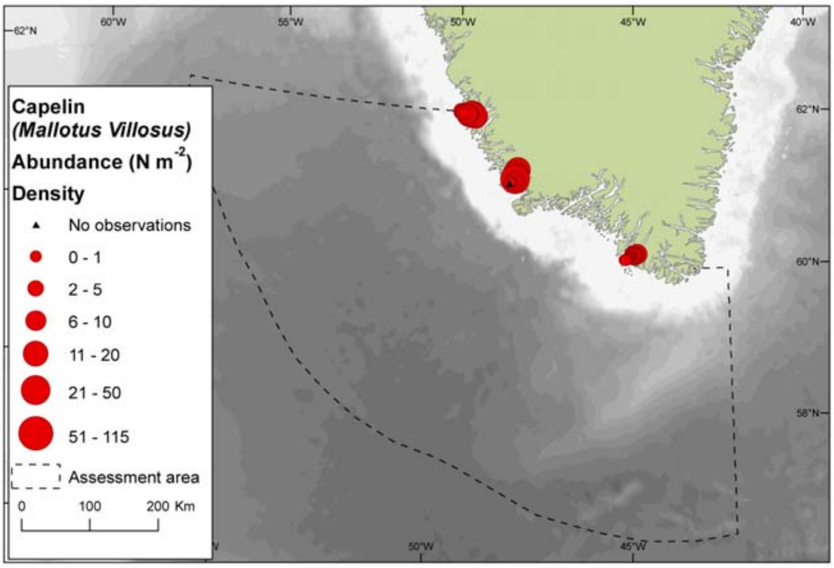


Figure 4.4. Capelin (*Mallotus villosus*) abundance (N m^{-2}) from acoustic measurements from September 2005 in the 0-50 m column (Bergstrøm & Vilhjalmarsson 2007). High capelin abundance was found in the fjord systems.

Biology: Sometime during autumn to spring, capelin migrate to the fjords, where they form dense schools prior to spawning. Spawning takes place in shallow water (<10 m) and often on the beach in the period from April to June. Deep water spawning known from other capelin populations (e.g., Vilhjálmsson 1994)) has not been documented in Greenland. Capelin spawn when they are typically 3-5 years of age (Hedeholm et al. 2010). Although not strictly semelparous, a large proportion of the spawning stock dies, especially males, suggesting that the stock should be considered as one time spawners (Huse 1998, Friis-Rødel & Kanneworff 2002). Outside the spawning season, capelin reside primarily in the upper pelagic (0-150 m) but concentrations are sometimes found in deeper waters down to 600 m (Huse

1998, Friis-Rødel & Kanneworff 2002). As elsewhere, Greenland capelin form a crucial energy converting link from lower to higher trophic levels making it an ecosystem key species (Hedeholm 2010). Hence, in South Greenland capelin feed (depending on size) primarily on copepods, krill and hyperiid amphipods (Hedeholm 2010). Typical of Arctic food chains, these fatty prey entail that capelin also have a high energy content (Hedeholm 2010) making them high quality prey for various apex predators such as cod (Hedeholm 2010), harp seals (Kapel 1991), whales and various seabirds (Friis-Rødel & Kanneworff 2002, Vilhjálmsson 2002) .

Sensitivity and impacts of oil spill: Key locations for capelin include spawning beaches. These are numerously present in most of the fjords in the assessment area, from the bottom of fjords to the coastal region. Given the high degree of spawning mortality, any year in which spawning fails on a large scale will be detrimental to the population. Hence, an oil spill near spawning beaches can be extremely damaging to the local capelin stocks (Mosbech et al. 2004b). The recovery time of such an event is unknown, as it is still unknown whether each fjord hosts a separate genetically isolated stock or if they mix. Additionally, within the assessment area, only the near coastal shelf area is of importance to capelin and here capelin is not as vulnerable as they are highly mobile. Furthermore, because they are pelagic feeders they are not as susceptible to long-term effects as benthic feeders.

Sandeels, *Ammodytes* spp.

Biology: Sandeels (or sand lance) are small bentho-pelagic fish with a central position in many marine food webs. Two species occur in Greenland: the lesser sandeel (*Ammodytes marinus*) and northern sandeel (*A. dubius*). They are extremely similar and difficult to distinguish, and most surveys have recorded sandeels simply as *Ammodytes* spp. Where they occur in high abundance, sandeels are typically a key prey for many seabirds, marine mammals, and larger fish species. They feed on zooplankton in the pelagic zone, mainly copepods, particularly *Calanus finmarchicus*. Sandeels spend a large part of their time buried in sandy sediments, and are most active during the night, when they feed in the water column. Feeding occurs mainly during spring and summer, and for a large part of the year they remain buried. Sandeels are thus habitat specialists, and the highest abundances are found on major sand banks at up to 100 m depth. However, smaller areas with suitable sandy sediments, e.g. around islands where currents are strong, are also likely to be sandeel habitat. Probably because the assessment area has few major banks, there are no surveys of sandeel adults or larvae. However, it is likely that sandeels play an important ecological role in the shelf ecosystem, particularly as prey for breeding seabirds and summer-feeding baleen whales.

Sensitivity and impacts of oil spill: Being habitat specialists, sandeels are very sensitive to localised oil spills, particularly if the oil settles on the sea floor. Detailed sea floor topography and sediment characteristics are not well known in the assessment area, and it is therefore not possible to identify specific areas of high importance for sandeels. Earlier studies indicated that sandeels off West Greenland spawned during the summer (Andersen 1985), but more recent surveys have found abundant young larvae during summer (Munk et al. 2003, Simonsen et al. 2006), indicating mean hatching dates around 1 May.

Redfish, ***Sebastes mentella*** **and** ***Sebastes marinus***

Biology: Four species of redfish live in the North Atlantic, but only deep-sea redfish (*Sebastes mentella*) and golden redfish (*Sebastes marinus*) are common in West Greenland waters (Møller et al. 2010). Both deep-sea redfish and golden redfish are highly valuable commercial species. Survey indices for both redfish species combined in the Greenland shrimp survey varied between 1 and 2.4 billion individuals from 1992 to 1996, but have decreased since then to approximately 84 million individuals in 2009 (Nygaard & Jørgensen 2010), equivalent to a 25-fold abundance decrease in 15 years.

Wolffish, ***Anarhichas minor***, ***Anarhichas lupus*** **and** ***Anarhichas denticulatus***

Biology: Three species of wolffish live in the waters of Greenland, spotted wolffish (*Anarhichas minor*), Atlantic wolffish (*Anarhichas lupus*), and northern wolffish (*Anarhichas denticulatus*). Whereas Atlantic wolffish is a highly commercial and valuable fish, spotted wolffish is of less commercial interest, and northern wolffish of no commercial interest and only consumed in a few countries. All three species of wolffish are distributed across the North Atlantic from USA to Spitsbergen and the Barents Sea and along the coasts of northern Europe. Survey indices indicate that the biomass of Atlantic wolffish is very low compared to the mid-1980s, and that the biomass of spotted wolffish increased between 2002 and 2008.

American plaice, ***Hippoglossoides platessoides***

American plaice is distributed throughout the North Atlantic from the coast of Murmansk to southern Labrador and USA. Survey indices indicate that the biomass of American plaice in West Greenland waters is low compared to the 1980s (Nygaard & Jørgensen 2010).

Thorny skate, ***Amblyraja radiata***

Thorny skate is a distributed throughout the North Atlantic from Hudson Bay, along the coast to USA, Greenland to Iceland, the English Channel, the Baltic, Svalbard and the Barents Sea. Survey indices indicate that the biomass of thorny skate in West Greenland has decreased substantially since the 1980s (Nygaard & Jørgensen 2010).

4.6 Seabirds

David Boertmann, Daniel S. Clausen & Morten Frederiksen (AU)

The assessment area is in a conservation context and both nationally and internationally very important for marine birds, particularly in winter and during the migration seasons in spring and autumn. The wintering seabirds include not only birds of Greenland origin, but also birds from Canada, Svalbard, Iceland, Norway, Russia and other countries (Boertmann et al. 2004, Boertmann et al. 2006). In spring and autumn, large numbers of seabirds migrate through the assessment area, mainly between breeding areas in the Barents Sea and Greenland Sea regions, Iceland and Northwest Greenland, and wintering areas in Newfoundland waters, the Labrador Sea and the Davis Strait. Finally, seabirds breeding in the south Atlantic use the assessment area as their winter quarters (during the northern summer).

The most important species wintering in the assessment area are common eider, harlequin duck and thick-billed murre. Particularly important wintering areas are the coastal waters of the northern Julianehåb Bugt including Bredefjord, the central part of the bay including the fjords Lichtenau and

Uunartoq, and the archipelagos off Nanortalik including the outer parts of Tasermiut Fjord (Fig. 4.5).

The most important populations passing through the assessment area on migration are thick-billed murres from Svalbard and Iceland, little auks from Svalbard and East Greenland, Atlantic puffins from Iceland, black-legged kittiwakes from throughout the North Atlantic, and ivory gulls from North Greenland, Svalbard and Russia.

The following paragraphs give an overview of the birds utilising the marine environment and therefore potentially exposed to oil spills from exploration and exploitation activities in the licence blocks off the South Greenland coast.

Besides the species described below, a number of seabird species occur in low numbers within the assessment area, for example Leach's storm petrel (*Oceanodroma leucorhoa*), sooty shearwater (*Puffinus griseus*), four species of skuas/jaegers (*Catharacta/Stercorarius* spp.), and herring gull (*Larus argentatus*).

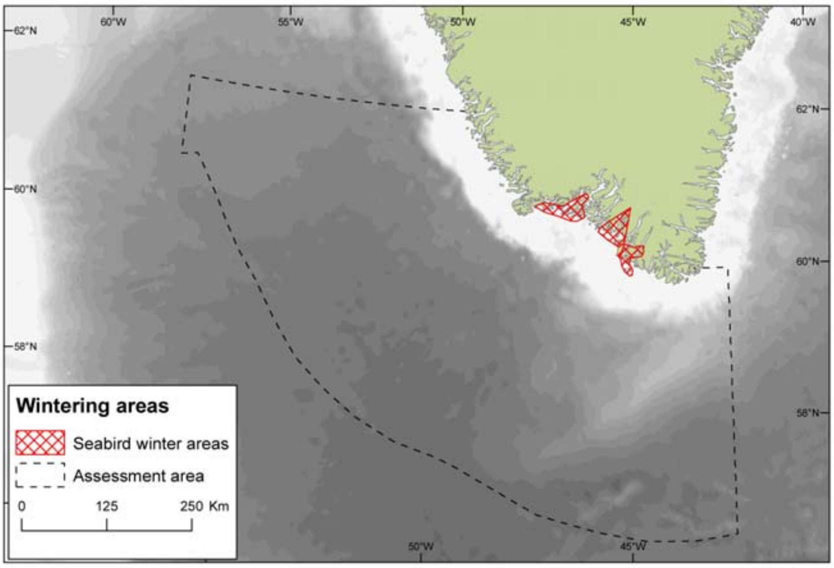


Figure 4.5. Important near-shore wintering areas for seabirds in the assessment area (Boertmann et al. 2004).

4.6.1 Breeding birds

In total, 20 species of seabirds breed in the area (Table 4.2). These species usually breed in colonies on steep cliffs or low islets, although some may also breed dispersed – such as great black-backed gull and Arctic skua. The distribution and numbers of birds in the colonies are fairly well known, and approx. 130 seabird breeding colonies are known in the area (Fig. 4.6). However, many colonies have not been surveyed since 2003, and especially the southernmost part of the region near Cape Farewell has not been surveyed thoroughly and may hide colonies with important species such as murres, razorbills and puffins.

Table 4.2. Selected birds utilising the marine environment off South Greenland.

Species	Scientific name	Occurrence*	Colonial breeder in region (number of colonies)	Habitats
Great northern diver	*Gavia immer*	su, mi		Coastal
Red-throated diver	*Gavia stellata*	b, su, mi		Coastal
Northern fulmar	*Fulmarus glacialis*	b, mi, w	Yes (2)	Offshore
Great shearwater	*Puffinus gravis*	mi, mo, su		Offshore
Great cormorant	*Phalacrocorax carbo*	su, w		Coastal
Mallard	*Anas platyrhynchos*	b, mo, w	No	Coastal
Long-tailed duck	*Clangula hyemalis*	b, mo, w	No	Coastal
Harlequin duck	*Histrionicus histrionicus*	mo, w		Coastal
Red-breasted merganser	*Mergus serrator*	b, mo, w	No	Coastal
Common eider	*Somateria mollissima*	b, mo, w	Yes (>35)	Coastal
King eider	*Somateria spectabilis*	w	No	Coastal
White-tailed eagle	*Haliaeetus albicilla*	b, w	No	Coastal
Arctic skua	*Stercorarius parasiticus*	b, mi, w	Yes/no	Coastal/offshore
Lesser black-backed gull	*Larus fuscus*	b	Yes (>25)	Coastal
Iceland gull	*Larus glaucoides*	b, w	Yes (c. 35)	Coastal/offshore
Glaucous gull	*Larus hyperboreus*	b, w	Yes (c. 35)	Coastal/offshore
Great black-backed gull	*Larus marinus*	b, w	Yes/no (c. 60)	Coastal
Black-legged kittiwake	*Rissa tridactyla*	b, mi, w	Yes (13)	Coastal/offshore
Ivory gull	*Pagophila eburnea*	mi, w		Coastal/offshore
Arctic tern	*Sterna paradisaea*	b	Yes (16)	Coastal/offshore
Common murre	*Uria aalge*	b, w	Yes (1)	Coastal/offshore
Thick-billed murre	*Uria lomvia*	b, mi, w	Yes (2)	Coastal/offshore
Razorbill	*Alca torda*	b	Yes (15)	Coastal/offshore
Black guillemot	*Cepphus grylle*	b, w	Yes (c. 95)	Coastal/offshore
Little auk	*Alle alle*	mi, w		Offshore
Atlantic puffin	*Fratercula arctica*	b, mi, w	Yes (5)	Coastal/offshore

*b: breeding, w: wintering, su: summering, mi: migrant in spring or autumn, mo: moulting in late summer/early autumn.

The colonies are generally small, especially compared to the large colonies of fulmars, murres and little auks found in the regions of Disko Bay and Northwest Greenland. Most of them hold less than 200 breeding pairs, but a few colonies have more than 1000 pairs, particularly the large colonies in the archipelago of Ydre Kitsissut (approx. 2300 thick-billed murres) and in the Arsuk Fjord (approx. 500 thick-billed murres and 2000 kittiwakes). In a conservation context, these two colonies are very important because of the presence of thick-billed murres and kittiwakes (both red-listed in Greenland, see Table 6.1). Furthermore, Ydre Kitsissut has a very diverse seabird community, including the largest colony of the nationally red-listed (as Endangered) common murre in Greenland (Kampp & Falk 1994). Another archipelago with a high diversity of breeding seabird is Indre Kitsissut (Boertmann 2004). Colonies with nationally red-listed species such as common eider, Atlantic puffin and black-legged kittiwake are also important.

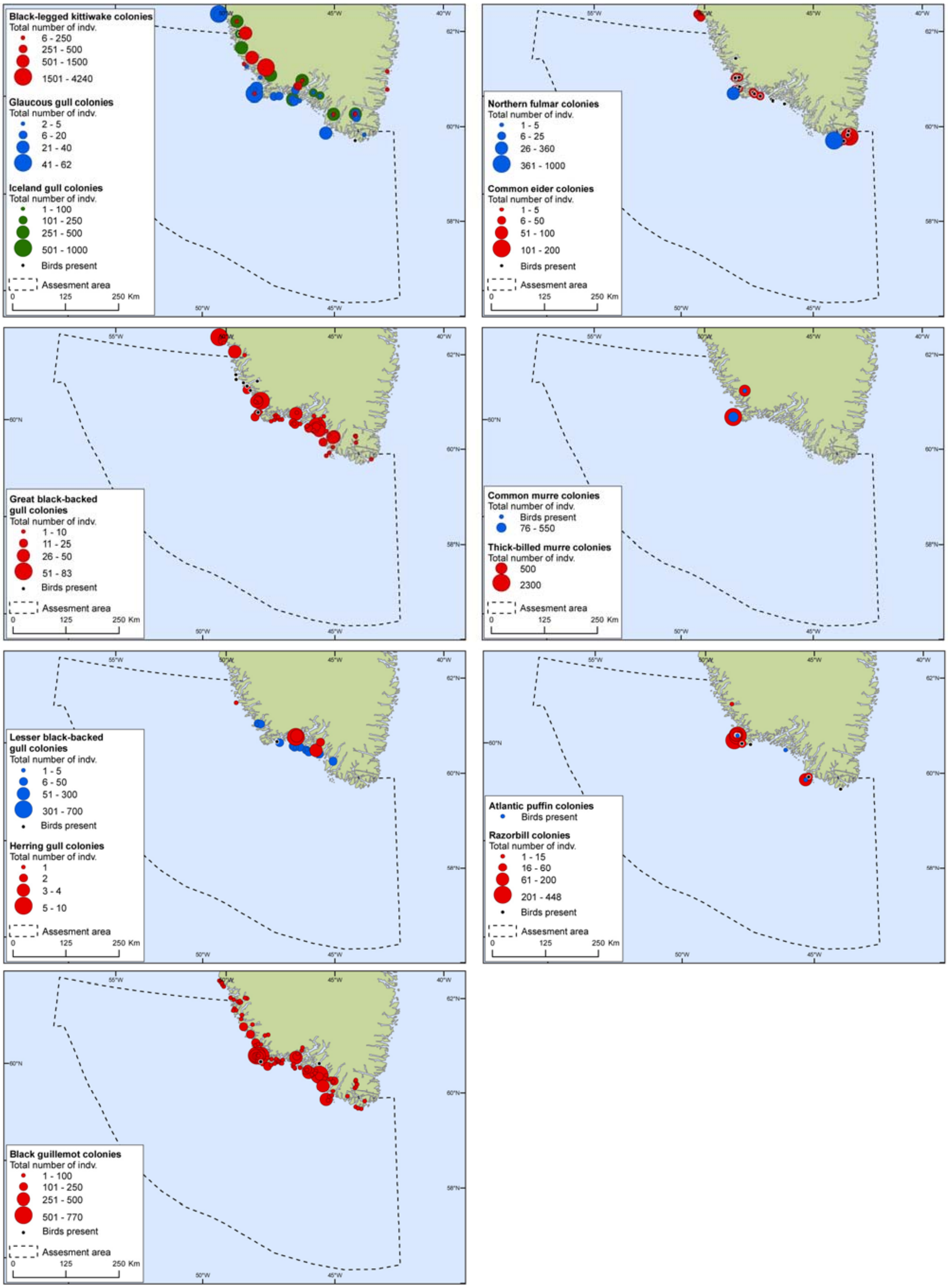


Figure 4.6. Breeding colonies of seabirds in the assessment area (Boertmann et al. 1996, updated).

4.6.2 Seabirds at sea

Offshore seabirds have been surveyed within the assessment area from ship and aircraft. Summer data are available from a single ship-based survey and from an aircraft-based survey in July 1999 (Boertmann & Mosbech 2001a, 2002). Autumn data derive from several ship-based surveys, including Marine Mammal and Seabird Observers (MMSOs) on seismic survey ships (AU unpubl. data, Boertmann & Mosbech 2001b, Boertmann in press). Winter data only exist from a single ship-based survey (Durinck & Falk 1996) and from an extensive airborne survey in March 1999 (Merkel et al. 2002). In addition to Greenland surveys, summer data also derive from the Eastern Canadian Seabird-at-Sea program, which includes transects overlapping waters of the assessment area (Gjerdrum et al. 2008, Fifield et al. 2009). There are no data from the spring season (April-May). In general, all Greenland surveys have covered coastal and shelf waters, and seabird data from the deep oceanic parts of the assessment area are missing. Besides the Canadian surveys, only a single survey in September 2006 included some transects in offshore waters.

High concentrations of seabirds have been observed in the shelf waters in Julianehåb Bugt in summer and autumn (Fig. 4.7). These mainly consist of kittiwakes and fulmars, and a large part are probably non- and perhaps post-breeding birds from colonies outside the assessment area, including the entire North Atlantic region (Lyngs 2003, Frederiksen et al. 2012). Such birds are present throughout the summer months, and are often in company with great and sooty shearwaters breeding in the southern hemisphere. Especially great shearwaters have been reported in very large moulting flocks in Julianehåb Bugt in the 1950s (Salomonsen 1967), but such aggregations have not been encountered in recent decades.

a) Summer

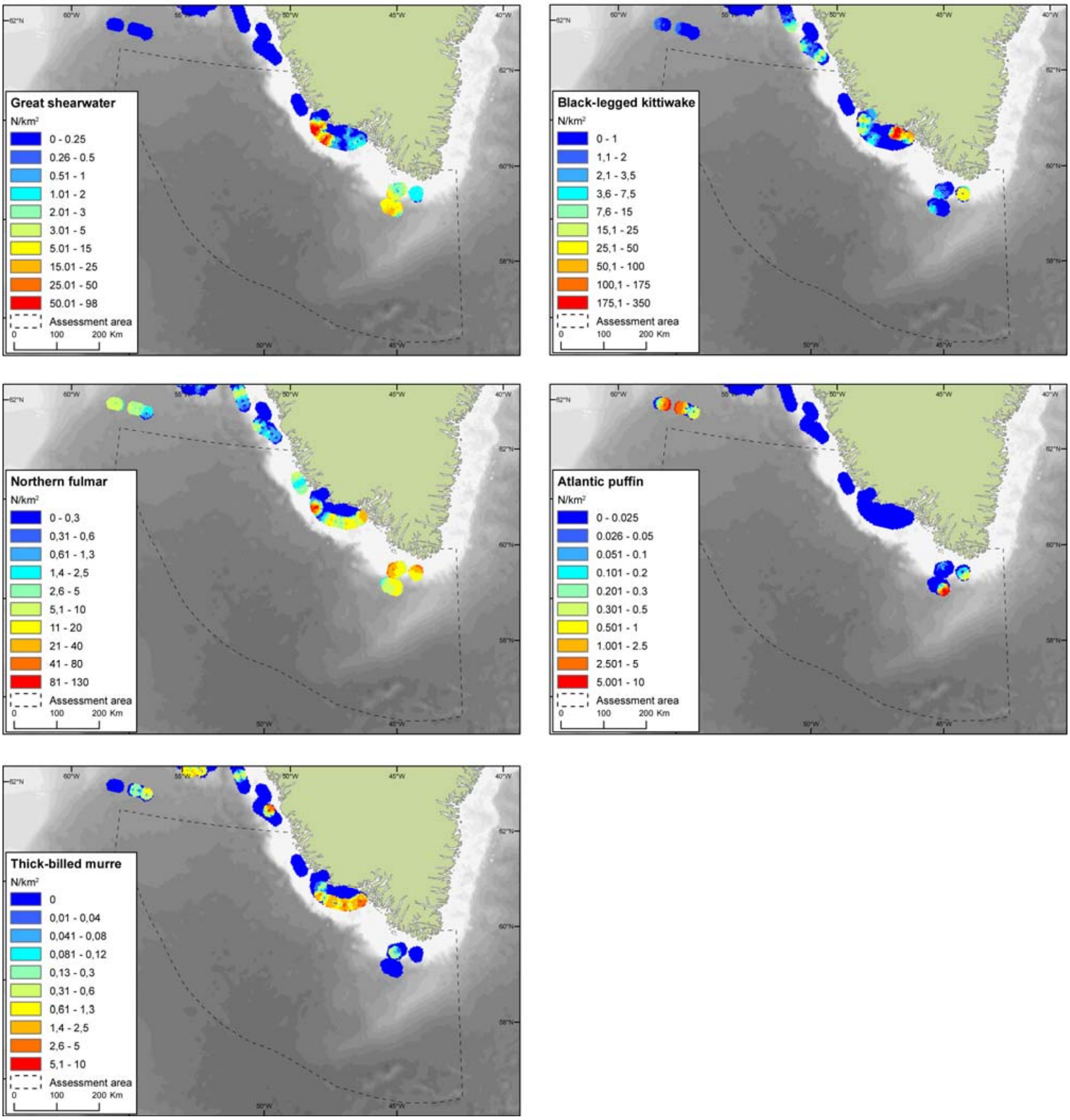


Figure 4.7a. At-sea distribution of seabirds in the assessment area during summer (Jun-Aug) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons and species.

b) Autumn

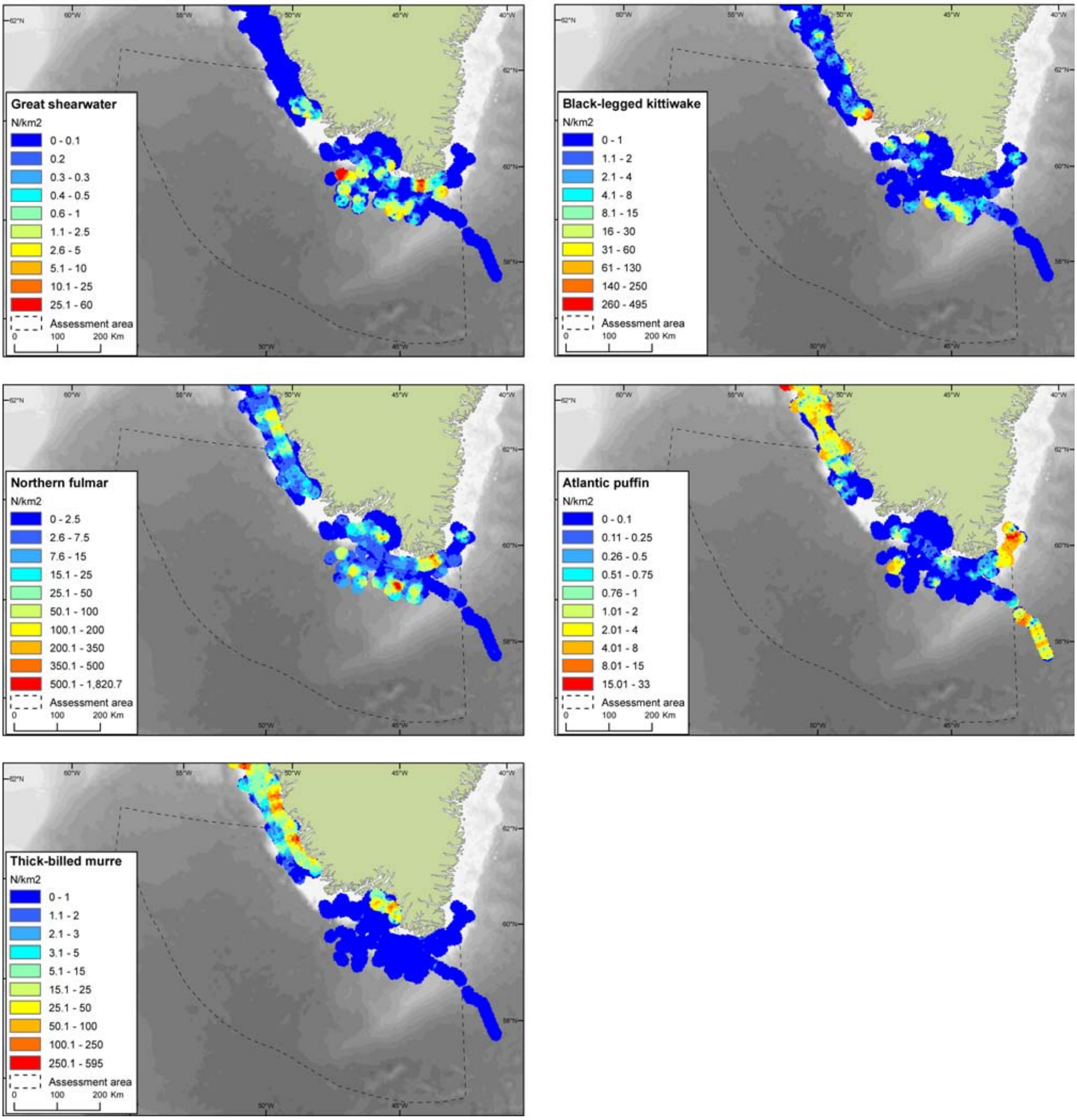


Figure 4.7b. At-sea distribution of seabirds in the assessment area during autumn (Sep-Dec) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons and species.

c) Winter

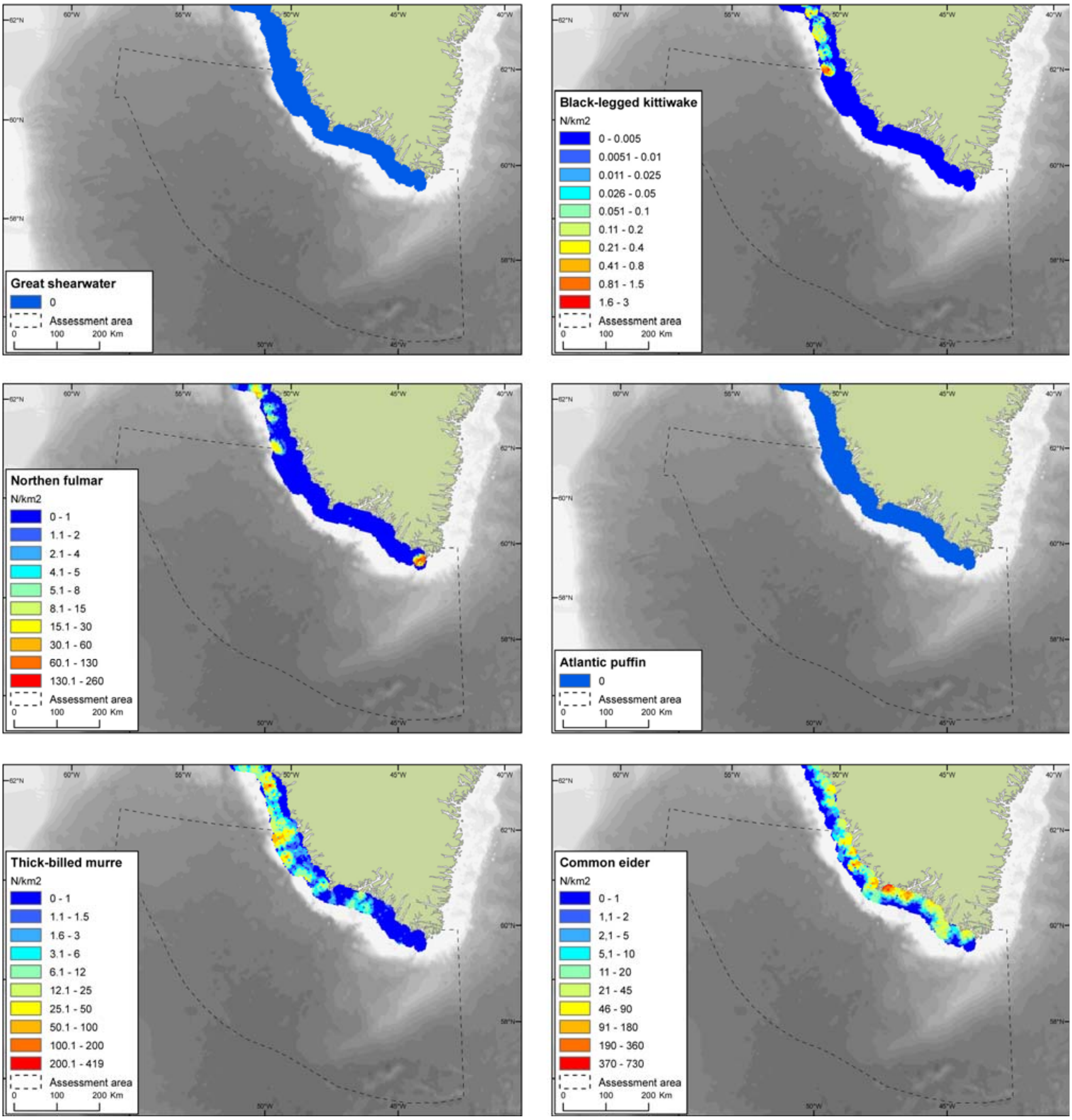


Figure 4.7c. At-sea distribution of seabirds in the assessment area during winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons and species.

Auks also occur offshore, and several species are involved. The most important is the thick-billed murre. The highest densities of this species have been recorded in coastal waters in autumn (Fig. 4.7). Ring recoveries indicate that large numbers of murres from the eastern Atlantic (Svalbard, Russia) and Iceland move to southwest Greenland (Kampp 1988, Lyngs 2003). In late October 2011, high densities of thick-billed murres were observed on the shelf off Julianehåb Bugt (D. Boertmann, unpubl. data), and such high densities may also occur in the assessment area during winter.

The winter population of thick-billed murres in West Greenland, deriving from the Barents Sea and Iceland, is estimated at 1.45 million birds (Barrett et al. 2006). All these birds, plus birds from the same breeding areas wintering in Canadian waters, migrate through the assessment area in spring (February and March) and autumn (late October and November).

Little auks from the large colonies in Svalbard (> 1million pairs (Anker-Nilssen et al. 2000)) and East Greenland (3.5 million pairs (Kampp et al. 1987)) at least pass through the assessment area on migration. Many probably also spend the winter there in offshore waters, as indicated by the fact that all the winter recoveries of birds ringed in Svalbard are from West Greenland (Bakken et al. 2003). The Canadian surveys reported relatively high densities (1-21 birds/km^2) of little auks in May to August in the assessment area (Fifield et al. 2009), but with no details regarding specific dates or presence of ice. A recent tracking study of five little auks from breeding sites in East Greenland (Mosbech et al. 2011b) showed that four of the birds wintered in waters off Newfoundland, although one spent November in offshore waters covered by this report before moving on to Newfoundland. The fifth bird wintered south of Iceland.

Atlantic puffins occur in relatively high numbers and locally in densities of up to 10 birds/km^2 in offshore parts of the assessment area in September and October (Boertmann & Mosbech 2001b, Boertmann in press). These birds seem to be of Icelandic origin, although they could also come from the Faroes, Scotland and Norway. Whether they are on passage to winter quarters further west or have a post-breeding staging area in the Davis Strait is unknown.

Ivory gulls breeding in the northeast sector of the Arctic Atlantic (Northeast Greenland, Svalbard and the Russian Arctic) move south in autumn in the drift ice off East Greenland to winter quarters mainly in the marginal ice zone in the Labrador Sea and the Davis Strait, where they arrive in December (Orr & Parsons 1982, Gilg et al. 2010). This means that the majority of the entire northeast Atlantic population of the ivory gull moves through the assessment area in late November and early December (Gilg et al. 2009, Gilg et al. 2010). In years when the drift ice in winter moves into the assessment area from the west, ivory gulls will be present, but the fraction of the population is unknown. In spring, most of the gulls probably move the same way back through the assessment area, although it has been shown that they can migrate northwards in the Davis Strait and across the Greenland Ice Sheet to Northeast Greenland (O. Gilg pers. comm.). Observations from 2011 show that adult ivory gulls are present in Julianehåb Bugt as early as late October (D. Boertmann, unpubl. data), a fact not revealed by the satellite-tracked birds.

The ivory gull is of high conservation concern (Gilg et al. 2009, Gilg et al. 2010), being listed as Near threatened on the international Red List (IUCN 2011), as Vulnerable on both the Greenland and the Svalbard Red Lists (Boertmann 2007b, Kålås et al. 2010), and as Endangered by the Committee on the Status of Endangered Wildlife in Canada.

Black-legged kittiwakes from colonies throughout the Atlantic range occur in the assessment area during the non-breeding season, from August to March. Large numbers of recoveries of kittiwakes ringed in Europe indicate the importance of the area (e.g. Coulson 2002, Bakken et al. 2003). A recent multi-colony study using geolocation (Frederiksen et al. 2012) has allowed estimation of the number of adult kittiwakes present in the assessment area at various times of the year (Fig. 4.8). The number peaks in October (450,000, or 10% of the Atlantic population) and again in February (300,000), with fewer birds present in mid-winter. In addition, large (probably similar) numbers of pre-breeders also occur. Most of these birds occur offshore in the deep Labrador Sea (Frederiksen et al. 2012). Although common, the kittiwake is declining and red-listed in Greenland and many other Atlantic countries.

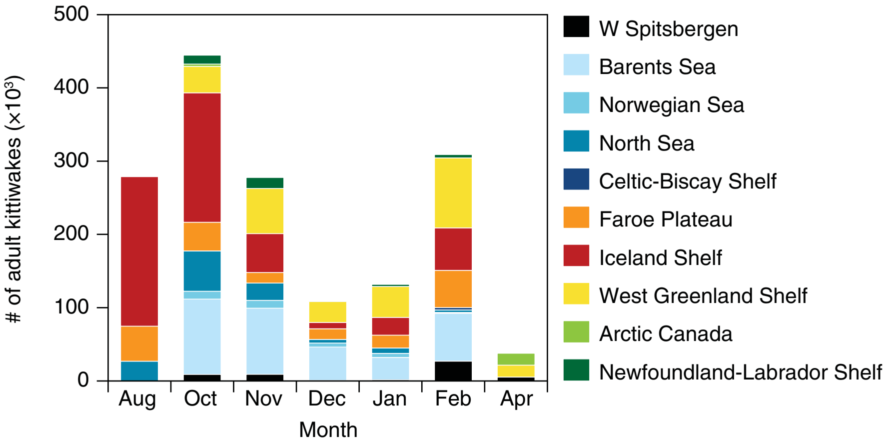


Figure 4.8. Estimated numbers and breeding origin of adult black-legged kittiwakes in the assessment area during the non-breeding season, based on birds tagged with geolocators in 18 Atlantic colonies (Frederiksen et al. 2012).

4.6.3 Coastal habitats

The coastal waters and adjacent coasts are utilised by a number of bird species, including true seabirds and also species which during certain periods of their annual life cycle may occur inland and at freshwaters. Knowledge on coastal birds derives mainly from some of the surveys reported above in the paragraphs on breeding birds and birds at sea.

The most important of the coastal seabirds is the common eider. Besides breeding in the assessment area in relatively low numbers (see above), moulting and wintering birds occur. Moulting common eiders are generally found in small flocks scattered along the rocky coasts of West Greenland, including the assessment area. During the aerial survey in July 1999, several flocks of moulting common eiders were located in the outer parts of Julianehåb Bugt, most of these far from the coast. In winter, the population of common eiders in the assessment area is very large. The survey in March 1999 resulted in an estimate of 96,000 wintering common eiders in Julianehåb Bugt (Fig. 4.7) (Merkel et al. 2002).

Another very important species in this habitat is the harlequin duck. It occurs here almost throughout the year, although breeding takes place inland at rivers. However, moulting post- and non-breeding males assemble at rocky coasts from July, and these birds are later accompanied by the post-breeding females and juveniles of the year, and they all winter in the same habitats. At these exposed, rocky coasts, high concentrations of harlequin ducks occur. The species is red-listed in Greenland (Table 6.1), due to a small population size. A survey for moulting flocks of this species was carried out in July 1999, covering the entire coast between Disko Bay and western Julianehåb Bugt (Fig. 4.9) (Boertmann & Mosbech 2002). The highest densities (10-20 birds/km) located during the survey were found along the coasts between Arsuk and Paamiut. During a subsequent survey for seabird breeding colonies by boat in 2003, harlequin ducks were searched for along the coasts south of Arsuk Fjord and all the way to Cape Farewell. Only very few were observed along the coasts not surveyed in 1999 (Boertmann 2004), indicating that moulting harlequin ducks are mainly found west of Bredefjord. Satellite tracking has revealed that harlequin ducks move from Canadian breeding grounds to Greenland coasts to moult (Chubbs et al. 2008), and a significant (but unknown) part of the birds recorded in July 1999 were probably of Canadian origin (Boertmann & Mosbech 2002).

The winter distribution of harlequin ducks has not been surveyed, but it is assumed to include the southern part of the moulting range, and high numbers have been reported from the Arsuk area (Boertmann 2003, 2008).

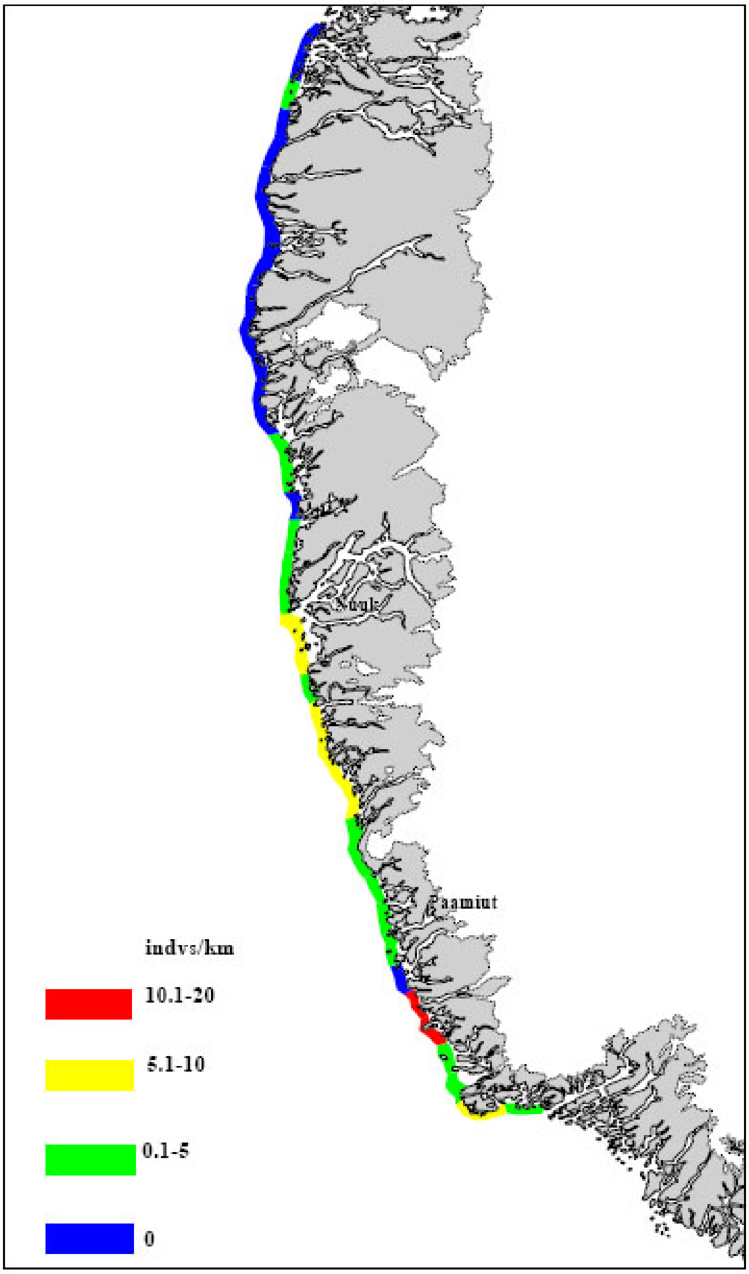
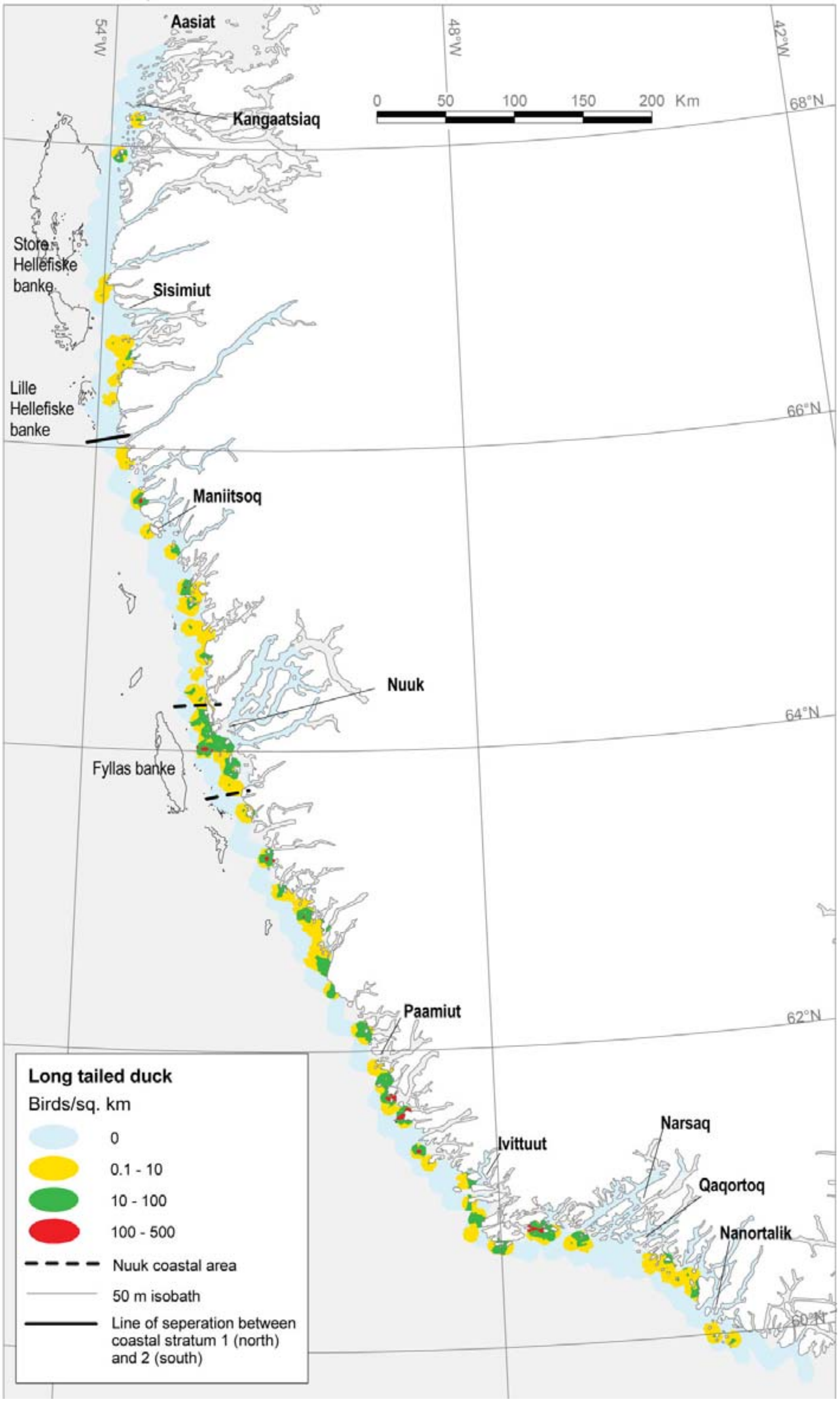


Figure 4.9. The density of moulting harlequin ducks recorded in July 1999 expressed as the number of birds recorded per km surveyed coastline (Boertmann & Mosbech 2002). The moulting period is July to September.

Other duck species which occur in the marine environment are mallard, long-tailed duck and red-breasted merganser. The long-tailed duck breeds scattered along sheltered coasts and moulting birds assemble in shallow bays and fjords. However, there are no major concentrations of moulting birds known from the assessment area. A survey in March 1999 resulted in an estimate of 94,000 wintering long-tailed ducks in Southwest Greenland, distributed mainly south of Nuuk (Fig. 4.10), and high densities were recorded in the western part of Julianehåb Bugt (Merkel et al. 2002). Satellite tracking has shown that breeding birds from Northeast Greenland move to the assessment area during winter (Mosbech et al. 2011a), and Icelandic breeders are also known to winter in this area (Lyngs 2003).

Figure 4.10. Distribution and interpolated densities of long-tailed duck in Southwest Greenland based on aerial surveys in February/March 1999 (Merkel et al. 2002).



Box 1

Field study of seabirds at Ydre Kitsissut 2009-11: preliminary results

Jannie Fries Linnebjerg, Anna Reuleaux & Morten Frederiksen (AU)

The archipelago Ydre Kitsissut (60°46’ N, 48°28’ W) west of Nunarsuit has a uniquely diverse and important community of breeding seabirds, including scarce species such as common murre and Atlantic puffin. It is also the largest colony of cliff-nesting seabirds in the assessment area. Unfortunately, little is known about which areas at sea are important for the birds nesting here, both during and outside the breeding season. There is also a need for updated information on population status, as previous visits (most recently in 1999) have demonstrated an on-going decline in the number of breeding thick-billed and common murres (Falk et al. 2000). Therefore, a dedicated field study was carried out during the 2009-11 breeding seasons; preliminary results of the work are presented here.

Population status

Previous surveys had found a combined population of thick-billed and common murres of 9015 in 1985, 9900 in 1992, and 5943 in 1999. In 2009, photographic counts showed that only 2408 murres were present, equivalent to a decline of nearly 60% since 1999 or 8.7% decline/year. In 2010, 3449 murres were counted, implying a 42% decline since 1999, or 4.8%/year. The reasons for this decline are presently unclear, but illegal egg collection has taken place regularly in the colony, and continues to do so (P.N. Hansen, pers. comm.). This may have contributed to the decline. Other seabird species with less accessible nests (e.g. razorbill, Atlantic puffin and black guillemot) seem to have more stable or increasing populations.

Foraging areas during the breeding season

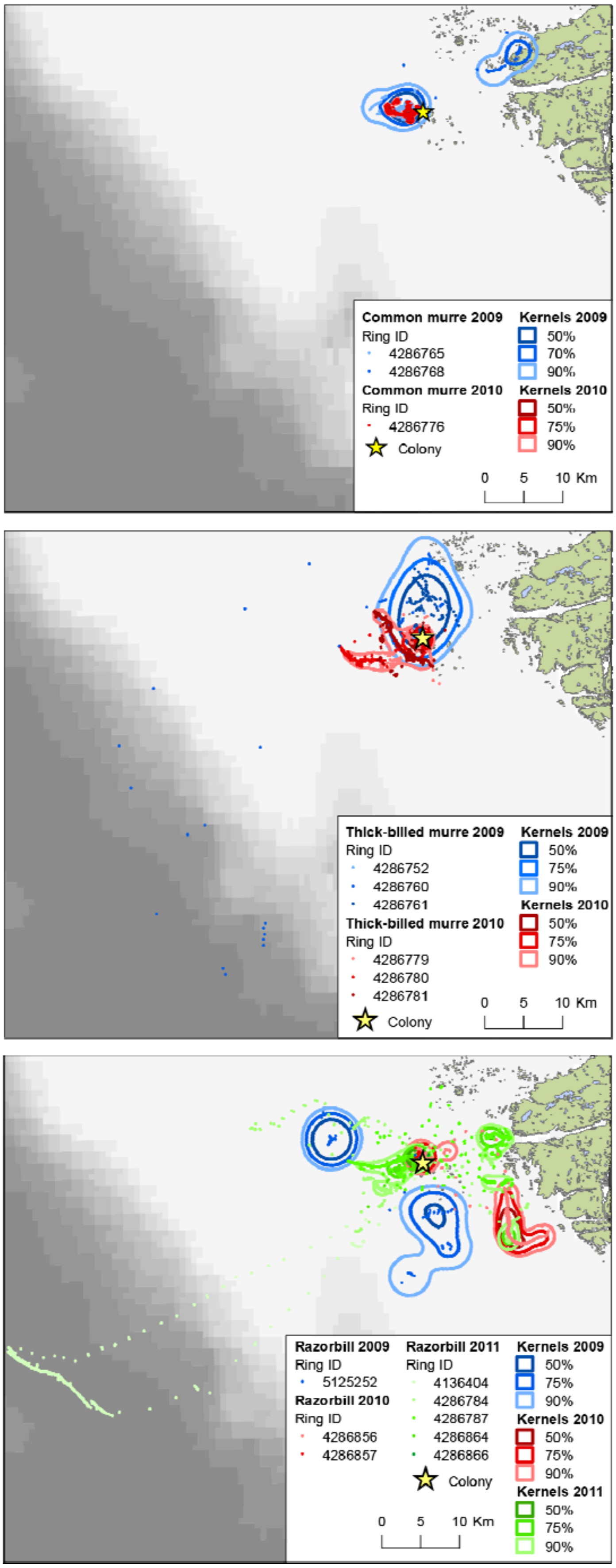
We used GPS data loggers to investigate the space use of three species of seabirds (common murre, thick-billed murre and razorbill) during the breeding season (Fig. 1). Most birds of all species foraged in relatively shallow water close to the colony and towards the mainland to the east, normally within 20 km of the nest site. However, a few birds (one thick-billed murre in 2009 and one razorbill in 2011) also foraged in deep waters at or beyond the shelf break up to 60 km from the colony. The most important areas appeared to be west and east/southeast of the colony, whereas relatively few birds foraged to the north and south. There are few data on prey choice (chick diet of thick-billed murres in 2010 was predominantly capelin), but the considerable variation observed in the direction and length of foraging trips indicates that birds feed on a variety of prey, probably including both benthic and pelagic fish. An oil spill off South Greenland during summer would be likely to cause severe impacts on locally breeding seabirds, if the oil were to reach a 20 km zone around Ydre Kitsissut.

Migration and wintering areas

Migration of four auk species was followed using geolocators, tiny data loggers which record light levels and provide rough daily estimates of position (Fig. 2). The four species showed very different patterns. Common murres largely spent the winter off the coast of Southwest Greenland, although one individual spent the late winter period off East Greenland and another mainly stayed offshore in the Labrador Sea. Similarly, most thick-billed murres stayed off South and Southwest Greenland, but one bird spent part of the winter in the southern Labrador Sea east of Newfoundland. In contrast all razorbills migrated to the east coast of North America, where they spent the early part of the winter off Newfoundland, later migrating to the Bay of Fundy near Nova Scotia. Some birds continued south along the US east coast as far as the Carolinas. Finally, one black guillemot was tracked to a wintering area well north of the colony around Nuuk. These results indicate that an oil spill off South Greenland during winter could impact local breeding populations of murres in addition to winter visitors from other parts of the range.

Falk K, Kampp K, Merkel FR (2000). Monitering af lomviekolonierne i Sydgrønland, 1999. Pinngortitaleriffik, Grønlands Naturinstitut. Nuuk, Greenland. 26 pp.

Box 1 continued



Figur 1. Foraging trips recorded for common murres, thick-billed murres and razorbills from Ydre Kitsissut during the breeding seasons of 2009, 2010 and 2011. All trips were recorded by GPS loggers, and the sampling interval was 10 min in 2009 and 2 min in 2010 and 2011. The birds mostly foraged within 20 km of the colony, and only two birds went to the continental shelf break (one thick-billed murre in 2009 and one razorbill in 2011). The maps also show 50%, 75% and 90% kernel contours, indicating areas where birds spend most time. Positions within 300 m of the colony are disregarded.

Box 1 continued

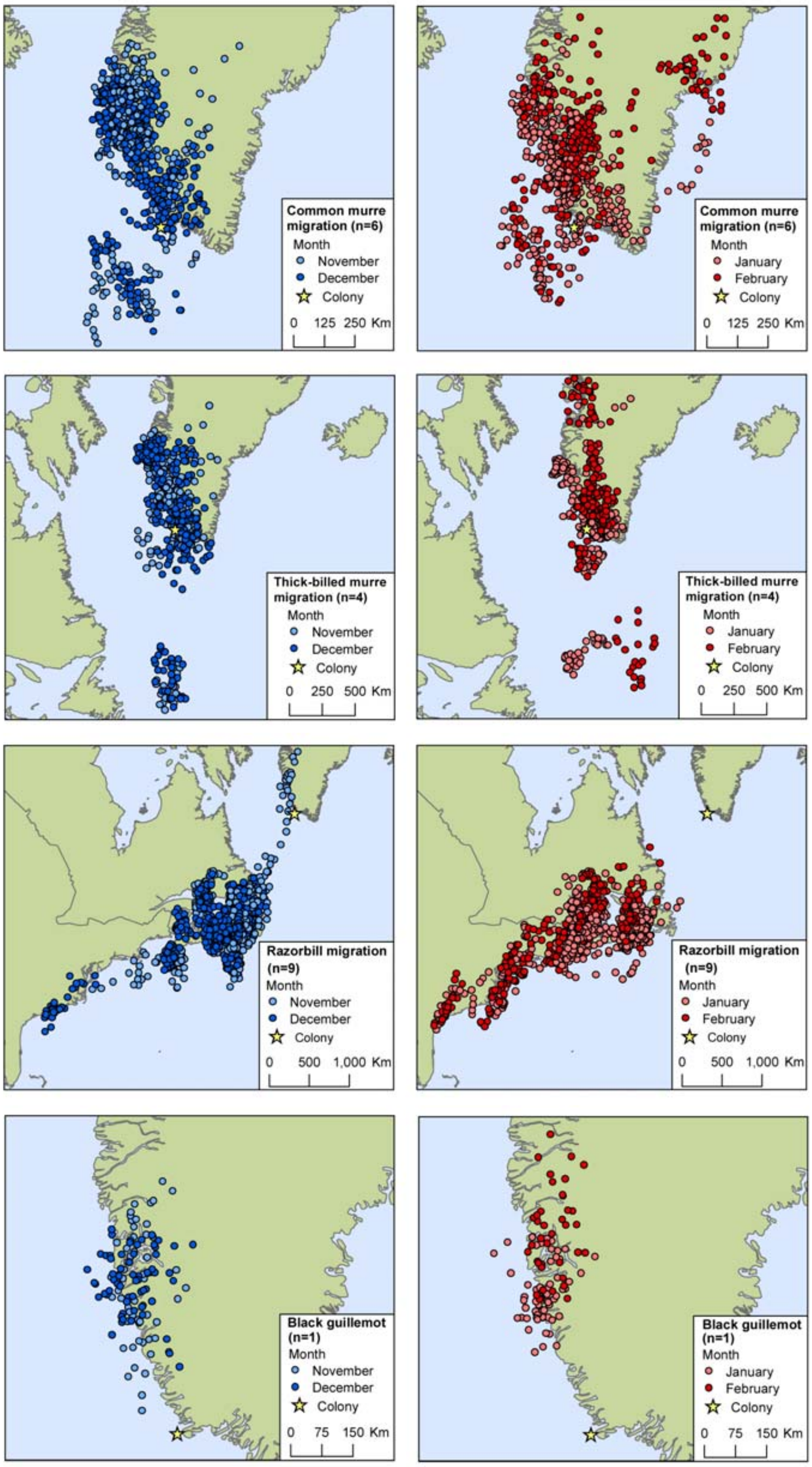


Figure 2. Migration patterns of common and thick-billed murres, razorbills and black guillemots from Ydre Kitsissut during the 2009/10 and 2010/11 winters. Light-level geolocators were used to track migratory movements. Positions derived through geolocation have a mean error of about 185 km, and therefore some positions occur on land. As can be seen on the maps, the murres, razorbills and black guillemots have different migratory behaviour. The murres stay in local waters around South Greenland, the black guillemots stay in local waters along the West Greenland coast whereas the razorbills migrate to the east coast of Canada/USA. Individual positions shown here have not been fully analysed and should not be taken too literally; however, the greater picture is reliable.

Black guillemots in Southwest Greenland are more or less resident; some local breeders move north in winter, while few birds from further north in Greenland move to the assessment area (Lyngs 2003). During an aerial survey in 1999, a total of 12,000 black guillemots were estimated in the coastal zone between the southern tip of Greenland and Disko Bay, with relatively high concentrations near Nanortalik (Merkel et al. 2002).

White-tailed eagles breed in low numbers dispersed along the coasts. Especially the Paamiut region is a stronghold for the population. The eagle population in Greenland is isolated from other populations and is by many authors considered as an endemic subspecies. Due to the low population numbers, the eagle is red-listed as Vulnerable.

Great cormorants breed north of the assessment area, and many birds winter in South Greenland (Lyngs 2003), where they stay in near-shore waters. In recent decades, cormorants have been more frequent in summer in South Greenland, and breeding colonies may occur unnoticed here and there.

King eiders are also winter visitors in the assessment area. They occur mainly in the outer part of the coastal waters, and often together with the much more numerous common eiders.

Finally two species of divers utilise the coastal waters. They mostly occur as non-breeders from spring to autumn, but especially breeding red-throated divers also forage at sea despite having the nest at a pond or lake.

4.6.4 Oil spill sensitivity

Seabird aggregations on the water are especially sensitive to oil spills. As described above, such aggregations occur at breeding colonies, in offshore feeding areas and at moulting sites. The most vulnerable breeding colonies will be those at or close to the outer coast (e.g. Ydre Kitsissut), as oil spills probably will not enter far into the fjords. The most vulnerable moulting concentrations are those of common eiders and harlequin ducks, as they tend to occur at exposed coasts. Feeding concentration areas are more difficult to designate, because such sites often show a marked variation in temporal and spatial distribution, and a variation which often is unpredictable (but see Box 1 for foraging areas of auks breeding at Ydre Kitsissut).

Areas where migrating seabirds concentrate are not known from the assessment area, but such areas probably occur especially along ice edges and coastlines, which act as guiding lines for migrating seabirds.

4.7 Marine mammals

4.7.1 Polar bear

Erik W. Born (GINR)

Polar bear, *Ursus maritimus*

Occurrence, distribution and population identity: Polar bears occurring in Southwest Greenland arrive in the area with the drift ice flowing south of Cape Farewell from East Greenland (e.g. Born & Rosing-Asvid 1989, Rosing-Asvid 2002).

The East Greenland drift ice is usually present in Southwest Greenland during January-July (Buch 2000b), but has been recorded to arrive as early as in November in some years. Its overall geographical extent and northern limit along Southwest Greenland fluctuates annually (Fabricius et al. 1995, Buch 2000b, Rosing-Asvid 2006). Usually the drift ice reaches north to Paamiut, but in the late 19th century it occasionally reached as far north as Sisimiut (Fabricius et al. 1995, Buch 2000b).

Catches reported in the *Hunters-Lists-of-Game* from the area Nanortalik-Paamiut (1950-1983) indicate that polar bears may occur in Southwest Greenland all year round, with a peak in January/March-June (Born & Rosing-Asvid 1989, Siegstad et al. 2000). This pattern was also observed in the *Piniarneq* catch recording system during 1993-1998 (Rosing-Asvid 2002). However, according to Rosing-Asvid (2002), catches reported during summer and fall 'in recent years' relate to hunters from Southwest Greenland travelling up the southeast coast of Greenland in small boats, and thus concern bears outside the assessment area.

For the period 1950-1983 there is a positive and statistically significant correlation ($r=0.68$, $p<0.01$, $df=31$) between the annual number of bears caught in Southwest Greenland and in the Tasiilaq area on the East coast, indicating that in both areas the occurrence of polar bears is to a large extent governed by the amount of drift ice (Born & Rosing-Asvid 1989).

Studies (e.g. genetics, satellite telemetry) have not been conducted to specifically address the identity of polar bears in Southwest Greenland. However, the appearance of bears in Southwest Greenland in close association with the timing of the influx of drift ice from East Greenland has led to the inevitable conclusion that the vast majority of polar bears in the assessment area belong to the East Greenland subpopulation (Born & Rosing-Asvid 1989, Born 1995, Obbard et al. 2010). A gap in winter and spring sea ice cover between the range of the neighbouring Davis Strait and Baffin Bay subpopulations and that of bears in Southwest Greenland (Born 1995, Buch 2000b) makes it highly unlikely that polar bears from Davis Strait and Baffin Bay occur within the Southwest Greenland assessment area.

Polar bears in the East Greenland subpopulation are genetically distinct from those in the Davis Strait and Baffin Bay subpopulations (Paetkau et al. 1999). So far, two polar bears that were tagged east of Greenland have been recovered in Southwest Greenland. One was tagged off Northeast Greenland and the other near Franz Josef Land (Larsen 1986, Born & Rosing-Asvid 1989, Born 1995). This latter incident demonstrates that presumably very infrequently polar bears may arrive in the assessment area from other subpopulations.

Demography and status of the subpopulation: Based on relatively few tissue samples from bears shot in Southwest Greenland and reports from hunters, it appears that both sexes and all age groups except females with cub-of-the-year may occur in Southwest Greenland (Rosing-Asvid 2002). However, the rare observation in April 2010 in Southwest Greenland of a mother bear with two cubs that had emerged from the den less than one month before indicates that maternity denning may take place in the assessment area.

Due to a lack of population inventories, the status of the East Greenland subpopulation to which polar bears occurring in Southwest Greenland belong remains undetermined (Obbard et al. 2010). The total catch from the population in Southwest, Southeast and Northeast Greenland decreased significantly during the 20th century (e.g. Sandell et al. 2001, Born 2008). Whether this reflects a decrease in the overall population remains unclear (Obbard et al. 2010). However, apart from being subject to hunting, the East Greenland population is also suspected to be negatively influenced by habitat destruction (decrease in optimal sea ice habitat) and relatively high levels of various anthropogenic pollutants that may threaten its viability (Obbard et al. 2010).

Numbers in the assessment area: The number of polar bears that occur within the assessment area may be inferred from the catches reported prior to the introduction of quotas in 2006. Since 1 January 2006 there has been a quota on the take of polar bears in Greenland (Lønstrup 2006). During allocation of regional quotas, the Greenland Department of Fisheries, Hunting and Agriculture assumes that polar bears harvested in Southwest Greenland belong to the East Greenland subpopulation. Accordingly, since 2007 the quota for Southwest Greenland has amounted to 4/year of the total quota of 54-64 (2011) for East Greenland (Born et al. 2010, Anon 2011a).

Because Southwest Greenland has a relatively dense human population (e.g. Born 2000) which are actively fishing and hunting using skiffs and boats for the major part of the year, it is unlikely that many polar bears occurrin in this area would remain undetected. Therefore, prior to 2006 most polar bears in Southwest Greenland were likely shot.

During 1970-1983/84 a catch of an average of ca. 5 polar bears/year was reported from Southwest Greenland (range: 1-14/year; Born & Rosing-Asvid 1989, Rosing-Asvid 2002). Since the introduction of a new catch reporting system (*Piniarneq*) until the introduction of quotas, the reported catch averaged 7.0/year (sd=5.0, range: 0-15, n=13 years) (Born et al. 2010).

Before the mid-1920s, more bears were killed in some years in Southwest Greenland. Especially many were killed during the period 1876-1925, with 73 hides purchased by the trade company during 1907/08 (Rosing-Asvid 2002). However, following the intensification of the catch of polar bears in Southeast and Central East Greenland during the 20th century, annual catches in Southwest Greenland have remained low (Rosing-Asvid 2002) .

Hence, if catches prior to quotas in 2006 are regarded as a proxy for the number of polar bears in the area, between 0 and 15 polar bears may occur in Southwest Greenland during a single year.

Future trends: During 1979-2006 the sea ice in the East Greenland area has decreased by 9.8%/decade which is among the highest rates of decrease observed regionally in the Arctic (Perovich & Richter-Menge 2009). This also influences the amount of drift ice available in Southeast and Southwest Greenland, and likely therefore also the number of polar bears that occur in these areas.

The decrease in sea ice and optimal habitat for polar bears in East and Southwest Greenland is predicted to continue. Using 10 of the scenarios of the Intergovernmental Panel on Climate Change for projected decrease of sea ice and resource selection functions based on data from satellite telemetry on polar bear habitat preferences including data from East Greenland

(1993-1998), Durner et al. (2009) forecasted that optimal polar bear habitat in East Greenland (and Southwest Greenland) will decrease substantially during the next 50–100 years. The decrease will be most pronounced during spring and summer. A decrease in sea ice in the southern range of the polar bear implies that areas with optimal polar bear sea-ice habitat in Northeast and North Greenland will become more important. Hence, one may expect that as a consequence progressively fewer polar bears will occur in Southeast and Southwest Greenland in the future.

Sensitivity: While moving on drift ice, polar bears frequently enter the water to swim (Aars et al. 2007), thereby increasing their risk of becoming fouled in the case of an oil spill. In Svalbard, four polar bears that were monitored for between 12 and 24 months with satellite-linked dive recorders spent an average of 0.9 to 13.1% of their time per year in water. The maximum duration of swimming events ranged between 4.3 and 10.7 h, and dives reached 11.3 m depth (Aars et al. 2007). Polar bears are very sensitive to oiling as they depend on the insulation from their fur, and because they may ingest toxic oil as part of their natural grooming behaviour (Øritsland et al. 1981, Geraci & St. Aubin 1990). Therefore, polar bears that have contact with oil are likely to succumb (Isaksen et al. 1998). Female polar bears in dens seem to be rather tolerant towards disturbance, because the snow provides acoustic insulation. They will occasionally relocate if disturbed and will do so most frequently early in the denning season. There are examples of activities taking place rather close (500 m) to denning female bears without abandonment of the den (Linnell et al. 2000). However, there seem to be large variation in the individual thresholds among female bears with regard to leaving a den (Linnell et al. 2000). Female brown bears (*Ursus arctos*) with cubs which have been forced to leave their den showed elevated cub mortality (Linnell et al. 2000).

Conclusions: Hence, during most years the occurrence of polar bears in the assessment area is from January to June, with a spatial ‘concentration’ in the Julianehåb Bugt between Cape Farewell and ca. 60° 45′ N.

The number of polar bears arriving in Southwest Greenland shows great annual fluctuation, partially correlated with the amount of East Greenland drift ice and the persistence of this ice in Southeast and Southwest Greenland. Catch data indicates that up to 15 polar bears may arrive in the assessment area annually and consequently be affected by human activity. Predictions of future decrease in sea ice in Southwest Greenland may imply a simultaneous decrease in polar bears frequenting the area.

4.7.2 Seals

Aqqalu Rosing-Asvid (GINR)

The occurrence of seals in the assessment area is strongly tied to the seasonal presence of drift ice. Large amounts of drift ice normally reach Cape Farewell around the start of January, and when the pulse of ice is strongest in June-July, it often covers the coastal waters in the entire assessment area. This drift ice restricts the range of hunters significantly, and for parts of the year most seals in the area will remain undisturbed by hunting. In recent years, some harp seals have started to give birth on the drift ice in the assessment area in early April, whereas hooded seals always have used the drift ice as a foraging platform in May-June on their migration toward the moulting area off Southeast Greenland. The drift ice has also prevented hunting near the southernmost colony of harbour seals during their breeding period (in June). Furthermore, the drift ice transports a steady flow of ice-associated ringed seals and bearded seals into the assessment area.

In 2009 and 2010, a field project was carried out as part of this SEIA, primarily to study the distribution and movements of the Critically endangered harbour seal in South Greenland. Data on other seal species were also collected, including the first observations in Greenland of grey seals. Results of this field study are presented in Box 2 and Appendix 1.

All seals are sensitive to oil pollution, but the most critical and important habitats in the assessment area based on results from the SEIA seal project and earlier studies in the area are:

- The drift ice (mainly the frontal part), which during the last decade has been the breeding area to a small (around 1000) but growing number of harp seals. The pups are very sensitive to oil spills during the first 3-4 weeks following their birth (a two week period around 1 April).

- The drift ice (mainly the outer parts) is also important to a large fraction (the majority) of the West Atlantic hooded seal population. Many of these seals spend some time foraging, with this ice as a platform to rest on, during May-early June, before they continue their migration to the moulting area off the Greenland southeast coast.

- The small group of islands Qeqertat (59.88° N, 43.45° W) is the most important site for the remnant population of harbour seals in South Greenland, and it is the only place in Greenland where the existence of grey seals has been documented.

Hooded seal, *Cystophora cristata*

Hooded seals pass through the assessment area when migrating from their whelping areas off Newfoundland and in the Davis Strait to the moulting area off Southeast Greenland and back again (Fig. 4.11). They give birth in late March/early April. The pups only lactate for about four days and put on about 7 kg/day. They quickly gain a thick layer of insulating blubber, whereas the woolly lanugo pelage, which characterises other Arctic seal pups, is already lost during the foetal stage. The migration towards Southeast Greenland starts a few weeks after birth, and both adult seals and pups occur in the assessment area in high numbers during May-June. This time of year they are often seen resting on the drift ice, and most of the subsistence hunt occurs in this period. After the moult (July-August), the adult seals quickly pass through the assessment area again towards the Davis Strait and Baffin Bay, whereas most of the juvenile seals stay off the East Greenland coast until they reach maturity.

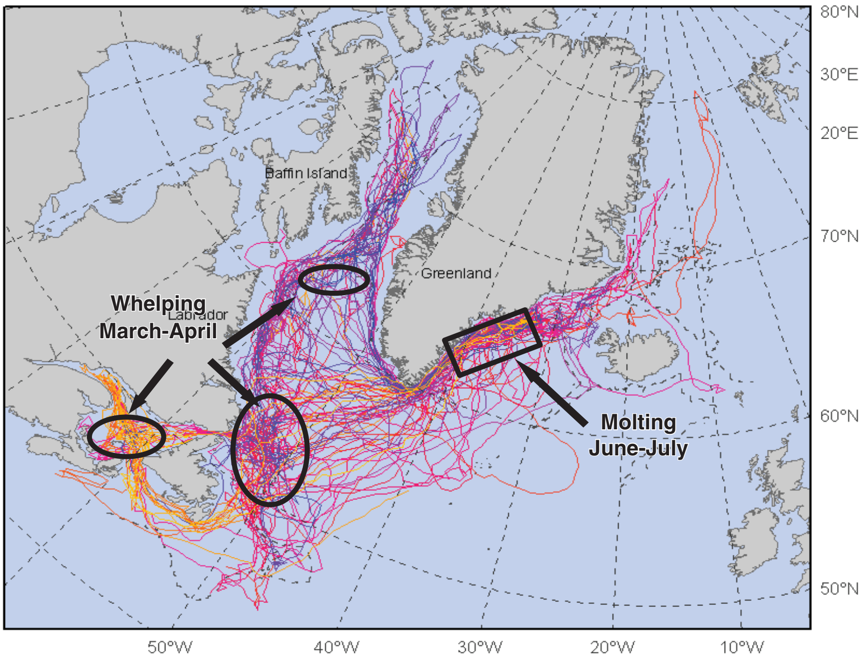


Figure 4.11. Track lines from adult hooded seals, showing the annual migration pattern from the moulting area off Southeast Greenland to foraging areas between Greenland and Canada, to the breeding areas in the Davis Strait and off Newfoundland and back to the moulting area. Source: Andersen et al. (2009).

The hooded seal is a deep diver, feeding regularly below 500 m (down to around 1500 m). Many of the adult hooded seals forage along the continental slope where they mainly take large fish and squids.

The hooded seal is listed as 'Least Concern' on the Greenland Red List. The hooded seal population is managed internationally through a working group under ICES and NAFO. The seals in South Greenland are part of the West Atlantic population consisting of around 600,000 individuals (ICES 2006).

Hooded seals spend most time in the assessment area during May-June, at which time they are also found in the highest concentrations in the area. In this period, they are mainly distributed along the outer edge of the drift ice (the extent of which differs from one year to another).

Harp seal, *Pagophilus groenlandicus*

Most of the harp seals in the assessment area are migrant visitors, normally seen in highest numbers in June-July, but some individuals (mainly juveniles) stay in the area throughout the year. The migrant seals mainly come from the West Atlantic population (Kapel 1995). During the last decade, some harp seals have started to give birth off South Greenland on the drift ice present off the west coast during spring and summer. This was first documented in 2007, when some (1000+) harp seals gave birth in the assessment area (Rosing-Asvid 2008). Hunters have reported that this phenomenon has reoccurred every year since then, and they have the impression that the number of pups is increasing.

Harp seals are gregarious, and adult seals often travel in flocks typically consisting of 5–20 individuals (sometimes up to hundreds). Capelin is their main prey in the coastal parts of the assessment area (Kapel 1991).

Box 2

Field study of seals in South Greenland 2009-10: preliminary results

Aqqalu Rosing-Asvid (GINR), Rune Dietz, Jonas Teilmann, Morten Tange Olsen & Signe May Andersen (AU)

The available published information about the distribution, abundance, space use and foraging behaviour of seals in the assessment area is very limited. This is particularly the case for the harbour seal, which is red-listed as Critically endangered in Greenland. Only few small populations are known, with the largest one occurring in the assessment area. In order to improve our ecological understanding and provide input to the Strategic Environmental Impact Assessment, a detailed study involving tagging of seals took place in the Cape Farewell area in 2009 and 2010. An important haul-out site for harbour seals at the group of islands Qeqertat (59.88 – 59.90° N, 43.45 – 43.48° W) was found by an initial survey of the area. Field work took place around these islands during 27 Aug – 7 Sep 2009 and 1 – 7 Sep 2010. During these periods, a total of 22 seals of five species (14 harbour seals, three bearded seals, two ringed seals, one harp seal, one grey seal) were equipped with satellite transmitter tags, some of which recorded diving behaviour as well as position. Here, we present selected preliminary results of the study (see also Appendix 1 for further details).

Harbour seal
Up to 32 harbour seals were counted at the haul-out site, and mark-recapture studies indicated that the population using the Qeqertat area is unlikely to be > 40 individuals. Eight harbour seals were tagged in 2009 and six in 2010. Most individuals remained in the Cape Farewell area, mainly within the fjords although some individuals also used areas further offshore (Fig. 1). Four seals made excursions north along the East Greenland coast. Three of these were adults, which all spent time during the breeding season (June-July) at a particular site 250 km from Qeqertat (Fig. 1). It is likely that this represents an otherwise unknown breeding site for the species. Dive depth and duration increased during the winter (Fig. 2), and this study recorded the deepest (5-600 m) and longest (20-25 min) dives documented for the species. These long and deep dives took place within the fjords and sounds of the Cape Farewell area.

Bearded seal
Three male bearded seals were captured and tagged (one in 2009, two in 2010). All three were mainly stationary within the fjords of the Cape Farewell area, with most positions occurring < 30 km from the tagging site and within a few km of the shore (Fig. 3). One seal made a two-week excursion north along the East Greenland coast in June, spending most of the time in a fjord 370 km from the tagging site. Mean dive depth and duration varied over the year (Fig. 2), and this study recorded the deepest (5-600 m) and longest (20-25 min) dives documented for the species.

Grey seal
This study provided the first documented occurrence of grey seals in Greenland. One or two individuals were seen in 2009, and in 2010 a juvenile male (pup of the year) was caught. This individual was tagged, and limited data indicated that it used the southeast coast of Greenland north of the tagging site.

Space use of seals in the Cape Farewell area
Tagging demonstrated that all species mainly used areas close to the coast, often within the fjords and sounds of the Cape Farewell area (Fig. 4). Few positions occurred outside the 500 m isobath or more than 40 km from the coast. This area is thus very important for all five seal species (harp and grey seal not shown), particularly the Critically endangered harbour seal and the grey seal.

Box 2 continued

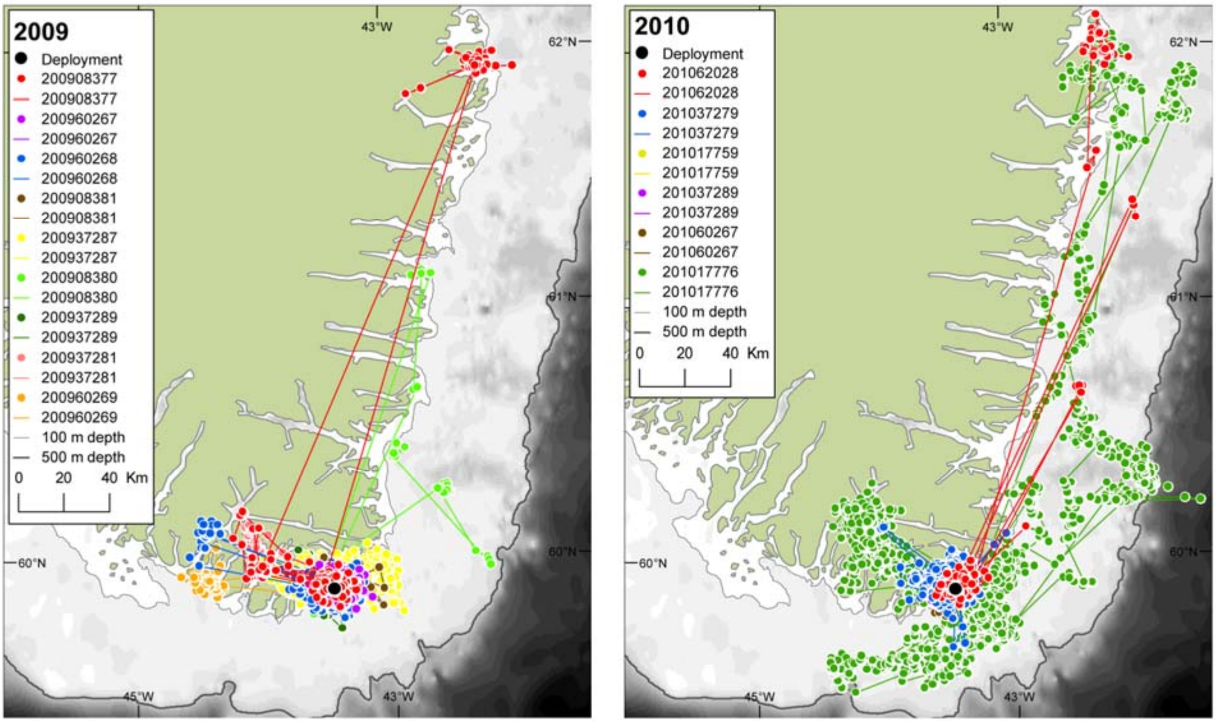


Figure 1. Positions of 14 satellite-tracked harbour seals, eight tagged in September 2009 (left; 200937281 and 200908377 double-tagging of the same individual) and six in September 2010 (right). Contact with the transmitters lasted 10-363 days.

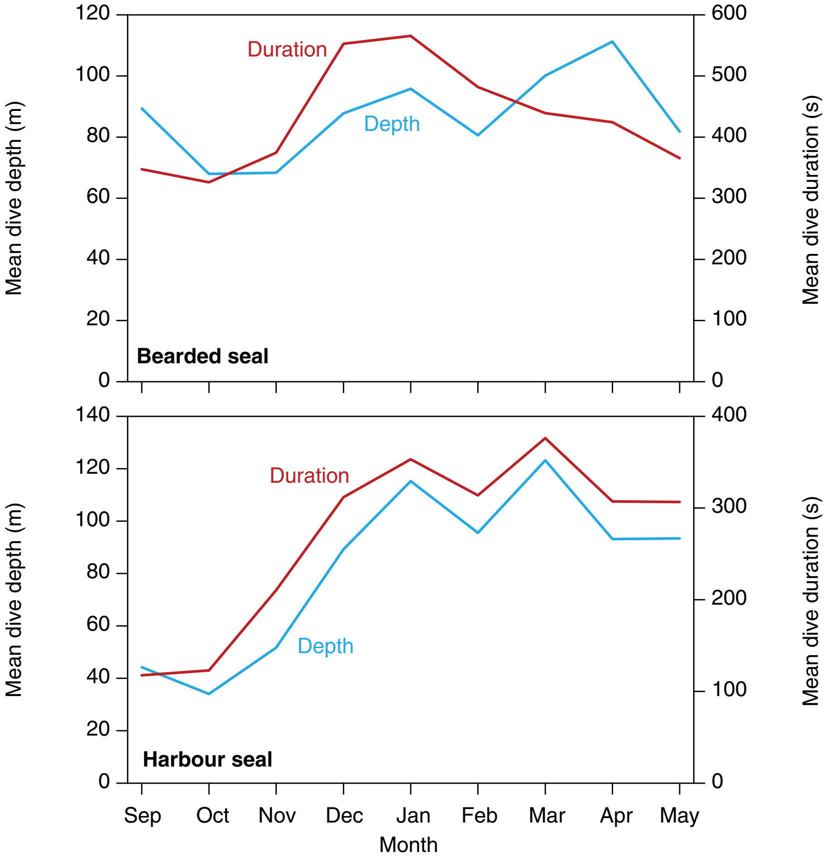


Figure 1. Positions of 14 satellite-tracked harbour seals, eight tagged in September 2009 (left; 200937281 and 200908377 double-tagging of the same individual) and six in September 2010 (right). Contact with the transmitters lasted 10-363 days.

Box 2 continued

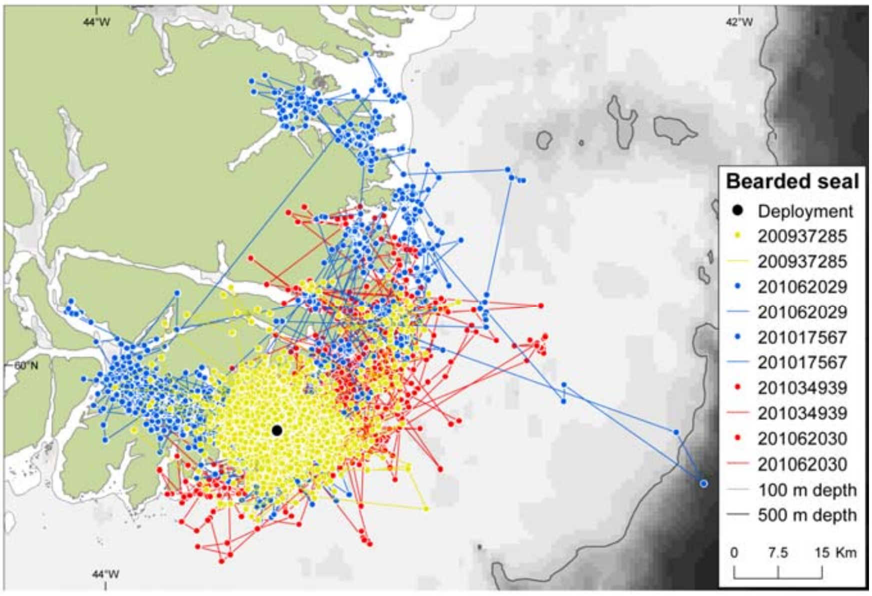


Figure 3. Positions of three satellite-tracked bearded seals, one tagged in September 2009 and two in September 2010. In addition to the tracks shown, one seal made a brief (two-week) excursion 370 km up the east coast of Greenland (see Fig. 4). Contact with the transmitters lasted 106-399 days; all three seals were double-tagged, indicated by two IDs with the same colour).

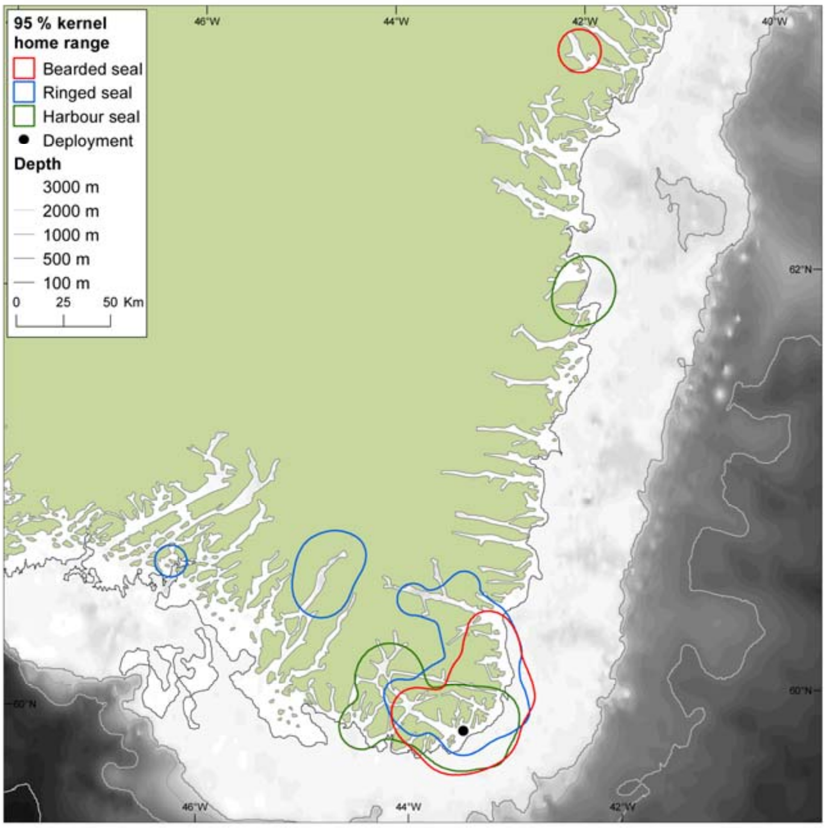


Figure 4. Space use of bearded, ringed and harbour seals in the Cape Farewell region, shown as 95% kernel home range contours. The map is based on data from three bearded seals, two ringed seals and 14 harbour seals tagged in 2009 and 2010.

The harp seal is listed as 'Least Concern' on the Greenland Red List. The seals occurring in the assessment area belong to a population of around 8 million (ICES 2011).

The newly established whelping patch in south Greenland will be very sensitive to oil spills during late March-late April. The position of the whelping patch has so far been near the front of the drift ice, but the position of the front differs significantly from year to year. Fig. 3.4 shows the maximum extent of ice in March, which will be close to the position of the ice front by early April when harp seals give birth. The front of the ice will some years be on the east coast and some years north of the assessment area, but in most years it will be in the assessment area.

Ringed seal, *Pusa hispida*

The ringed seal is a small seal adapted to life in ice-covered waters, where it maintains breathing holes and gives birth in lairs made in a snowdrift covering a breathing hole. The main breeding habitats are considered to be coastal fast ice and consolidated drift ice. The pups are born in late March and April, and lactation lasts for about 7 weeks (Hammill et al. 1991). The assessment area might hold breeding ringed seals during very cold winters with heavy ice cover. Most of the ringed seals that are found in the assessment area are pups of the year, and they are likely to have been born somewhere along the east coast. The number of these young seals seems to increase in the assessment area during fall and spring (this is reflected in the subsistence hunt, Fig. 5.6). The increase observed in fall might be related to ice formation in the East Greenland fjords. Adult seals will at this time make breathing holes and establish territories, and the young seals therefore move towards areas with more open water. In spring when the pulse of drift ice is strong, ringed seals associated with the ice also come to the assessment area.

Polar cod (*Boreogadus saida*), Arctic cod (*Arctogadus glacialis*) and amphipods seem to be the main prey of ringed seals in their more northerly core habitat. An on-going study from the southernmost part of the assessment area has found amphipods and polar cod to be important, but capelin is also an important supplement in this area (A. Rosing-Asvid unpubl. data).

The ringed seal is listed as 'Least Concern' on the Greenland Red List. There are no estimates of population size, but the hunt is believed to be sustainable because the ringed seals inhabit a large area, of which the Greenland hunters only explore a tiny fraction.

The core habitat of this population is considered to be fjords along the Greenland east coast, but ringed seal core habitat changes with the severity of the winter. During cold winters, glacier fjords in the assessment area will hold some breeding ringed seals.

Bearded seal, *Erignathus barbatus*

Bearded seals are widespread in the Arctic and usually occur in low densities. They can make breathing holes, but prefer to stay in thin ice, and in the northern part of their range they either winter in reoccurring leads and polynyas, or follow the pulse of the expanding and shrinking sea ice. Birth takes place in April–May on drifting ice or near ice edges with access to open water, and the lactation period is up to 24 days (Gjertz et al. 2000).

Male bearded seals vocalise intensively during the mating season (March-June), and individual seals can be recognised on their songs. Studies that use the song to recognise individual seals have shown that male bearded seals show a high degree of site fidelity (Van Parijs & Clark 2006).

Detailed catch statistics from an on-going sampling program in the southernmost settlement in Greenland (Aappilattoq) show that only adult males and young juvenile seals are caught in South Greenland during the period without drift ice in the area (typically August-January). Adult females are included in the catch when the drift ice arrives. This indicates a pattern of stationary males and migrating females. The hunt only allows bearded seal to establish territories in the easternmost part of the assessment area, where the hunters only rarely come.

According to the literature, bearded seals feed on fish and benthic invertebrates in waters preferably shallower than 100 m (Burns 1981, Gjertz et al. 2000).

The bearded seal is listed as 'Data Deficient' on the Greenland Red List. The population occurring in the assessment area is believed to be part of a population extending along the Greenland east coast. The number of seals in the population is unknown, but their uniform and widespread distribution is believed to be a good protection against over-exploitation.

The bearded seal is more or less evenly distributed in a large part of the Arctic, and no breeding or foraging areas seem to be important to a large number of seals. They are relatively rare in the part of the assessment area where hunting takes place, but are frequently seen in the easternmost part of the assessment area (east of Cape Farewell), where only few hunters come.

Harbour seal, *Phoca vitulina*

Harbour seals concentrate near land-based haul-out sites and give birth on land. This species has only inhabited Greenland in interglacial periods, and it is therefore a relatively new species with only a few thousand years of adaptations to the Greenland environment (Andersen et al. 2011). This might explain why it has never in historic times been nearly as numerous as any of the ice-associated seal species. Its distribution is linked to the sub-Arctic open water area. It gives birth during June to a pup without the woolly lanugo pelage that characterises the Arctic seal pups (this pelage is lost during foetal stage). As a replacement for this, the pup has a nice relatively long-haired fur, which in combination with the rareness of harbour seals have made the fur particularly exclusive and wanted by hunters. This exclusiveness may be the reason why the trousers in the West Greenland traditional woman's full dress have to be made of skin from young harbour seals. The harbour seals in Greenland have therefore been overexploited throughout the last century, and most of the catch during the last two decades have been in the eastern part of the assessment area.

The harbour seal is listed as 'Critically Endangered' on the Greenland Red List. The number of harbour seals has declined significantly during the past century, and most of the traditional haul-out sites have been abandoned (Teilmann & Dietz 1993). Southeast Greenland has been considered one of the last strongholds for this species, but clear signs of overexploitation exist here as well (Rosing-Asvid 2010a). A complete ban on harbour seal hunting throughout Greenland was imposed 1 December 2010.

At present, a small group of islands (Qeqertat, 59.88° - 59.90° N, 43.45° - 43.48° W) seems to be the centre for the remnant population of harbour seals in South Greenland (see also Box 2).

Grey seal, *Halichoerus grypus*

Grey seals have not previously been documented in Greenland. The first documentation was in 2009, when one or possibly two grey seals were seen and photographed during fieldwork at Qeqertat (Rosing-Asvid et al. 2010). In September 2010, a grey seal (this time a pup of the year) was seen, caught and equipped with a transmitter.

As the grey seal is a new species in Greenland, it is not listed in the Red List. However, it fulfils the criteria for inclusion in the category Critically Endangered due to the low number of seals in the population. A complete ban on grey seal hunting in all of Greenland was imposed 1 December 2010.

All three observations in Greenland are from Qeqertat, which also hosts the only known harbour seal colony in this part of Greenland. Whether these islands are the centre for a very small group of grey seals, or whether these grey seals belong to an unknown colony somewhere on the east coast or had only strayed from another country (most likely Iceland) is unknown.

Sensitivity to oil spills

The effects of oil on seals were thoroughly reviewed by St Aubin (1990). Seals are vulnerable to oil spills, because oil can damage the fur, produce skin irritation and seriously affect the eyes as well as the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, and anal and urogenital orifices. In addition, oil can poison seals through ingestion or inhalation. Furthermore, oil spills can have a disruptive effect by interfering with normal behaviour patterns. Pups are most affected by oil (St Aubin 1990 and references therein), because they are very stationary during the weaning period and therefore cannot move away from oil spills. The pups of most of the Arctic species are protected against the cold by a thick coat of woolly hair (lanugo pelage), and for these pups oil will have a strong negative effect on the insulating properties of this fur. The mother seals recognise their pups by smell, and a changed odour caused by oil might therefore affect the mother’s ability to recognise its pup. Although the sensory abilities of seals should allow them to detect oil spills through sight and smell, seals have been observed swimming in the midst of oil slicks, suggesting that they may not be aware of the danger posed by oil (St Aubin 1990). Finally, oil spills may also affect seals indirectly by affecting habitat and food sources.

Seals are also sensitive to disturbance at their breeding and haul-out sites on drift ice (harp seal), fast ice (ringed seal) or on land (harbour seal). In addition, bearded seals are likely to be sensitive to acoustic disturbance.

4.7.3 Whales, dolphins and porpoises (order Cetacea)

Tenna Kragh Boye, Malene Simon & Fernando Ugarte (GINR)

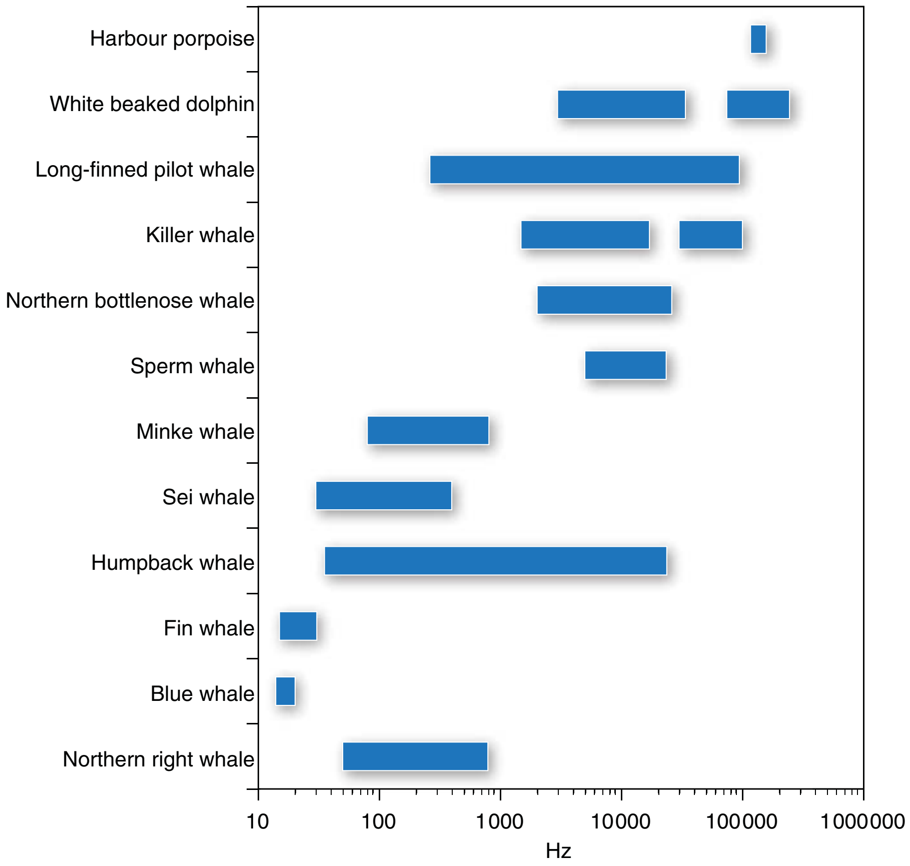
The order Cetacea, which includes whales, dolphins and porpoises, is divided into two sub-orders: Mysticeti (baleen whales) and Odontoceti (toothed whales). Baleen whales catch prey by filtering large volumes of prey-laden water through a curtain of baleen plates hanging from the roof of their mouth, while toothed whales catch individual prey with their teeth. There are also general differences in their residency and migration patterns, with most baleen whales showing well-defined seasonal migrations between breeding and feeding grounds. Relevant for evaluating the impact of human activities, baleen whales and toothed whales differ in the frequency ranges of the sounds used for communication, navigation and feeding. Baleen whales emit low frequency calls (10 – 10,000 Hz), audible over distances of tens of kilometres (Mellinger et al. 2007). In contrast, toothed whales use higher frequencies (80 Hz – 130 kHz) to produce tonal sounds for communication, and clicks for echolocation and communication (Mellinger et al. 2007). An overview of the frequencies used by the cetaceans present in the assessment area is given in Table 4.3 and Fig. 4.12.

Hearing and sound production are vital for cetaceans and can be affected by anthropogenic noise, including the sounds produced by hydrocarbon exploration and exploitation activities. Potential effects from anthropogenic noise include behavioural changes (e.g. avoidance of the area or disruption of feeding/breeding), physical damage (mainly to auditory organs) and masking (obscuring of sounds of interest to the animal by interfering sounds).

Table 4.3. The frequency range of the most common sounds used by cetaceans in the assessment area. The frequency range is given by the minimum and maximum frequencies in Hz

Species	Latin	Sound type	Min freq. (Hz)	Max freq. (Hz)	References
Mysticetes					
Humpback whale	*Megaptera novaeangliae*	Call / song	35	24,000	(Payne & Payne 1985)
Fin whale	*Balaenoptera physalus*	Call / song	15	30	(Watkins et al. 1987)
Minke whale	*Balaenoptera acutorostrata*	Call / song	80	800	(Mellinger et al. 2000)
Sei whale	*Balaenoptera borealis*	Call / song	30	400	(Rankin & Barlow 2007)
Blue whale	*Balaenoptera musculus*	Call / song	14	20	(Cummings & Thompson 1971)
Northern right whale	*Eubalaena glacialis*	Call / song	50	600	(Clark 1982, Vanderlaan et al. 2003)
Odontocetes					
Sperm whale	*Physeter macrocephalus*	Click	5,000	24,000	(Madsen et al. 2002)
Long-finned pilot whale	*Globicephala melas*	Click	4,100	95,000	(Eskesen et al. 2011)
		Whistle	260	20,000	(Rendell & Gordon 1999)
White beaked dolphin	*Lagenorhynchus albirostris*	Click	75,000	250,000	(Rasmussen & Miller 2002)
		Whistle	3,000	35,000	(Rasmussen & Miller 2002)
Killer whale	*Orcinus orca*	Click	30,000	100,000	(Simon et al. 2007)
		Whistle/call	1,500	18,000	(Ford 1989, Thomsen et al. 2001)
Harbour porpoise	*Phocoena phocoena*	Click	120,000	150,000	(Villadsgaard et al. 2007)
N. bottlenose whale	*Hyperoodon ampullatus*	Click	2,000	70,000	(Wahlberg et al. 2011)

Figure 4.12. The main frequency range of sounds used by cetaceans in the assessment area. See also Table 4.3 for details.



Recent knowledge about the distribution and abundance of cetaceans in the assessment area comes from aerial surveys carried out by GINR in September 2005 and September 2007. Additional information about the seasonality, distribution and biology of cetaceans come from a variety of sources, including passive acoustic monitoring devices moored across the Davis Strait, north of the assessment area, recording continuously from October 2006 to September 2008, as well as scientific studies and catch statistics.

With the exception of blue whales, sei whales and sperm whales, which are protected by law, and bottlenose whale, whose blubber has a laxative effect, all cetaceans are hunted in Greenland and are considered as an important resource for both economic and cultural reasons.

Baleen whales (Mysticeti)

The six species of baleen whales occurring in the assessment area belong to two families: rorquals (*Balaenopteridae*, five species) and right whales (*Balaenidae*, one species). Among the rorquals, minke whales (*Balaenoptera acutorostrata*), fin whales (*Balaenoptera physalus*), humpback whales (*Megaptera novaeangliae*) and sei whales (*Balaenoptera borealis*) are seasonal inhabitants and relatively abundant. Blue whales (*Balaenoptera musculus*) are rare, but also seasonally present. The occurrence of the Critically endangered northern right whale (*Eubalaena glacialis*) is poorly known, but this species may use the assessment area during migration or as a feeding ground.

West Greenland is an important foraging area where baleen whales target dense patches of prey, and the distribution of the whales is correlated with the abundance of certain prey items, such as capelin (*Mallotus villosus*), krill

(*Meganyctiphanes norvegica* and *Thysanoessa sp.*) and sandeel (*Ammodytes sp.*) (Heide-Jørgensen & Laidre 2007, Laidre et al. 2010, Simon et al. 2010) For instance, during a survey in September 2005 focusing on the distribution of cetaceans, krill and capelin, the overall distribution of fin, minke, humpback and sei whales was strongly correlated with high densities of krill deeper than 150 m, with a high density area within and north of the assessment area (Laidre et al. 2010). Previous studies have shown how a sudden shift in distribution of the prey resources may cause an equivalent shift in the distribution of the whales (Weinrich et al. 1997). Therefore, changes in prey distribution due to climatic changes will affect distribution and abundance of baleen whales in the assessment area and Greenland waters in general.

The distribution of most species of cetaceans is affected by sea ice. The main source of sea ice in the assessment area is the ice that drifts from East Greenland, which can be extensive during summer and early fall. Sea ice is a limiting factor for the northern distribution of fin whales, and this may also be true for other species of rorquals. Changes in sea ice coverage further north may likely have an effect on the distribution of baleen whales in the assessment area as well, but this has not been investigated yet. In the following text, we briefly describe the biology and occurrence of the different species of baleen whales within the assessment area.

Humpback whale, *Megaptera novaeangliae*

Humpback whales are about 13 m long and weigh 28 t. They migrate between low-latitude breeding grounds in the Caribbean and high-latitude feeding grounds in Greenland. They arrive in the assessment area in spring (May) and stay until late autumn (October). However, some individuals skip the migration and overwinter in Greenland waters (Simon 2010).

Humpback whales in Greenland feed mainly on capelin, sandeel and krill. They travel along the coast into fjords and bays to benefit from shallow aggregations of capelin (Heide-Jørgensen & Laidre 2007). Yet, it seems like the majority of humpback whales stay offshore to take advantage of large prey patches on the banks within the assessment area (Laidre et al. 2010). Although individual humpback whales show site fidelity toward specific foraging sites, returning year after year to the same area within few kilometres (Boye et al. 2010), they do not stay in the same area for the entire feeding season but travel between foraging sites (Heide-Jørgensen & Laidre 2007).

In 1966 humpback whales became protected from commercial whaling and in 1986 a moratorium was established. In 1981, Whitehead *et al.* (1983) estimated the population size of West Greenland humpback whales to constitute 85-200 animals. The many years of protection have resulted in an increase of humpback whale abundance. Today around 3,000 humpback whales feed along the west coast of Greenland, and the rate of increase of the population is estimated to 9.4 % per year (Heide-Jørgensen et al. 2008a, Heide-Jørgensen et al. in press). Hence, humpback whales are considered as Least concern on both the IUCN Red List (2008) and the Greenland Red List (Boertmann 2007b).

Fin whale, *Balaenoptera physalus*

The North Atlantic fin whales reach an average length of 19–20 m and an average weight of 45–75 t, which makes them the second largest animal on the planet after the blue whale. Fin whales are found worldwide from temperate to polar waters, but are less common in the tropics. About 3,200 fin whales seasonally visit West Greenland waters (from Cape Farewell to north of Disko Island), with a large abundance both north of and within the assessment area between 60° and 61° N along the 200 m contour (Heide-Jørgensen et al. 2008a, Laidre et al. 2010). In Greenland, fin whales target prey such as sandeel, offshore patches of krill and coastal aggregations of capelin (Kapel 1979). The strong correlation between offshore krill abundance and high densities of rorquals, including fin whales, indicates that parts of the assessment area are important fin whale feeding grounds (Laidre et al. 2010).

Fin whales were believed to migrate south to unknown breeding grounds during winter, but passive acoustic monitoring shows that fin whales are present in Davis Strait until the end of December, and an increase of fin whale song suggest that mating starts in October-November while the whales are still off West Greenland (Simon et al. 2010). The southward migration of the fin whales coincides with the formation of sea ice, suggesting that ice coverage is an important limiting factor for the northern distribution of fin whales during winter (Simon et al. 2010). The occurrence of fin whales in the assessment area during winter has not been investigated.

In Greenland, fin whales are placed in the category of Least concern on the Greenland Red List due to the large abundance and signs of increase in the North Atlantic (Boertmann 2007b). However, on a global scale the species is considered as Endangered as a result of a major decline in abundance of fin whales due to whaling in the Southern hemisphere (IUCN 2008).

Minke whale, *Balaenoptera acutorostrata*

The minke whale is the smallest (about 7 m and 8 t) and most abundant baleen whale in Greenland waters. They migrate between low latitude breeding grounds and high latitude feeding grounds, arriving in Greenland during spring. Based on a survey from 2007, the population in West Greenland is estimated as larger than 16,609 animals (Heide-Jørgensen et al. 2008b, Heide-Jørgensen et al. 2010). However, large variations in the relative minke whale abundance across years suggest that the fraction of minke whales using the West Greenland banks as a summer feeding ground may vary from year to year (Heide-Jørgensen & Laidre 2008). There is genetic evidence that minke whales in the assessment area belong to a distinct population that summers in what the International Whaling Commission recognises as the West Greenland management area (Andersen et al. 2003, Born et al. 2007). As many other marine mammals, minke whales are likely to move between Greenland and East Canada (Horwood 1989). Furthermore, minke whale catch data show distinct sexual segregation in the West Greenland subpopulation, where mostly females are found in West Greenland and within the assessment area (Laidre et al. 2009).

Minke whales are found both offshore and inshore in bays and fjords within the entire assessment area. They are the most piscivorous (fish-eating) of the baleen whales and feed mainly on sandeel and capelin (Kapel 1979). Both IUCN (2008)and the Greenland Red List (Boertmann 2007b) place minke whales in the Least concern category.

Sei whale, *Balaenoptera borealis*

Sei whales are on average 14 m long and weigh 20–25 t. They feed almost exclusively on krill (Kapel 1979), although small schooling fish and squid form an important part of their diet in some areas. The species is believed to make seasonal migrations between low-latitude wintering grounds and high-latitude feeding grounds. However, the distribution of sei whales is poorly understood. The occurrence of sei whales in West Greenland may be linked to years with increased influx of warm currents from East Greenland (Kapel 1985). Sei whale sound signals were recorded in the Davis Strait in August-September 2006-07 (Simon 2010). The abundance of sei whales in West Greenland was estimated from a ship survey in 2005 to 1,599 individuals (95% CI = 690-3,705). As with fin, humpback and minke whales, there were high density areas within the assessment area. The overall distribution of these rorquals is correlated with high densities of krill deeper than 150 m (Laidre et al. 2010). Sei whales are considered Endangered on the IUCN Red List (2008) of threatened species and listed as Data deficient on the Greenland Red List (Boertmann 2007b). Recent satellite tracking data from the University of the Azores indicate that there is an important summer feeding ground for sei whales at the southern part of Greenland, close to the continental slope (Prieto et al. 2010).

Blue whale, *Balaenoptera musculus*

Blue whales are the largest animals ever to have existed on earth and reach an average length of 25 m and weigh up to 120 t. Blue whales are globally distributed from the low latitudes to polar waters, where dense drift ice and the ice edge limit their northern and southern distributions (Norris 1977). As with other rorquals, it is assumed that blue whales travel between foraging areas at high latitudes in the summer and low-latitude breeding areas during winter. Their main prey is krill, but also capelin and sandeel are part of their diet (Kapel 1979).

Observations of blue whales in West Greenland are rare, and their presence in the assessment area is poorly known. Several sightings have been reported but largely in the area between 62°-66° N at the border and north of the assessment area (Sears & Larsen 2002). Individuals have been documented to travel between foraging areas in the Gulf of St. Lawrence and West Greenland, which suggest a shared population of blue whales between West Greenland and Eastern Canada (Sears & Larsen 2002). Passive acoustic monitoring in 2006-2007 revealed blue whale calls in August-September in the Davis Strait (Simon 2010).

Globally, blue whales are considered as Endangered on the IUCN Red List (2008) because most populations, including those in the North Atlantic, were decimated by whaling in the 20th century. The number of blue whales occurring in West Greenland is unknown, and therefore the species is classified as Data deficient on the Greenland Red List (Boertmann 2007b). In the Central North Atlantic, blue whales are common only around Iceland/East Greenland, where sighting surveys between 1987 and 2001 indicate about 1,000 blue whales, and the population may be growing at a rate of about 4-5 % per year (Pike et al. 2010). Blue whales are extremely rare in the Eastern North Atlantic, and in the Western North Atlantic only common in the Gulf of St. Lawrence, where about 400 animals have been photo-identified (Ramp et al. 2006). The stock structure of blue whales in the North Atlantic is unknown, but the different timing of depletions by commercial whaling in Norway, Iceland and the Western Atlantic suggests that discrete feeding aggregations exist.

Northern right whale, ***Eubalaena glacialis***

Due to their slow movements, and the fact that they float when dead, North Atlantic right whales were an easy target during centuries of whaling and were hunted close to extinction by 1900. The species is considered Critically endangered on the IUCN Red List, and the Western population is estimated to constitute only 300 animals (IWC 2001) while the Eastern population is considered extinct (Clapham et al. 1999). The Southeast tip off Greenland, (60-62° N, 33-35° W) was previously an important whaling ground, called the Cape Farewell Ground, and one of several summer feeding grounds for North Atlantic right whales (Reeves & Mitchell 1986). Today the main distribution area stretches from the calving grounds off Florida to foraging areas off southeast Labrador in the Western North Atlantic (Kraus et al. 1986, Winn et al. 1986). However in, 2007 sounds of North Atlantic right whales were recorded on the Cape Farewell Ground where the species was considered to be extirpated (Mellinger et al. 2011). The knowledge of the migratory behaviour of this critically endangered species is scarce, and due to the recent recordings of whales on the Cape Farewell Ground and to previous finding of trans-Atlantic migrations of North Atlantic right whales between the East coast of the United States and northern Norway (Jacobsen et al. 2004, Mellinger et al. 2011), it is considered possible that this species may enter the assessment area during migration between feeding areas.

Toothed whales (*Odontoceti*)

Six species of toothed whales occur regularly in the assessment area: long-finned pilot whale (*Globicephala melas*), white-beaked dolphin (*Lagenorhynchus albirostris*), harbour porpoise (*Phocoena phocoena*), killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*) and northern bottlenose whale (*Hyperoodon ampullatus*). There are sporadic reports of narwhals and belugas that are vagrants from other areas (GINR unpubl. data). As for the baleen whales, a change in prey distribution due to climatic changes will likely affect the toothed whale distribution. Likewise, changes in ice coverage and in temperature may have an effect on the distribution of toothed whales as well. Particularly, the extent of the ice drifting from East Greenland could be an important factor limiting the availability of suitable habitat for toothed whales in the assessment area.

Sperm whale, ***Physeter macrocephalus***

Sperm whales are the largest of the toothed whales and reach lengths of 18 m and weights of 50 t. Although they are found in all oceans, the species has a sexual segregation where females and calves reside in tropical and subtropical waters year round, while males inhabit high latitude feeding grounds with occasional visits to their low latitude breeding grounds (Best 1979). Sperm whales prey on a variety of deep-sea fish and cephalopods. Stomach samples from 221 sperm whales caught between Iceland and Greenland showed that benthic or pelagic fish (especially the lumpsucker, *Cyclopterus lumpus*) constituted the majority of the diet, but also oceanic cephalopods were an important part of the sperm whale diet in this area (Martin & Clarke 1986). Stomach content of sperm whales caught in West Greenland contained exclusively fish (Kapel 1979).

The abundance of sperm whales in Greenland and within the assessment area is not known, but sperm whales are encountered on a regular basis (e.g. Larsen et al. 1989). Sperm whales are found mainly in deep waters along the continental slope but they can also be seen in deep fjords and have been observed in the Nuuk fjord system, north of the assessment area, in both 2009 and 2010 (GINR, unpubl. data). Echolocation clicks of sperm whales have also been recorded close to the West Greenland continental shelf in the Davis Strait (GINR, unpubl. data). Male sperm whales feed both at shallow depths of approximately 117 m and at the sea bottom at depths down to 1860 m, showing flexible feeding habits (Teloni et al. 2008). Within the assessment area, sperm whales are expected to use deep-sea waters close to the continental slope and underwater canyons with high abundance of cephalopod or fish prey.

The International Whaling Commission considers the North Atlantic sperm whales as belonging to a single population (Donovan 1991) which is further supported by genetic analyses (Lyrholm & Gyllensten 1998). On a global scale sperm whales are categorised as Vulnerable (IUCN 2008), but due to poor documentation of sperm whale abundance around Greenland the species is listed as not evaluated on the Greenland Red List (Boertmann 2007b).

Long-finned pilot whale, *Globicephala melas*

The long-finned pilot whale occurs in temperate and sub-polar zones, but is according to Greenland catch statistics occasionally also found as far North as Upernavik (Department of Fisheries, Hunting and Agriculture, unpubl. data). In the USA, long-finned pilot whales have seasonal movements that appear to be dictated by their main prey, the long-finned squid (*Loligo pealei*) (Payne & Heinemann 1993, Gannon et al. 1997). Long-finned pilot whales are found in groups of up to 100 individuals. Recently, distribution and abundance of pilot whales were estimated along the West Greenland coast, based on an aerial survey from 2007. The survey showed that pilot whales also here preferred deep offshore waters. The highest abundance was found north of the assessment area at Store Hellefiskebanke, yet groups were also seen within the assessment area off the southern tip of Greenland (Hansen 2010). Hansen (2010) estimated the West Greenland population to constitute 7,440 individuals. Pilot whales occurring in the assessment area (and the rest of Greenland) probably belong to a large North Atlantic population, whose range extends beyond the assessment area. Based on comparisons of body measurements of long-finned pilot whales from Newfoundland and the Faroe Islands, Bloch and Lastein (1993) suggested that pilot whales from the eastern and western North Atlantic are segregated into two separate stocks. A genetic comparison of long-finned pilot whales from the US East Coast, West Greenland, the Faeroe Islands and the UK showed that West Greenland pilot whales are distinct from those in the other locations and suggests that population isolation occurs between areas of the ocean which differ in sea surface temperature (Fullard et al. 2000). Abundance in the central and eastern North Atlantic has been estimated to 780,000 animals (Buckland et al. 1993). Hence pilot whales are abundant and considered as Least concern on the Greenland Red List (Boertmann 2007b) and as Data deficient on the IUCN Red List (2008) due to inadequate data on abundance at a global level.

White-beaked dolphin, *Lagenorhynchus albirostris*

White-beaked dolphins are endemic to the North Atlantic Ocean where they inhabit cold temperate and sub-Arctic areas (Reeves et al. 1999). Here, they feed on a variety of small schooling fishes such as herring, cod and whiting along with squid and crustaceans (Jefferson et al. 2008). Their diet in Greenland waters is not known, but cod, capelin and sandeel may constitute prey items. White-beaked dolphins are mostly found in groups of up to 30 individuals, but may occur in larger groups of hundreds of individuals (Rasmussen 1999, Jefferson et al. 2008). They occur in offshore waters and on continental shelves. In West Greenland a recent study has shown that the species is found between the coastline and up to 90 km offshore, and a positive correlation between depth, slope and abundance of white beaked dolphins was documented with larger abundances on steep slopes and deep waters (Hansen 2010). The same study found a correlation between depth and group size, with smaller groups occurring in deep water while larger groups were found at depths between 300-1,000 m.

The majority of white-beaked dolphins are found in South Greenland within the assessment area, whereas the Disko area appears to represent the northernmost range of the species (Reeves et al. 1999, Hansen 2010). However, unverified catch statistics indicate that white-beaked dolphins may occur as far north as Upernavik (GINR, unpubl. data). White-beaked dolphins are poorly studied in West Greenland, and the first abundance estimate was only recently calculated at 11,800 animals in West Greenland (Hansen 2010). White-beaked dolphins are considered as not applicable on the Greenland Red List (Boertmann 2007b).

Killer whale, *Orcinus orca*

These top predators are found in all oceans, at various depths and do not seem to have any latitudinal restrictions on their home range, other than sea ice. However, abundance is higher in colder waters near shore (Jefferson et al. 2008). Killer whales feed on prey varying from small schooling fish to large marine mammals, and their high dietary specialization divides them into ecotypes. Examples of prey choice are herring in Norway (Christensen 1982), sharks in New Zealand (Visser 2005), sea lions and elephant seals in Patagonia (Lopez & Lopez 1985) and either minke whales, fish or seals and penguins in the Antarctic (Pitman & Ensor 2003). Mating between different ecotypes rarely occurs (Pilot et al. 2009). Most killer whales live in natal pods, where mating occur outside the pod during interaction with other groups (Pilot et al. 2009). Groups most often contain between 3-30 individuals, but may count more than 100 animals (review in Baird 2000)

Studies on killer whales in Greenland are almost non-existent, and their distribution is poorly understood. Yet, Heide-Jørgensen (1988) reviewed published and unpublished information available and carried out a questionnaire-based investigation of sightings of killer whales in Greenland. He found that killer whales were observed in all areas of West Greenland, with more sightings in Qaanaaq, Disko, Nuuk and Qaqortoq. However, sightings are sparse along the West Greenland coast (Teilmann & Dietz 1998).

It is not known whether the killer whales found in Greenland constitute their own population or are part of a larger population within the Atlantic Ocean. The notion of a population in the Northeast Atlantic with a range including West Greenland and East Canada is supported by satellite tracking of a single individual from August to November 2009 that moved from the Canadian High Arctic (Lancaster Sound), via Baffin Bay and the Davis Strait, to waters west of the Azores (Petersen et al. 2009). Due to the scarce knowledge in Greenland, killer whales are listed as not applicable on the Greenland Red List (Boertmann 2007b). Despite the extensive studies on killer whales in other areas of the world they are listed as Data deficient on the IUCN Red List (IUCN 2008) due to ambiguities regarding taxonomy.

Harbour porpoise, *Phocoena phocoena*

Harbour porpoises are the smallest cetaceans found in Greenland and reach a length of 1.8m and a weight of up to 90 kg. They are among the most abundant whale species in the North Atlantic and also in West Greenland, where they occur from the southernmost tip to the Avanersuaq district in Northwest Greenland (Teilmann & Dietz 1998). However, the main distribution of harbour porpoises in West Greenland lies between Sisimiut and Paamiut (Teilmann & Dietz 1998), which corresponds to the area from 62°-67° N at the border and north of the assessment area. In West Greenland the harbour porpoises inhabit fjords, coastal and continental shelf areas, and abundance decreases with depth (Hansen 2010). Although ice formation forces harbour porpoises to leave the area north of Disko from January to April, catch statistics show that they are present year round in West Greenland. Yet, it is possible that the majority leave the coast for offshore waters during late autumn and return during spring (Teilmann & Dietz 1998).Their main prey consists of fish and squid, and in West Greenland capelin (*Mallotus villosus*) is the predominant part of their diet (Lockyer et al. 2003).

Until recently the abundance of harbour porpoises in West Greenland was unknown, but stock size has now been estimated at approximately 33,300 animals (Hansen 2010). It is believed that this stock is separated from neighbouring populations in Iceland and Newfoundland. Because population size has only recently been estimated, it is not clear yet whether the hunt of harbour porpoise in Greenland is sustainable. Hence, harbour porpoises are listed as Data deficient on the Greenland Red List (Boertmann 2007b), but their large abundance in the Northern hemisphere put them in the Least concern category on the IUCN Red List (IUCN 2008).

Northern bottlenose whale, *Hyperoodon ampullatus*

This species is found only in the North Atlantic, where they inhabit deep waters off the continental shelf and near submarine canyons (Jefferson et al. 2008). This 7-9 meter long whale is a deep diving species, diving as deep as 1,400 meters (Hooker & Baird 1999) to forage on primarily squid (e.g. Lick & Piatkowski 1998), but other invertebrates and fish also occur in their diet. They live in groups where especially the males may form long-term associations (Gowans et al. 2001). Bottlenose whales are present in Greenland during summer and are found within the assessment area (Mosbech et al. 2007). However, because the species has been poorly studied in Greenland, abundance, distribution and seasonality patterns along the West coast are unknown. The only place where bottlenose whales have been studied in detail is off Nova Scotia, Canada, where they show high site fidelity, relatively small home range and little genetic exchange with other areas (Hooker et al. 2002, Whitehead & Wimmer 2005, Dalebout et al. 2006). All these factors make bottlenose whales vulnerable to human disturbance.

Due to the scarce knowledge on bottlenose whales in Greenland, the species is listed as not applicable on the Greenland Red List (Boertmann 2007b). Also, the lack of data regarding the effects of anthropogenic disturbance along with depletion of stocks due to previous whaling places the species as Data deficient on a global scale (IUCN 2008).

4.8 Valued ecosystem components (VECs) in the assessment area

Morten Frederiksen (AU)

Based on the available knowledge, summarised in the preceding sections, and an evaluation of the ecological, economic and cultural importance of organisms and habitats, the following VECs are suggested for the South Greenland assessment area. See section 2.2 for a description of the VEC concept and how it has been applied here.

Pelagic hotspots

The shelf break and banks are assumed to have high primary productivity in spring due to nutrient-rich upwelling events induced by currents, wind and tide. There are limited *in* situ data in the assessment area to support this, but remote sensing data indicate a pronounced spring bloom along the shelf break, peaking in April. The enhanced primary production is grazed by abundant copepods, which again are utilised by fish larvae and small pelagic fish.

Overwintering zooplankton

The deep offshore waters of the Labrador Sea (partly within the assessment area) are exceptionally important as an overwintering area for *Calanus finmarchicus*, the most abundant mesozooplankton organism in the North Atlantic. This copepod underpins important commercial fisheries throughout the North Atlantic through its critical role as food for 'forage' fish and larvae of commercial species.

The tidal/subtidal zone

The tidal and subtidal zone is an important habitat for macrophytes, many invertebrates, fish, marine mammals and seabirds. Among others, it provides critical spawning and nursery habitat for e.g. capelin and lumpsucker. Capelin is an ecological key species, important for larger fish species, whales, seals, seabirds and human use, while lumpsucker supports a small-scale commercial fishery. The benthic macrofauna, such as bivalves and sea urchins, plays a key role for benthic feeding birds, such as common eider and long-tailed duck. In addition, this zone is very important for hunting and recreational use, including tourism.

Ikaite columns

The ikaite columns in Ikka Fjord are unique geological structures on a worldwide scale. As a habitat they host a similarly unique community, and are home to several species not found anywhere else.

Benthos and demersal fish

The sea floor and the adjacent parts of the water column support commercially important fisheries of northern shrimp, snow crab and potentially Atlantic cod. In addition, sandeels, which are important food for many seabirds and whales, require sandy sediments.

Breeding seabirds

The assessment area holds relatively small populations of breeding seabirds, but diversity is high and several uncommon species occur here. Important species include common and thick-billed murre and razorbill.

Non-breeding seabirds

Large numbers of migrating, wintering and moulting seabirds from the entire North Atlantic occur in the assessment area. Among the most important species are wintering thick-billed murres and common eiders, moulting harlequin ducks, migrating ivory gulls and black-legged kittiwakes, and summering great shearwaters. Several of these species are important quarry species for hunters.

Seals

The assessment area contains the most important known site for the harbour seal in Greenland. In addition, large numbers of hooded seals migrate through the area, and in recent years harp seals have established a new whelping area in the drift ice. Seals are also important quarry for local hunters.

Large whales

The shelf break in the assessment area is a very important summer and autumn foraging area for several species of rorquals, including humpback, minke, sei and fin whales. Sperm whales are also likely to use the area on a regular basis. In addition, it is possible that individuals of the extremely rare and threatened northern right whale occur in the Cape Farewell area.

5 Natural resource use

AnnDorte Burmeister, Helle Siegstad, Nanette Hammeken Arboe, Anja Retzel, Rasmus Hedeholm (GINR) & Daniel S. Clausen (AU)

5.1 Commercial fisheries

Commercial fisheries represent the most important export industry in Greenland, underlined by the fact that fishery products accounted for 88% of the total Greenlandic export revenue (1.7 billion DKK) in 2009 (Statistics Greenland 2010). The four most important species on a national scale are deep-sea shrimp (export revenue in 2009: 1,044 million DKK), Greenland halibut (398 million DKK), Atlantic cod (130 million DKK) and snow crab (45 million DKK) (Statistics Greenland 2010). Shrimp, snow crab and cod are the main commercially exploited species within the assessment area. Greenland halibut, lumpsucker, wolffish, redfish and salmon are exploited in more coastal regions of the area.

5.1.1 Cod fishery

The inshore Atlantic cod fishery in West Greenland started in 1911, and expanded over the next decades. Annual catches above 20,000 t have been taken inshore during the period 1955-1969, and in 1980 and 1989 catches of approximately 40,000 t were landed (Horsted 2000). From 1993 to 2001 the inshore catches were low – in the range 500-2,000 t. Until 2009 the inshore fishery for Atlantic cod was not regulated by catch ceilings. The offshore commercial fishery started in 1924. In West Greenland this fishery rapidly expanded to reach 120,000 t in 1931 – a level that remained for a decade (Horsted 2000). In 1962 the offshore landings culminated with landings of 440,000 t. After this historic high, landings decreased sharply by 90 % to 46,000 t in 1974 and even lower in 1977. The offshore fishery completely collapsed in 1993. From 1994 to 2001, no directed offshore cod fishery took place.

Since 2005, the commercial fishery for Atlantic cod has expanded in South Greenland. The offshore fishery increased rapidly between 2007 and 2008 from 1,000 to 10,000 t (Fig. 5.1). In 2009, the catches declined to 3,500 t. The highest catches were taken around Cape Farewell in 2008 and 2009. For the inshore fishery in South Greenland, catches peaked in 2007 with 7,500 t, and have since then declined to 4,300 t. In 2010, the areas around Qaqortoq (NAFO area 1F, south of 60°45'N) only caught 1,000 t, whereas the areas around Paamiut (NAFO area 1E, between 60°45'N-62°30'N) caught 3,300 t.

In the assessment area, the main season for both the inshore and offshore fishery is the summer/early fall period. For the offshore fishery, drift ice coming down along the East Greenland coastline can however sometime hinder the fishery during summer. In the inshore fishery, the majority of catches are caught in pound nets.

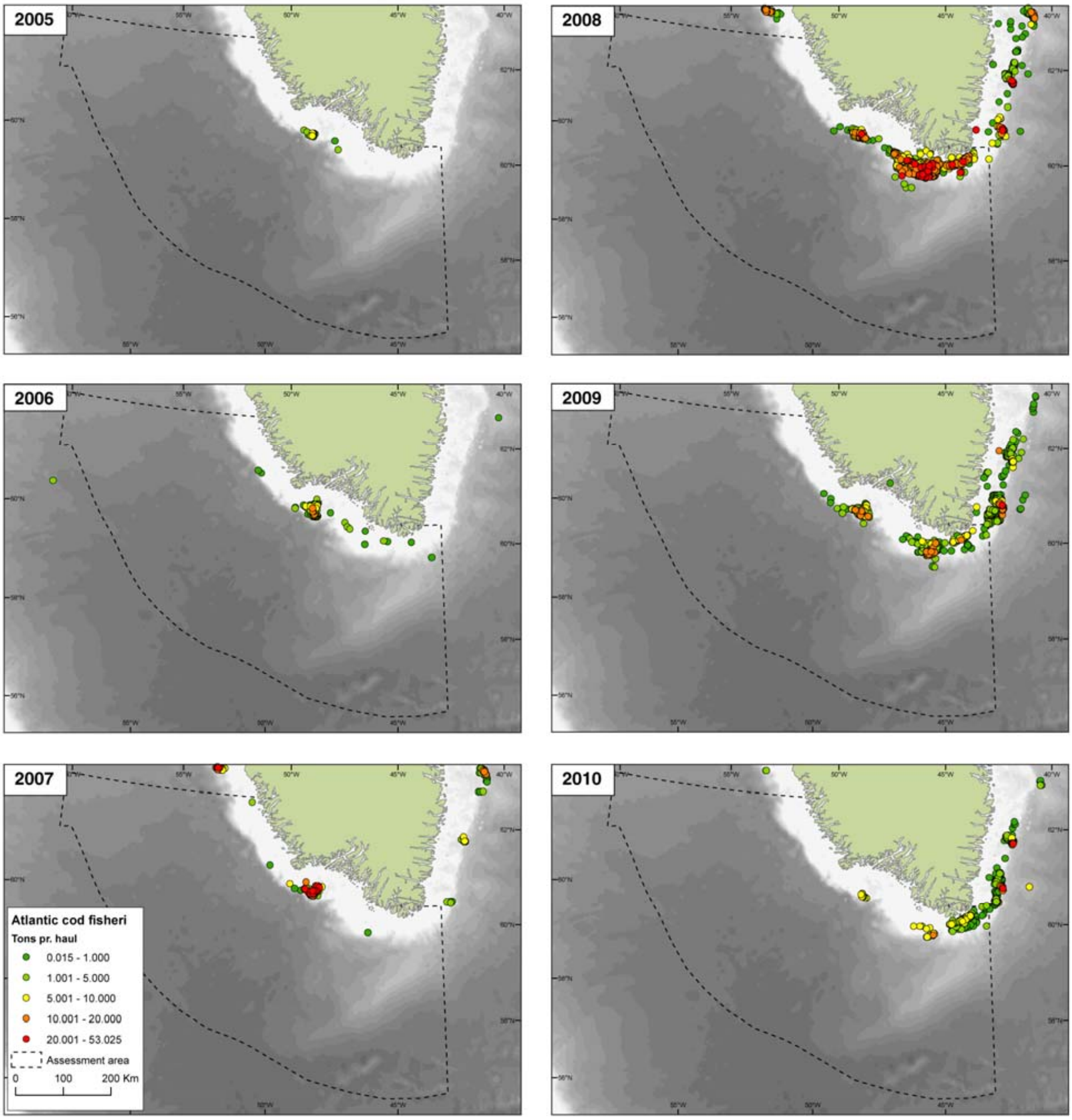


Figure 5.1. Distribution of offshore commercial catches (t/haul) based on logbook data of Atlantic cod in South Greenland in 2005-2010.

5.1.2 Shrimp fishery

In West Greenland waters, the Northern shrimp fishery extends from 59° 30′ N to 74° N, mainly on the bank slopes and in Disko Bay. The shrimp fishery was started in 1935 as a small-scale fishery mainly in inshore areas. Since then it has developed slowly to a total catch of up to 150,000 t/year (2004 - 2008). The major part of the catch is taken by large modern trawlers, which process the catches on board.

According to logbook records, the fishery was concentrated between 66° N and 69° N from the development of the fishery in the 1970s, but from the late 1980s the fishery spread southwards (Arboe & Kingsley 2010). In the assessment area south of 62° N, the fishery was initiated in the late 1980s. The intensity of the fishery in this area quickly rose, and from the mid-1990s to the early 2000s the catches of Northern shrimp accounted for 10 % to 15 % of the total catch. Julianehåb Bugt used to be a very important fishing ground, where only the coastal fleet was allowed to fish, and approximately 75% of the catches in the area south of 62° N have been taken in Julianehåb Bugt (Fig. 5.2). Since the mid-2000s, the fishery has declined in the area south of 62° N, and there has been no fishery in Julianehåb Bugt since 2008.

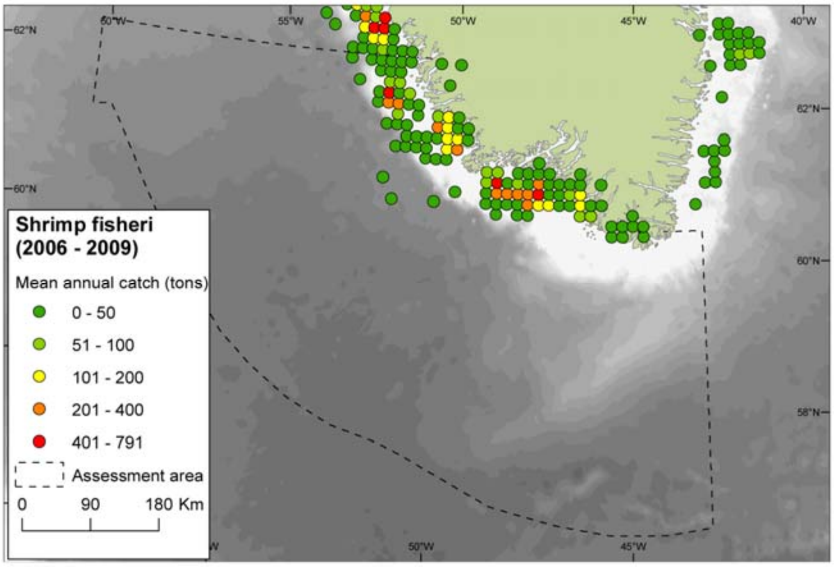


Figure 5.2. The distribution of shrimp fishery in the assessment area 2006-2009.

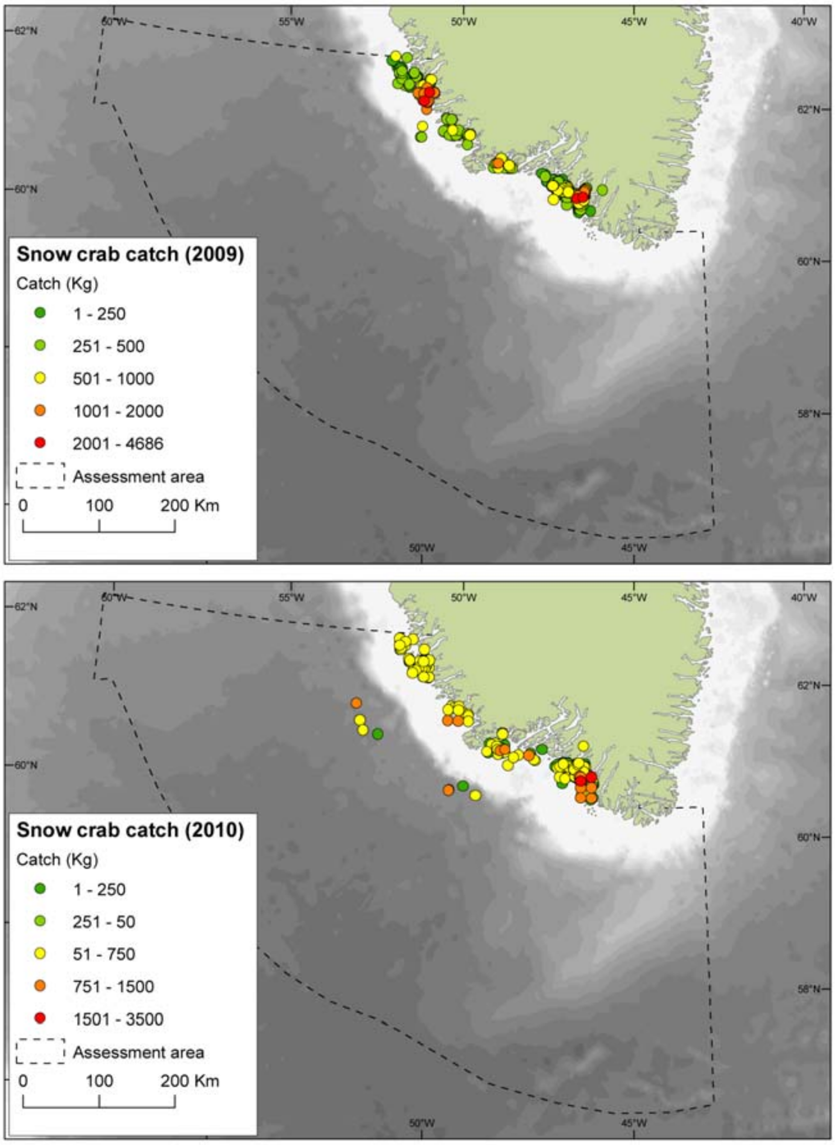
5.1.3 Snow crab fishery

Snow crabs are important for the communities in the assessment area. Fishing is permitted between 60° N and 74° N on the west coast of Greenland. The commercial fishery for snow crab started in 1996. Landings peaked in 2002 at approximately 15,000 t, and the snow crab was at that time the third most important species in total export income for Greenland. The fishery in the assessment area is situated along the inner and outer edges of the offshore banks and in a restricted area in the northern part of Julianehåb Bugt, in the adjacent waters close to Sydprøven and in a small part of the fjord Tesermiut close to Nanortalik (Burmeister 2010). Total catches taken offshore in the assessment area peaked at 822 t in 2001. In the successive years, the catch declined substantially to approx. 138 t in 2008 (Burmeister 2010). However, a new industry was opened in Narsaq in 2009 and a small fishery was introduced at 187 t increasing to 330 t in 2010 (Fig. 5.3).

5.1.4 Greenland halibut fishery

The commercial fisheries for Greenland halibut take place in the fjords and are conducted by small vessels using gill nets and longlines. The catches in the assessment area (NAFO Divisions 1E and 1F) have in recent years amounted to less than 200 t. There is at present no offshore fishery for Greenland halibut in the assessment area, probably due to the steep and rough bottom and strong currents.

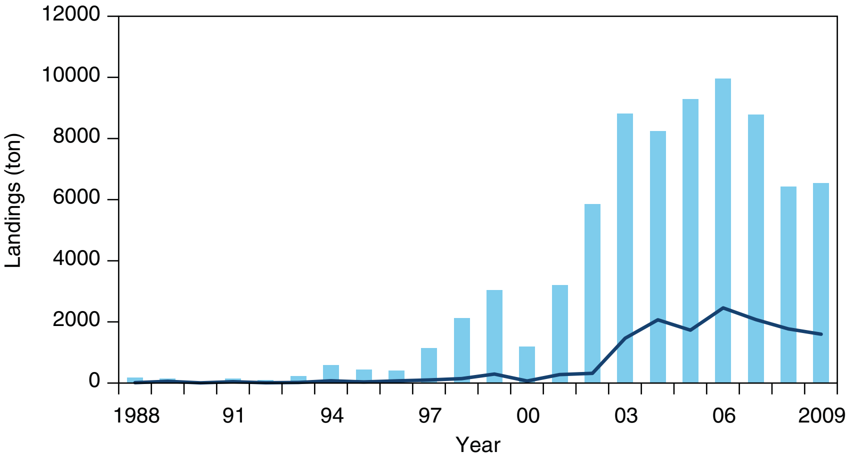
Figure 5.3. The distribution of snow crab fishery in the assessment area 2009 and 2010.



5.1.5 Lumpsucker fishery

Lumpsucker is caught commercially along the entire Greenland west coast (Lyberth 2004). Catches vary between years, but have increased considerably in the last decade (Fig. 5.4). The same pattern is seen in the assessment area, with catches being largest in the northern part (Fig 5.5). The lumpsucker fishery is mainly conducted using gillnets from 1st of March to 30th of June, and is currently unregulated by catch ceilings. Based on landings, lumpsucker was last assessed in Greenland in 2004 (Lyberth 2004). However, the biomass has not been estimated, and the vast majority of the fishery (>98%) is not required to keep log books, making speculations on population development tentative.

Figure 5.4. Landings (ton) of lumpsucker in Greenland. Bars represent all of Greenland and the solid line represents catches in the assessment area. Data from Greenland Statistics.



5.2 Subsistence and recreational harvest

Tenna Kragh Boye, Malene Simon, Lars Maltha Rasmussen, Aqqalu Rosing-Asvid & Fernando Ugarte (GINR)

Subsistence harvest in Greenland does not solely refer to the value of the meat or other household products derived from skin, bone or teeth, but also to the income that such products can generate on a local or non-local market. In the assessment area, only subsistence hunters ('full-time' hunters) are allowed to hunt baleen whales and polar bears, while seals, seabirds and the species of toothed whales regularly present in the area are accessible to recreational hunters also.

Hunting and fishing are integrated parts of Greenlandic culture. Subsistence hunting is still of economic importance, and recreational hunting and fishing activities contribute significantly to private households. In Southwest and South Greenland, much subsistence fishing and hunting of marine mammals and seabirds have gradually developed into recreational activities.

Small-scale fishing and hunting are important activities in the area, both in the larger towns, but especially in the smaller settlements, where there are fewer options for alternative employment. The income generated from commercial hunting, i.e., the local sale of meat and skin, is an important source of livelihood and as a supplementary food supply for hunters and their relations (Rasmussen 2005). Hunting is considered to be a fundamental element of Greenlandic culture, and products such as skin, bones, antlers, teeth etc. are assets in clothing, jewellery and art.

A proportion of the catch presented under the commercial fisheries section includes subsistence and recreational fisheries. Data on subsistence and recreational fisheries in Greenland are not separated. It is however assumed that the majority of the Greenlanders participate in or benefit from subsistence and recreational fisheries.

Many fish species are utilised on a subsistence basis, the most important being spotted wolffish, Greenland halibut, redfish, Atlantic cod, polar cod (*Boreogadus saida*), Greenland cod (*Gadus ogac*) and Greenland shark (*Somniosus microcephalus*).

5.2.1 Birds

Birds have historically played an important role as a supplement to hunting marine mammals and caribou, and to fishing. The most important hunted bird species are thick-billed murre, common eider and king eider, little auk, black guillemot and black-legged kittiwake.

Catches have since 1993 been reported annually to Piniarneq, the official Greenlandic hunting statistics, which represents the major source of information on bird hunting. The data are generally not quality-assured, but the reported numbers of birds are assumed to represent comparable indices of hunting over time. Since 1996, the reported catch of all species has been greatly reduced (Fig. 5.5). Since 1996, thick-billed murre has been by far the most important hunted seabird followed by common eider. Within the assessment area, the reported take of thick-billed murres decreased from 78,000 in 1996 to 23,000 in 2008. The common eider bag was reduced to from 23,000 to 7,000 from 2000 to 2002, when the hunting season was shortened by approximately two months, and has since stabilised around 9.000 birds annually.

Specific hunting seasons are established by the Department of Fisheries, Hunting and Agriculture and vary between species and regions. For most species, the main hunting season in the assessment area is from 15 October to 1 March (15 March for common eider). Daily quotas for the most hunted species are 30 birds for commercial licences and 5 for recreational licences (Anon 2009).

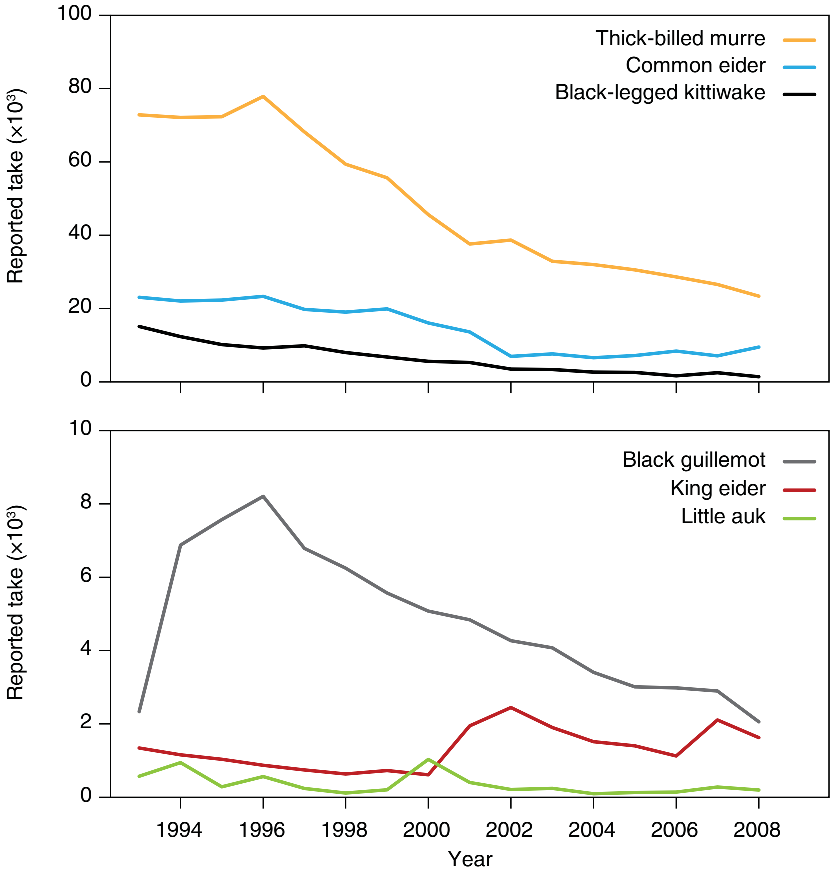


Figure 5.5. Annual reported take of six seabird species in the assessment area (Nanortalik to Paamiut), 1993-2008. Top panel: thick-billed murre, common eider and black-legged kittiwake; bottom panel: black guillemot, king eider and little auk. Data: Piniarneq, Greenland hunting statistics, Department of Fisheries, Hunting and Agriculture.

5.2.2 Seals

Seals are important for both part time and full time hunters in the assessment area. The skins are purchased and prepared for the international market by a tannery in Southwest Greenland, and the meat is consumed locally. In the period 2000 - 2008, more than half a million sealskins were traded in Greenland. However, in 2008/09 the market for sealskins collapsed, and now it is difficult to sell the skins (Rosing-Asvid 2010b).

Harp seals are caught in high numbers (Fig. 5.6), especially during summer. In winter and early spring, most of the West Atlantic harp seals congregate near the whelping areas off Newfoundland. However, a small fraction of the seals stay in West Greenland throughout the year. The annual catch in the assessment area is around 10-15,000 adult seals and 7-10,000 juvenile seals.

Hooded seals can also be caught throughout the year, but most catches are done during spring just after whelping, when many hooded seals are close to the assessment area, or in the fall when seals migrate through the assessment area after moulting towards their foraging grounds in the Davis Strait and Baffin Bay (Fig. 5.6). The Greenland catch is believed to be sustainable, and there is no limitation on the hunt. The annual catch in the assessment area is about 1-2,000 seals.

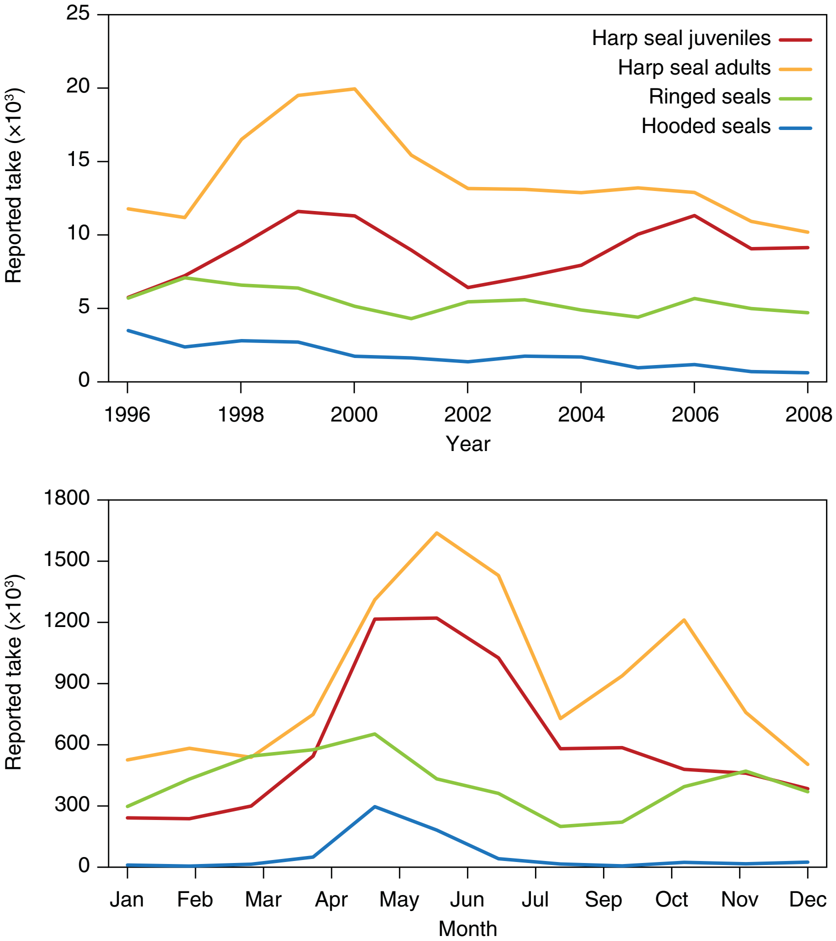


Figure 5.6. Annual reported take of three seal species in the assessment area (Nanortalik to Paamiut), 1996-2008. Top panel: annual development of the catch; bottom panel: monthly distribution of the catch. Data: Piniarneq, Greenland hunting statistics, Department of Fisheries, Hunting and Agriculture.

Ringed seals are normally associated with sea ice, and some ringed seals live in or near glacier fjords in the assessment area throughout the year. The catches increase during winter and spring. Most catches are juvenile seals, some of which are likely to have been "pushed" out of the fjords where adult seals establish territories when fast ice starts to form. Ringed seals are caught in highest numbers in the southernmost part of the assessment area. The annual catch is about 3-5,000 seals (Fig. 5.6).

The annual catch of bearded seals in the assessment area is about 1-200 seals.

The number of harbour seals taken in the northern part of the assessment area (north of Qaqortoq) declined from 60-80 per year in the early 1960s to near zero in the early 1980s. The decline in the population was recognised locally, and regulations in 1982 protected some of the haul-out sites against both hunting and disturbance, but this protection came too late. According to the local wildlife officer, harbour seals have left the area and are now only seen on rare occasions.

In the southern part of the assessment area (south of Qaqortoq), a steady catch averaging around 20 harbour seals per year was reported from the 1950s up until the 1980s. These seals probably came from a population living in the easternmost part of the assessment area. In the 1990s, catches started to increase and they peaked in 2003 with more than 100 seals per year, after which the catch numbers dropped significantly. The drift ice from East Greenland normally prevents hunting near the breeding area during the breeding season in June and for part of the summer as well. During 2003-2005, however, an unprecedented lack of drift ice allowed hunting in this area throughout the year, leading to high catches, which probably diminished the population significantly (Rosing-Asvid 2010a). The harbour seal has been fully protected in Greenland since 1 December 2010.

5.2.3 Baleen whales

Minke whales, fin whales and humpback whales are hunted in West Greenland, and annual quotas are set every 5 years by the International Whaling Commission (IWC) (Table 5.1). The Greenland government then divides the quota among the different municipalities.

Fin whales have been regularly hunted in Greenland since the 1920s and minke whales since the 1940s. From 1995 to 2009, the quota for fin whales remained stable at 19 whales per year, but this quota was seldom used, and with the introduction of an annual quota of 9 humpback whales for West Greenland in the years 2010-2012, the fin whale quota was correspondingly reduced to 10 whales per year. The quota for minke whales for West Greenland is 178 whales per year, with the possibility of transferring up to 15 animals from one year to the next (IWC 2010).

With the exception of a period between 1987 and 2009, humpback whales have been hunted in Greenland for centuries (Fabricius 1780). Four out of the 9 humpback whales from the quota of 2010 and 2011 can be taken within, or close to the assessment area (APNN 2011).

Table 5.1. 2011 quotas for the three species of baleen whales caught in West Greenland waters within the assessment area (APNN 2011).

Species	West Greenland quota	Quota in the assessment area	Catch in the assessment area in 2010
Minke whale (*Balaenoptera acutorostrata*)	185 (178 + 7 transferred from 2010)	Open (12 for collective hunt)	48
Fin whale (*Balaenoptera physalus*)	10	Open	0
Humpback whale (*Megaptera novaeangliae*)	9	4	3

Most minke whales are hunted from boats equipped with harpoon cannons loaded with explosive penthrite grenades, but a limited number of minke whales can be taken as 'collective hunt' from dinghies (Anon 2010). In 2010, the total catch of minke whales reported in zones within the assessment area was 48 individuals: 13 for the Paamiut area, 3 for the Narsaq area, 24 for the Qaqortoq area and 8 for Nanortalik (Department of Fisheries, Hunting and Agriculture, unpubl. data). Most minke whale catches within the assessment area are females due to a sexual segregation, where females tend to migrate further north than males to their summer feeding grounds, resulting in more females than males in West Greenland (Laidre *et al.* 2009).

Fin whales and humpback whales can only be hunted using harpoon cannons and explosive penthrite grenades (Anon 2010). Due to a lack of boats equipped with harpoon cannons in the northernmost parts of West Greenland, fin whales and humpback whales are normally taken from Disko Bay and southward. In 2010, five fin whales were caught; however, none were caught within the assessment area. Of the quota of nine humpback whales for each of the years 2010 and 2011, one whale was given to the municipality of Kujalleq within the assessment area and three to the municipality of Sermersooq, which covers part of the assessment area. Two humpback whale licenses were given to the municipality of Qaasuisup, and three whales were given to the municipality of Qeqqata, both north of the assessment area. In addition to the hunt, up to approximately five humpback whales are unintentionally caught in fishing gear every year in Greenland.

5.2.4 Toothed whales

Harbour porpoises, pilot whales and, to some extent white-beaked dolphins, killer whales, and perhaps bottlenose whales are hunted in the assessment area. The catch of these species is unregulated, but there is a voluntary reporting system that has included harbour porpoises since 1993. Pilot whales and killer whales were included in the reporting system in 1996 and white-beaked dolphins and bottlenose whales were added in 2003. The data are entered into a large database administrated by the Ministry of Fisheries, Hunting and Agriculture. The data presented below come from this database. A validation of killer whale data showed that there are human mistakes in the reporting.

In the period from 1993-2009, an average of 2,123 harbour porpoises were caught annually. Of the 36,093 catches reported from 1993-2009 in West Greenland, 7,198 harbour porpoises (i.e. 20%) were taken within, or close to the assessment area (i.e. between Nanortalik and Paamiut) (Fig. 5.7).

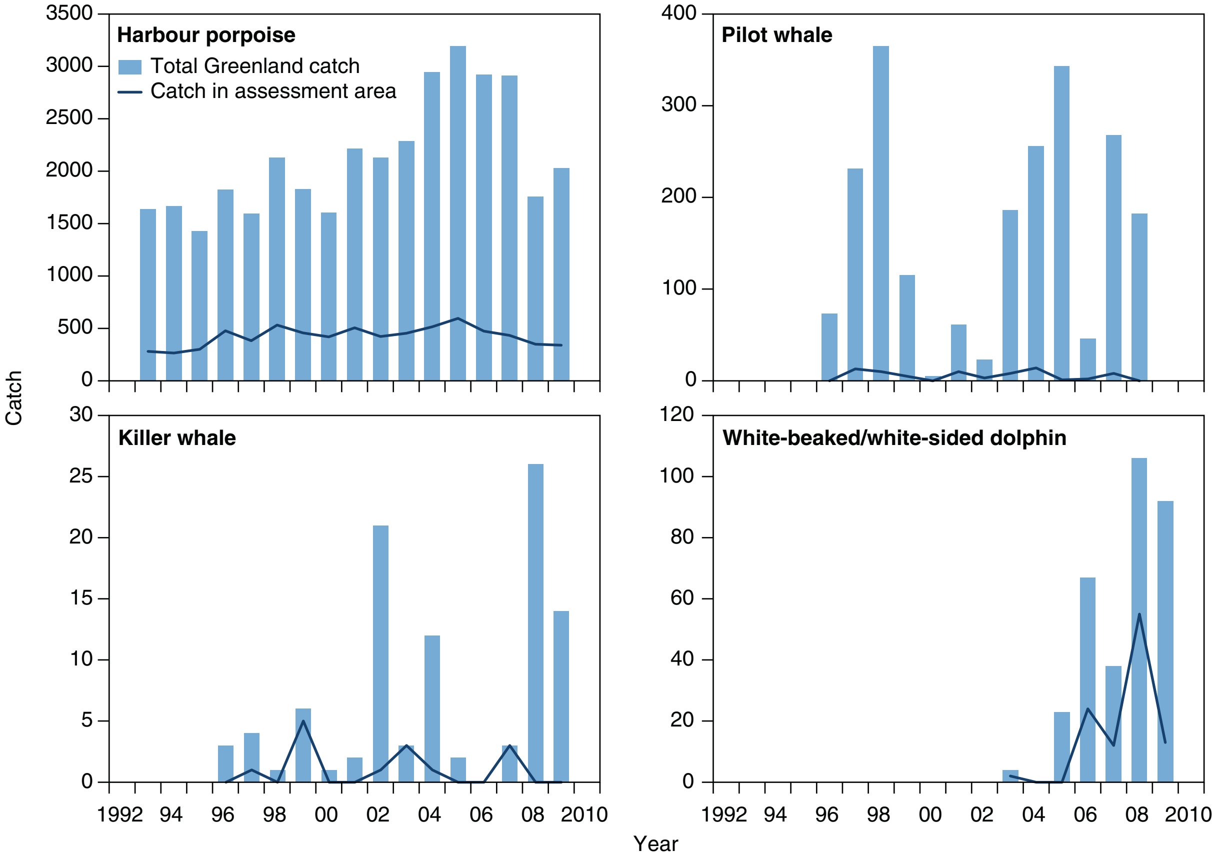


Figure 5.7. Annual reported catch of toothed whales in the assessment area and in Greenland.

Due to their unpredictable occurrence, pilot whales, white-beaked dolphins and killer whales are caught opportunistically. Annual catches of pilot whales in West Greenland vary between 0 and 300, and from 1996-2008 a total of 2,154 pilot whales have been caught in West Greenland. Most pilot whales are caught south of Disko Bay but north of the assessment area, and only few are caught south of 62° N within Greenland waters (less than 4% of the catches from 1996-2008, Fig. 5.7).

White-beaked dolphins and white-sided dolphin are not separated in the reporting system, as both species have the same name in Greenlandic. However, we can assume that the vast majority of dolphin catches are indeed white-beaked dolphins, as white-sided dolphins have a more southern distribution. On average, 47 dolphins have been caught annually in the period from 2003-2009 (Fig. 5.7). Out of 330 dolphins reported caught in West Greenland from 2003-2009, 106 (i.e. 32%) were caught in the assessment area.

Killer whales are hunted partly for human subsistence and partly to feed sledge dogs. They are also considered as competitors for seal and whale hunters, and this is an additional reason for the hunting of killer whales. From 1996-2009, a total of 98 killer whales have been caught in West Greenland and the annual average catch for the entire period was 7, ranging between 0 and 26 killer whales per year (Fig. 5.7). The killer whales have been caught irregularly along the entire West coast from Upernavik in the north to Nanortalik in the south, with 14 % of the catches (i.e. 14 animals) taken within the assessment area.

Bottlenose whales are not eaten in Greenland because their blubber causes diarrhoea in humans as well as dogs. Nevertheless, a few catches have been reported. It is possible that these reports are mostly mistakes, but unvalidated data show that catches reported from 2006, 2007, 2008 and 2009 were 2, 9, 21 and 1 bottlenose whales, respectively. Of the total catch of 33 whales, five were caught within the assessment area.

6 Protected areas and threatened species

David Boertmann (AU)

6.1 International nature protection conventions

According to the Convention on Wetlands (the Ramsar Convention), Greenland has designated eleven areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, so far only one Ramsar site in Greenland has been protected by law. Only one of the Ramsar sites is situated within the assessment area (Fig. 6.1). This is the archipelago of Ydre Kitsissut, which holds – in a Greenland context - a highly diverse seabird assemblage (Egevang & Boertmann 2001).

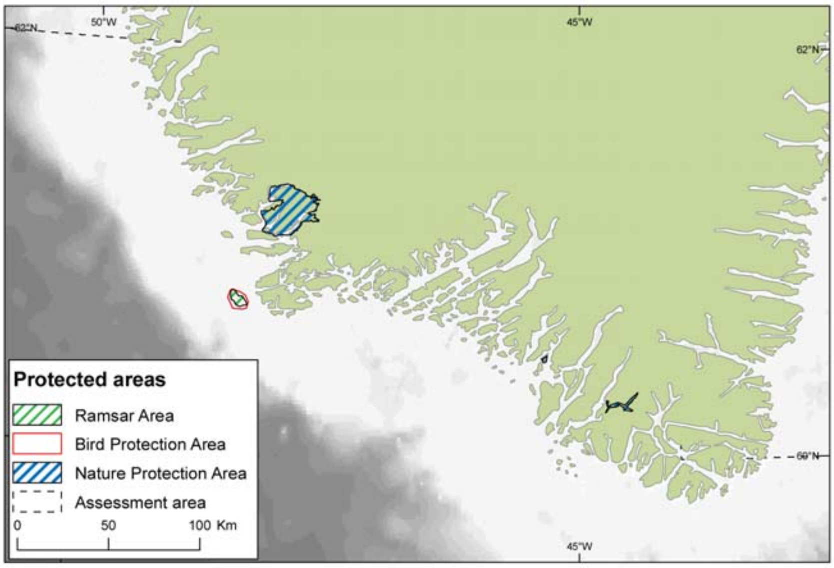


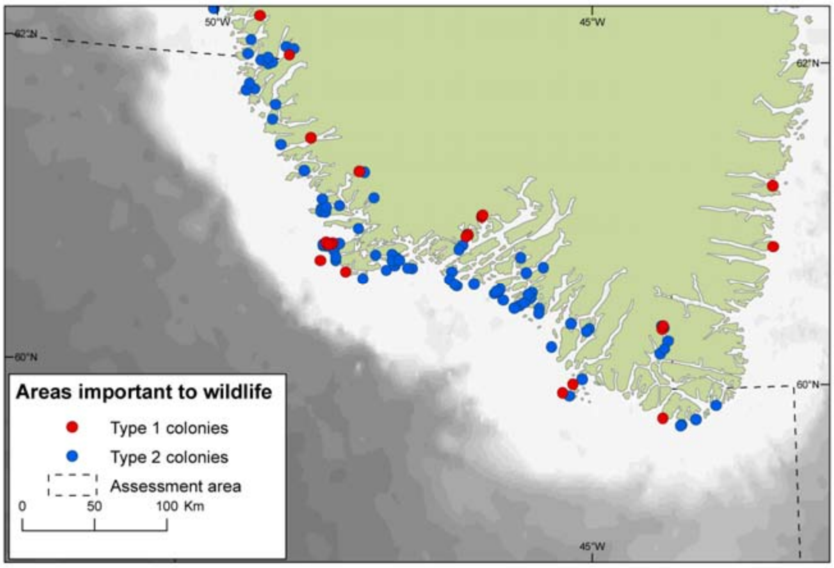
Figure 6.1. Areas within or near the assessment area protected according the Greenland Nature Protection Law or designated as Important Bird Areas (IBAs) or Ramsar sites.

6.2 National nature protection legislation

There are three areas protected according to the Greenland Nature Protection Law. Among these, the only marine/coastal site is the interior part of Ikka Fjord, where the unique ikaite columns are found (see section 4.4). The two other protected areas are inland sites, protected due to lush birch (*Betula*) shrub. Both are found in valleys northeast of Nanortalik, at the fjord Tasermiut.

One site (Ydre Kitsissut) is protected as a seabird breeding sanctuary according to the Bird Protection Executive Order (Fig. 6.1). This order also states that, in general, all seabird breeding colonies are protected from disturbing activities (cf. Fig. 4.6). According to the Mineral Extraction Law, a number of 'areas important to wildlife' are designated, and in these, mineral exploration activities are regulated in order to protect wildlife. Several seabird breeding colonies are designated under this legislation (Fig. 6.2).

Figure 6.2. Areas designated as 'important to wildlife' by the BMP in the field rules for prospecting and exploration activities. Type 1 colonies host breeding northern fulmars, thick-billed or common murres, razorbills or black-legged kittiwakes, while type 2 colonies host breeding common eiders, black guillemots, Atlantic puffins, Arctic terns or gulls (except kittiwakes).



6.3 Threatened species

Greenland has red-listed (designated according to risk of extinction) two species of mammals and twelve species of birds occurring in the assessment area (Table 6.1, cf. Boertmann 2007b).

A number of species have been categorised as 'Data Deficient' (DD) or 'Not Applicable' (NA) and may be red-listed when additional information becomes available (Table 6.2).

Table 6.1. Nationally red-listed species (associated with the marine environment) occurring in the assessment area.

Species	Red List category
Polar bear	Vulnerable (VU)
Harbour seal	Critically endangered (CR)
Great northern diver	Near threatened (NT)
Common eider	Vulnerable (VU)
Harlequin duck	Near threatened (NT)
White-tailed eagle	Vulnerable (VU)
Gyrfalcon	Near threatened (NT)
Black-headed gull	Vulnerable (VU)
Black-legged kittiwake	Vulnerable (VU)
Ivory gull	Vulnerable (VU)
Arctic tern	Near threatened (NT)
Thick-billed murre	Vulnerable (VU)
Common murre	Endangered ((EN)
Atlantic puffin	Near threatened (NT)

Greenland has a special responsibility for species where a significant part (20 %) of the global population occurs in the country, implying that their global survival depends on a favourable conservation status in Greenland. National responsibility species occurring in the assessment area include two mammals and six birds (Table 6.2). Endemic species or subspecies are also of national responsibility as the total global population is found within Greenland. No endemic species occur in the assessment area, but three bird species occur with biogeographically isolated populations (Table 6.2).

Table 6.2. National responsibility species (defined as more than 20 % of the global population in Greenland, including also endemic subspecies), species with isolated population in Greenland and species listed as 'Data Deficient' (DD) occurring in the assessment area. Only species which may occur in marine habitats included.

National responsibility species	Species listed as Data Deficient (DD)	Species with isolated populations in Greenland
Polar bear	Harbour porpoise	Great cormorant
Bearded seal	Sei whale	Red-breasted merganser
Mallard	Blue whale	Harlequin duck
Common eider		
White-tailed eagle		
Iceland gull		
Black guillemot		
Little auk		

The International Union of Nature Conservation maintains a list of globally threatened species (IUCN 2011). Five globally threatened species (one bird and four mammals) occur within the assessment area (Table 6.3).

Table 6.3. Species occurring in the assessment area and listed as globally threatened (IUCN 2011).

Species	Red List category
Ivory gull	Near Threatened (NT)
Polar bear	Vulnerable (VU)
Fin whale	Endangered (EN)
Blue whale	Endangered (EN)
Sperm whale	Vulnerable (EN)

6.4 NGO-designated areas

The international bird protection organisation BirdLife International has designated a number of Important Bird Areas (IBAs) in Greenland (Heath & Evans 2000). These areas are particularly important areas for birds, and should be protected by national regulations. They are designated using an extensive set of criteria, for example that at least 1 % of a biogeographical population occurs in the area. For further information see the IBA website (Link). There is only one IBA within the assessment area, again the important archipelago Ydre Kitsissut, which is also a Ramsar site and included among the protected seabird breeding sites.

7 Background levels of contaminants

Doris Schiedek (AU)

Knowledge on background levels of contaminants in sediment and biota in areas with foreseen hydrocarbon exploration and exploitation is important, since it serves as a baseline for the monitoring and assessment of potential contamination of the environment caused by these activities. Occurrence of contaminants in the aquatic environment and in biota has been studied in Greenland over the years in various regions and with different purposes. An overview is given in Boertmann et al. (2009). In the following, the present knowledge is summarised with focus on studies with relevance for the South Greenland assessment area.

7.1 Current knowledge of contaminant levels

Baseline data on lead, cadmium, mercury and selenium levels in molluscs, crustaceans, fish, seabirds, seals, walruses, whales and polar bears have been compiled for different geographical regions, including West, Northwest and Central West Greenland (Dietz et al. 1996). Data have only been included for animals not affected by local pollution sources, i.e. former mine sites. The overall conclusion was that lead levels in marine organisms from Greenland were low, whereas cadmium, mercury and selenium levels were high, in some cases exceeding Danish food standard limits. No clear conclusions could be drawn in relation to geographical differences concerning lead, mercury and selenium concentrations. In general, cadmium levels were higher in biota from Northwest Greenland compared to southern areas.

7.1.1 AMAP monitoring activities

In 1991, the Arctic Monitoring and Assessment Programme (AMAP) was established to monitor identified pollution risks and their impacts on Arctic ecosystems. The Arctic is a region with almost no industry or agriculture. Most of the persistent organic pollutants (POPs) and a substantial part of the metals (e.g. mercury) found in the Arctic environment are of anthropogenic origin. The POPs, mercury and other substances have reached the Arctic as a result of long-range transport by air and via oceans and rivers (AMAP 2004). Once in the Arctic, contaminants can be taken up in the lipid-rich Arctic marine food web. In general, the level of mercury has increased in the Arctic, with implications for the health of humans and wildlife. There is also some evidence that the Arctic is a ‘sink’ for global atmospheric mercury (Outridge et al. 2008).

As part of AMAP, a biological time trend programme was set up in Greenland with focus on a suite of POPs, including PCBs (polychlorinated biphenyls) and different trace metals, i.e. cadmium (Cd), mercury (Hg) and selenium (Se). A detailed overview of the contaminant levels and temporal trends in the monitored species is given in Schiedek (2011), including results from the latest AMAP assessment in 2009 (Muir & de Wit 2010). In general, the AMAP assessments have revealed that POPs are clearly present in Arctic biota and their levels are generally highest in species belonging to the top trophic level (e.g. great skua, glaucous gull, great black-backed gull, killer whale, pilot whale, Arctic fox and polar bear). The AMAP activities have also documented a decrease in the levels of some POPs (e.g. PCBs and DDT), as result of the introduction of bans and restrictions relating to their use in other parts of the world (AMAP 2004, Muir & de Wit 2010). At the same time, however, levels of new persistent pollutants are increasing (AMAP 2004, Muir & de Wit 2010). These substances have also been detected in animals from Greenland, such as the brominated flame retardants hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA), chemicals which are produced in high volumes. In recent years, their presence has been reported in sediment and biota from the marine environment (Frederiksen et al. 2007). Concentrations of HBCDs in animals from West Greenland are generally lower than in the same species from East Greenland. The same effect has previously been described for other halogenated compounds such as PBDEs and polybrominated diphenyl ethers (Vorkamp et al. 2007).

7.1.2 Past and present mining activities

From 1854 to 1987, cryolite was mined at Ivittuut, close to Arsuk Fjord, as an open pit operation. Since 1982, an environmental monitoring programme has been carried out. It revealed that the nearby fjord was polluted with lead and zinc, resulting in accumulation of lead and zinc in intertidal biota (seaweed and mussels), affecting a large part of the fjord. Waste rock used as landfill at the coastline was identified as the major source of this pollution. Over the entire monitoring period (1982 to 2010), a decline in both zinc and lead levels was observed in biota from Arsuk Fjord. In 2010, zinc levels were approx. 3 times lower than in 1982, indicating diminishing transport of lead from the source to the sea. The lead concentrations in blue mussels (*Mytilus edulis*), however, were still 200–500 times higher than in blue mussels from other parts of Greenland with no known local lead sources. In some parts of the fjord, i.e. around Ivittuut, the lead concentration in blue mussels was still so high in 2010 that their consumption could not be recommended (Johansen et al. 2010). Zinc concentrations have also generally decreased, but at a slower rate.

The Nalunaq gold mine, situated 8 km from the coast in Kirkespirdalen, about 40 km northeast of Nanortalik, was opened in 2004 after an extensive exploration programme and environmental baseline studies had been carried out (Glahder et al. 2010). Until 2007, the gold ore was shipped to a reprocessing plant at Rio Narcea in Spain. From 2007-2009, the ore was reprocessed at Nugget Pond in Newfoundland, Canada. During the latest environmental monitoring study in 2010, the impact from the mining activities on the marine environment was found to be very low; i.e., no elevated concentrations of trace elements were found in blue mussels, shorthorn sculpin (*Myoxocephalus scorpius*) or in resident Arctic char (*Salvelinus alpinus*). In lichens, which are indicators for airborne pollution, concentrations of Cu, Cr, As and Co were, as in previous years, significantly elevated in the mining area compared to the background levels, very likely caused by dust from the road leading to the mine site (Glahder et al. 2010).

7.1.3 Tributyltin (TBT)

The antifouling agent tributyltin (TBT) can be found in many coastal waters in both industrial and developing countries, with the highest levels in harbours and along shipping lanes (Sousa et al. 2009). In remote areas such as the Arctic environment, TBT levels are usually low, except close to harbours, as shown for Sisimiut north of the assessment area (Villumsen & Ottosen 2006), and near shipping lanes (Strand & Asmund 2003, AMAP 2004, Berge et al. 2004). The presence of TBT residues in harbour porpoises from Greenland documents that organotin compounds have also spread to the Arctic region, even though the observed concentrations are relatively low (Jacobsen & Asmund 2000, Strand et al. 2005).

7.1.4 Petroleum hydrocarbons and polycyclic aromatic hydrocarbons (PAH)

Petroleum hydrocarbons represent several hundred chemical compounds in products derived from crude oil, e.g. gasoline, kerosene, and diesel fuel. Of primary interest for the assessment of environmental impacts are the aromatic hydrocarbons (i.e., benzene, ethylbenzene, toluene, and xylenes). Another important group are polycyclic aromatic hydrocarbons (PAHs), which originate from two main sources: combustion (pyrogenic) and crude oil (petrogenic). PAHs represent the most toxic fraction of oil and are released to the environment through oil spills and discharge of produced water (see also section 9.4.1). Sixteen PAHs are included on the lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency.

Levels of petroleum hydrocarbons (incl. PAHs) are generally low in the Arctic marine environment and often close to background concentrations, except in areas with anthropogenic impact such as harbours. Presently, the majority of petroleum hydrocarbons in the Arctic originate from natural sources such as seeps (Skjoldal et al. 2007). From the studies of PAH levels in biota and sediment (including sediments from offshore areas, municipal waste dump sites and sites with no known local pollution sources) performed so far in Greenland, including the assessment area, levels of petroleum compounds in coastal and offshore areas also appear to be relatively low and could be regarded as background concentrations. PAH levels measured so far in South Greenland in the sediment are also low, except at a municipal waste dump near Nanortalik (Fig 7.1).

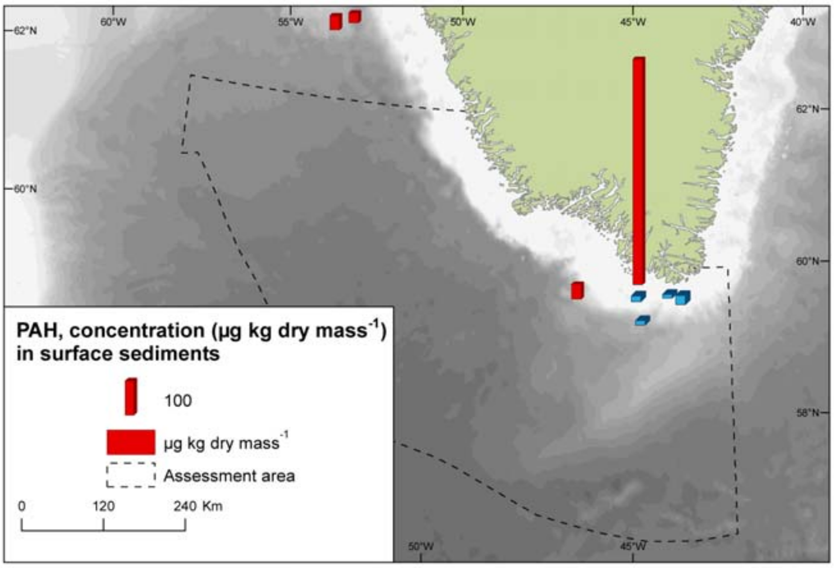


Figure 7.1. Polycyclic aromatic hydrocarbon (PAH) concentrations (µg/kg dry mass) in surface sediments (usually the top 0-1 cm) in the assessment area. Coloured bars indicate PAH concentrations and sampling done by different companies/institutions. Red bars are sampled by Aarhus University and blue bars by Cairn Energy PLC. Values are based on 16 PAHs, in accordance with the United States Environmental Protection Agency (EPA). These 16 PAHs are prioritised by EPA and are often targeted for measurement in environmental samples. Note: the anomalously high PAH value was measured at a waste dump site near Nanortalik.

7.1.5 Conclusions on contaminant levels

In general, the AMAP studies have revealed that levels of organochlorines in Arctic biota are highest in the marine organisms belonging to the top trophic level (e.g. whales). This is particularly true for bio-magnification of PCBs and DDT. AMAP activities have also shown a decrease in the levels of some POPs (e.g. PCBs and DDT), as a result of the introduction of bans and restrictions relating to their use in other parts of the world (AMAP 2004, Muir & de Wit 2010). At the same time, however, new persistent pollutants, such as brominated flame retardants are increasing (AMAP 2004, Muir & de Wit 2010), also in animals from Greenland. Levels of petroleum compounds, including PAHs, are relatively low in the Greenland environment and are regarded as background concentrations.

The short overview given in this section also documents that our present knowledge on contaminant levels in marine organisms from West Greenland, including the assessment area, is still limited. Further studies are needed to better understand if and to what extent biota in the assessment area are already impacted by contaminants, but also to serve as baseline for future monitoring and assessments. In this respect, it is also important to know more about the relation between contaminant loads and potential biological impacts, including sublethal health effects or impairments.

7.2 Biological effects

The research and monitoring activities described in the previous section clearly indicate the presence of different kinds of contaminants (e.g. POPs, heavy metals) in biota from Greenland. Regional differences have been found as well as differences among species, with the highest concentrations in top predators (e.g. polar bear, seals). However, contaminant levels in Greenlandic biota are often still lower than in those from more temperate regions, e.g. the North Sea or Baltic Sea. The question arises whether the levels found in the Arctic are sufficiently high to cause biological effects and what the threshold levels of impact might be.

As part of the AMAP assessment in 2009, the most recent studies have been reviewed and summarised with regard to biological effects and how they are related to exposure to specific POPs (Letcher et al. 2010). First attempts have been made to assess known tissue/body compartment concentration data in the context of possible threshold levels on top trophic level species, including seabirds (e.g. glaucous gull), polar bears and Arctic char. There was only little evidence for widespread effects on the health of Arctic organisms. However, on a smaller scale, effects have been documented. Based on the "weight of evidence" found in different studies performed on Arctic and sub-Arctic wildlife and fish, several key species and populations have been identified as potentially affected (Letcher et al. 2010). Among those are East Greenland polar bear and ringed seal, Greenland shark from the Baffin Bay/David Strait, and a few populations of freshwater Arctic char.

Pollution effects on polar bears have also been investigated in more detail, since this species exhibit the highest levels of certain contaminants (e.g. organochlorines, PBDEs, PFCs or mercury) in the Arctic, in particular the populations from East Greenland and Svalbard (Norway). Effects on polar bear health caused by the complex, biomagnified mixture of these substances were summarised and assessed by Sonne (2010). This review showed that hormone and vitamin concentrations, liver, kidney and thyroid gland morphology as well as reproductive and immune systems of polar bears are likely to be influenced by contaminant exposure.

Threshold levels documenting the impact of contaminants on biota have been estimated for various chemicals in a range of species, both under laboratory conditions and in the field in European waters. These studies have clearly indicated that organisms are affected by contaminants and that their physiological responses depend on the duration and extent of exposure. The effects observed range from enzyme inhibition and changes in cellular processes, to immuno-suppression, neurotoxic and genotoxic effects up to reproduction impairment or histopathology alterations as the endpoint of the pollutant impact. Differences in the response are notable among species and regions (van der Oost et al. 2003, Lehtonen et al. 2006, Picado et al. 2007). Toxicity tests have also widely been used in temperate regions to relate environmental concentrations to biological effects, but only a few tests have been performed so far on Arctic and sub-Arctic species.

This makes it difficult to estimate whether threshold values determined for temperate species are valid for comparison with the situation in the offshore waters of Greenland. Species living in the Arctic and sub-Arctic have very specific life strategies and population dynamics as a result of adaptation to the harsh environment. Moreover, their fat content and seasonal turnover could differ when compared to more temperate species (AMAP 2004). The lower temperatures in Greenland waters are also likely to have an impact on the toxicity of contaminants. Presently, only limited data are available to determine whether cold-adapted species are more (or less) sensitive to contaminants than temperate species.

In this respect, biota inhabiting offshore waters in South Greenland might have a special status. In terms of species composition, the communities are similar to what is found in cold-temperate ecosystems, e.g. in Norway. However, in terms of hydrography and temperature regime, a different adaptation strategy is probably required, which could also influence species' response to the presence of contaminants.

Presently, we do not have sufficient information allowing any assessment of whether or not species living in South Greenland show similar physiological responses when exposed to contaminants, including petroleum hydrocarbons as their more temperate counterparts, e.g. in Norway.

7.2.1 Polycyclic aromatic hydrocarbons (PAH) and possible effects on biota

As pointed out above, PAH levels are relatively low in Greenland biota. With increasing human activities, e.g. in relation to oil exploration, this may change, and reliable environmental monitoring tools are required to identify any potential impact on the biota, e.g. in the assessment area.

PAHs are taken up by marine organisms directly from the water (via the body surface or gills) or through the diet. Many studies have indicated that PAHs are more or less metabolised by invertebrates, and generally efficiently metabolised by vertebrates such as fish (Hylland et al. 2006). Therefore, and in contrast to most persistent organic pollutants, PAHs are not biomagnified in the marine food web. Dietary exposure to PAHs may however be high in species that preferentially feed on organisms with low ability to metabolise PAHs, such as bivalves (Peterson et al. 2003). At the other end of the food chain, filter-feeding zooplankton can be exposed to high levels through filtering out oil droplets containing PAHs from the surrounding water.

The effects of PAHs on organisms are extensive and occur at various levels, including biochemical and physiological and/or genotoxic effects (Hylland et al. 2006). The responses and tolerance to PAHs can vary considerably in organisms, depending on the geographical range of the species, but also on the particular PAH mixture. PAHs are a large group of diverse substances, ranging from two-ring naphthalenes and naphthalene derivates to complex ring structures containing up to 10 rings. Effects in relation to PAH exposure have also been found at the population level, possibly reflecting the pre-exposure history and/or heritable genetic changes in populations chronically exposed to PAHs.

PAHs are also major contributors to the toxicity of produced water released during oil and gas production. Produced water is a complex mixture and contains numerous toxic compounds, such as dispersed oil, metals, alkylphenols, and PAHs. The composition varies between wells, among others due to the different chemicals added during the oil production process. Possible effects on biota caused by PAHs are discussed in more details in chapter 9 and 10.

In general, it can be stated that exposure to PAHs causes effects at different biological levels, and that the thresholds can differ depending on the species and the ecosystem.

To be able to better assess potential risks for Arctic and sub-Arctic biota and their environment due to petroleum related contamination, e.g. oil spills, more integrated studies are needed. Th existing knowledge concerning the sensitivity of key species in the assessment area and their responses to oil or PAH exposure also needs to be improved.

Studies performed in Norway on species from North Sea, sub-Arctic and Arctic environment have documented that the application of a range of biomarkers should be considered when assessing biological effects. Moreover, assessment criteria specific for Greenland have to be established, allowing the assessment of unacceptable impacts. Such criteria should be based on ecotoxicological tests that cover the sensitivity range of relevant species at different trophic levels, e.g. OSPAR Environmental Assessment Criteria. Toxicological tests with relevant species for the assessment area are presently not available for establishing such criteria. Knowledge concerning species sensitivity, assessment criteria as well as an adequate monitoring strategy should be available.

As the species composition has some similarity to parts of Norway, it might be possible to build on results from studies and monitoring activities performed for instance in Norway and to use similar target species. However, this needs to be further explored and studied before major drilling activities,

8 Impacts of climate change

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8.1 General context

One of the main findings of the AMAP assessment concerning the impacts of climate change on snow, water, ice and permafrost in the Arctic has been that the period 2005-2010 was the warmest ever recorded in the Arctic environment (AMAP 2011). Since 1980, the increase in annual average temperature has been twice as high in the Arctic region as in other parts of the world. Changes in weather patterns and ocean currents have been observed, including higher inflows of warm water entering the Arctic Ocean from the Pacific.

Average autumn-winter temperatures are projected to increase by 3 to 6° C by 2080, even when using scenarios with lower greenhouse gas emissions than those recorded in the past ten years. It has also been predicted that sea ice thickness and summer sea ice extent will continue to decline, although with considerable variation from year to year. A nearly ice-free summer is now considered likely for the Arctic Ocean by mid-century (AMAP 2011).

In Greenland, 2010 was marked by record-high air temperatures, ice loss by melting and marine-terminating glacier area loss. Summer seasonal average (June-August) air temperatures around Greenland were 0.6 to 2.4° C above the 1971-2000 baseline and were highest in the west. A combination of a warm and dry 2009-2010 winter and the very warm summer resulted in the highest melt rate since at least 1958, and an area and duration of ice sheet melting that was above any previous year on record since at least 1978. There is now clear evidence that the ice area loss rate of the past decade (on average 120 km^2/year) is greater than before 2000 (Box et al. 2010).

On-going and future warming has an impact on the marine ecosystems in Greenland in many ways. An increase in water temperature has a direct influence on organisms and their metabolism, growth and reproduction. Depending on the acclimation capacity of local species, changes in distribution patterns and species' diversity are to be expected, with profound consequences for the composition of biological communities and their productivity, thus influencing ecosystems on local and regional scales.

Oceanographic conditions in the Labrador Sea and off Southwest Greenland are strongly influenced by currents, particularly the balance between the cold East Greenland Current and the warm Irminger Current. It is likely that this balance will be affected by future warming, but the direction and extent of such changes are difficult to predict.

Changes in the oceanographic conditions will affect primary production and thus the timing, location and species composition of phytoplankton blooms. This will in turn affect zooplankton communities and the productivity of fish; i.e. mismatch in timing of phytoplankton and zooplankton production due to early phytoplankton blooms may reduce the efficiency of the food web. Food web effects could also occur through changes in the abundance of top-level predators, but the effects of such changes are more difficult to predict. Generalist predators are likely to be more adaptable to changed conditions than specialist predators. All in all, significant alterations are to be expected for the entire food web.

The current warming trends are often linked to anthropogenic carbon dioxide (CO_2) accumulation in the atmosphere. At the same time, increased CO_2 concentrations will reduce ocean pH and carbonate ion concentrations, and thus the level of calcium carbonate saturation. If emissions of CO_2 to the atmosphere continue to increase, acidification of the oceans may cause some calcifying organisms, such as coccolithophores, corals, echinoderms, molluscs and crustaceans, to have difficulties forming or maintaining their external calcium carbonate skeletons. Other effects of ocean acidification on marine organisms could include slower growth, decreased reproductive potential or increased susceptibility to disease, with possible implications for ecosystem structure and elemental cycling (e.g., Orr et al. 2005, Fabry et al. 2008, Kroeker et al. 2010).

Marine ecosystems in the Arctic region are already changing in response to a warming climate as documented by Wassmann et al. (2011). They found clear evidence for changes for almost all components of the marine ecosystems, also in West Greenland, reaching from planktonic communities to large mammals. Their evaluation was based on several types of footprints of responses in biota to climate change, such as range shifts, including poleward range shift of sub-Arctic species, changes in abundance, growth/condition, behaviour/phenology and community/regime shifts (Table 8.1). Some of the on-going and expected changes and their relevance for the assessment area are described below.

Table 8.1. Summary of types of footprints of responses of marine organisms living in the Arctic region to climate change (Wassmann et al. 2011).

Responses	Nature of changes
Range shift	Northward displacement of sub-Arctic and temperate species, cross-Arctic transport of organisms from the Pacific to the Atlantic sectors
Abundance	Increased abundance and reproductive output of sub-Arctic species, decline and reduced reproductive success of some Arctic species associated to the ice and species now used as prey by predators whose preferred prey have declined
Growth and Condition	Increased growth of some sub-Arctic species and primary producers, and reduced growth and condition of icebound, ice-associated, or ice-borne animals
Behaviour and Phenology	Anomalous behaviour of ice-bound, ice-associated, or ice-borne animals with earlier spring phenological events and delayed fall events
Community and regime shifts	Changes in community structure due to range shifts of predators resulting in changes in the predator-prey linkages in the trophic network

8.2 Primary production and zooplankton

Presently, marine Arctic ecosystems are dominated by the diatom-feeding *Calanus glacialis* and *C. hyperboreus*; both favoured food for specialised important seabirds, such as the little auk. A prolonged production period could favour a mixed diatom-dinoflagellate community, which could result in a food chain based on *Calanus finmarchicus* – *Metridia longa*, which are less valuable as food for planktivorous birds and mammals (bowhead whale and little auk). Thus, climate change is likely to change primary production from strongly pulsed to a more prolonged and unpredictable production of diatoms (rich in polyunsaturated fatty acids) with consequences for the higher trophic levels (Kattner et al. 2007).

In Southwest Greenland, including the assessment area, *C. finmarchicus* is already the dominant *Calanus* species, outnumbering both *C. glacialis* and *C. hyperboreus* by a factor of 3 throughout the year, depending on food availability (Pedersen et al. 2005, and references therein). With increasing temperatures the predominance of *C. finmarchicus* will further increase as also shown experimentally by Kjellerup et al. (submitted). Such a scenario will presumably cause a trophic cascade due to less energy content per individual (Hansen et al. 2003, Falk-Petersen et al. 2007). In addition, the proportion of biomass accounted for by *C. finmarchicus* will further increase (Hirche & Kosobokova 2007) due to its higher growth rate and shorter life cycle (Scott et al. 2000). Thus, a regime shift towards *C. finmarchicus* will without doubt influence important seabirds such as the little auk negatively (Karnovsky et al. 2003), and at the same time favour pelagic fish like herring (Falk-Petersen et al. 2007) and their predators (Stempniewicz et al. 2007).

C. finmarchicus also plays an important role as prey for larval stages of the Atlantic cod. In West Greenland waters, *C. finmarchicus* is the most important food source for cod larvae (Drinkwater 2005). Changes in its abundance and distribution will likely have a direct effect on the distribution of Atlantic cod and other fish species as well.

Since *C. finmarchicus* grazes on phytoplankton, its spatial distribution and life cycle are not only influenced by temperature, but also by algal food abundance measured as chlorophyll *a* concentrations. There is already some evidence that chlorophyll maxima occur earlier in the year off Greenland based on satellite data collected from 1997–2009 (Kahru et al. 2011), indicating changes in the development of phytoplankton blooms and thus primary production.

A change or increase in the primary production season in the assessment area could not only influence *C. finmarchicus*, but also favour certain other zooplankton species, with consequences on the community level.

Phytoplankton is also a conduit for the uptake, processing and transformation of carbon dioxide. Changes in the amount of carbon that flows and cycles through the food web will change the amount of carbon retained in the ocean or respired back into the atmosphere. These changes may fundamentally alter the structure of marine Arctic ecosystems, including the assessment area.

8.3 Benthic fauna

Climate variability can also modify interactions between the pelagic and the benthic realm in the assessment area. Future fluctuations in zoobenthic communities will depend on the temperature tolerance of the present species and their adaptability. If further warming occurs, those species tolerating a wide temperature range will become more frequent, causing changes in the zoobenthic community structure and probably its functional characteristics, especially in coastal areas with consequences for the higher trophic levels. At the time being, our knowledge about temperature tolerance and adaptability of macrobenthic species in the assessment area is limited, and it is not possible to make predictions of changes in biogeography and species interactions. In the review by Wassmann et al. (2011), 12 examples of changes in benthic communities are presented. Impacts of climate change included species-specific changes in growth, abundance and distribution ranges, and community-level changes in total species composition. Most of the examples found were geographically concentrated around Svalbard and the Bering Sea where research effort is highest. Nevertheless, they can be regarded as examples of changes occurring in many other marine Arctic ecosystems, including the assessment area.

Future warming of the Arctic is also likely to affect freshwater run-off from rivers and glaciers positively. Besides a freshening of surface waters in nearshore areas, this will also lead to increased turbidity and inorganic sedimentation, with potential effects on the species composition of benthic communities (e.g. Włodarska-Kowalczuk & Pearson 2004, Włodarska-Kowalczuk et al. 2005, Pawłowska et al. 2011, Węsławski et al. 2011).

8.4 Fish and shellfish

Fish species form an essential link between lower and higher trophic levels; the larvae or juveniles of many fish species feed on zooplankton, and fish are important prey for many seabirds and marine mammals. Changes in temperature and oceanographic conditions will influence fish populations directly through distributional shifts to areas with preferred temperatures, and indirectly through the food supply and the occurrence of predators. Survival of organisms and populations depend upon the degree to which they can match in time the occurrence and production of their prey. Changes in climate can cause changes in the timing of the production cycles of phytoplankton, zooplankton or fish, in some cases through an influence on migration times.

Marine fish have complex life histories with eggs, larvae, juveniles, and adults of the same species often occurring in different geographic locations and at different depths. Changes in temperature may have different effects on the various life stages of a species (Pörtner & Peck 2010). If a species has to shift its spawning areas due to an altered temperature regime, its continued success will depend on factors such as whether current systems in the new area take the eggs and larvae to suitable nursery areas, and whether the nursery areas are adequate in terms of temperature, food supply, depth, etc. Changes in spawning and nursery areas caused by climatic changes may, therefore, also lead to changes in population or species abundance (Dommasnes 2010).

Changes in the distribution and abundance of fish populations will have consequences for the entire food web, also in the assessment area. Some of the more abundant species are likely to move northward due to the projected warming, including Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*) and Atlantic cod, and this may favour piscivorous birds and mammals. Greenland halibut is expected to shift its southern boundary northward or restrict its distribution more to continental slope regions (ACIA 2005).

The interaction between changing climate and distribution of certain fish species has been documented for previous warming periods off Greenland with consequences for the abundance of Atlantic cod and Greenland halibut (Horsted 2000, Drinkwater 2006, Stein 2007). Ecosystem changes associated with the warm period during the 1920s and 1930s included northward expansion of boreal species, such as cod, haddock and herring, while cold water species such as capelin retreated northwards. Higher recruitment and growth led to increased biomass of important commercial species (i.e. cod and herring). During a period (1960-1970) of decreasing air and ocean temperatures, cod abundance (including cod larvae) declined again in this region (Horsted 2000, Drinkwater 2006). Coinciding with the decrease in cod was an increase in northern shrimp and Greenland halibut. Meanwhile, the shrimp fishery replaced cod as a dominant industry in West Greenland (Hamilton et al. 2003).

Similar responses of cod as observed during the previous warm period could be expected in relation to the present warming period. For the West Greenland offshore cod stock, their abundance, recruitment, and individual growth rates have increased during the recent warming, but continue to remain at levels much lower than observed during the early 20th century warming (Drinkwater 2009). How far north Atlantic cod will be distributed if temperatures increase further is not possible to indicate yet.

For northern shrimp, the duration of egg development and hatching is determined by local bottom temperature and correlated with the spring phytoplankton bloom (Koeller et al. 2009). Shrimp appear to have adapted to present local temperatures and occurrence of spring bloom in matching hatching to food availability. Changes in water temperatures and food base composition may influence the distribution and abundance of shrimp.

Current knowledge on distribution and abundance of capelin in Greenland (including the assessment area) and elsewhere suggests that expected climate changes in the region would have a large impact on this important species. Minor temperature increases will most likely increase capelin productivity, provided sufficient prey resources are available (Hedeholm et al. 2010). A more pronounced increase in water temperature will probably result in a northward shift in distribution (Hansen & Hermann 1953). Moreover, a stable capelin spawning population could disappear from the southernmost part of Greenland (Huse & Ellingsen 2008).

Changes in physical conditions in high latitude ecosystems will probably also affects fisheries. Positive effects of warming have already been documented for the distribution and abundance of Arcto-Norwegian cod (MacNeil et al. 2010). This population shows stronger year classes in warm years and poor year classes in cold, and warming has led to a northern range expansion in Norway (Drinkwater 2006, Drinkwater 2009). As a result of warming, yields are predicted to increase by approximately 20 per cent for the most important cod and herring stocks in Iceland, and approximately 200 per cent in Greenland over the next 50 years (Arnason 2007). Climate-driven fish invasions into Arctic marine ecosystems, including the assessment area, are expected to exceed those of any other Large Marine Ecosystem (Cheung et al. 2010). Despite possible positive effects of climate warming predicted for fisheries, it is still not clear how invading species interact with species already present and how this affects food web interactions, including in the assessment area.

8.5 Marine mammals and seabirds

The impacts of climate change on marine mammals and seabirds are likely to be severe, even though not so easy to estimate since patterns of changes are non-uniform and highly complex (ACIA 2005). Laidre et al. (2008) compared seven Arctic and four sub-Arctic marine mammal species with regard to their habitat requirements and evidence for biological and demographic responses to climate change. Sensitivity of the different species to climate change was assessed using a quantitative index based on population size, geographic range, habitat specificity, diet diversity, migration, site fidelity, sensitivity to changes in sea ice, sensitivity to changes in the trophic web, and maximum population growth potential (R_{max}). Marine mammals depending on sea ice (e.g. hooded seal, polar bear or narwhal) appear to be most sensitive. Species such as ringed seal and bearded seal are less sensitive, primarily due to their large circumpolar distributions, large population sizes, and flexible habitat requirements. Owing to their dependence on sea-ice habitat, the impacts of continued climate change will increase the vulnerability of all polar bear sub-populations. Population and habitat modelling have projected substantial future declines in the distribution and abundance of polar bears (Lunn et al. 2010).

Arctic seabirds, which typically depend on large, energy-rich zooplankton, are likely to be negatively affected by increasing temperatures and decreasing ice cover, while more temperate piscivorous species may benefit from these changes (cf. Kitaysky & Golubova 2000). Changes in the extent and timing of sea-ice cover over the past several decades, for example, have led to changes in phenology and reproduction of thick-billed murres in Canada, with adverse consequences for nestling growth (Gaston et al. 2005). A circumpolar study of population change of both thick-billed and common murres showed that both species tended to decline following major changes in sea temperature (Irons et al. 2008). Within the assessment area, it is likely that the breeding population of the partly planktivorous thick-billed murre will be gradually replaced by the cold-temperate sibling species, the piscivorous common murre (Gaston & Irons 2010). This will probably be a very slow process due to pronounced site fidelity and human disturbance. Other temperate species, which may be favoured by increasing temperatures, include the recent immigrant lesser black-backed gull. In general, the timing of spring migration and breeding of most species is likely to advance substantially in the coming decades. North of the assessment area, the phenology has already changed for common eider and thick-billed murre (AU & GINR, unpubl. data). This may also be the case for the assessment area, but so far no data exist. Changing breeding conditions north of the assessment area, e.g., phenology, prey availability or available breeding habitats, may lead to changing numbers of wintering birds within the assessment area.

8.6 Conclusions

The examples given above clearly indicate that climate change has a large potential to modify marine ecosystems, particular in high latitude regions, either through a bottom-up reorganization of the food web by altering the nutrient or light cycle, or top-down reorganization by altering critical habitat for higher trophic level (Macdonald et al. 2005). Alterations in the density, distribution or abundance of keystone species at various trophic levels could have significant and rapid consequences for the structure of the ecosystems in which they currently occur.

In 2008, the United Nations Environment Programme passed a resolution expressing ‘extreme concern’ over the impacts of climate change on biodiversity. Although climate change is a pervasive stressor, other stressors, such as long-range transport of contaminants, unsustainable harvesting of wild species and resource development are also impacting marine Arctic biodiversity (CAFF 2010).

Pathways, distribution patterns and/or toxicity of a range of contaminants are likely to change, and native organisms are likely to become less tolerant to contaminant exposure due to higher temperatures (Macdonald et al. 2005, Schiedek et al. 2007).

To be able to assess potential impacts of petroleum exploration-related impacts on the marine environment, a holistic approach - including climate, chemicals and biodiversity - is needed to fully understand marine ecosystems in Greenland, including the assessment area, and how human activities affect them.

9 Impacts of potential routine activities

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9.1 Summary of petroleum activities

Utilisation of an oil/gas field develops through several phases, which to some extent overlap. These include exploration, field development and production, and finally decommissioning. The main activities during exploration are seismic surveys, exploration drilling and well testing. During field development, drilling continues (production wells, injection wells, delineation wells), and production facilities, pipelines and shipment facilities, etc. are constructed. Production requires maintenance of equipment and, during decommissioning, structures and facilities are dismantled and removed. These phases occur over long periods of time, usually several decades. For example, in the North Sea, oil exploration started in the 1960s and petroleum activities still continue today

9.1.1 Seismic surveys

The purpose of seismic surveys is to locate and delimit oil/gas fields, to identify drill sites and later during production to monitor developments in the reservoir. Marine seismic surveys are usually carried out by a ship that tows a sound source and a cable with hydrophones, which receive the echoed sound waves from the seabed. The sound source is an array of airguns (for example 28 airguns with a combined volume of 4330 inch^3) that generates a powerful pulse at 10-second intervals. Sound absorption is generally much lower in water than in air, causing the noise created by seismic surveys to travel very long distances, potentially disturbing marine animals. Regional seismic surveys (2D seismics) are characterised by widely spaced survey lines, while the more localised surveys (3D seismics) usually cover small areas with densely spaced lines. Rig site investigations and shallow geophysical investigations use comparatively much smaller sound sources than used during 2D seismic surveys. For example, a company carrying out site surveys used a single airgun (150 inch^3). Vertical seismic profiles (VSPs) are essentially small-scale seismic surveys carried out during exploration drilling. They are highly localised and of short duration (a few days), and their effects will be covered by the discussion of seismic surveys in general.

9.1.2 Exploration drilling

Exploration drilling follows the seismic surveys. Offshore drilling takes place from drilling ships or semi-submersible platforms, both of which have been used in Greenland waters. Most of the potential oil exploration areas in West Greenland waters are too deep for using a third type of drilling platform, jack-up rigs, which rest on the seabed. It is assumed that drilling can take place throughout the year in the assessment area, although ice conditions may cause local constraints. Drilling requires the disposal of cuttings and drill mud. In the strategic EIA of the Lofoten-Barents Sea area it was assumed that approximately 450 m^3 cuttings were produced and approximately 2,000 m^3 mud used per well (Akvaplan-niva & Acona 2003). The drilling of the three exploration wells in the Disko West area in 2010 generated between 665 and 900 m^3 cuttings/well and in total 6,000 t of drilling mud. Energy consumption is very high during drilling, resulting in emissions of combustion gases such as CO_2, SO_2 and NO_x.

High levels of underwater noise are generated during drilling, mainly from the propellers, which secure the position of floating rigs. This noise has the potential to disturb marine mammals and acoustically sensitive fish (Schick & Urban 2000, Popper et al. 2004).

9.1.3 Drilling mud and cuttings

Drilling muds are used to optimise drilling operations. Muds were previously oil-based (OBM), but due to their toxicity they have now been replaced mainly by water-based muds (WBM), or for drilling under certain difficult conditions by synthetic-based muds (SBM). The drilling results in a mixture of drilling mud fluids and solids, rock fragments (cuttings) and certain chemicals. Cuttings and mud have usually been deposited on the sea floor surrounding drill sites, causing impacts on the benthic communities.

9.1.4 Appraisal drilling

If promising amounts of oil and gas are confirmed, field appraisal is used to establish the size of the field and the most appropriate production method, in order to assess whether the field is commercially viable. Appraisal may take several years to complete. Several appraisal wells are drilled to confirm the size and structure of the field, and well logging (analysis) provides data on the hydrocarbon bearing rocks. Well testing provides hydrocarbon samples and information on flow rate, temperatures and pressures. If appraisal confirms a commercial reservoir, the operator may then proceed to development.

9.1.5 Other exploration activities

One activity that may have environmental impact during the exploration phase is helicopter transport, which causes strong noise and can scare birds and marine mammals over a range of many kilometres.

Well testing takes place when a well has been drilled and the presence of hydrocarbons and the potential for production is to be evaluated. The testing activities normally imply the use and release to the sea of various chemicals, occasionally including radioactive compounds.

9.1.6 Development and production

Field development also includes seismic surveys and extensive drilling activities (delineation wells, injection wells, etc.), and drilling will take place until the field is fully developed. An oil development feasibility study in the sea west of Disko Island (north of the assessment area) assessed the most likely scenario to be a subsea well and gathering system tied back to a production facility either in shallower water established on a gravity-based structure or onshore (APA 2003). From the production facility crude oil subsequently has to be transported by shuttle tankers to a trans-shipment terminal.

Environmental concerns during the development will mainly be related to seismic surveys, to drilling, to the construction of the facilities on the seabed (wells and pipelines) and to discharges to sea and emissions to air. The major discharge to the sea is produced water.

9.1.7 Produced water

Produced water is by far the largest 'by-product' of the production process. Some Canadian offshore fields produced between 11,000 and 30,000 m^3/day (Fraser et al. 2006), and the total amount produced on the Norwegian shelf was 174 million m^3 in 2004 (OLF 2005). Produced water contains small amounts of oil, salts from the reservoir and chemicals added during the production process. Some of these chemicals are acutely toxic, or are radioactive, contain heavy metals, have hormone disruptive effects or act as nutrients which influence primary production (Lee et al. 2005). Some are persistent and have the potential to bio-accumulate. The produced water moreover contributes most of the oil pollution during normal operations, e.g. in Norway up to 88 % (OLF 2005).

Produced water has usually been discharged to the sea after a cleaning process, which reduces the amount and concentration of oil to levels accepted by the authorities. In the Norwegian sector of the North Sea, for example 30 mg/l and a 15 % reduction in total amount compared to year 2000 levels as recommended by OSPAR. In Norway released produced water in recent years had an average oil content of 11 mg/l (Anon 2011a).

Discharges of produced water and chemicals to the water column appear to have acute effects on marine life only in the immediate vicinity of the installations due to the dilution effect. However, long-term effects of releases of produced water have not been studied, and several uncertainties have been expressed concerning, for example, hormone-disrupting alkylphenols and radioactive components with respect to toxic concentrations, bioaccumulation, etc. (Meier et al. 2002, Rye et al. 2003, Armsworthy et al. 2005).

Due to environmental concerns in the Arctic environment, further reductions of discharges are planned in some areas, e.g. by the policy in the Lofoten-Barents Sea area (Anon 2003), where produced water will be re-injected except during an accepted maximum 5 % 'off-normal' operation time (Anon 2003).

9.1.8 Air emissions

Emissions to the air occur during all phases of petroleum development, including seismic survey and exploration drilling, although the major releases occur during development and production. Emissions to air are mainly combustion gases from local energy generation (for drilling, production, pumping, transport, etc.). For example, the drilling of a well may produce 5 million m^3 exhaust per day (LGL 2005). Flaring of gas and trans-shipment of produced oil also contribute to emissions. The emissions consist mainly of greenhouse gasses (CO_2, CH_4), NO_x, VOC and SO_2. Production activities produce large amounts of CO_2 in particular, and, for example, the emission of CO_2 from a large Norwegian field (Statfjord) was more than 1.5 million t in 1999 (SFT 2000), and the drilling of the three exploration wells in 2010 in the Disko West area resulted in the emission of 105,000 t of CO_2.

Another very active greenhouse gas is methane (CH_4), which is released in small amounts together with other VOCs from produced oil during transshipment.

9.1.9 Other activities

Ship transport of produced oil will be an integrated part of the production phase. The APA (2003) assessment presents a scenario where ships containing 160,000 m^3 will depart every 5 days from a highly productive field off Disko Island. Something similar could be expected for the assessment area.

Decommissioning is initiated when production wells are terminated, and will generate large amounts of waste material, which have to be disposed of or regenerated.

9.1.10 Accidents

There are serious, acute and long-term environmental concerns in relation to accidents and off-normal operations. As expressed by the recent Oil and Gas Assessment by AMAP (Skjoldal et al. 2007), the main issue of environmental concern for the marine Arctic environment is a large oil spill, which particularly in ice-covered waters represents a threat to animal populations and even to species.

9.2 Impacts of exploration activities

In general all activities related to exploration are temporary and will be terminated after a few years if no commercial discoveries are made. Another important aspect in relation to exploration is that activities can only take place during months when the sea is navigable, i.e. more of less free of ice.

Environmental impacts of exploration activities relate to:

- Noise from seismic surveys and drilling
- Cuttings and drilling mud
- Disposal of various substances
- Emissions to air
- Placement of structures.

In relation to exploration, only the most significant impacts (from noise, cuttings and drilling mud) will be considered. The other issues will be dealt with in the production and development sections, as they are much more significant during these phases of the life cycle of a petroleum field.

9.2.1 Seismic noise

Noise from seismic surveys

The main environmental impacts from seismic sound generators can potentially include:

- physical damage: injury to tissue and auditory damage from the sound waves
- disturbance/scaring (behavioural impacts, including masking of underwater communication by marine mammals).

A recent review of the effects of seismic sound propagation on different biota concluded that 'seismic sounds in the marine environment are neither completely without consequences nor are they certain to result in severe and irreversible harm to the environment' (DFO 2004). Nevertheless, there are some potential detrimental consequences. Short-term behavioural changes (such as avoidance of areas with seismic activity) are known and in some cases well documented, but longer-term changes are debated and studies are lacking.

In Arctic waters, there are certain special conditions which should be considered. It cannot be assumed that there is a simple relationship between sound pressure levels and distance to source due to refraction caused, for example, by a strongly stratified water column. It is therefore difficult to base impact assessments on simple transmission loss models (spherical or cylindrical spreading), and to apply assessment results from more southerly latitudes to the Arctic (Urick 1983). For example, the sound pressure may be very strong in convergence zones far (> 50 km) from the sound source, and this is particularly evident in stratified Arctic waters. This has recently been documented by means of acoustic tags attached to sperm whales, which recorded high sound pressure levels (160 dB rel. to 1 µPa peak to peak) more than 10 km from a seismic array (Madsen et al. 2006).

Another issue rarely addressed is that airgun arrays generate significant sound energy at frequencies many octaves higher than the frequencies of interest for geophysical studies. This increases concern regarding the potential impact, particularly on toothed whales (Madsen et al. 2006).

Impact of seismic noise on fish

Several experts agree that adult fish will generally avoid seismic sound waves, seek towards the bottom, and will not be harmed. Young cod and redfish, as small as 30–50 mm long, are able to swim away from the mortal zone near airguns (comprising a few metres) (Nakken 1992).

It has been estimated that adult fish react to an operating seismic array at distances of more than 30 km, and that intense avoidance behaviour can be expected within 1–5 km (see below). Norwegian studies measured declines in fish density at distances more than 10 km from sites of intensive seismic activity (3D). Negative effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during the spawning season. Outside spawning grounds, fish stocks are probably not affected by the disturbance, but fish can be displaced temporarily from important feeding grounds (Engås et al. 1996, Slotte et al. 2004).

Adult fish held in cages in a shallow bay and exposed to an operating airgun (0.33 l, source level at 1 m 222.6 dB rel. to 1 µPa peak to peak) down to 5–15 m distance sustained extensive ear damage, with no evidence of repair nearly 2 months after exposure (McCauley et al. 2003). It was estimated that a comparable exposure could be expected at ranges < 500 m from a large seismic array (44 l) (McCauley et al. 2003). It thus appears that the fish avoidance behaviour demonstrated in the open sea protects fish from damage. In contrast to these results, marine fish and invertebrates monitored with a video camera at an inshore reef did not move away from airgun sounds with peak pressure levels as high as 218 dB (at 5.3 m rel. to 1 µPa peak to peak) (Wardle et al. 2001). The reef fish showed involuntary startle reactions, but did not swim away unless the explosion source was visible to the fish at a distance of only about 6 m. Despite a startle reaction displayed by each fish every time the gun was fired, continuous observation of fish in the vicinity of the reef using time-lapse video and tagged individuals did not reveal any sign of disorientation, and fish continued to behave normally in similarly quite large numbers, before, during and after the gun firing sessions (Wardle et al. 2001). Another study during a full-scale seismic survey (2.5 days) also showed that seismic shooting had a moderate effect on the behaviour of the lesser sandeel (*Ammodytes marinus*) (Hassel et al. 2004). No immediate lethal effect on the sandeels was observed, either in cage experiments or in grab samples taken during night when sandeels were buried in the sediment (Hassel et al. 2004).

The studies cited above indicate that behavioural and physiological reactions to seismic sounds among fish may vary between species (for example, according to whether they are territorial or pelagic), and also according to the seismic equipment used. Generalisations should therefore be interpreted with caution.

Impact of seismic noise on zoo- and ichtyoplankton

Zooplankton and fish larvae and eggs (ichtyoplankton) cannot avoid the pressure wave from the airguns and can be killed within a distance of less than 2 m, and sublethal injuries may occur within 5 m (Østby et al. 2003). The relative volume of water affected is very small and population effects, if any, are considered to be very limited in e.g. Norwegian and Canadian assessments (Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope 2003). However, in Norway specific spawning areas in certain periods of the year may have very high densities of fish larvae in the uppermost water layers, and the Lofoten-Barents Sea area is closed for seismic activities during the cod and herring spawning period in May–June (Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope 2003). It was concluded in an assessment of seismic activities in the Disko West Area that it was most likely that impacts of seismic activity (3D) were negligible on the recruitment to fish stocks in West Greenland waters (Mosbech et al. 2007). In general, densities of fish eggs and larvae are low in the upper 10 m, and most fish species spawn in a dispersed manner in winter or spring, with little or no temporal overlap with seismic activities (cf. Table 4.1). There are very limited data on fish egg and larvae as well as zooplankton densities from the assessment area, but it can be assumed that the density will be similar to other Greenland waters. It is therefore most likely that impacts of seismic activity (even 3D) on zooplankton and on the recruitment to fish stocks are negligible in the assessment area.

Impact of seismic noise on fisheries

Norwegian studies (Engås et al. 1996) have shown that 3D seismic surveys (a shot fired every 10 seconds and 125 m between 36 lines 10 nm long) reduced catches of Atlantic cod and haddock (*Melanogrammus aeglefinus*) at 250–280 m depth. This occurred not only in the shooting area, but as far as 18 nautical miles away. The catches did not return to normal levels within 5 days after shooting (when the experiment was terminated), but it was assumed that the effect was short-term, and that catches would return to normal after the studies. The effect was moreover more pronounced for large fish compared to smaller fish.

The commercial fishery most likely to overlap in space with seismic surveys in the assessment area is the fishery for northern shrimp and snow crab.

A Canadian review (DFO 2004) concluded that the ecological effect of seismic surveys on fish is low, and that changes in catchability probably are species-dependent. A Norwegian review (Dalen et al. 2008) concluded that the above described results of Engås et al. (1996) cannot be applied to other fish species, or to fisheries taking place at other water depths. For example Greenland halibut has no swim bladder, which means that its hearing abilities are reduced compared to fish with a swim bladder, in particular at higher frequencies, as it is likely to be sensitive to only the particle motion part of the sound field, not the pressure field. Moreover, the fishery takes place in much deeper waters than in the Norwegian experiments with haddock and Atlantic cod.

Based on these contradicting results and the fact that the offshore fishery of Greenland halibut has not been studied, it is difficult to assess the effect of seismic activity. However, if catches are reduced by a seismic survey, the effect is most likely temporary and will probably only affect specific fisheries for a few days.

It should be mentioned that there are other examples where fisheries have increased after seismic shooting, which was assumed to be an effect of changes in the vertical distribution of the fish (Hirst & Rodhouse 2000).

The few studies available on seismic impacts on crustacean fisheries did not find any reduction in catchability (Hirst & Rodhouse 2000, Christian et al. 2003, Andriguetto-Filho et al. 2005, Parry & Gason 2006), indicating that the shrimp and crab fisheries within the assessment area (Fig. 5.2 and 5.3) will not be affected by seismic surveys.

Impact of seismic noise on birds

Seabirds are generally not considered to be sensitive to seismic surveys, because they are highly mobile and able to avoid the seismic sound source. However, in inshore waters, ship traffic near seabird colonies and moulting concentrations may cause disturbance, and therefore such traffic is regulated.

Next to nothing is known about underwater hearing in diving seabirds, and no studies have attempted to assess possible impact of exposure to airgun sounds during diving. Seabird hearing abilities underwater are likely to be inferior to marine mammals and restricted to lower frequencies, not extending into the ultrasonic range. Diving birds are not known to use hearing underwater, but may do so. Diving birds may potentially suffer damage to their inner ears if diving very close to the airgun array, but unlike the case for mammals, the sensory cells of the inner ear of birds can regenerate after damage from acoustic trauma (Ryals & Rubel 1988), and hearing impairment, even after intense exposure, is thus temporary.

Impact of seismic noise on marine mammals

Responses of marine mammals to noise fall into three main categories: physiological, behavioural and acoustic (Nowacek et al. 2007). Physiological responses include hearing threshold shifts and auditory damage. Behavioural responses include changes in surfacing, diving and heading patterns, and may result in avoidance of the area or reduced feeding success. Low frequency sounds may effectively mask the calls of baleen whales, thus interfering with their social activities and/or navigation and feeding activities. Acoustic responses to masking by anthropogenic noise include changes in type or timing of vocalisations. In addition, there may be indirect effects associated with altered prey availability (Gordon et al. 2003).

There is strong evidence for behavioural impacts on marine mammals from seismic surveys (Compton et al. 2008). Mortality has not been documented, but there is a potential for physical damage, primarily auditory. Under experimental conditions, temporary elevations in hearing threshold have been observed (Richardson et al. 1995, Committee on Characterizing Biologically Significant Marine Mammal Behavior 2005). In the USA, a sound pressure level of 180 dB rel. to 1µPa (root mean square) or higher is believed to provoke temporary or permanent threshold shifts and is adopted by the US National Marine Fisheries Service as a mitigation standard to protect whales (NMFS 2003, Miller et al. 2005).

Displacement is a behavioural response, and there are many documented cases of displacement from feeding grounds or migratory routes of marine mammals exposed to seismic sounds. The extent of displacement varies between species and also between individuals within the same species. For example, a study in Australia showed that migrating humpback whales avoided seismic sound sources at distances of 4-8 km, but occasionally came closer. In the Beaufort Sea, autumn-migrating bowhead whales avoid areas where the noise from exploratory drilling and seismic surveys exceeds 117–135 dB, and they may avoid the seismic source by distances of up to 35 km (Reeves et al. 1984, Richardson et al. 1986, Ljungblad et al. 1988, Brewer et al. 1993, Hall et al. 1994, NMFS 2002, Gordon et al. 2003), although a Canadian study showed somewhat shorter distances (Lee et al. 2005). White whales avoided seismic operations in Arctic Canada by 10-20 km (Lee et al. 2005). Stone & Tasker (2006) showed a significant reduction in marine mammal sightings during seismic surveys in the UK during periods of shooting compared with non-shooting periods. In the Mediterranean, bearings to singing fin whales estimated with passive acoustic monitoring indicated that whales moved away from the airgun source and out of the area for a time period that extended well beyond the duration of the airgun activity (Castellote et al. 2010). In contrast, minke whales have also been observed as close as 100 m from operating airgun arrays (AU unpubl. data), potentially close enough to sustain physical damage.

The ecological significance of displacement effects is generally unknown. If alternative areas are available, the impact will probably be low, and the temporary character of seismic surveys also will allow displaced animals to return after the surveys.

In West Greenland waters, satellite tracked humpback whales utilised extensive areas and moved between widely spaced feeding grounds, presumably searching for their preferred prey (krill, sandeel and capelin) as prey availability shifted through the season (Heide-Jørgensen & Laidre 2007). The ability of humpback whales to find prey in different locations may suggest that they would have access to alternative foraging areas if they were displaced from one area by a seismic activity. However, even though many areas can be used, a few key zones seem to be especially important. The satellite-tracked humpback whales favoured a zone on the shelf within the assessment area with high concentrations of sandeel (Heide-Jørgensen & Laidre

2007). Similarly, a modelling study based on cetacean and prey surveys showed that rorquals (fin, sei, blue, minke and humpback whale) and krill aggregate in three high density areas on the West Greenland banks (Laidre et al. 2010). One of these important feeding areas (Julianehåb Bugt) occurs in the assessment area. Thus, displacement from major feeding areas can have a negative impact on the energy uptake of the rorquals that are in West Greenland to feed before their southward migration. Given the extent of oil exploration in Greenland, there is a risk of cumulative effects if multiple surveys occur at the same time in adjacent areas, and marine mammals thus are excluded from key habitats and unable to use alternative foraging grounds.

The US National Marine Fisheries Service defines the radius about a seismic ship with received sound levels of 160 dB (rel. to 1µPa) as the distance within which some cetaceans are likely to be subject to behavioural disturbance (NMFS 2005). Actual distances would depend on the source levels of the airgun array, the salinity and temperature layers of the water and the depth of the observation. A few studies have observed lack of measurable behavioural changes by cetaceans exposed to the sound of seismic surveys taking place several kilometres away. For instance, Madsen et al. (2002) found no reaction of sperm whales to a distant seismic survey operating at tens of km distance. More recently, Dunn & Hernandez (2009) did not detect changes in the behaviour of blue whales that were at 15-90 km from operating airguns. The authors estimated that the whales experienced sounds of less than 145 dB (rel. to 1µPa) and concluded that, while their study supports the current US-NMFS guidelines, further studies with more detailed observations are warranted (Dunn & Hernandez 2009).

An acoustic effect widely discussed in relation to whales and seismic surveys is the masking effect of communication and echolocation sounds. There are, however, very few studies which document such effects (but see Castellote et al. 2010, Di Iorio & Clark 2010), mainly because the experimental setups are extremely challenging. Masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures. The whales and seals in the assessment area use a wide range of frequencies (from < 10 Hz to > 100 kHz, Fig. 4.12), and the low frequency sounds of seismic surveys are likely to overlap in frequency with at least some of the sounds produced by these marine mammals.

Masking is likely to occur from the continuous noise from drilling and ship propellers, as documented for beluga whales and killer whales in Canada (Foote et al. 2004, Scheifele et al. 2005). Due to the low frequency of their phonation, baleen whales (followed by seals) would be the marine mammals mainly affected by auditory masking from seismic surveys (Gordon et al. 2003), and it has been shown that blue whales increase their calling rate during seismic surveys, probably as a compensatory behaviour to the elevated ambient noise (Di Iorio & Clark 2010). Likewise, changes in the acoustic parameters of fin whale calls in the presence of airgun events indicate that fin whales also modify their acoustic behaviour to compensate for increased ambient noise (Castellote et al. 2010).

Sperm whales showed diminished forage effort during airgun emission, but it is not clear if this was due to masking of echolocation sounds or to behavioural responses of the whales or the prey (Miller et al. 2005).

The most noise-vulnerable whale species in the assessment area will be the baleen whales: minke, fin, blue and humpback whale and the toothed whales, sperm whale and probably bottlenose whale, which all are present in the area during the ice-free months when seismic surveys usually take place. At the time of writing this assessment, we were not aware of any detailed studies on the effect of seismic surveys on bottlenose whale, pilot whale, white-beaked dolphin or harbour porpoise.

In general, seals display considerable tolerance to underwater noise (Richardson et al. 1995), confirmed by a study in Arctic Canada where ringed seals showed only limited avoidance of seismic operations (Lee et al. 2005). In another study, ringed seals were shown to habituate to industrial noise (Blackwell et al. 2004).

Mitigation of impacts from seismic noise

Mitigation guidelines generally recommend a soft start or ramp up of the airgun array each time a new line is initiated (review by Compton et al. 2008). This will allow marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals.

Secondly, it is recommended to bring skilled marine mammal observers on board the seismic ships, in order to detect whales, and to instruct the crew to delay shooting when whales are within a certain distance (usually 500 m) from the array. The detection of nearby whales in sensitive areas can be more efficient, depending on species, if supplemented by the use of hydrophones for recording whale vocalisations (Passive Acoustic Monitoring), although whales may be present without emitting sounds. There are problems with respect to visual observations. In Arctic waters, very high sound pressures may occur far from the sound source and out of sight of the observer (see above). Another problem is that seismic surveys are carried out day and night, and visual observations are only possible in daylight.

A third mitigating measure is to close areas in sensitive periods. The spawning grounds for herring and cod are closed for seismic surveys in the Lofoten-Barents Sea area during the spawning season.

BMP/DCE(AU) have issued a set of guidelines for conducting seismic surveys in Greenland waters (Kyhn et al. 2011), and protection areas (where seismic surveys are regulated) for narwhal and walrus are designated in areas outside the present assessment area
(http://www.bmp.gl/petroleum/approval-of-activities/offshore).

Finally, it is recommended that local authorities and the hunters' organisations be informed before seismic activities take place in their local area. This may help hunters take into account that animals may be disturbed and displaced from certain areas at times when activities are taking place.

In Arctic Canada, a number of mitigation measures were applied to minimise impacts from seismic surveys on marine mammals and the subsistence hunting of these species (Miller et al. 2005). Some were identical to those mentioned above, and the most important was a delay in the start of seismic operation, both until the end of the beluga whale hunt and the period of occupation of especially important beluga whale habitats. Some particularly important beluga whale areas were even completely closed for surveys.

In the BMP/DCE guidelines for seismic surveys (Kyhn et al. 2011), some important issues to consider when the impacts of a seismic surveys have to be assessed were listed:

- The species that could be affected, as tolerance to seismic surveys varies between species
- The natural behaviour of these species when surveys are taking place. Disturbance varies according to species' annual cycles, e.g. the degree of sensitivity of animals engaged in mating and calving or those feeding or migrating.
- The severity and duration of impact. Even a strong startle reaction to an approaching survey vessel may have only a small total impact on the animal whereas a small, but prolonged (days or weeks) disturbance to feeding behaviour could have a much larger impact.
- Total number of animals likely to be affected. It is not possible to conduct seismic surveys in the Arctic without affecting marine mammals at all. The number of animals likely to be affected should be assessed in relation to the size of the population, local stocks and season.
- Local conditions for sound transmission, as hydrographical and bathygraphical conditions may result in highly unusual sound transmission properties. Potential consequences of these effects should be included in the assessment.
- When planning surveys, the overall exposure should be sought minimised to the degree possible in using the smallest possible airgun array to get the data needed. The total exposure is a complex function of number of animals exposed, the time each animal is exposed, and the sound level each animal experiences. Nevertheless, reducing any of the three parameters will also reduce the total exposure and thus the possibility of reducing one or more factors should be considered in the planning.

Conclusions on disturbance from seismic noise (Table 9.1)

The species most sensitive to seismic noise in the assessment area are the baleen whales minke, fin, blue and humpback, and toothed whales such as sperm and bottlenose whales. These may be at risk of being displaced from critical summer habitats. A displacement will also impact the availability (for hunters) of whales if the habitats include traditional hunting grounds.

Table 9.1. Overview of potential impacts of a single seismic 2D survey on VECs in the South Greenland assessment area. See section 4.8 for a summary of the VECs. It is important to note that a single seismic survey is temporary (days or a few weeks), and that cumulative impacts of several simultaneous or consecutive surveys may be more pronounced.

VEC	Typical vulnerable organisms	Population impact – worst case*		
		Displacement	Sublethal effect	Direct mortality
Pelagic hotspots	Copepods, fish larvae	-	Insignificant (L)	Insignificant (L)
Overwintering zooplankton	None			
Tidal/subtidal zone	None			
Ikaite columns	None			
Benthos and demersal fish	None			
Seabirds (breeding)	None			
Seabirds (non-breeding)	None			
Seals	None			
Large whales	Baleen and toothed whales	Short term (L)	Insignificant (R)	None

* L = local, R = regional and G = global

As seismic surveys are temporary, the risk for long-term impacts is low. Long-term impacts nevertheless have to be assessed if several surveys are carried out simultaneously or in the same potentially critical habitats during consecutive years (cumulative effect).

Few impacts of seismic noise on commercial fisheries are expected in the assessment area.

Noise from drilling rigs

This noise has two sources, the drilling process and the propellers keeping the drilling ship/rig in position. The noise is continuous, in contrast to the pulses generated by seismic airguns (Kyhn et al. 2011).

Generally a drilling ship generates more noise than a semi-submersible platform, which in turn is noisier than a jack-up. Jack-ups will most likely not be employed within the assessment area, due to water depths and the hazard from drift ice and icebergs.

Whales are believed to be the organisms most sensitive to this kind of underwater noise, because they depend on the underwater acoustic environment for orientation and communication, and it is believed that this communication can be masked by the noise. Seals (especially bearded seal) and walruses also communicate when underwater. However, systematic studies on whales and noise from drilling rigs are limited. It is generally believed that whales are more tolerant of fixed noise than noise from moving sources (Davis et al. 1990), and auditory masking from boat noise has been demonstrated for white whales and killer whales in Canada (Foote et al. 2004, Scheifele et al. 2005). In Alaskan waters, migrating bowhead whales avoided an area with a radius of 10 km around a drilling ship (Richardson et al. 1995), and their migrating routes were displaced away from the coast during oil production on an artificial island, although this reaction was mainly attributed to the noise from support vessels (Greene et al. 2004).

Rorquals (fin, minke, humpback and blue whale), white-beaked dolphins and harbour porpoises in shelf waters, as well as sperm whales, bottlenose whales and pilot whales on the continental slope, could be displaced by drilling operations. However, there is no knowledge so far on critical habitats for these species.

Conclusion on noise from exploration drilling rigs (Table 9.2)

Exploration activities are temporary, and displacement of marine mammals caused by noise from drilling rigs will also be temporary. The most vulnerable species in the assessment area are the cetaceans, especially baleen whales such as blue, fin, minke and humpback whales, and toothed whales such as sperm whale and harbour porpoise. If alternative habitats are available to the whales, no long-term effects are expected, but if several rigs operate in the same region there is a risk for cumulative effects and displacement from key habitats.

Table 9.2. Overview of potential impacts of potential noise[1] and discharges[2] from a single exploration drilling on VECs in the South Greenland assessment area. See section 4.8 for a summary of the VECs. This assessment assumes the application of current (2011) mitigation guidelines, see text for details.

VEC	Typical vulnerable organisms	Population impact – worst case*		
		Displacement	Sublethal effect	Direct mortality
Pelagic hotspots[2]	Zooplankton, fish larvae	-	Insignificant (L)	Insignificant (L)
Overwintering zooplankton	None			
Tidal/subtidal zone	None			
Ikaite columns	None			
Benthos and demersal fish[2]	Atlantic cod, sandeels	Short term (L)	Minor (R)	None
	Deep-water corals	Long term (L)	Minor (L)	Minor (L)
Seabirds (breeding)	None			
Seabirds (non-breeding)[2]	Common eider, harlequin duck	Short term (L)	Insignificant (R)	None
Seals	None			
Large whales[1]	Ballen and toothed whales	Short term (L)	Minor (L)	None

* L = local, R = regional and G = global.

9.2.2 Drilling mud and cuttings

Drilling creates substantial quantities of drilling wastes composed of rock cuttings and the remnants of drilling mud. Cuttings and mud have usually been deposited on the sea floor beneath the drilling rig, where they can change the physical and chemical composition of the substrate (e.g. increased concentrations of certain metals and hydrocarbons) (Breuer et al. 2008). The liquid base of the drilling mud may be water (WBM – water-based mud) or synthetic fluids (SBM - synthetic-based mud; ethers, esters, olefins, etc.). Previously oil was used (OBM – oil-based mud), but this has been almost eliminated due to environmental concerns. OBMs may be used for special drillings, but then the mud is injected into wellbores or brought to land for treatment.

The general pattern of impacts on benthic animals from cuttings from Norwegian wells is that OBM cuttings elicit the most widespread impacts and WBM cuttings the least. Ester-based cuttings have been shown to cause severe but short-lived effects due to their rapid degradation, which may result in oxygen depletion in the sediments. Olefin-based cuttings are also degraded fairly rapidly, but without causing oxygen deficiency and hence have short-lived and moderate effects on the fauna.

Most of the impact studies of mud and drill cutting are made with OBMs (e.g., Davies et al. 1984, Neff 1987, Gray et al. 1990, Ray & Engelhardt 1992, Olsgaard & Gray 1995, Breuer et al. 2004). Effects from OBMs were widespread (up to 6 km from the release site) and persisted longer than the release phase. Furthermore, the area affected continued to increase in size for several years after discharges ceased (Breuer et al. 2008), and sub-lethal effects on fish living near drill sites were also detected in some species (Davies et al. 1984). SBMs also lead to impacts on benthic fauna, though less pronounced than around platforms where OBMs were used (Jensen et al. 1999).

Field studies of impacts from WBMs are relatively few. A few specially designed surveys indicated that effects are restricted to a distance of less than 100 m from the platforms (Schaaning et al. 2008 and references therein). The use of WBM combined with cleaning of the cuttings may therefore limit the effects on the benthos to highly localised areas around each exploration drill site. This potentially moves any effects from the seafloor to the water column, where dilution is a major factor in reducing impacts. In Norway, the change to WBM has resulted in a marked decrease in the level of impacts on the seafloor (Renaud et al. 2007).

Cold water corals and sponges are also sensitive to suspended material in the water column (Freiwald et al. 2004, SFT 2008). Large numbers of corals have been found in the western part of the Davis Strait and Labrador Sea (Edinger et al. 2007a), and in Greenland waters they are frequently encountered in survey trawls (K. Sünksen, pers comm.), indicating that corals occur along the continental shelf of Southwest Greenland. Recently, trawling has been banned in 2 areas south of Maniitsoq (64° N) due to the observations of high abundance of corals. As the seabed at all potential drill sites is surveyed for these organisms before drilling, it should be possible to avoid impacts on key habitats for this sensitive biota in Greenlandic waters.

Multiple drilling carried out when a field is developed may cause more widespread effects on the benthos, and it is important to note that the seafloor fauna in the assessment area is still poorly known. Discharges of cuttings with water-based drill fluids are likely to disperse widely in the water column before reaching the seabed, and may also impact pelagic organisms such as plankton (Røe & Johnsen 1999, Jensen et al. 2006). However, more knowledge is needed about hydrodynamics to evaluate the spreading, dilution and sedimentation of the substances. Biological effects from particles in water-based mud have been observed on fish and bivalves under laboratory conditions (Bechmann et al. 2006).

Mitigation of impacts from the release of drilling mud and cuttings

The best way of mitigating impacts from drilling mud and cuttings in the marine environment is to bring it to land or re-inject the material into well bores. This, however, creates other environmental impacts such as increased emissions of greenhouse gasses from the transport and pumping, and problems with treatment or re-use on land, where the salt content in otherwise non-toxic mud may cause problems (SFT 2008), which has to be balanced against the impacts on the water column and on the seafloor. A recent report (SFT 2008) therefore recommends that general zero-discharge demands for water-based drill cuttings and mud are not introduced in Norway.

It is generally assessed that the impacts from water-based muds are limited, and they are usually released to the marine environment when the drilling is over. However, as part of the requested post-drill environmental monitoring that licence holders in Greenland waters have to perform during exploration drilling, particle transport in relation to drilling mud has to be modelled, and sediment traps have to be set up to measure the potential spatial distribution of these particles. Impacts can be further reduced by application of environmentally friendly drilling chemicals, such as those classified by OSPAR (HOCNF) as ‘green’/PLONOR (Pose Little Or No Risk to the Environment) or ‘yellow’. However, in general these chemicals have not been evaluated under Arctic conditions regarding degradation and toxicity, and all chemicals to be discharged should therefore be assessed and evaluated before they are approved for release.

In Norway, releases to the marine environment of environmentally hazardous substances (‘red’ and ‘black’ chemicals) have been reduced by 99 % during 1997-2007 by applying international standards, Best Available Technology (BAT) and Best Environmental Practice (BEP) (SFT 2008). In Greenland, the use of 'black' chemicals is not allowed, and the use of 'red' chemicals requires specific permission. The use of red chemicals is highly restricted and carefully evaluated, as red chemicals should be substituted whenever possible and discharges reduced.

In Greenland, the oil content in drill cuttings should be monitored continuously, and discharge of oil-contaminated drill cuttings is not allowed.

Conclusion on discharges from exploration drilling (Table 9.2)

Within the assessment area, only very local effects on the benthos are to be expected from discharging water-based muds (WBM) during exploration drilling. However, baseline studies and environmental monitoring should be conducted at all drill sites to document spatial and temporal effects, and to assess if there are unique communities or species that could be harmed.

9.3 Impacts of appraisal activities

The activities during the appraisal phase are similar to the exploration activities (see above), and the impacts are the same. However, there is an increased risk of cumulative impacts as the phase usually takes place over several years.

9.4 Impacts of development and production activities

In contrast to the temporary activities of the exploration phase, the activities during development and production are usually long-lasting, depending on the amount of producible petroleum products and the production rate. The activities are numerous and extensive, and the effects on the environment can be summarised under following headings:

- solid and fluid waste materials to be disposed of
- placement of structures
- noise from facilities and transport
- emissions to air

9.4.1 Produced water

During production, several by-products and waste products are produced and have to be disposed of in one way or the other. Produced water is by far the largest contribution from an oil field.

Generally, is it assumed that the environmental impacts from produced water discharged to the sea are small due to dilution. For example, the discharges during the 5 % 'off normal time' in the Lofoten-Barents Sea have been assessed not to impact stocks of important fish species, but in the same assessment it is also stated that the long-term effects of the release of produced water are unknown (Rye et al. 2003). There is particular concern regarding poly-aromatic hydrocarbons (PAHs), hormone-disrupting phenols, radioactive components and nutrients in relation to toxic concentration, bioaccumulation, fertilisation, etc. (Rye et al. 2003).

Impacts on the marine environment from produced water can be reduced by injecting it into well bores. This is not always possible (SFT 2008), and in such cases international standards (OSPAR) should as a minimum be applied: This means that the oil content should not be higher than 30 mg/l. In Norway, released produced water in recent years had an average oil content of 11 mg/l (Anon 2011b).

Nutrient concentrations can be very high in produced water (e.g. ammonia up to 40 mg/l). When diluted, these nutrients may have an ecological effect as fertilisers, which could impact especially the abundance and community composition of primary producers, i.e. planktonic algae (Rivkin et al. 2000, Armsworthy et al. 2005).

Even though oil concentrations in produced water on average are low, oil sheen may occur on the water surface where the water is discharged, especially in calm weather. This gives reason for concern, because sheen is sufficient to impact seabirds, and such impacts may be significant (Fraser et al. 2006).

To test potential effects of produced water on organisms, cages with either Atlantic cod or blue mussels were positioned at various distances (0-5000 m) and different directions from oil platforms in Norway. In addition, two reference locations were used, both 8000 m away from the respective platform. PAH tissue residues in blue mussels ranged between 0-40ng/g ww depending on the distance to the oil rigs, with significantly elevated concentrations up to 500 m from the platforms. PAH bile metabolites in cod confirmed exposure to effluents, but levels were low when compared to those found in cod from coastal waters (Hylland et al. 2008). The biological effects found in the blue mussels reflect exposure gradients and that the mussels were affected by components in the produced water.

Atlantic cod was also used to assess possible impacts of alkylphenols, also present in produced water and suspected to cause endocrine disruptive effects in fish (Lie et al. 2009). In another study, the genotoxic potential of water-soluble oil components on Atlantic cod have been documented (Holth et al. 2009).

Finally, the release of produced water under the ice gives reason for concern, because there is a risk of accumulation just below the ice, where degradation, evaporation, etc. are slow and the sensitive under-ice ecosystem including the eggs and larvae of the key species polar cod may be exposed (Skjoldal et al. 2007).

9.4.2 Other discharged substances

Besides produced water, discharges of oil components and different chemicals occur in relation to deck drainage, cooling water, ballast water, bilge water, cement slurry and testing of blowout preventers. BAT, BEP, applying international standards (OSPAR and MARPOL) and introduction of less environmentally damaging chemicals or reduction in volume of the releases are ways in which the effects should be reduced to acceptable levels. It should be mentioned that the release of environmentally hazardous substances from the oil industry to the marine environment in Norwegian areas have been reduced by 99 % over 20 years by applying these measures (SFT 2008). Sanitary waste water is usually also released to the sea. The environmental impacts of these discharges are generally small from a single drilling rig or production facility, but releases from many facilities and/or over long time periods may also be of concern.

Ballast water from ships poses a special biological problem, namely the risk of introduction of non-native and invasive species (also termed Aquatic Nuisance Species) to the local ecosystem (Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope 2003). This is generally considered as a severe threat to marine biodiversity and, for example, blooms of toxic algae in Norway have been ascribed to release of ballast water from ships. There are also many examples of introduced species which have impacted fisheries in a negative way (e.g. the comb jelly *Mnemiopsis leidyi* in the Black Sea (Kideys 2002)).

Presently, the Arctic seas are the least severely affected areas by non-native invasive species as shown by Molnar et al. (2008). However, many tankers releasing ballast water near an oil terminal and the increasing water temperatures, particularly in the Arctic, may increase the risk of successful introduction of alien, invasive species in the future.

There are methods to minimise the risk from releasing ballast water, i.e. by applying the International Ballast Water Management Convention, which restricts and regulates the exchange of ballast water. The International Maritime Organization (IMO) has adopted this convention and requires that ships follow a strict ballast water management plan, and in future install ballast water management systems to treat the ballast water before its release into the environment (IMO 1998). All vessels and drilling units involved in hydrocarbon activities in Greenland have to follow the IMO guidelines or the relevant Canadian regulations.

In addition, invasive species can be introduced by transport of organisms attached to the hull of the ships.

9.4.3 Placement of structures

The construction of subsea wells and pipelines has the potential to destroy parts of important habitats on the seafloor. In other regions, sponge gardens and reefs of cold water corals are considered as sensitive, but such biogenic habitats have not yet been located in the assessment area. This is likely due to lack of knowledge, as the survey effort is low. An assessment of the impact of such constructions must wait until production site location is known and site-specific EIAs and background studies have been carried out. Structures may also have a disturbance effect, particularly on marine mammals.

Illumination and flaring attract birds during the night (Wiese et al. 2001). In Greenland, this issue is particularly important for common eiders. Under certain weather conditions (e.g. fog and snowy weather) on winter nights, eiders are attracted to lights on ships (Merkel 2010b). Occasionally, hundreds of eiders are killed on a single ship, and not only are eiders killed, but these birds are so heavy that they destroy aerials and other structures (Boertmann et al. 2006). A preliminary study of this issue has been conducted by GINR (Merkel 2010b).

A related problem occurs in the North Sea, which millions of songbirds cross on their nocturnal autumn and spring migrations. Large numbers of songbirds are under certain weather conditions attracted to light from illumination and flaring (Bourne 1979, Jones 1980). No such migrations take place in the assessment area. However, concern for nocturnally migrating little auks has recently been expressed (Fraser et al. 2006), and this species occurs in very large numbers in the assessment area. A method to mitigate the attraction of birds is to change the colour of the illumination so as not to attract birds, e.g. to green light (Poot et al. 2008).

Placement of structures will affect fisheries due to exclusion (safety) zones. These areas, however, are small compared with the total fishable area. A drilling platform including exclusion zone with a radius of 500 m covers approx. 7 km^2. In the Lofoten-Barents Sea area, the effects of exclusion zones on the fisheries are generally estimated as small, except in areas where very localised and intensive fishery activities take place. In such areas, reduced catches may be expected, because there are no alternative areas available (OED 2006). Pipelines in the Lofoten-Barents Sea area are not expected to impact fisheries, because they will be constructed in a way allowing trawling across them, although a temporary exclusion zone must be expected during the pipeline construction phase. Experience from the North Sea indicates that large ships will trawl across subsea structures and pipelines, while small ships often choose to avoid the crossing of such structures (Anon 2003).

Another effect of the exclusion zones is that they act as sanctuaries, and in combination with the artificial reefs created by the subsea structures (Kaiser & Pulsipher 2005) attract fish and even seals. Especially fish may thus be exposed to contaminants from release of produced water, and this should be monitored.

Placement of structures onshore also imposes a risk of spoiling habitats for unique coastal flora and fauna.

When dealing with placement of structures, particularly on land and in coastal habitats, aesthetic aspects must be considered in a landscape conservation context. The risk of spoiling the impression of pristine wilderness is high. Background studies in the field combined with careful planning can reduce such impacts on the landscape. Landscape aspects are also the most important when dealing with potential effects on the tourism industry. The main asset of Greenland tourism – the unspoilt nature – is readily rendered much less attractive by buildings, infrastructure and other facilities.

9.4.4 Noise/Disturbance

Noise from drilling and the positioning of machinery is described above. These activities continue during the development and production phase, supplemented by noise from many other activities. If several production fields are active in a limited area, the cumulative impacts of noise particularly on the occurrence of cetaceans must be addressed. Bowhead whales in the Beaufort Sea avoided close proximity (up to 50 km) to oil rigs, which resulted in significant loss of summer habitat (Schick & Urban 2000). This could be a problem for some of the baleen whale stocks in the assessment area.

One of the more significant sources of noise during development and production is ships and helicopters used for intensive transport operations (Overrein 2002). Ships and helicopters are widely used in the Greenland environment today, but the level of these activities is expected to increase significantly in relation to development of one or more oil fields within the assessment area. Supply ships will sail between offshore facilities and coastal harbours. Shuttle tankers will sail between crude oil terminals and the trans-shipment facilities on a regular basis, even in winter. The loudest noise levels from shipping activity result from large icebreakers, particularly when they operate in ramming mode (probably a rare event in the assessment area). Peak noise levels may then exceed the ambient noise level up to 300 km from the sailing route (Davis et al. 1990).

Ship transport (incl. ice-breaking) has the potential to displace marine mammals, particularly if the mammals associate negative events with the noise, and in this respect species (fin whales, minke whales, humpback whales) which are hunted from motor boats will be expected to be particularly sensitive. Seabird concentrations may also be displaced by regular traffic. The impacts can be mitigated by careful planning of sailing routes.

Helicopters produce a strong noise which can scare marine mammals as well as birds. Seabird concentrations are sensitive to helicopter flyovers. The most sensitive seabird species are cliff-nesting auks (thick-billed murre, common murre, razorbill) at breeding sites. They will often abandon their nests for long periods of time, and when scared off their breeding ledges, they may push their egg or small chick off the ledge, resulting in a failed breeding attempt (Overrein 2002). There are only few breeding colonies of thick-billed murre within the assessment area (Fig. 4.6), and only one is situated at the outer coasts where helicopters may pass over en route to offshore installations. Concentrations of feeding birds can also be sensitive, as they may lose feeding time due to the disturbance.

Flying in Greenland, both with fixed-wing aircrafts and helicopters, is regulated in areas with seabird breeding colonies (order of 8 March 2009 on protection and hunting of birds). During the period 15 April to 15 September, the distance to colonies of thick-billed murre and a number other species must be > 3000 m both horizontally and vertically, while the distance to other colonies (common eider, Arctic tern etc.) must be > 200 m.

Flying in relation to mineral exploration is also regulated by special field rules issued by Bureau of Minerals and Petroleum. These rules encompass areas with staging and moulting geese, areas with moulting sea ducks etc.

The effects of disturbance of moulting sea ducks can be mitigated by applying specific flight altitudes and routes, as many birds will habituate to regular disturbances as long as these are not associated with other negative impacts such as hunting (Burger 1998).

Noise from offshore construction activities such as blasting have the potential to produce behavioural disturbance and physical damage among marine mammals, particularly cetaceans (Ketten 1995, Nowacek et al. 2007). Off Newfoundland, Ketten et al. (1993) found damage consistent with blast injury in the ears of humpback whales trapped in fishing gear after blasting operations in the area. In this case, the blasting did not provoke obvious changes in behaviour among the whales, even though it may have caused severe injury, suggesting that whales may not be aware of the danger posed by loud sound. Such impacts are, however, local and will mainly be a threat on an individual level.

9.4.5 Air emissions

The large amounts of greenhouse gases released from an oil field will increase the total Greenland emission significantly. The CO_2 emission from the Statfjord field in Norway, for example, is twice the total current Greenland CO_2 emission, which in 2008 was 685,500 t (Nielsen et al. 2010). Such amounts will have a significant impact on the Greenland greenhouse gas emission in relation to the Kyoto Protocol (to the United Nations Framework Convention on Climate Change) and its potential successor. Another very active greenhouse gas is methane (CH_4), which is released in small amounts along with other VOCs from produced oil during trans-shipment or from vented gas.

Another matter is the contribution of greenhouse gasses from combustion of the produced oil, which depending on the amounts will contribute to the global increase of CO_2 in the atmosphere.

Emissions of SO_2 and NO_x contribute, among other effects, to acidification of precipitation, and may impact particularly nutrient-poor vegetation types inland far from the release sites. The large Norwegian field Statfjord emitted almost 4,000 t NO_x in 1999. In the Norwegian strategic EIA on petroleum activities in the Lofoten-Barents Sea area, it was concluded that NO_x emissions even from a large-scale scenario would have insignificant impact on the vegetation on land, but also that there was no knowledge about tolerable depositions of NO_x and SO_2 in Arctic habitats where nutrient-poor habitats are widespread (Anon 2003). This lack of knowledge also applies to the terrestrial environment of the assessment area.

Emissions of black carbon from combustion are of particular concern in the Arctic, because the black particles reduce albedo from snow and ice surfaces, thus increasing the melt rate. Emissions of black carbon are particularly problematic when using heavy fuel oil. This is, however, not allowed in Greenland waters in relation to oil activities, where only low-sulphur (< 1.5 % by weight) gas oils may be used.

The international Convention on Long-Range Transboundary Air Pollution includes all these emissions, but when Denmark signed the protocols covering NO_x and SO_2 some reservations were made in the case of Greenland.

9.4.6 Cumulative impacts

Cumulative impacts are changes to the environment that are caused by an activity in combination with other past, present and future human activities. The impacts are summed up from individual activities both in space and time. Impacts from a single activity can be insignificant, but the sum of impacts from the same activity carried out at many sites at the same time and/or throughout time can become significant. Cumulative impacts also include interaction with other human activities impacting the environment, such as hunting and fishing; moreover, climate change is also often considered in this context (Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope 2003).

An example could be many seismic surveys carried out at the same time in a restricted area. A single survey will leave many alternative habitats available, but extensive activities in several locations may exclude, for instance, baleen whales from key habitats. This could reduce their food uptake and reproductive success due to decreased storage of the lipids needed for winter migration and breeding activities.

The concentration of oil discharged with the produced water is low, but the amounts of produced water from a single platform are considerable and many platforms will release even more. Bioaccumulation is an issue of concern when dealing with cumulative impacts of produced water. The low concentrations of PAH, trace metals and radionuclides all have the potential to bioaccumulate in fauna on the seafloor and in the water column. This may occur in the benthic community and subsequently be transferred to the higher levels of the food web, i.e. seabirds and marine mammals feeding on benthic organisms (Lee et al. 2005).

Seabird hunting is widespread and intensive in West Greenland, and some of the seabird populations have been declining, mainly due to unsustainable harvest. Tightened hunting regulations were introduced in 2001, which was followed by reduced numbers of shot birds being reported. In particular, common eider and thick-billed murre colonies in and near the assessment area have decreased in numbers over the past decades. Both species rely on a high adult survival rate, giving the adult birds many seasons to reproduce. The common eider population has been recovering since 2001 (Merkel 2010a), while the murre population is still decreasing in several of the colonies in West Greenland. Extra mortality due to an oil spill or sub-lethal effects caused by contamination from petroleum activities have the potential to be additive to the hunting impact and thereby enhance the population decline (Mosbech 2002). Within the assessment area, the breeding colonies of thick-billed murres have declined considerably. Thick-billed murres and other cliff-nesting auks are particularly vulnerable during the swimming migration, which is performed by flightless adults (due to moult) and chicks still not able to fly.

9.4.7 Mitigating impacts from development and production

As a consequence of previous experience, e.g. from the North Sea, the Arctic Council guidelines (PAME 2009) recommend that discharges are as far as possible prevented. When water-based muds are employed, additives containing oil, heavy metals, or other bioaccumulating substances should be avoided, or criteria for the maximum concentrations should be established (PAME 2009). Only chemicals registered in HOCNF and the Danish product register (PROBAS) should be allowed, and only those which by OSPAR are classifed as ‘green’ (PLONOR) or ‘yellow’. Moreover, wherever possible ‘zero discharge of drilling waste and produced water’ should be applied. This can be obtained by application of new technologies, such as injection and cuttings re-injections. In the Arctic Offshore Oil and Gas Guidelines, it is requested that ‘discharge (of drilling waste) to the marine environment should be considered only where zero discharge technology or re-injection are not feasible’ (PAME 2009).

If zero-discharge is not possible or not assessed as having the largest ‘Net Environmental Benefit’, releases to the marine environment should at least follow the standards described by OSPAR, applying a sound environmental management based on the Precautionary Principle, BAT and BEP.

Based on knowledge about site-specific biological, oceanographic and sea-ice conditions, discharges should occur at the depth where they have the least environmental impact, e.g. near the seafloor or at a suitable depth in the water column to prevent large sediment plumes or sedimentation in sensitive areas. Such plumes have the potential to affect benthic organisms, plankton and productivity, and may also impact higher trophic levels such as fish and mammals. The discharges should be evaluated on a case-by-case basis.

In the Barents Sea off Norway, cuttings and drilling muds are not discharged (except top hole drilling, which usually is carried out with sea water as drilling fluid) due to environmental concerns; instead they are re-injected in wells or brought to land (Anon 2003), which on the other hand leads to increased emissions to air from transport and pumping.

Disturbance can be mitigated by careful planning of the noisy activities in order to avoid activities in sensitive areas and periods, based on detailed background studies of the sensitive components of the environment.

Impacts from placement of structures inland is best mitigated by the same measures as described for activities involving disturbance, i.e. careful planning based on detailed background studies of the sensitive components of the environment in order to avoid unique and sensitive habitats.

9.4.8 Conclusions on development and production activities

Drilling will continue during development and production phases, and drilling mud and cuttings will be produced in much larger quantities than during exploration. If these substances are released to the seabed, impacts must be expected on the benthic communities near the release sites. Therefore, strict regulation based on toxicity tests of the mud chemicals and monitoring of effects on the sites is essential to mitigate impacts.

However, the release giving most reason for environmental concern is produced water. Recent studies have indicated that the small amounts of oil and nutrients can impact birds and primary production, and there is also concern for the long-term effects of radionuclides and hormone-disruptive chemicals. These effects should be mitigated by regulation, monitoring of the sites, and new technology to clean the water.

There will be a risk of release of non-native and invasive species from ballast water, and this risk will increase with the effects of climate change, unless new regulations, such as the coming Ballast Water Convention, will ensure that ballast water is cleaned prior to release. The risk of introducing new species by means of fouling on ship hulls is also likely to increase along with increased shipping in the Arctic.

Emissions from production activities to the atmosphere are substantial and will contribute significantly to the Greenland contribution of greenhouse gases.

Drilling, ships and helicopters produce noise, which can affect marine mammals and seabirds. The most sensitive species within the assessment area are the colonial seabirds. There is a risk of permanent displacement of populations from critical habitats and therefore for negative population effects.

Placement of structures has both biological and aesthetic impacts. The biological impacts include mainly permanent displacement from critical habitats. Destruction of unique seabed communities, such as sponge gardens and cold water coral reefs, is also a risk. The aesthetic impacts primarily include impacts on the pristine landscape, which again may impact on the local tourism industry.

The commercial fishery may be affected by closure zones if rigs, pipelines and other installations are placed at important fishing ground, but the impact on the fishery will probably be relatively low. Fish and seals that are attracted to artificial reefs created by subsea structures may be exposed to contaminants from the release of produced water.

There is a risk of reduced availability of hunted species, because they can be displaced from traditional hunting grounds.

In general, the best way of mitigating impacts from development and production activities is to combine a detailed background study of the environment (in order to locate sensitive ecosystem components) with careful planning of structure placement and transport corridors. Then BEP, BAT and applying international standards such as OSPAR and HOCNF can do much to reduce emissions to air and sea. A discharge policy, as planned for the Barents Sea, can contribute substantially to minimising the impacts. Furthermore, monitoring of effects on the sites is essential.

Before oil activities are initiated, appropriate information to local societies, both on a regional and local scale is very important. In the context of mitigating impacts, information on activities potentially causing disturbance should be communicated to e.g. local authorities and hunters' organisations, as hunters may be impacted e.g. by the displacement of important quarry species. Such information may help hunters and fishermen to plan their activities accordingly.

9.5 Impacts of decommissioning

The impacts from decommissioning activities are mainly from noise at the sites and from traffic, assuming that all material and waste are taken out of the assessment area and deposited at a safe site. There will also be a risk of pollution from accidental releases. However, the activities are short term and careful planning and adoption of BAT, BEP and international standards would minimise impacts. An important issue to address in the planning phase is to design installations for easy removal when activities are terminated.

10 Impacts of accidental oil spills

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10.1 Oil spill properties

A serious issue of environmental concern in relation to hydrocarbon activities in the marine Arctic environment is the risk of a large oil spill (Skjoldal et al. 2007). The probability of such an event is low, and in general the global trend in spilled amounts of oil is declining (Schmidt-Etkin 2011). However, the impacts from a large spill can be severe and long-lasting, especially in northern areas.

Several circumstances enhance the potential for severe impacts of a large oil spill in the assessment area. The sub-Arctic conditions reduce the degradation of oil, prolonging potential effects. The seasonal occurrence of ice in coastal areas may influence the distribution and fate of oil (see below), but will also make oil spill response difficult in periods with extensive ice cover or otherwise harsh weather conditions. Therefore, exploration drilling is not allowed when ice is present, and drilling operations must be completed well before the start of the ice season.

According to the AMAP oil and gas assessment, oil tankers are the primary potential spill source (Skjoldal et al. 2007). Another potential source is spills from a blowout during drilling, which in contrast to a tanker spill are continuous and may last for many days. For example, the spill from the *Deepwater Horizon* blowout in 2010 lasted 106 days before it was stopped by relief drilling.

10.1.1 Probability of oil spills

Large oil spills are generally very rare incidents. However, the risk exists and cannot be eliminated. In relation to oil drilling in the Barents Sea, it has been calculated that a blowout between 10,000 and 50,000 t would on average happen once every 4,600 years in a small-scale development scenario, and once every 1,700 years in an intensive development scenario (Anon 2003). The likelihood of a large oil spill from a tanker accident is estimated to be higher than for a blowout (Anon 2003).

Drilling in deep waters (between 1000 and 5000 feet ~ 305-1524 m) and ultra-deep waters (> 5000 feet ~ 1524 m) increases the risk of a long-lasting oil spill, due to the high pressures encountered in the well and to the difficulties of operating at these depths.

The risk of a deep-sea blowout in the Labrador Sea (Appendix 2)

Acona have carried out an evaluation of the risk and potential size of a blowout in the Greenland sector of the Labrador Sea. The main points are:

- Generally, the risk of blowouts is low. Based on historical data and recent improvements in risk management, it is estimated that a blowout will occur once for each 12,987 exploration wells drilled. The risk is about 50% higher in deep water (here defined as > 1000 m). At very large depths (> 2500 m), the risk may be even higher due to the increased likelihood of encountering hydrocarbon reservoirs at high temperature and pressure (where the risk is approx. 6 times higher than for normal wells), but the empirical basis for this is very limited.

- Because no actual drill data are available for the assessment area, six virtual wells have been simulated, with varying geological characteristics (similar to those found on the Canadian side of the Labrador Sea). If a blowout occurs, it is most likely to happen at the sea floor. Under these conditions, the most likely duration of a blowout is estimated as 14 days, and the maximum duration is estimated to be 75 days. The most likely flow rate is 519 m^3/day (equivalent to a total spill of 7,266 m^3, assuming a 14-day spill). However, under some (realistic) conditions, the flow rate could be as high as 9,910 m^3/day (equivalent to a total spill of 138,740 m^3, assuming a 14-day spill). The assessment of spill duration is based on the likelihood of natural collapse of the well, as well as the application of several countermeasures, including capping and relief drilling.

- Acona assess that the regulatory requirements for risk management and contingency planning in Greenland are at least as high as those applied in Norway, Canada and the United States.

10.1.2 The fate and behaviour of spilled oil

Previous experience with spilled oil in the marine environment gained in other parts of the world shows that fate and behaviour of the oil vary considerably. Fate and behaviour depend on the physical and chemical properties of the oil (light oil or heavy oil), where and how it is released (surface or subsea, depth, instantaneous or continuous), and on the conditions of the sea into which it is released (temperature, ice, wind and current).

General knowledge on the potential fate and degradation of spilled oil relevant for the Greenland marine environment has been reviewed by (Pritchard & Karlson 2002). Ross (1992) evaluated the behaviour of potential offshore oil spills in West Greenland with special regard to the potential for clean-up. Simulations of oil spill trajectories in West Greenland waters have previously been performed by Christensen et al. (1993) using the SAW model, and by SINTEF (Johansen 1999) using the OSCAR model in preparation for Statoil’s exploration drilling in the Fylla field in 2000. More recently, DMI simulated oil spill drift and fate in the Disko West area (Nielsen et al. 2006) and in eastern Baffin Bay (Nielsen et al. 2008). As a part of this assessment, DMI have carried out new simulations of oil spills in South Greenland waters, both at the surface and in the form of a deep-sea blowout (see section 10.2 below).

Surface spills

Oil released to open water surfaces spreads rapidly resulting in a thin slick (often about 0.1 mm in the first day) covering a large area. Wind-driven surface currents move the oil at approx. 3 % of the wind speed and cause turbulence in the surface water layer, which breaks the oil slick up into patches and causes some of the oil to disperse in the upper water column. This dispersed oil will usually stay in the upper 10 m (Johansen et al. 2003). Low temperatures and the presence of sea ice can hamper the process of dispersal considerably, and the complexity of an oil spill in ice can be much larger than a similar oil spill in open water.

The oil spill simulations generally have addressed surface spills and the subsequent drift. However, oil may also sink to the seabed, depending on the density of the spilled oil. Even light oil may sink if it adsorbs onto sediment particles in the water (Hjermann et al. 2007). Sediment particles can be numerous in coastal Greenland surface waters, where turbid melt water from glaciers can disperse widely into the open sea.

Subsurface spills

Blowouts on a platform will initially cause a surface spill, but may continue as a subsurface spill if the rising drill tubes from the wellhead collapses. The risk of a collapse is higher in deeper water. The oil in a subsurface blowout can float to the surface or remain for a longer time in the water column. The oil that remains in the water column will typically initially be dispersed in small droplets. Whether oil in a subsea blowout remains in the water column as a dispersed plume or floats to the surface depends on oil type, oil/gas ratio, temperature and water depth. As the potential oil type and oil/gas ratio is unknown for the assessment area, the behaviour of the oil cannot be predicted with any certainty. This is the reason for the discrepancy between DMI models of subsurface spills in West Greenland, in which all oil quickly floated to the surface (Nielsen et al. 2006), and SINTEF models, where oil from subsurface spills did not reach the surface at all, but rather formed a subsea plume at a depth of 300-500 m (Johansen 1999). In the SINTEF model, high total hydrocarbon concentrations (> 100 µg/l) were estimated in an area close to the outflow.

10.1.3 Dissolution of oil and toxicity

The total oil concentration in water is a combination of the concentration of small dispersed oil droplets, and oil components dissolved from these and the surface slick. The process of dissolution is of particular interest, as it increases the bioavailability of the oil components. The rate and extent to which oil components dissolve in seawater depends mainly on the proportion of water-soluble fractions (WSF) in the oil, the degree of natural dispersion, surface spreading and water temperature.

PAHs are among the toxic components of crude oil. The highest PAH concentration found in the water column in Prince William Sound within a six-week period after the *Exxon Valdez* spill was 1.59 µg/l, at 5 m depth. This is well below levels considered to be acutely toxic to marine fauna (Short & Harris 1996).

SINTEF (Johansen et al. 2003) reviewed available standardised toxicity studies, and found acute toxicity down to 0.9 mg oil/l and applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 µg/l for a 96-hour exposure. This was based on fresh oil leaking a dissolvable fraction, which is most toxic for eggs and larvae. Later, the weathered oil will be less toxic.

Water-soluble components (WSC) could leak from oil encapsulated in ice. Controlled field experiments with oil encapsulated in first-year ice for up to 5 months have been performed in Svalbard. Leakage of water-soluble components to the ice is of special interest, because of a high bioavailability to marine organisms, relevant both in connection with accidental oil spills and release of produced water (Faksness & Brandvik 2005).

10.2 The DMI oil spill simulations

As part of this assessment, the Danish Meteorological Institute (DMI) has carried out two sets of oil spill simulations for the South Greenland region. The first (Ribergaard et al. 2010, Appendix 3) dealt with a potential surface oil spill at five sites in the current license areas, while the second attempted to model a deep-water spill at one of these sites (Ribergaard 2011, Appendix 4).

The oil spill simulations are based on the output (in terms of horizontal and vertical current velocities) of a detailed 3D model of ocean hydrodynamics, including sea ice (HYCOM-CICE). This model is again forced by the ERA Interrim reanalysis from the European Centre for Medium-Range Weather Forecasts (ECWMF), and thus builds on actual (reconstructed) weather conditions in the region in recent years (2003-2009). In addition to this physical forcing, the oil spill model (DMOD) incorporates oil type/composition (light vs. heavy oils), and physico-chemical processes affecting the oil after release (evaporation and emulsification). The output is a predicted distribution of virtual oil particles in space and time, which is often best summarised in map form.

10.2.1 Modelling of surface spills (Appendix 3)

The fate of oil from a surface spill was modelled from five sites in the current (2011) exploration license areas. The model assumed a continuous spill of 30,000 t at a rate of 3,000 t/day, and followed the fate of the oil for 30 days (10 days of spill duration, and 20 days post-spill). The oil type used in the model was a Statfjord crude, with a density of 886.3 kg/m^3. Spills were modelled as taking place in either August or October, and were initiated on day 1, 11, 21 and 31 of these months in the seven years 2003-2009. Thus, for each spill site and release month, 28 simulations were carried out using reconstructed weather conditions (see above).

The dispersal of the oil was more extensive in October-November than in August-September, due to the higher wind speeds during autumn. All scenarios indicated that the oil was more likely to spread north-westwards along the West Greenland coast than in the opposite direction, driven by the prevailing currents. The probability of substantial amounts of oil reaching the coast was high in all scenarios, although no scenarios showed oil reaching the coast east of Cape Farewell. Depending on the spill site, oil reached the coast either in Julianehåb Bugt or northwest of Nunarsuit, and coastlines well north of the current assessment area were likely to be affected, at least up to 64° N (Fig. 10.1).

It should be noted that the model representation of the Greenland coastline is quite rough and does not include fjords. The model thus cannot be used to predict whether oil is likely to enter the fjords, and if so whether it will be retained there. The probability of such an event is likely to depend on whether net outflow from a given fjord is positive at all stages of the tidal cycle, i.e. whether freshwater outflow always exceeds peak tidal inflow. Fjord systems are likely to differ substantially in this respect. Given that exploration licenses have been granted close to the coast in South Greenland, a better understanding of the conditions under which oil will enter fjord systems would be very valuable.

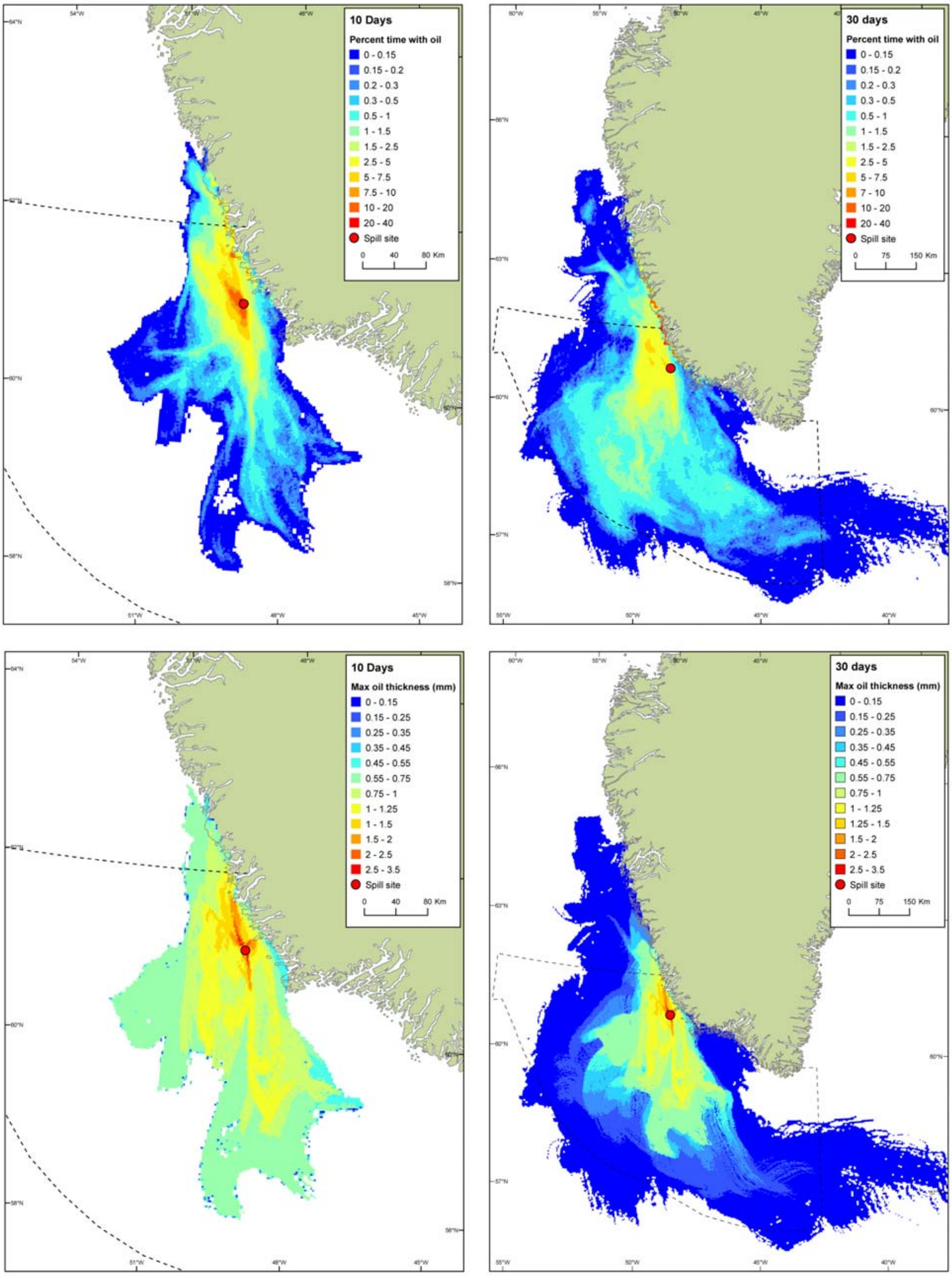


Figure 10.1. Maps showing the horizontal dispersal of oil from a simulated surface spill in October at the marked location (see text for details). The upper panels show the cumulative percentage of time each model cell has oil present after 10 and 30 days, as an average of 28 simulations. The lower two panels show the maximum thickness of the oil slick in any of the 28 simulations, again after 10 and 30 days.

10.2.2 Modelling of deep-sea spills (Appendix 4)

The fate of oil from a deep-sea oil spill was modelled in a similar way. Only one spill site was used, at a depth of 3,070 m approx. 100 km south of Nunarsuit, and the spill was initiated on 1, 11, 21 or 31 August 2003-2009. As above, the spill rate was assumed to be 3,000 t/day for 10 days, leading to a total spill of 30,000 t. The fate of the oil was followed for another 112 days. Four oil types with varying composition and density were modelled: two North Sea crudes (Statfjord and Ekofisk), and two refined products (Bunker C and Iso 450). Although the oil type present in the assessment area is unknown at present, the current best guess is that the Statfjord crude is the most representative (J. Bojesen-Koefoed, GEUS, pers. comm.).

The physico-chemical processes determining what happens to spilled hydrocarbons under high pressure and low temperature are only partly understood, and this hampers the modelling of deep-sea spills (Thibodeaux et al. 2011). Among the major unknowns are the actual composition of the oil, including the gas-to-oil ratio, the formation and dissolution of gas hydrates (methane clathrates), and how these factors affect the size and buoyancy of oil droplets. Application of dispersing agents at the wellhead is also likely to affect droplet size, and thus the rate at which droplets rise towards the surface, and whether or not they remain at depth forming plumes at and around deep pycnoclines (density gradients), as was seen after the *Deepwater Horizon* spill (see section 10.5).

The horizontal dispersal of the oil at the surface was similar to a surface spill at the same location, although the longer period modelled revealed that a small fraction of the oil could reach as far north as 66° N. For three of the four oil types, nearly all oil reached the surface within a few days of being released. Only for Bunker C oil did an appreciable fraction remain at depth. Bunker C is a refined heavy oil (density 992.6 kg/m^3), and crudes of similar composition and density are rare and probably unlikely to occur in the assessment area (J. Bojesen-Koefoed, GEUS, pers. comm.).

After 30 days, 20% of the Bunker C oil in the model remained dispersed in the water column, at a mean depth of ~300 m. Over the next three months, this fraction gradually decreased to 10%, and the mean depth to ~75 m. This oil showed a horizontal dispersal similar to that of oil at the surface, although the rate of spread from the spill site was slower due to lower current velocities at depth. The model also predicted the vertical distribution of the oil in the water column, something that could in principle be converted into oil concentrations. However, as described in section 10.5, the processes determining the dispersion and dissolution of hydrocarbons in water under high pressure are poorly understood. In connection with the *Deepwater Horizon* spill, studies are on-going to improve the scientific understanding of these processes, but it has not been possible to include the still unpublished results of this work in the DMI model.

Theoretical oil concentrations can be calculated based on assumptions about spill size and dispersal. If e.g. a spill of 30,000 t was dispersed equally over 100 km^2, it would form a continuous 0.3 mm thick layer. If this amount of oil was normally distributed in the water column with a standard deviation of 150 m (value taken from the DMI simulation), the mean oil concentration (all components) in a 300 m thick zone around the mean depth would be approx. 750 µg/l. Assuming 90% of the oil rises to the surface, the concentration at depth would be 75 µg/l. Although these calculations are purely theoretical and very simplistic (e.g. biodegradation is not taken into account), they indicate that toxic concentrations are possible after a spill of this size.

10.3 Oil spill impacts on the environment

There are generally two types of effects from oil in the marine environment: physical contact (e.g. with bird plumage and fish eggs), and intoxication from ingestion, inhalation and contact. Contact gives acute effects, while intoxication can give both acute and long term (sublethal) effects.

Table 10.1 gives an overview of potential impacts from a large oil spill, which are discussed further in the following sections.

Table 10.1. Overview of potential impacts of a large oil spill on VECs in the South Greenland assessment area. See section 4.8 for a summary of the VECs.

VEC	Typical vulnerable organisms	Population impact – worst case*		
		Displacement	Sublethal effect	Direct mortality
Pelagic hotspots	Zooplankton, fish larvae	-	Moderate (R)	Moderate (R)
Overwintering zooplankton	*Calanus finmarchicus*	-	Major (R)	Major (R)
Tidal/subtidal zone	Capelin, bivalves	Long term (R)	Major (R)	Major (R)
Ikaite columns	Endemic species	-	Major (G)	Major (G)
Benthos and demersal fish	Atlantic cod, sandeels, shrimp, bivalves	Short term (L)	Moderate (R)[1]	Moderate (L)
Seabirds (breeding)	Auks, common eider	Short term (L)	Major (R)	Major (R)
Seabirds (non-breeding)	Auks, common eider, harlequin duck	Short term (L)	Major (R)	Major (R)
Seals	Harbour seal, harp seal, hooded seal	Short term (L)	Moderate (R)	Minor (R)
Large whales	Baleen whales	Short term (L)	Moderate (R)	Minor (R)

* L = local, R = regional and G = global. [1]Tainting of commercial species.

10.3.1 Oil spill impact on plankton and fish incl. larvae of fish and crustacean

Adult fish and shrimp

In the open sea, an oil spill at the surface will usually not result in oil concentrations that are lethal to adult fish, due to dispersion and dilution. Furthermore, many fish can detect oil and will attempt to avoid it, and therefore populations of adult fish in the open sea are not likely to be significantly affected by an oil spill. The situation is different in coastal areas, where high and toxic oil concentrations can build up in sheltered bays and fjords, resulting in high fish mortality (see below).

Adult shrimps live on and near the bottom in relatively deep waters (100-600 m), where oil concentrations from a surface spill will be very low, if detectable at all. No effects were seen on the shrimp stocks (same species as in Greenland) in Prince William Sound in Alaska after the large oil spill from *Exxon Valdez* in 1989 (Armstrong et al. 1995). Under certain conditions, a subsea blowout may cause high concentrations of oil and dispersants in the water column, as observed during the *Deepwater Horizon* spill in 2010 (Thibodeaux et al. 2011). In such a situation, shrimps may be affected.

Fish and crustacean larvae

Eggs and larvae of fish and shrimp are more sensitive to oil than adults. Theoretically, impacts on fish and crustacean larvae may be significant and reduce the annual recruitment strength with some effect on subsequent populations and fisheries for a number of years. However, such effects are extremely difficult to identify and filter out from natural variability, and they have never been documented after spills.

The distribution of fish eggs and early larval stages in the water column is governed by density, currents and turbulence. In the Barents Sea, the pelagic eggs of cod will rise and be distributed in the upper part of the water column. As oil is also buoyant, the highest exposure of eggs will be under calm conditions, while high-energy wind and wave conditions will mix eggs and oil deeper into the water column, where both are diluted and the exposure limited. As larvae grow older, their ability to move around becomes increasingly important for their depth distribution.

In general, species with distinct spawning concentrations and with eggs and larvae in distinct geographic concentrations in the upper water column will be particularly vulnerable. The Barents Sea stock of Atlantic cod is such a species, where eggs and larvae can be concentrated in the upper 10 m in a limited area. Based on oil spill simulations for different scenarios and different toxicities of the dissolved oil, individual oil exposure and population mortality has been calculated for the Barents Sea stock of Atlantic cod. The population impact is to a large degree dependent on whether there is a match or a mismatch between high oil concentrations in the water column (which will only occur for a short period when the oil is fresh) and the highest egg and larvae concentrations (which will also only be present for weeks or a few months, and only concentrated in surface water in calm weather). For combinations of unfavourable circumstances and using the PNEC with a 10 X safety factor (Johansen et al. 2003), there could be losses of around 5 %, and in some cases up to 15 %, for a blowout lasting less than 2 weeks, while very long-lasting blowouts could give losses of eggs and larvae in excess of 25 %. A 20 % loss in recruitment to the cod population is estimated to cause a 15 % loss in the cod spawning biomass and to take approx. eight years to recover fully.

Hjermann et al. (2007) reviewed the impact assessment of Barents Sea stock of Atlantic cod, herring and capelin by Johansen et al. (2003), and suggested improvements by focusing more on oceanographic and ecological variation in the model. It was also emphasised that it is not possible to draw firm conclusions on long-term effects due to variations in the ecosystem. At best, we can attempt, by modelling, to attain a quantitative indication of the possible outcomes of oil spills in an ecosystem context. Qualitatively, we can assess at which places and times an oil spill may be expected to have the most significant long-term effects.

Compared to the Lofoten-Barents Sea-area, there is much less knowledge available on concentrations of eggs and larvae from West Greenland, including the assessment area. However, the highly localised spawning areas of cod with high concentrations of egg and larvae for a whole stock near the surface, as seen in the Lofoten-Barents Sea, do not currently occur in West Greenland. However, during the 20th century spawning grounds of cod existed in West Greenland, and re-colonisation by cod of the assessment area is possible. Currently, the cod fishery in Southwest Greenland is highly influenced by recruitment from Icelandic spawning grounds. Occasionally, significant numbers of juvenile cod from Iceland are transported with the Irminger Current to Greenland waters.

Eggs of Atlantic cod concentrate in the upper 10 m of the water column, whereas larvae of shrimp and Greenland halibut are found deeper and would therefore be less exposed to harmful oil concentrations from an oil spill at the surface. This implies that an oil spill will most likely impact a much smaller proportion of a season's production of eggs and/or larvae of these species than modelled for cod in the Barents Sea. Impacts on recruitment to Greenland halibut and northern shrimp stocks therefore most likely will be insignificant. A subsea blowout with the properties and quantities of the *Deepwater Horizon* spill in 2010, when large plumes of dispersed oil occurred in the water column, may expose eggs and larvae over much larger areas and depth ranges and potentially cause impact on the recruitment and stock size of these demersal species. At the same time, dilution and dispersion in deep water may also diminish exposure of the most sensitive upper 50 m of the water column.

Besides Greenland halibut and northern shrimp, a subsea blowout may have consequences for snow crab and sandeel. Sandeel is a key species in the ecosystem in the assessment area, and the potential effects of oil spills on this species should be further investigated. With respect to snow crab and shrimp, it should be noted that the assessment area is among the most important fishing grounds in Greenland, implying that consequences for the fishing industry could be high if larvae concentrations are exposed to a major subsea oil spill.

Copepods, the food chain and important areas

Copepods are very important in the food chain and can be affected by the toxic oil components (WSF, PAH) in the water below an oil spill. However, given the usually restricted vertical distribution of these components to the upper zone during surface oil spills, and the wider depth distribution of the copepods, a spill at the surface is not likely to cause major population effects. Ingestion of dispersed oil droplets at greater depth from a subsea blowout or after a storm may be a problem. Studies of the potential effects of oil spills on copepods in the Barents Sea (Melle et al. 2001) showed that populations were distributed over such large areas that a single surface oil spill would only impact a minor part and not pose a major threat (Anon 2003). Recent studies showed negative effects of pyrene (PAH) at concentrations of 10-100 nM on reproduction and food uptake among *Calanus* species (Jensen et al. 2008), and on survival of females, feeding status and nucleic acid content in *Microsetella* spp. from western Greenland (Hjorth & Dahllöf 2008). Negative effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *C. finmarchicus* and *C. glacialis* were also demonstrated (Hjorth & Nielsen 2011).

Again, the experience learned from the *Deepwater Horizon* oil spill, where large subsea plumes of dispersed oil were found at different depths, may change these conclusions of relatively mild impacts to more acute and severe impacts for large subsea spills. The assessment area is extremely important in a North-west Atlantic context for overwintering populations of *C. finmarchicus*. Although these copepods do not feed while diapausing at great depth, they may be sensitive to the presence of toxic oil components or dispersal agents. It is likely that both oil plumes (if present) and copepods will be concentrated at deep pycnoclines, i.e. vertical density gradients, and this may increase exposure. Specific studies of the sensitivity of diapausing copepods to oil are lacking.

Important areas for plankton, including fish and crustacean larvae, are often where hydrodynamic discontinuities occur. Special attention should therefore be given to the implication of oil spills in connection with such sites, particularly during the spring bloom. Fronts, upwelling areas and the marginal ice zone are examples of such hydrodynamic discontinuities where high surface concentrations of phytoplankton and zooplankton, including shrimp and fish larvae, can be expected. Little information is available on recurring hydrodynamic discontinuities in the assessment area.

The most sensitive season for primary production and plankton – i.e. where an oil spill can be expected to have the most severe ecological consequences – is the spring bloom, when high biological activity of the pelagic food web from phytoplankton to fish larvae is concentrated in the surface layers.

10.3.2 Oil spill impacts on benthic flora

The direct impact of an oil spill is an expected mass mortality among macroalgae and benthic invertebrates on oiled shores from a combination of chemical toxicity and smothering. Another more subtle way oil spill can impact algae is by petroleum hydrocarbons interfering with the sex pheromone reaction as observed in the life history of *Fucus vesiculosus* (Derenbach & Gereck 1980).

There are different reports on the impact of oil contamination on macroalgal vegetation and communities. After the *Exxon Valdez* oil spill in 1989 in Alaska the macroalgae cover in the littoral zone (mainly *Fucus gardneri*) was lost. It has taken many years to fully re-establish these areas with years of fluctuations in the *Fucus* cover, and some areas are still considered as recovering (NOAA 2010). These fluctuations may be a result of the grazer-macroalgae dynamics as was shown after the *Torrey Canyon* accident at the coast of Cornwall, UK (Hawkins et al. 2002). Regarding Prince William Sound, the fluctuations were considered as a result of homogeneity of the developing *Fucus* population (e.g., genetics, size and age), which made it more vulnerable to natural environmental impacts (e.g., no adult *Fucus* plants to protect and assure recruitment), thus resulting in a longer time span to restore *Fucus* population heterogeneity (Driskell et al. 2001).

In contrast, no major effects were observed in a study on impact of crude and chemically dispersed oil on shallow sublittoral macroalgae at northern Baffin Island (Cross et al. 1987).

The scenarios of the *Exxon Valdez* accident and the Baffin Island Oil Spill (BIOS) study were somewhat different, as the *Exxon Valdez* oil spill included heavy oil, while in the case of BIOS the oil tested was a medium crude oil (Sergy & Blackall 1987). Furthermore, the BIOS studies on macroalgae were conducted in the upper sublittoral and not in the littoral zone, where the most dramatic impacts were observed in connection with the *Exxon Valdez* oil spill (Dean & Jewett 2001).

Cleaning of the shoreline may increase the impacts of the oil contamination. After the *Exxon Valdez* oil spill, adult *Fucus* plants were coated with oil but did not necessarily die. Part of the cleanup effort involved washing shores with large volumes of high-pressure hot seawater. This treatment caused almost totally mortality of adult *Fucus*, and probably scalded much of the rock surface and thereby *Fucus* germlings. In the long term, though, no significant difference was observed in *Fucus* dynamics at oiled and unwashed vs. oiled and washed sites (Driskell et al. 2001). Use of dispersants in cleaning up oil spills may increase recovery time of the treated shores. Recovery lasted from 2-3 years to at least 10 years after the *Torrey Canyon* spill in South England, and up to 15 years on shores badly affected by dispersants (Hawkins et al. 2002).

How pyrene might affect natural algae and bacteria communities in Arctic sediment was studied near Sisimiut (West Greenland) using microcosms. Benthic microalgae were especially sensitive to pyrene, and increased toxicity was found at high levels of UV light already at low pyrene concentrations (Petersen & Dahllöf 2007, Petersen et al. 2008). The pronounced pyrene effects caused algal death and organic matter release, which in turn stimulated bacterial degradation of organic matter.

10.3.3 Oil spill impacts on benthic fauna

Bottom-living organisms (benthos) are generally very sensitive to oil spills and high hydrocarbon concentrations in the water. The sensitivity of many benthic species have been studied in the laboratory and a range of sub-lethal effects have been demonstrated from exposures not necessarily comparable to actual oil spill situations (Camus et al. 2002a, Camus et al. 2002b, Camus et al. 2003, Olsen et al. 2007, Bach et al. 2009, Hannam et al. 2009, Bach et al. 2010, Hannam et al. 2010).

Effects will occur especially in shallow water (< 50 m), where toxic concentrations can reach the seafloor. In such areas intensive mortality has been recorded following an oil spill, for example among crustaceans and molluscs (McCay et al. 2003a, McCay et al. 2003b). Oil may also sink to the seafloor as tar balls, which happened after the *Prestige* oil spill off northern Spain in 2002. No effects on the benthos were detected (Serrano et al. 2006), but the possibility of an impact is apparent. Sinking of oil may also be facilitated by suspended sediment particles, which are abundant in melt-water runoff from glaciers and may disperse widely into the open sea.

Effects on benthos have been documented from the *Deepwater Horizon* spill in the Gulf of Mexico in 2010, where deep-water plumes moved tens of kilometres away from the blowout site (Diercks et al. 2010a, Schrope 2011, Thibodeaux et al. 2011), but it is too early to draw firm conclusions.

Many benthos species, especially bivalves, accumulate hydrocarbons, which may cause sub-lethal effect (e.g. reduced reproduction). Such bivalves may act as vectors of toxic hydrocarbons to higher trophic levels, particularly bearded seal and common eider. Knowledge on benthos in the assessment area is too fragmentary to assess impacts of potential oil spills. The impact of potential oil spills on benthos in the assessment area has not been assessed in detail yet.

However, in broad terms, the shallow water (down to 50 m) communities have high species richness (bivalves, macroalgae etc.) and the fauna is available to higher trophic levels. Another feature is that individuals of several species have an estimated maximum age of more than 25 years (the bivalves *Mya* spp., *Hiatella arctica*, *Chlamys islandica* and the sea urchin *Strongylocentrotus droebachiensis*). This indicates that the benthic communities may be very slow to recover after any type of disturbance that causes mortality of these old individuals, which often constitute the major part of the biomass. From a biodiversity perspective, the high prevalence of species found at only one site and of species represented only by a single specimen also suggests that mortality induced from disturbance from oil spills or exploration potentially can cause a significant reduction in the total species richness for a long time.

10.3.4 Oil spill impacts on coastal habitats

One of the lessons learned from the *Exxon Valdez* oil spill was that the nearshore areas were the most impacted habitats (NOAA 2010). Many of the animal populations from this habitat are assessed to have recovered (birds, fish), but certain populations are still under recovery (several bird species, clams, mussels) and a few were recently assessed as 'not recovered' (pigeon guillemot *Cepphus columba* – a close relative to the black guillemot in Greenland, and also Pacific herring *Clupea pallasii*) (NOAA 2010).

In coastal areas where oil can be trapped in shallow bays and inlets, oil concentrations can build up in the water column to levels that are lethal to adult fish and invertebrates (e.g., McCay 2003).

An oil spill from an activity in the assessment area which reaches the coast has the potential to reduce stocks of capelin and lumpsucker, because these fish spawn here and the sensitive eggs and larvae may be exposed to high oil concentrations. Arctic char *Salvelinus alpinus* may be forced to stay in oil-contaminated shallow waters when they congregate before moving up into their native river to spawn and winter. Other fish species that can be affected in coastal waters include Atlantic halibut (*Hippoglossus hippoglossus*), capelin, lumpsucker and local populations of Atlantic cod.

In coastal areas where oil may be buried in sediment, among boulders and imbedded in crevices in rocks, a situation with chronic oil pollution may persist for decades and cause small to moderate effects. Many coastal areas in the assessment area are similar in morphology to those of Prince William Sound, where oil was trapped below the surface after the *Exxon Valdez* oil spill. In a study performed 12 years after the oil spill, it was estimated how much oil remained on the beaches of Prince William Sound. Oil was found on 78 of 91 beaches, randomly selected according to their oiling history. The analysis revealed that over 90 % of the surface oil and all of the subsurface oil originated from the *Exxon Valdez* (Short et al. 2004). Today (2010) oil still lingers in buried patches on the affected shores, and their presence may be a source for continued exposure to oil for sea otters and birds that seek food in sediments (NOAA 2010).

Oil may also contaminate terrestrial habitats occasionally inundated at high water levels. Salt marshes are particularly sensitive and, they represent important feeding areas for geese. During the *Braer* spill in Shetland, oil containing spray carried by wind impacted even fields and grasslands close to the coast.

Due to their location at the head of a convoluted fjord system, the ikaite columns in Ikka Fjord are unlikely to be exposed even after a major offshore oil spill (see also section 10.2). However, if they are exposed, the unique fauna and flora are likely to be highly impacted by e.g. toxic effects of oil components.

The tourism industry may be impacted by a large oil spill hitting the coasts. Tourists travelling to Greenland to encounter the unspoilt Arctic wilderness will most likely avoid oil-contaminated areas.

The coastal area have been mapped and classified according to their sensitivity to oil spills (Mosbech et al. 2000), see Fig. 10.2.

10.3.5 Oil spill impacts on fisheries

Tainting (unpleasant smell or taste) of fish flesh is a severe problem related to oil spills. Fish exposed even to very low concentrations of oil in the water, in their food or in the sediment where they live may be tainted, leaving them useless for human consumption (GESAMP 1993, Challenger & Mauseth 2011). The problem is most pronounced in shallow waters, where high oil concentrations can persist for longer periods. Flatfish and bottom-living invertebrates are particularly exposed. Tainting has, however, not been recorded in flatfish after oil spills in deeper offshore waters, where degradation, dispersion and dilution reduce oil concentrations to very low levels. Tainting may also occur in fish living where oil-contaminated drill cuttings have been disposed of.

A very important issue in this context is the reputational damage an oil spill will cause to fish products from the affected areas. It will therefore be necessary to suspend fishery activities in an affected area, to avoid even the risk of marketing contaminated products (Rice et al. 1996, Challenger & Mauseth 2011, Graham et al. 2011). This problem may apply to the large-scale commercial northern shrimp fishery within the assessment area, as well as to the local fisheries targeting Atlantic cod, lumpsucker, capelin, wolffish etc. Large oil spills may cause heavy economic losses due to problems arising in the marketing of the products. Strict regulation and control of the fisheries in contaminated areas are therefore necessary to ensure the quality of the fish available on the market. In offshore areas, fishery suspension will usually last some weeks, and in coastal waters longer. The coastal fishery was banned for four months after the *Braer* incident off Shetland in 1993, and for nine months after the *Exxon Valdez* incident in Alaska in 1989 (Rice et al. 1996). However, some mussel and lobster fishing grounds were closed for more than 18 and 20 months respectively after the *Braer* incident. During the *Deepwater Horizon* spill, 230,000 km^2 were closed for both commercial and recreational fishing, and in September 2010 c. 83,000 km^2 were still closed (Graham et al. 2011). Some fisheries even remained closed one year after the spill (Law & Moffat 2011, NOAA 2011a).

10.3.6 Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Burger & Gochfeld 2002). Birds which rest and/or dive from the sea surface, such as auks, seaducks, cormorants and divers (loons), are most exposed to oil slicks, compared with birds which spend more time flying and on land. However, all seabirds face the risk of coming into contact with spilled oil on the surface. This particular vulnerability is attributable to their plumage. Oil soaks easily into the plumage and destroys its water repellence and thus insulation and buoyancy properties. Therefore, oiled seabirds readily die from hypothermia, starvation or drowning. Birds may also ingest oil by cleaning their plumage and by feeding on oil-contaminated food. Oil irritates the digestive organs, damages the liver, kidney and salt gland function, and causes anaemia. Sublethal and long-term effects may be the result. However, the main cause of seabird losses following an oil spill is direct oiling of the plumage.

Many seabirds aggregate in small and limited areas for certain periods of their life cycles. Even small oil spills in such areas may cause very high mortalities among the birds present. The high concentrations of seabirds found at coasts, e.g. breeding colonies, wintering areas or in offshore waters at important feeding areas, are particularly vulnerable.

Oiled birds which have drifted ashore are often the focus of the media when oil spills occur, as evidence of the high individual sensitivity to oil spills. However, the main concern must be whether populations suffer from oiling. To assess this issue, extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem are necessary.

The seabird species most vulnerable to the impacts of oil spills are those with low reproductive capacity and a correspondingly high average lifespan (low population turnover). Such a life strategy is found among most seabirds, including auks, fulmars and many sea ducks. Thick-billed murres, for example, do not breed before 4–5 years of age and the females only lay a single egg per year. This very low annual reproductive output is counterbalanced by a very long expected life span of 15–20 years or more. These seabird populations are therefore particularly vulnerable to additional adult mortality caused, for example, by an oil spill.

If a breeding colony of birds is completely wiped out by an oil spill, it must be re-colonised from neighbouring colonies. Re-colonisation is a slow process, and depends on the proximity, size and productivity of these colonies. If the numbers of birds in neighbouring colonies are declining, for example due to hunting, there will be no or only few birds available for re-colonisation of a site.

Breeding birds

Many seabird species breed in the assessment area (cf. section 4.6), and a majority are associated with habitats (sea-facing cliffs or on low islets) along the outer coastline, and are thus highly exposed to drifting oil. A further risk situation is when adults accompany their chicks away from the colony, as happens for auks and sea ducks. Ducks move further inshore to find sheltered areas, while auks move offshore and disperse over extensive areas. Two of the species breeding in the assessment area, Atlantic puffin and common murre, are rare breeders in Greenland and listed as Near threatened and Endangered, respectively, on the Greenland Red list (Boertmann 2007b). The auks are also colonial breeders, which mean that a large proportion of the Greenland population risks being wiped out by a single oil spill.

Staging, moulting and wintering birds

A large oil spill in the assessment area may potentially affect seabirds from many areas of the North Atlantic, due to Southwest Greenland being an internationally important foraging area throughout most of the year. The visitors include non-breeding birds from Europe and the southern hemisphere (e.g., black-legged kittiwakes and great shearwaters, respectively), moulting birds from Canada (e.g. harlequin ducks) and wintering birds from a range of breeding areas in the North Atlantic (e.g. thick-billed murres). In the coastal areas off Southwest Greenland, the number of wintering birds is estimated to count more than 3.5 million birds, and a large proportion of these are found within the assessment area. In addition, an unknown but large number of murres, puffins, kittiwakes and especially little auks utilise areas further offshore (Boertmann et al. 2004, Boertmann et al. 2006). Large numbers of eiders, murres and little auks are also assumed to pass through the assessment area when migrating back and forth to breeding areas in the high Arctic (Mosbech et al. 2006a, Mosbech et al. 2006b, Mosbech et al. 2007, Boertmann et al. 2009). Thus, the number of birds potentially affected by a large oil spill in the assessment area could be very large.

10.3.7 Oil spill impacts on marine mammals

Marine mammals are relatively robust and can generally survive short periods of fouling and contact with oil, except for polar bears and seal pups, for whom even short exposures can be lethal (Geraci & St. Aubin 1990).

Seal pups are very sensitive to direct oiling, because they have not developed an insulating blubber layer and are dependent on their natal fur for insulation (Geraci & St. Aubin 1990). The population of harp seals whelping on the drift ice of Southwest Greenland are thus particularly vulnerable. For the polar bear, contact with oil also means loss of isolation properties of the fur. Polar bears can pick up the oil when they swim between ice floes and may also unavoidably ingest oil as part of the grooming behaviour; both can be lethal. In the assessment area, however, the numbers of polar bears is low and their occurrence is dependent on the presence of sea ice.

Marine mammals have to come to the surface to breathe. Therefore, inhalation of vapours from oil is a potential hazard to seals and cetaceans. AA recent report indicates that the loss of killer whales after the *Exxon Valdez* oil spill in 1989 was related to inhalation of oil vapours from the spill (Matkin et al. 2008). These killer whales did not avoid the oil spill and were observed surfacing in oil-covered water. Harbour seals found dead shortly after the *Exxon Valdez* oil spill had evidence of brain lesions caused by oil exposure, and many of these seals were disoriented and lethargic over a period of time before they died (Spraker et al. 1994). In periods with ice cover, when oil can fill the spaces between the ice floes, the risk of inhalation of toxic vapour may be even more serious, because marine mammals have to surface in these ice-free spaces where the oil may be gathering.

There is also concern relating to damage to eye tissue on contact with oil, as well as for the toxic effects and injuries in the gastrointestinal tract if oil is ingested during feeding at the surface (Albert 1981, Braithwaite et al. 1983, St Aubin 1990). Surface feeding whales such as the bowhead, minke, fin, sei, blue and humpback whales are specially exposed to this threat. Furthermore, baleen whales are at risk during even short exposures to oil, because they feed by filtering prey-laden water through their baleen plates. The effect of fouling of baleen plates by oil and the long-term effects are uncertain, but oil may seriously affect filtration (Werth 2001).

The risk of long exposures, such as inhalation of oil vapours, ingestion and contact with eye tissues, is aggravated because animals may not be able to perceive oil as a danger and have repeatedly been reported to swim directly into oil slicks (e.g., Harvey & Dalheim 1994, Smultea & Würsig 1995, Committee on the Cumulative Environmental Effects of Oil and Gas Activities on Alaska's North Slope 2003, Matkin et al. 2008).

As top predators, marine mammals have a risk of being affected through accumulated toxic substances in the food chain. Walrus is especially sensitive because they feed on bivalves buried in the seabed in shallow waters where toxic concentrations of oil can reach the seafloor. Species feeding on benthic organisms such as polychaetes, bivalves and sea cucumbers (e.g. bearded seals) are particularly vulnerable.

Scarce and thus vulnerable species of marine mammals in the assessment area include the harbour seal, which is red-listed as Critically endangered in Greenland. The largest known population occurs in the Cape Farewell area. The very rare globally endangered northern right whale has recently been observed east of Cape Farewell and may also occur in the area.

Assessing oil-related mortality of marine mammals is difficult because carcasses are rarely found in conditions suitable for necropsies. Nevertheless, increased mortality of killer whales, sea otters and harbour seals exposed to the *Exxon Valdez* event in Prince William Sound has been well documented (e.g., Spraker et al. 1994, Matkin et al. 2008). In the Gulf of Mexico, the rate of stranded cetaceans increased after the *Deepwater Horizon* event in 2010, from a 2003-2007 mean observed rate of 17 strandings per year to 101 in 2010. Both numbers are expected to represent only a small fraction of the true number dying (Williams et al. 2011), and because search effort is likely to have been higher in 2010, it is difficult to assess the magnitude of the increase in mortality.

10.3.8 Long-term effects

A synthesis of 14 years of oil spill studies in Prince William Sound since the *Exxon Valdez* spill (Peterson et al. 2003) documented that delayed, chronic and indirect effects of marine oil pollution occur. Oil persisted in certain coastal habitats beyond a decade in surprisingly high amounts and in highly toxic forms. The oil was sufficiently bio-available to induce chronic biological exposure and had long-term impacts at the population level. Heavily oiled coarse sediments formed subsurface reservoirs of oil where it was protected from loss and weathering in intertidal habitats. In these habitats, e.g. harlequin ducks preying on intertidal benthic invertebrates showed clear differences between oiled and un-oiled coasts. At oiled coasts, they displayed the detoxification enzyme CYP1A nine years after the spill. Harlequin ducks at oiled coasts had lower survival, with an annual mortality rate of 22 % instead of 16 %, their body mass was smaller, and they showed a decline in population density as compared with stable numbers on un-oiled shores (Peterson et al. 2003). The oil still lingers in the environment, and both the harlequin duck and other populations of coastal birds are still assessed as ‘recovering’ (NOAA 2010).

Long-term chronic effects of oil on marine mammals can include decreased survival and lowered reproductive success (NOAA 2011b). In the first year after the 1989 *Exxon Valdez* spill, a well-studied pod of local killer whales experienced a 41% loss; there has been no recruitment to the pod since the spill (Matkin et al. 2008). The cause of the apparent sterility is unknown, but this case shows that immediate death is not the only factor that can lead to long-term loss of population viability.

Many coasts in the assessment area in West Greenland have the same morphology as the coasts of Prince William Sound, where oil was trapped. This indicates that similar long-term impacts must be expected in the assessment area if spilled oil beaches on the coasts.

Another indication of long-term effects was seen 17 months after the Prestige oil spill off northern Spain in November 2002. Increased PAH levels were found in both adult gulls and their nestlings, indicating not only exposure from the residual oil in the environment, but also that contaminants were incorporated into the food chain, because nestlings would only have been exposed to contaminated organisms through their diet (e.g. fishes and crustaceans) (Alonso-Alvarez et al. 2007, Pérez et al. 2008).

10.3.9 Mitigation of oil spills

The risk of oil spills and their potential impact can be minimised with high HSE (Health, Safety and Environment) standards, BAT (Best Available Technology), BEP (Best Environmental Practice) and a high level of oil spill response. However, the latter is difficult during winter due to harsh weather conditions and, in parts of the assessment area, ice that prevents effective oil recovery methods. Most importantly, careful planning should be used to avoid risky activities at the most sensitive locations and times.

An important tool in oil spill response planning and implementation is oil spill sensitivity mapping, which has been carried out in the assessment area (Mosbech et al. 2004a) and is expected to be updated as new information becomes available. See also the following section.

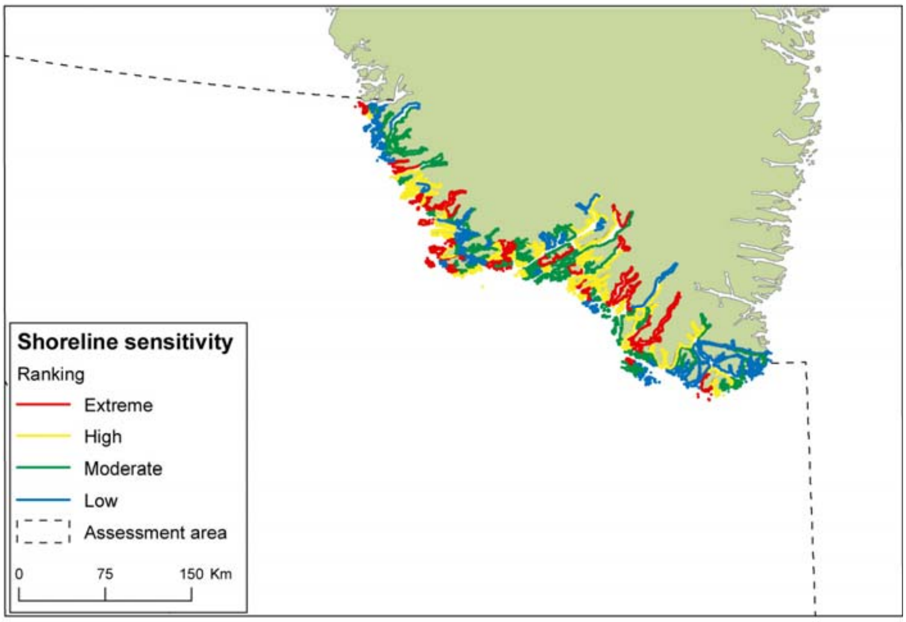
A supplementary way to mitigate the potential impact on animal populations that are sensitive to oil spills, e.g. seabirds, fish and marine mammals, is to manage populations by regulation of other population pressures (such as hunting), so that they are fitter and better able to compensate for extra mortality due to an oil spill.

10.4 Oil spill sensitivity mapping

The coastline of the assessment area has been mapped according to its sensitivity to oil spills (Mosbech et al. 2004a). This atlas integrates all available knowledge on coastal morphology, biology, resource use and archaeology; and classifies coastal segments of approx. 50 km lengths according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coast topography, logistics, and proposed oil spill countermeasures. Included are also extensive descriptions of ice conditions, climate and oceanography.

An overview of the sensitivity classification of the coastlines in this assessment area is shown in Fig. 10.2. A large proportion of the coastline is classified as highly or extremely sensitive to oil spills, especially in the central part of the assessment area. The sensitivity atlas should be updated as new information becomes available; for example, the recently discovered hotspot for harbour seals near Cape Farewell is not included.

Figure 10.2. Oil spill sensitivity of coastlines in the assessment area according to the oil spill sensitivity atlas (Mosbech et al. 2004a).



10.4.1 Seasonal summary of offshore oil spill sensitivity

In relation to this assessment, the classification of the offshore areas is particularly relevant and this has been updated with the newest available data (Fig. 10.3). The offshore areas were defined on the basis of a cluster analysis in order to obtain ecologically meaningful areas, and sensitivity was calculated separately for the four seasons. The cluster analysis included twelve variables: air temperature, air pressure, sea surface temperature (2 different measurements), temperature at 30 m depth, salinity at the surface and at 30 m depth, wind speed, ice coverage, sea depth, slope of seabed and distance to the coast (for details see Mosbech et al. 2004b).

For each season and offshore area, various symbols are shown in Fig. 10.3 for important species or species groups according to their relative abundance. For each season, the relative (to neighbouring areas) sensitivity to oil spills has been calculated for each offshore area, ranging from low to extreme sensitivity. This classification is based on the relative density of species or groups, but also species-specific sensitivity values, an oil residency index, a human use factor and a few other parameters. Note that the sensitivity ranking shown in Fig. 10.3 is relative for each season and therefore cannot be directly compared between seasons. It is also important to note that the sensitivity values are based on densities rather than total abundances, so that large offshore areas with low densities (but high total abundances) of e.g. seabirds rank lower than smaller inshore areas with higher densities.

A direct comparison of seasons for this assessment area, based on absolute sensitivity values and averaged across all offshore areas, shows that autumn is most sensitive to oil spills (index value 28), followed by summer (value 24), while winter and spring are least sensitive to oil spill (value 21). One general reason that autumn is relatively more sensitive than the other seasons is the occurrence of large numbers of non-breeding seabirds, which all are very sensitive to oil (especially auks and sea ducks).

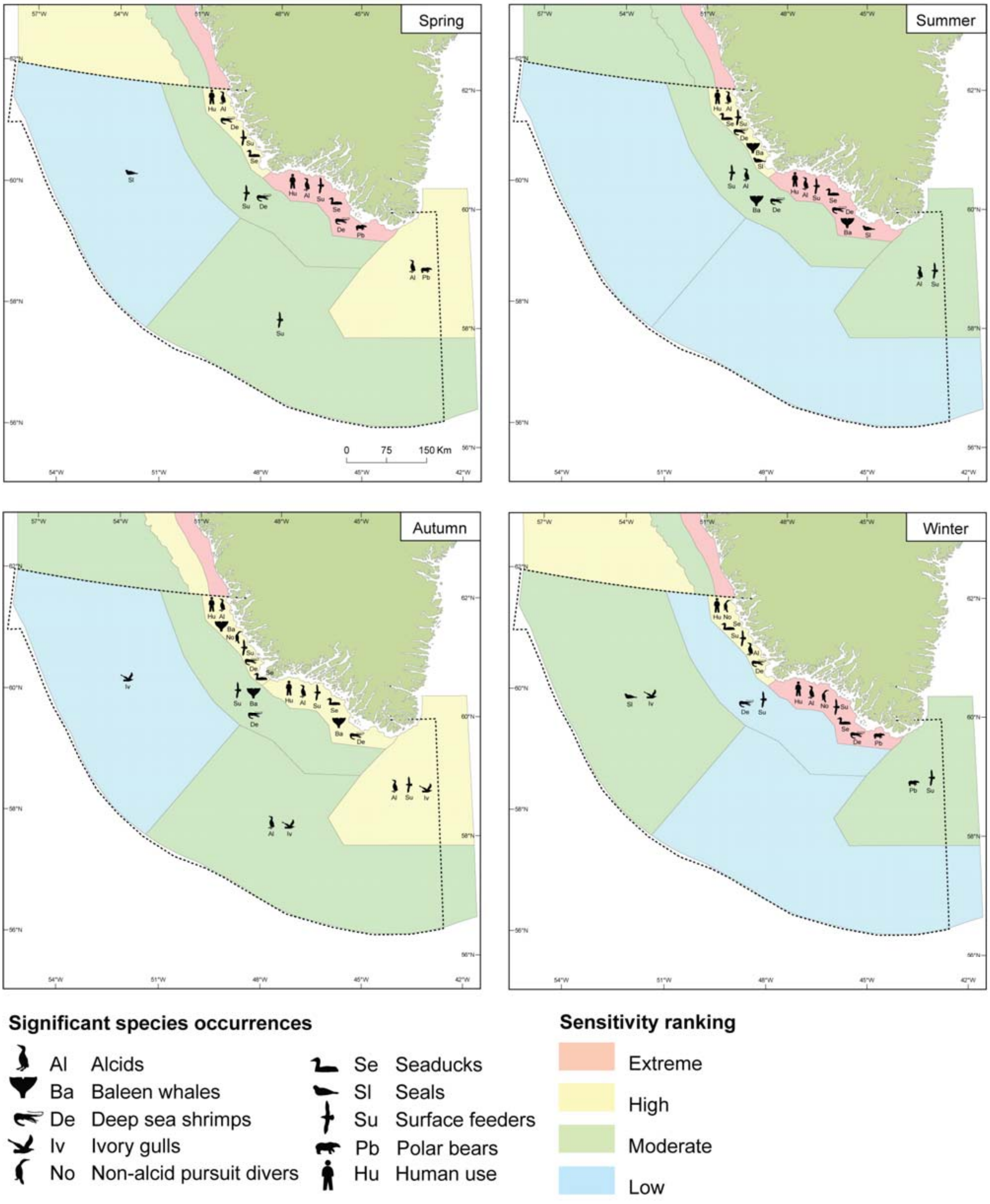


Figure 10.3. Oil spill sensitivity of offshore areas in the assessment area, based on and further developed from the oil spill sensitivity atlas (Mosbech et al. 2004a). The sensitivity scale is relative to neighbouring areas. Symbols for species or species groups relate to their relative density, while the sensitivity ranking also includes other parameters, such as species-specific oil sensitivity, oil residency and human use.

Throughout the year, the more coastal areas are scored as most sensitive, mainly due to the presence of high concentrations of breeding and non-breeding seabirds (auks and sea ducks) and the commercial shrimp fishery. During summer and particularly autumn, the sensitivity increases due to the presence in these areas of large numbers of foraging baleen whales, moulting common eiders and harlequin ducks, non-breeding surface-feeding seabirds (mainly great shearwater and black-legged kittiwake), and in autumn migrating ivory gulls.

10.5 Case study: the *Deepwater Horizon* spill

Very little information is available to support environmental impact assessments of deep-sea oil exploration and possible effects from spills under the conditions prevalent in the deep part of the assessment area (> 3000 m), i.e. difficult access, high pressure and low temperature. In the context of the present assessment, it is therefore relevant to review and assess the observations made and knowledge gained from the event in the Gulf of Mexico in 2010, when the *Deepwater Horizon* drilling rig exploded and sank, causing the release of large quantities of crude oil at a great depth. The environmental impacts of the spill are, at the time of writing, not yet fully understood or described (Graham et al. 2011, Schrope 2011), and it has not been possible to include clear conclusions in this SEIA. However, a natural resource damage assessment is available (Graham et al. 2011), and in the following the known consequences of the *Deepwater Horizon* subsea blowout and potential implications for the assessment area are described and discussed. A more detailed assessment will be included in a later version of this assessment.

10.5.1 Extent of the spill

On 20 April 2010, a catastrophic blowout caused an explosion on the *Deepwater Horizon* drilling rig that cost 11 lives and many injuries, and sent the rig to the sea floor. Oil spilled out at approximately 1500 m depth for 84 days with total estimates of more than 7.0×10^5 m^3 of oil and large amounts of gas released into the ocean (Camilli et al. 2010, Crone & Tolstoy 2010), making it the largest documented peacetime oil spill. It has been estimated that 25 % of the oil was removed by emergency operations, 25 % evaporated or dissolved, 28 % was dispersed either naturally or with the aid of chemicals, and 22 % formed slicks or tar balls and ended up on the sea bottom or washed onto shores (Schrope 2011). Gas, primarily methane, also leaked from the damaged wellhead in amounts corresponding to 6.6×10^5 - 1.2×10^6 kg gas per day (Kessler et al. 2011). As part of the mitigation strategy, large amounts of the oil dispersant Corexit 9500 was injected directly at the wellhead (2,900,000 l) as well as at the sea surface (4,059,854 l) in order to disperse the oil (Hemmer et al. 2011).

10.5.2 Subsea plumes and oil concentrations

The *Deepwater Horizon* oil spill in the Gulf of Mexico in 2010 was unusual in size, location and duration (but similar to the *Ixtoc* blowout in 1979, also in the Gulf of Mexico), and revealed new and previously undescribed ways spilled oil could be distributed in the environment, although this probably also happened during the *Ixtoc* spill (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site at the sea floor at 1500 m depth. Dispersants were applied at the wellhead, and large subsea plumes of dispersed oil were formed at depths between 800 and 1200 m, moving long distances with prevailing currents (Diercks et al. 2010a, Thibodeaux et al. 2011). Oil also settled on the ocean floor far from the spill site (Schrope 2011). The oil dispersed at the wellhead and had a very slow buoyant migration towards the surface, which allowed volatile hydrocarbons to be dissolved in the water column. Addition of dispersants at the wellhead may have contributed to the formation of large plumes of dispersed oil, although it is likely that subsea plumes would have formed even in the absence of dispersants (Graham et al. 2011). The physico-chemical processes governing the behaviour and fate of hydrocarbons in water under high pressure and at low temperature (~5° C) are poorly understood (Thibodeaux et al. 2011), but include the interplay of gas and oil fractions, the solubility of various components, and potential formation of gas hydrates (Camilli et al. 2010, Hazen et al. 2010).

Two months after the spill, evidence of oil was observed in concentration gradients away from the wellhead site following isopycnal (density) surfaces (Camilli et al. 2010, Diercks et al. 2010b, Reddy et al. 2011). The reported plumes moved in consistence with current patterns in the region and consisted of a major plume reaching over 35 km in length between 1000 and 1200 m depth, with total PAH concentrations ranging from 29.4 µg/l to 189 µg/l (Diercks et al. 2010b), as well as a more diffuse plume between 50 and 500 m depth with a lower total PAH concentration range than the deeper plume (Camilli et al. 2010). Within 3 km of the wellhead, total PAH levels were above 150 µg/l, and subsurface plume samples consisted predominantly of smaller petroleum compounds such as methylnaphthalenes and other two-ringed PAHs, compared to surface samples (Diercks et al. 2010b, Reddy et al. 2011). For reference, concentrations of 161 µg/l methylnaphthalene have been reported to induce mortality and sublethal effects in copepods (Calbet et al. 2007). Any effect assessments of complex oil spills must consider that mixtures of PAHs have been reported to display additive effects (Barata et al. 2005).

Studies of deep-water blowout events have predicted that a substantial fraction of the released oil and gas would become suspended in pelagic plumes, and this may take place even in the absence of added dispersant agents (Johansen et al. 2001). The fate of oil in deep water is likely to be very different from that of surface oil, because processes such as evaporative loss and photooxidation do not take place (Joye & MacDonald 2010). Microbial oxidation and perhaps sedimentation on the seabed are the primary fates expected of the oil suspended in deep waters (Joye & MacDonald 2010). In the Gulf of Mexico, natural oil seeps contribute to the marine environment with estimated 140,000 t oil annually (Kvenvolden & Cooper 2003), so there should be an intrinsic potential for microbial degradation, in that the responsible organisms are present (Hazen et al. 2010). This was confirmed by observed bio-degradation rates faster than expected in the deep plumes at 5° C. However, microbial degradation of oil may have derived effects such as oxygen depletion, which in deep water may persist for long periods, because oxygen is not replenished *in situ* by photosynthesis as in surface waters (Joye & MacDonald 2010).

10.5.3 Dispersants

The use of dispersants is a trade-off between avoiding on one hand severe direct effects of oil on coastal environments, and on the other hand causing possible toxic effects of dispersants themselves as well as effects of dispersed oil in the water column and benthic systems.

Unique to the *Deepwater Horizon* event, large amounts of dispersants were applied directly at the spill site at 1500 m depth in order to mitigate the effects of the outflowing oil. Almost 8,000 m^3 of dispersants were applied altogether at the spill site during the spill (Kujawinski et al. 2011). Of these, close to 3,000 m^3 were injected directly at the wellhead. Use of dispersants under deep-sea conditions has not been done before the *Deepwater Horizon* event. Surfactants, which were key ingredients in the applied dispersant, were found to follow the subsea oil plumes and did not reach the sea surface, but underwent slow degradation. Concentrations of the dispersant (Corexit) reached 10-100 µg/l between 1 and 10 km from the injection site (Kujawinski et al. 2011). The observed dispersant concentrations and dispersant-to-oil ratios were lower than those tested in published assays showing no effects (Judson et al. 2010). Acute effects from the used dispersant (Corexit 9500A) have also been assessed alone and in mixtures with oil from the Gulf of Mexico under laboratory conditions (Hemmer et al. 2011). Lethal concentration values, where mortality reached 50 % (LC_{50}) in static tests after 48 and 96 hour exposure, indicated that Corexit 9500A had generally similar toxicity to other available dispersants when tested alone, but was less toxic when mixed with crude oil (Hemmer et al. 2011). Test organisms were two aquatic species, a mysid shrimp (*Americamysis bahia*), and a small estuarine fish local to the Gulf of Mexico, the inland silverside (*Menidia beryllina*).

Temperatures found at 1500 m depth in the Gulf of Mexico are low (approx. 5° C) and thus similar to those in deep-water areas off South Greenland. Nevertheless, the test organisms used are typical for the Gulf of Mexico, and the test results are thus not directly applicable to Arctic conditions.

10.5.4 Biodegradation

The total impact on the marine ecosystem from such a massive exposure to oil compounds is highly dependent on the dilution and persistence of the oil in the water, and the duration of the exposure. Apart from processes like weathering and chemical degradation, oil persistence can be affected by biodegradation. In contrast to oil from surface spills, oil from deep-sea spills is not subject to evaporation, which removes hydrocarbon from the oil fraction. At depth, oil hydrocarbons are released to the water through aqueous dissolution, and are subject to chemical and microbial degradation. During the *Deepwater Horizon* spill, massive amounts of methane were released together with the oil, and decreased oxygen concentrations were found associated with the methane (Kessler et al. 2011). The authors claimed a link between the reduced oxygen levels and biodegradation by marine microorganisms, mainly methanotrophic bacteria. This has been disputed due to uncertainties in hydrocarbon inputs and lack of a direct link between decreased oxygen levels and methane consumption (Joye et al. 2011). Other observations support biodegradation of the oil, both at the surface and in subsurface plumes (Hazen et al. 2010, Edwards et al. 2011). The natural yearly seepage of oil from the sea floor in the Gulf of Mexico has been estimated to 140,000 t, about 1/4 of the spill volume (Jernelöv 2010).

The microbial community possessed the potential to respire hydrocarbons at a higher rate than expected for the oligotrophic Gulf of Mexico (Kessler et al. 2011), with estimated oil half-lives of 1.2 to 6.1 days (Hazen et al. 2010), due to faster than expected hydrocarbon biodegradation rates at 5° C. The magnitude and importance of oil biodegradation is not clear, although it is hypothesised that the estimated respiration rates were potentially high enough to keep pace with the flux of oil reaching the surface from the well. Whether or not such biodegradation rates are relevant during a deep-sea spill in the assessment area is uncertain. Natural seeps of hydrocarbons from sediments are known along the coast of West Greenland (Bojesen-Koefoed et al. 2007), which enhances the possibility of existing communities of hydrocarbon-degrading bacteria. Presently we do not know if such natural seeps also occur in South Greenland, and the presence of such microbial communities and their ability to perform degradation at relevant rates remains to be studied.

10.5.5 Effects on plankton

Carbon isotopic studies indicated that carbon atoms from the oil in the subsurface plumes were transferred into the planktonic food web (Graham et al. 2010). It has been hypothesised that labile fractions of the oil extended throughout the shallow water column during northward slick transport and that this carbon was processed relatively quickly by prokaryotic organisms. In addition to benefitting from the energy input from oil carbon in the form of increased production, plankton may have been exposed to toxic concentrations of oil components. However, the magnitude and potential effects of such an exposure to the subsurface plumes have not yet been documented.

10.5.6 Fish and fisheries

Little is known on the possible biological impacts of the *Deepwater Horizon* spill on fish stocks in the Gulf of Mexico. Initially, there were some concerns regarding a massive impact on fish stocks, as the spill coincided with the spawning season of many fish species. One report presents evidence to the contrary. A study of juvenile fish in shallow sea grass habitats along the coast north of the spill site showed higher catches than a 5-year normal (Fodrie & Heck 2011). The authors conclude that no immediate losses of cohorts or shifts in species composition were found after the oil spill. They attribute the results to a lack of exposure, since large amounts of the spilled oil were retained in deep waters.

During the spill event, fisheries of several economically important stocks of fish and shellfish were closed in an effort to protect seafood safety and ensure consumer confidence (McCrea-Strub et al. 2011). In terms of potential economic losses, it has been estimated that more than 20% of the average annual U.S. commercial catch in the Gulf of Mexico was affected by the closures, indicating a potential minimum loss in annual landed value of US$ 247 million (McCrea-Strub et al. 2011).

10.5.7 Effects on mammals, birds and turtles

An assessment of mortalities of seabirds, sea turtles and marine mammals based on data on collected carcasses along the US coast in the Gulf of Mexico showed increased mortalities after the oil spill, with seabirds as the most affected group (Antonio et al. 2011). However, the data are somewhat uncertain as data on population sizes and mortality rates before the spill were limited. Regarding mammals, the observed increase in mortality based on number of carcasses found during and after the spill could not entirely be attributed to the spill (Antonio et al. 2011). On the other hand, another study pointed out that estimation of effects on mammals using carcass recoveries risks serious underestimations (Williams et al. 2011). Based on data on abundance, survival, and stranding records from 14 cetacean species in the Gulf of Mexico, it was suggested that counts of carcasses represent perhaps only 2 % of the true mortality (Williams et al. 2011). Therefore, the magnitude of effects of the *Deepwater Horizon* spill on marine mammals is still unknown.

10.5.8 Summary

The oil spill in connection with the accident on the *Deepwater Horizon* rig was one of the first and largest oil spill events recorded in a deep-sea environment. It presented several unique problems, especially for the mitigation efforts. Some issues were specific for the event (cause and chronology) and may not be of relevance in other spill events. Other conditions may have a more general character. For instance, the difficulty in reaching the point of the outflowing oil and gas because of its great depth led to restrictions and delays of the mitigation effort, and this can be assumed also to be the case for a deep-sea oil spill in the Arctic. The spilled oil was distributed differently compared to other large spills (e.g. *Exxon Valdez*), as large quantities were found in subsurface plumes, which followed local current systems in boundary layers. Smaller amounts than expected of the spilled oil reached the sea surface and eventually sensitive ecosystems along the coastlines of the Gulf of Mexico. Observations were made of an unusual segregation of petroleum hydrocarbons, where larger sized, less soluble compounds ascended towards the surface, leaving smaller compounds to dominate the subsurface plumes. That kind of distribution could be expected as well in Arctic deep-sea spills. The possible consequences of this segregation remain uncertain, but it probably would have a role to play regarding exposure history of the ecosystems, in the sense that benthic and pelagic communities would be exposed to different oil compounds. During the event, unprecedented large amounts of dispersants were applied directly at the great depth of the spill, with the aim of dispersing the oil. The mixture of oil and dispersants may in combination have represented a serious threat to pelagic and benthic organisms, but laboratory studies have not indicated any serious potential effects yet. No negative effects have yet been documented on fish or plankton communities.

One particularly problematic issue in terms of assessing the risks and impacts of deep-sea oil spills is that the physico-chemical processes governing the fate of the oil are poorly understood (Thibodeaux et al. 2011), which makes robust model predictions very difficult. It is thus difficult to assess (under the conditions prevailing off South Greenland) e.g. whether part of the oil would be likely to remain in subsea plumes rather than rising to the surface, and how this process might be affected by the addition of dispersants directly at the wellhead. Further empirical and theoretical studies are required to obtain the general understanding required for such predictions; Thibodeaux et al. (2011) outline the steps needed.

In general, very little is still known of the biological effects and consequences from the spill more than one year after the spill. Decreases in oxygen concentrations were observed in connection with the subsurface plumes and contributed to increased biodegradation of hydrocarbons by naturally occurring microbial communities. Increased mortalities of seabirds and mammals have been reported, but no direct link to the oil spill has been documented.

11 Preliminary identification of information needs and knowledge gaps for environmental management and regulation of oil activities in South Greenland

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11.1 Knowledge gaps

Several knowledge gaps need to be filled in order to a) assess, plan and regulate activities so the risk of environmental impacts in the assessment area are minimized, b) identify the most sensitive areas, and c) provide a baseline for 'before and after' studies in case of impacts from large accidents. Furthermore, climate change is acting rapidly in the Arctic, altering the ecological conditions and requiring long-term studies and monitoring to understand ecosystem dynamics and effects of human activities. Long time series are invaluable, and a coordinated long-term monitoring programme should be considered. Such a programme could take advantage of existing monitoring of harvested species and of international standards being developed by the Circumpolar Biodiversity Monitoring Programme under the Arctic Council's Commission for the Conservation of Arctic Flora and Fauna (CAFF).

Below is an annotated list of the main information needs and knowledge gaps identified in relation to hydrocarbon activities in the South Greenland assessment area. This list is not exhaustive and new gaps may appear, for example when the implications of climate change become more apparent.

Some knowledge gaps are specific for the assessment area, while others are generic to oil activities in the Arctic, cf. the Arctic Council's Oil and Gas Assessment (Skjoldal et al. 2007). The latter should be addressed by cooperative international research, where Greenland participation can secure that specific Greenland perspectives are included. The most important of these are also listed below.

11.1.1 Specific knowledge gaps for the assessment area

Identification of offshore hotspots and understanding of their ecological linkages.

Relevance: The current knowledge on the location of ecological hotspots in offshore parts of the assessment area is limited, as is our understanding of their ecological function. Such hotspots are likely to be particularly vulnerable to environmental impacts of hydrocarbon activities. As an example, it is known that many cetaceans feed along the shelf break, but what drives their distribution and whether it is predictable in time is poorly understood. Similarly, little is known about the importance of the multi-year drift ice ('Storis') for marine mammals, although this habitat may be particularly vulnerable to oil spills.

Methods: Interdisciplinary oceanographic surveys using ship and airplane platforms, including acoustic surveys of fish and zooplankton, year-round

Passive Acoustic Monitoring (PAM), and telemetry of marine mammals and seabirds.

Are diapausing copepod populations at depth in the assessment area likely to be affected by a subsea oil spill?

Relevance: Very large concentrations of *Calanus* copepods spend the winter at depths of several hundred meters in the Labrador Sea, Davis Strait and Baffin Bay, with the assessment area particularly important for *C. finmarchicus*. Copepods are extremely important ecosystem components, and it is critical to know whether this overwintering population is likely to be affected by a subsea oil spill. Therefore it is important to know *Calanus* annual distribution and abundance in the water column in the assessment area, and especially whether there are areas with particularly high concentrations. It is also important to know their sensitivity to oil exposure during the diapause.

Methods: To answer the question both zooplankton surveys and laboratory studies of ecotoxicology are needed. The oceanographic surveys mentioned above targeting ecological hotspots will give some of the data needed on distribution and abundance.

More detailed understanding of the fate and behaviour of hydrocarbons especially in deep water in the assessment area

Relevance: It is important to know the specific potential for microbial degradation of oil at various depth in the assessment area as this potential is important for planning of oil spill countermeasure strategies. The potential may depend on the local type of crude oil as well as natural seeps inoculating the area with oil degrading bacteria. Studies should also include the effect and degradation of dispersants.

Methods: State of the art characterization of microbial communities and their potential for oil degradation in the assessment area.

Biodiversity studies of deep-water macrobenthos, e.g. corals and sponges

Relevance: Very little information is available on the taxonomic diversity of large benthic organisms occurring at great depths (> 200 m) off South Greenland. In particular, the location, extent and species composition of high-diversity biogenic habitats such as sponge gardens and deep-water coral patches are very poorly known. These habitats are likely to be vulnerable to placement of physical structures as well as to oil spills.

Methods: Surveys using grab samples, dredges, side scan sonars and underwater video.

Detailed modelling studies of the likelihood of oil slicks entering complex, narrow fjord systems

Relevance: The DMI oil drift model assumes for simplicity that spilled oil remains at the outer coastline and does not enter fjord systems. However, there are important vulnerable VECs inside the fjords of South Greenland, not least the ikaite columns in Ikka Fjord. It is thus very relevant to improve our ability to predict whether and under which circumstances oil will enter these fjord systems.

Methods: Highly detailed hydrodynamic modelling of example fjord systems.

Impact of seismic exploration on the cetaceans of Southwest Greenland

Relevance: Seismic surveys are a necessary tool for geological exploration and exploitation of oil fields. However, the effects of seismic noise on cetaceans within the assessment area have not been investigated, despite the importance of the area as a migration corridor during spring and fall for baleen whales feeding off West Greenland. Furthermore, the assessment area includes important feeding grounds for sizable aggregations of marine mammals.

Methods: Passive acoustic monitoring, telemetry, visual surveys in conjunction with seismic, controlled exposure experiments.

11.1.2 Knowledge gaps generic to the Arctic

The effects of oil and different oil components on marine organisms have to some degree been studied in laboratories. However, effects in the field and especially in the Arctic are less well known and because the Arctic food web is dependent on a few key species, effects on these would be very relevant to study in order to assess and mitigate potential impacts. Assessment criteria and adequate monitoring strategies should be established.

Below are listed some important questions, which should be addressed before production activities are initiated in Greenland. Some of these should be addressed by international research cooperation. Many relate to how spills and releases behave and impact organisms under Arctic conditions.

In relation to oil spills some important questions to address include:

- Biological effects and sensitivity of PAHs and other oil components on key species (e.g. sandeel, capelin) under Arctic conditions

- Fate and rate of degradation of oil and chemicals in Arctic water and sediment. In particular, very little is known about what happens to hydrocarbons released at great depth, i.e. under very high pressure and at low temperatures. The formation and dissolution of gas hydrates under these conditions are poorly understood.

- Oil vapours and their effects on marine mammals

In relation to produced water there are similar questions:

- Fate, behaviour and toxicity of produced water in cold and ice-covered waters

- Biological effects and sensitivity of key species (e.g. sandeel, capelin) to the different components of produced water

In relation to seismic surveys:

- There is need for identifying which levels of acoustic energy are acceptable in areas important for marine organisms sensitive to low-frequency pulses.

Interaction of contaminants:

- There are knowledge gaps concerning the interactions between impacts of oil-related pollution and other contaminants such as POPs and heavy metals in relevant species in the assessment area. Integrated studies on these issues are needed.

11.2 Proposal for a new environmental study programme

Based on this SEIA for the South Greenland assessment area, DCE and GINR propose to develop a strategic environmental study programme for the area to strengthen the knowledge base for planning, mitigation and regulation of oil activities. The study programme will include an updated SEIA and Oil Spill Sensitivity Atlas.

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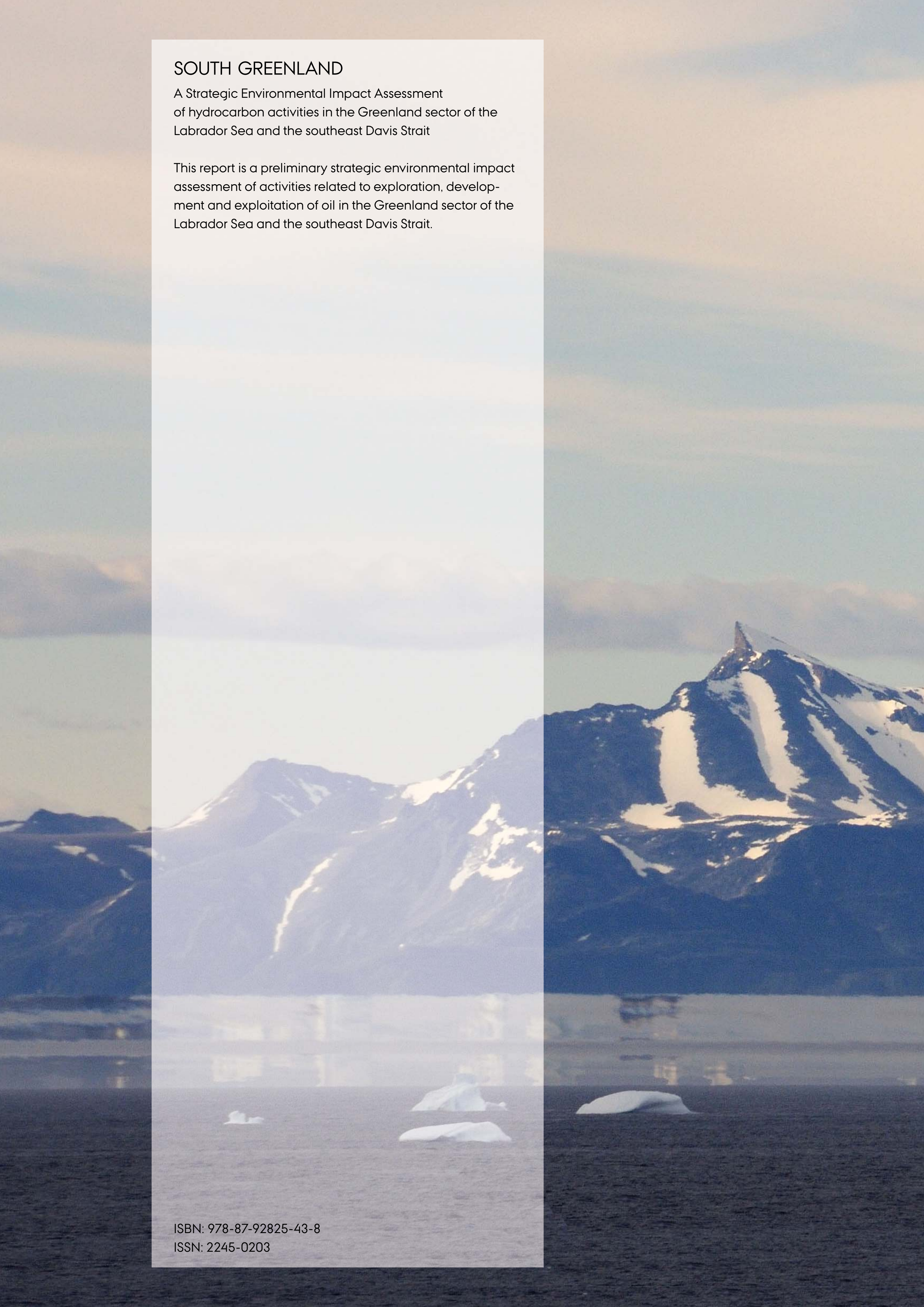

SOUTH GREENLAND

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