# THE DAVIS STRAIT

## A preliminary strategic environmental impact assessment of hydrocarbon activities in the eastern Davis Strait

Scientific Report from DCE – Danish Centre for Environment and Energy No. 15 2012

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# Data sheet

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| Series title and no.: | Scientific Report from DCE – Danish Centre for Environment and Energy No. 15 |
| Title: | The Davis Strait |
| Subtitle: | A preliminary strategic environmental impact assessment of hydrocarbon activities in the eastern Davis Strait |
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| Publisher: | Aarhus University, DCE – Danish Centre for Environment and Energy © |
| URL: | http://dmu.au.dk/en |
| Year of publication: | January 2012 |
| Editing completed: | December 2011 |
| Referees: | Kim Gustavsen and Hanne Bach, Aarhus University |
| Financial support: | Greenland Bureau of Minerals and Petroleum |
| Please cite as: | Merkel, F., Boertmann, D., Mosbech, A. & Ugarte, F (eds). 2012. The Davis Strait. A preliminary strategic environmental impact assessment of hydrocarbon activities in the eastern Davis Strait. Aarhus University, DCE – Danish Centre for Environment and Energy, 280 pp. Scientific Report from DCE – Danish Centre for Environment and Energy No. 15. http://www.dmu.dk/Pub/SR15.pdf. |
| | Reproduction permitted provided the source is explicitly acknowledged |
| Abstract: | This report is a preliminary strategic environmental impact assessment of activities related to exploration, development and exploitation of oil in the eastern Davis Strait. |
| Keywords: | Strategic environmental impact assessment, SEIA, oil exploration, oil exploitation, oil spill, Davis Strait, Southwest Greenland. |
| Layout: | Graphics Group, AU Silkeborg |
| Front page photo: | Lars Witting (arc-pic.com) |
| Greenland summary: | Bjørn Rosing |
| English proof reading: | Carey Smith |
| ISBN: | 978-87-92825-28-5 |
| ISSN (electronic): | 2245-0203 |
| Number of pages: | 280 |
| Internet version: | The report is available in electronic format (pdf) at http://www.dmu.dk/Pub/SR15.pdf |

# Contents

# Preface

The Bureau of Minerals and Petroleum (BMP) is planning for further exclusive licences for exploration and exploitation of hydrocarbons in the Greenland offshore areas of Davis Strait. To support the decision process BMP has asked DCE - Danish Centre for Environment and Energy and the Greenland Institute of Natural Resources (GINR) to prepare this preliminary Strategic Environmental Impact Assessment (SEIA) for the eastern Davis Strait between 62° and 67° N.

If more licences are granted, implementation of an environmental background study program is planned in order to fill the data gaps that have been identified and provide information required to support the environmental planning and regulation of the oil activities. The new information will be included in an updated SEIA, which will become the new reference document for the environmental work and substitute this preliminary version.

## Acknowledgement

For comments and valuable suggestions to earlier draft sections of this report, thanks to Dorte Krause-Jensen (AU), Kristine Arendt (GINR), Torkel Gissel Nielsen (DTU-Aqua), Morten Hjorth (AU) and Kaj Sünksen (GINR), and Kristin Laidre (GINR and PSC) for making data on krill and capelin abundance available.

# Summary and conclusions

This document is a preliminary Strategic Environmental Impact Assessment (SEIA) of activities related to exploration, development and exploitation of hydrocarbons in the eastern Davis Strait between 62° and 67° N.

The SEIA has been carried out by DCE - Danish Centre for Environment and Energy and the Greenland Institute of Natural Resources (GINR) for the Bureau of Minerals and Petroleum (BMP) to support the decision process concerning any further exclusive licences for exploration of hydrocarbons in the Greenland offshore areas of the Davis Strait. Based on existing published and unpublished sources, including three previous assessment reports that were prepared in connection with the existing licence blocks (Fig. 1.1.1), the SEIA describes the physical and biological environment including protected areas and threatened species, contaminent levels, and natural resource use. This description of the existing situation then forms the basis for assessment of the potential impacts of oil activities.

If more licences are granted in the assessment area implementation of an environmental background study programme is planned to fill the data gaps that have been identified and provide information required to support the environmental planning and regulation of the oil activities. The new information will be included in an updated SEIA, which will become the new reference document for the environmental work and substitute this preliminary version.

The assessment area is shown in Figure 1.1.1. This is the region that could potentially be impacted by a large oil spill deriving from activities within the expected licence areas; although the oil could drift beyond the borders of this area.

The expected activities in the 'full life cycle' of a petroleum field are briefly described. Because of harsh weather and extensive sea ice in the northern and western part of the assessment area, exploration activities would probably be hampered during winter and early spring (around December-April). However, if oil production is initiated activities will take place throughout the year.

## The environment

### The pelagic environment

The physical conditions of the study area are briefly described with focus on oceanography and ice conditions. The southern part of the assessment area generally has open water all year around, except for the most western part. In the north-western part sea ice is usually present from about February to April. Icebergs are occasionally present in late winter and early spring but rarely encountered north of Fyllas Banke. This is explained by the pattern of currents, the bathymetry and the distant iceberg sources.

Among the most important features of the environment are the shallow-water banks along the west coast of Greenland. High water velocity at these banks creates strong upwelling which in turn provides nutrients for sustained high primary productivity in these relatively shallow areas. The

banks are normally ice free or have open drift ice year round, except for the Store Hellefiskebanke in the northern part of the assessment area. The banks can sustain high productivity several months longer than the deep waters offshore. Another important feature of the area is the relationship between frontal hydrography and plankton communities at the transition between the waters of Arctic and temperate origin. Moreover, there are physical and chemical differences between (the shallow and freshwater influenced) in-shore and the offshore area. Therefore, physical processes in the frontal zones affect planktonic organisms in a number of ways, including nutrient entrainment, elevated primary and secondary production and plankton aggregation.

The assessment area is situated within the sub-Arctic region of the marine environment. The pelagic environment of the offshore part of the assessment area has not been studied in detail. However, based on knowledge from the shelf area and elsewhere in West Greenland, the pelagic environment is characterised by low biodiversity with often numerous and dense animal populations; a relatively simple food web from primary producers to top predators; and a few species playing a key role in the ecology of the region. The most significant ecological event in the marine environment is the spring phytoplankton bloom of planktonic algae, the primary producers in the food web. These are grazed upon by zooplankton, including the important copepods Calanus (mainly *C. finmarchicus*), which represent one of the key species groups in the marine ecosystem.

### Benthic fauna and flora

Benthic macrofauna species consume a significant proportion of the available production and, in turn, are an important food source for fish, seabirds and mammals. Some studies are available from the assessment area, but little is known about the spatial and temporal variation in community structure and there is a general lack of data from certain habitat types and from offshore areas. The macroalgae are found along shorelines attached to hard and stable substrate, and may occur at a depth of more than 50m. Biomass and production of littoral and sub-littoral macroalgae can be significant and are important for higher trophic levels of the food web as they provide substrate for sessile animals, shelter from predation, protection against wave action as well as currents and desiccation or are utilised directly as a food source. Existing knowledge of macroalgal diversity in the assessment area is very limited, and macroalgal species composition, biomass, production and spatial variation are largely unknown.

### Fish

Fish fauna in the offshore areas, including the marine shelf, is dominated by demersal (bottom living) species such as Greenland halibut, Atlantic halibut, redfish, wolffish and several less commercially interesting species. For the Greenland halibut, which is highly important for the commercial fishery (see below), the main spawning ground is presumed to be located within the assessment area and is important for stock recruitment both within and outside the assessment area (Northwest Greenland and Canada). Sandeel occur in dense schools on the banks and are important prey for some species of fish, seabirds and baleen whales. In the coastal zone, three important species spawn: Atlantic cod, capelin and lumpsucker. The capelin is important prey for larger fish, marine mammals, seabirds and for human use. Both the Atlantic cod and lumpsucker (the eggs) are utilised on a commercial basis. Arctic char is also an important species of the coastal waters and is the target of much recreational fishing. Other species utilised in small-scale commercial or subsistence fisheries include Atlantic salmon, Atlantic halibut and wolffish.

### Seabirds

Seabird colonies are numerous in the assessment area, but typically smaller in size compared with more northern breeding areas in West Greenland. In total, 20 species are known as regular breeders in the assessment area and the highest density of colonies is found in the extensive archipelago between 63° and 66°, despite the fact that this area has not been thoroughly surveyed for breeding birds. Two species are rare breeders to Greenland – the Atlantic puffin and the common murre are listed as near-threatened and endangered, respectively, on the Greenland Red list.

For 13 bird species the importance of the assessment area is classified as 'high' on a national or international scale due to the number of breeding, moulting or wintering birds (Tab. 4.7.1). The assessment area is especially important as a wintering area. It makes up a large proportion of the open water region in Southwest Greenland, where large numbers of seabirds from Russia, Iceland, Svalbard and Canada assemble October-May. More than 3.5 million birds are estimated to winter in the coastal areas alone. The most abundant species are thick-billed murre, common eider, king eider and little auks. A large, but unknown number of seabirds also migrate through or winter in the offshore areas.

### Marine mammals

Marine mammals are significant components of the marine ecosystem. Five species of seal occur in the assessment area, of which harp seals are numerous throughout the area during most of the year. Another species, the harbour seal, is listed as critically endangered in Greenland. The northernmost part of the assessment area overlaps with the southern edge of a key wintering habitat for walruses. Among the whales, several baleen whales, such as minke whales, fin whales, humpback whales and sei whales, are seasonal inhabitants of the assessment area and relatively abundant. The area is part of their foraging area during summer and the distribution of the whales often correlates with their main prey: capelin, krill and sandeel. The bowhead whale migrates through the area in the period January-February towards feeding and possibly mating grounds just north of the assessment area. Several toothed whales are common in the assessment area: harbour porpoise, long-finned pilot whale, northern bottlenose whale and white-beaked dolphin. The southern wintering grounds of beluga whales and narwhals extend into the northern part of the assessment area. Polar bears occur during winter and spring, depending on and in association with the very variable sea ice cover.

### Human use

Human use of natural resources occurs throughout the assessment area; subsistence and small-scale use is extensive in the coastal areas, while there are substantial commercial fisheries in the offshore parts. Due to open water being present all year round in most coastal areas, commercial, subsistence and recreational hunting is possible throughout the year, except in various closed seasons. Seabirds are among the most popular hunted resources and are bagged in large numbers. The most important species are thick-billed murre and common eider, and in 2008 approx. 35,000 murres and 11,000 eiders were reported harvested in the assessment area. Seals are also harvested in large numbers in the assessment area. The skins are purchased and prepared for the international market by a tannery in South Greenland and the meat is consumed locally. The most important species is the harp seal and around 30,000 animals per year are currently reported to be harvested from the assessment area. Walruses, belugas and narwhals are caught during winter and spring in the northern part of the assessment area and regulated by quotas. Also harbour porpoises, minke whales, fin whales and humpback whales are caught in the assessment area, with harbour porpoise and minke whale as far the most numerous species. Minkes and humpback and fin whales are subject to annual quotas set by the IWC. Quotas also regulate polar bear catches, but only a few animals are shot every year in the assessment area.

Commercial fisheries represent the most important export industry in Greenland, accounting for 88% of the total Greenlandic export revenue (1.7 billion DKK in 2009). Greenland halibut, deep-sea shrimp and snow crab are the main commercially exploited species within the assessment area and annual catches make up a large proportion of total landings in Greenland. The Atlantic cod fishery has increased over the past decade, but recruitment appears to be very unstable. Compared with historical levels (1960s) catches are still negligible and in 2009-10 the offshore fishery was closed in the assessment area. In the coastal area, various species are exploited on a small-scale commercial, subsistence or recreational basis, such as lumpsucker, wolffish, redfish, Atlantic cod, Greenland cod, capelin and Atlantic salmon.

Tourism is a growing industry in Greenland and now counts as the third largest economic activity in the country. The total number of guests in 2008 was 82,000 or 250,000 ‘bed nights’, of which the majority went to the assessment area, especially Nuuk. In addition, cruise ships bring in tourists in every increasing numbers. The coastal marine area is very important for tourist activity.

#### Climate change

Climate change has a large potential to modify marine ecosystems, particularly 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 to occur. For some populations, climate change may act as an additional stressor in relation to existing impacting factors such as hunting, leading to higher sensitivity to oil spill incidents. Other populations may become more abundant and robust as a consequence of climate change. Finally, species composition may change, with some species disappearing or moving north and other species moving in from the south.

#### Contaminants

Knowledge on background levels of contaminants such as hydrocarbons and heavy metals is also important in assessing sensitivity and environmental impacts from petroleum activities.

The levels of certain contaminants, i.e. organochlorines, are still high in Greenland due to long-range transport into the Arctic, particular in the higher trophic level (e.g. whales, polar bears).  In addition, new persistent pollutants, such as brominated flame retardants, are now appearing. Levels of petroleum compounds, including PAHs, are relatively low, except in harbour areas, and are regarded as background concentrations.

However, our present knowledge concerning contaminants in marine organisms in Greenland, including the assessment area, is still limited, particular the relation between contaminant loads and potential biological impact, including sublethal health effects or impairments. More knowledge about species' sensitivity and adequate monitoring strategies are also needed.

## Assessment

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 and production. However, the Arctic is changing due to climate change and this process seems to be accelerating. This means that conclusions and assessments may need to be adjusted in the future. Furthermore, a large part of the assessment area is poorly studied and increased knowledge may lead to additional adjustments.

## Normal operations – exploration

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

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 would also impact the availability of whales to hunters if the habitats include traditionally hunting grounds. Narwhals, beluga whales, bowhead whales and walruses are also sensitive to seismic noise, but their occurrence in the assessment area only overlaps briefly with the time in which seismic surveys are expected to take place.

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

The fishery at risk of impact from noise from seismic surveys in the assessment area is the Greenland halibut fishery. The risk is temporary (days or weeks) displacement of fish and consequently reduced catches from the trawling grounds. Although the precise location of the Greenland halibut spawning grounds is not known, planning of seismic surveys in the area where spawning is expected to take place should consider avoiding overlap with the spawning period (early winter). The fishery for northern shrimp and snow crab will probably not be affected.

Noise from drilling rigs will also be temporary but locally more permanent than seismic surveys. The most vulnerable species in the assessment area are cetaceans (whales and harbour porpoises) and the walruses. 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 of cumulative effects and displacement even from alternative habitats.

Drilling mud and cuttings that are released to 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 the water-based muds with non-toxic additives from the drilling of an exploration well. Any drilling should be avoided in the most vulnerable areas. Baseline studies at drill sites must be conducted prior to drilling to document whether unique communities or species such as coldwater coral and sponge gardens are at risk of being harmed by increased sedimentation. Post-drilling studies should be carried out to document whether activities caused any specific effects.

Exploration drilling is an energy-intensive process emitting large amounts of greenhouse gases. Even a single drilling will increase the Greenland contribution to global emissions significantly.

Finally, there is a risk of 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

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

Overall, impacts will depend on the number of activities, how far they are dispersed in the areas in question, and also on their duration. In this context it is important to consider cumulative impacts.

### Emissions and discharges

Drilling will continue during 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 environmental safe substances (such as the 'green' and 'yellow' substances classified by OSPAR) tested for toxicity and degradability under arctic conditions should be permitted to be discharged. In Greenland the use of 'black' chemicals is not permitted and use of 'red' chemicals requires specific permission. Even the non-toxic discharges 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.

The release giving most reason for environmental concern, however, is residue of oil in produced water. Recent studies have indicated that small amounts of oil can impact birds, fish and primary production. The most obvious way to mitigate effects of produced water is better cleaning before discharge or even better to re-inject the water into the wells as the policy is in the Lofoten-Barents Sea area.

Also of concern is discharge of ballast water as this carries the risk of introducing non-native and invasive species. Ballast water must therefore be handled and discharged subject to specific rules. The problem is currently not severe in the Arctic, but 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 that would contribute significantly to the Greenland emission of greenhouse gases. A single large Norwegian production field for example, emits more than twice the total Greenland $CO_2$ emission of today.

### Noise

Noise from drilling and the positioning of machinery, which will continue during the development and production phase, 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 (incl. ice-breaking) and helicopters, which becomes more persistent than in the exploratory phase, can both affect marine mammals and seabirds. The most sensitive species within the assessment area are the colonial seabirds, bowhead whales, narwhals, beluga whales, minke whales, fin whales, harbour porpoises and walruses – species that may associate noise with negative events (hunting). Traditional hunting grounds may also be affected. Applying 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 – walrus is highly sensitive, but occurs mainly north of the assessment area. However, feeding areas for king eiders wintering at the shallow-water shelf banks (especially Fyllas Banke) may also be at risk. Inland structures may locally impact breeding birds; obstruct rivers, with implications for anadromous Arctic char; damage coastal flora and fauna; and have an aesthetic impact on the pristine landscape, which in turn may impact the local tourism industry.

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

Illuminated structures and flares may attract seabirds in the hours of darkness, and there is a risk of mass mortality especially for eiders and possibly little auks.

### Cumulative impacts

There will be a risk of cumulative impacts when several activities take place either simultaneously or consecutive. For example, seismic surveys have a high potential for cumulative impacts. Cumulative impacts may also occur in combination with other human activities, such as hunting, or in combination with climate change.

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. Subsequent application of BEP, BAT and compliance with international standards such as OSPAR and HOCNF can do much to reduce emissions to air and sea.

## Accidents

The most environmentally severe accident from the activities described above would be 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.

Oil spill trajectory modelling was not carried out for this preliminary assessment.

Large oil spills have the potential to impact on all levels in the marine ecosystem, from primary production to the 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 for Prince William Sound in Alaska. For some populations oil spill mortality can to an extent be compensatory (be partly compensated by reduced natural mortality due to less competition), while for others it will largely be additive to natural mortality. Some populations may recover quickly while others will recover to pre-spill conditions very slowly, depending on their life strategies 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 remoteness will add to the severity of an oil spill.

For this impact assessment the offshore areas are divided into eight subareas and classified according to their sensitivity to oil spill, taking into account the relative abundance of species/species groups; species or population specific oil sensitivity values; oil residency; human use ; and a few other parameters. During all seasons the offshore areas closest to the coastal zone covering the shelf bank areas are among the most sensitive areas. These areas are especially important for migrating/wintering seabirds, human use of northern shrimp and snow crab, and as foraging areas for baleen whales. During spring and winter the southwest corner of the assessment area is also classified as highly sensitive to oil spill due to extensive Greenland halibut fishery and whelping areas for hooded seals in the western pack ice in March and April.

A comparison of seasons, based on absolute sensitivity values and averaged across all offshore areas, shows that winter is most sensitive to oil spill, closely followed by spring and autumn, while summer is least sensitive to oil spill. The main reason for this difference is the large number of wintering/migrating seabirds during winter, spring and autumn, which are all very sensitive to oil (especially auks and seaducks).

The coastal zone of the assessment area is even more sensitive to oil spill due to a higher biodiversity and due to the fact that oil may be trapped in bays and fjords where high and toxic concentrations can build up in the water. There is the potential for a number 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 in summer, during migration periods and especially in winter when seabirds from a variety of breeding locations in the North Atlantic gather in Southwest Greenland. Long-term impacts may occur in the coastal zone if oil is buried in sediments or among boulders, in mussel beds or is imbedded in crevices in rocks. Oil seeps from these sites and causes chronic pollution which may persist for decades. In Prince William Sound in Alaska such preserved oil has caused negative long-term effects on e.g. birds utilising the polluted coasts and several populations have not recovered. The coastal zone is also of crucial importance for local hunters and fishermen, and in the case of an oil spil, these activities may be adversely affected by closure zones and/or by changed distribution patterns of the targeted species. The tourist industry in the assessment area will probably also be impacted negatively by oil exposure in the coastal area.

Another vulnerable feature is the winter/spring period with ice- covered waters in the northern and western part of the assessment area. To begin with spilled oil would be contained between the ice floes and on the rough underside of the ice. However, oil in ice may be transported in an almost unweathered state over long distances and when the ice melts may impact the environment, e.g. seabirds and marine mammals, far from the spill site. Oil may also be caught along ice edges and in marginal ice zones with sensitive aggregations such as primary producers, seabirds and marine mammals.

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). However, knowledge of the behaviour of spilled oil in ice environments is very limited and the technology for cleaning up oil spills in ice-covered waters is inadequate and in need of further development.

#### Primary production and zooplankton

It is assessed that the impact of a surface oil spill in the assessment area on primary production and zooplankton in open waters will be low due to the large temporal and spatial variation in these events and occurrences. There is, however, a risk of impacts (reduced production) in localised primary production areas and the spring bloom will be the most sensitive period.

Experience learned from the Deepwater Horizon oil spill in the Mexican Gulf in 2010, where huge subsea plumes of dispersed oil were found at different depths, may change the conclusion of relatively mild impacts for extremely large subsea spills to more acute and severe impacts. It is too early to draw conclusions on the effects of a subsea spill like the spill from the Deepwater Horizon as there is still very little scientific information available on effects from this incident. But if large subsea plumes of dispersed oil in toxic concentrations occur, stronger impacts than from a surface spill must be expected, especially on primary producers, zooplankton and fish/shrimp larvae.

#### Fish and crustacean larvae

In general, eggs and larvae of fish and crustacean are more sensitive to oil than adults and may theoretically be impacted by reduced annual recruitment with some effect on subsequent populations and fisheries for a number of years. Atlantic cod is especially sensitive as their eggs and larvae can be concentrated in the upper 10m 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, an extremely 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 shrimp, Greenland halibut, 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 (< 10-15m), highly toxic concentrations of hydrocarbons can reach the seafloor with possible severe consequences for local benthos and thereby also for species utilising the benthos – especially common eider, king eider, long-tailed duck, bearded seal and walrus. A subsea spill with the size and properties of the spill from the Deepwater Horizon in the Mexican Gulf has the potential to impact the seabed communities in deep waters too.

### Adult fish

Impacts from a surface spill on adult fish stocks in the open sea are not expected. The situation is different however in coastal areas, where high and toxic oil concentrations can build up in sheltered bays and fjords resulting in high fish mortality (see above). Once more, a large subsea blowout could represent an exception as far as low impact is concerned. Considerable plumes of dispersed oil can occur in the water column from a subsea blowout and may impact the fish both directly or through the food chain. Greenland halibut would be exposed in both ways, because they move up from the seabed to the pelagic waters to feed.

### Fisheries

An oil spill in the open sea will affect fisheries mainly by means of temporary closure in order to avoid contaminated catch. Closure time would depend on the duration of the oil spill, weather, etc. The offshore fishery for Greenland halibut within the assessment area is large and a closure zone would probably extend further west and cover Canadian fishing grounds too. The reason is that Greenland halibut moves considerable distances over a very short time and contaminated (tainted) fish may move out of the assessment area and be caught far from a spill site.

The assessment area is also among the most important fishing grounds in Greenland for northern shrimp and snow crab, and closure zones may also 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 closure for 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 form part of the subsistence and recreational fishery.

### Seabirds

Seabirds are extremely vulnerable to oil spills in the marine environment as they usually spend much time at the surface where most oil spills occur. Their plumage is highly sensitive to oil, as only small amounts can 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 as high concentrations of seabirds are found all year around. A substantial number of these birds, including breeding birds, moulting birds as well as wintering birds, are associated with habitats along the highly exposed outer coastline. In these areas, oil spill response is hampered by remoteness, the complex coastal morphology and the often harsh weather conditions. The seabird species most vulnerable to oil spills are those with low reproductive capacity (low population turnover), a trait especially found among auks, fulmars and many seaducks. These species, e.g. thick-billed murres, little auks, eiders and long-tailed ducks, winter in the assessment area in large numbers as Southwest Greenland constitutes an international wintering area for seabirds from a range of breeding locations in the North Atlantic.

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, puffin, little auk, thick-billed murre, black guillemot and king eider. Especially the king eider is vulnerable in the offshore area as the birds assemble in large dense flocks on the shallow-water shelf banks during winter (Fyllas Banke and Store Hellefiskebanke). A major oil spill in these areas could seriously affect this population.

#### Marine mammals

Polar bears and seal pups are highly vulnerable to direct oiling and even short exposures can be lethal, as the oil affects the insulation properties of the fur. There are seal pup areas in the assessment area (see below), while polar bears are associated with the Davis Strait pack ice, of which the extent lying within the assessment area varies.

Whales, seals and walruses are vulnerable to surface oil spills. The baleens of the baleen whales may become smothered with oil. This may affect their filtration capability or lead to toxic effects and injuries in the gastrointestinal tract if oil is ingested. There is also the potential for inhalation of oil vapours and direct contact of the oil with eye tissues. The extent to which marine mammals actively avoid an oil slick and also how harmful the oil would 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.

Marine mammal species affected by an oil spill during winter in the assessment area could include bearded seal, hooded seal, ringed seal, harbour seal, bowhead whale, narwhal, white whale, polar bear, harbour porpoise, walrus, bottlenose whale and sperm whale. Harbour seals are especially vulnerable as they are endangered in Greenland, and hooded seals too, because whelping patches are located in the eastern Davis Strait pack ice. Marine mammals that use the area as a feeding ground 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 whale occurs only rarely in the assessment area but is vulnerable due to its very small population.

#### Mitigation

The risk of accidents and their environmental impacts can be minimised with high safety levels; planning to avoid the most sensitive areas and periods; and efficient contingency plans with access to adequate equipment and oil spill sensitivity maps where the most sensitive areas have been identified.

## Knowledge gaps and new studies

There is a general lack of knowledge on many of the ecological components and processes in the Davis Strait area. A preliminary identification of information needs and knowledge gaps for environmental management and regulation of future oil activities in the Davis Strait can be found in chapter 12. To manage future oil activities, more information is required in order to: a) assess, plan and regulate activities to minimise the risk of impacts; b) identify the most sensitive areas and update the Oil Spill Sensitivity Mapping; c) establish a baseline to use in 'before and after' studies for impacts from any large oil spills.

# Dansk resumé

Denne rapport er en foreløbig, strategisk miljøvurdering af aktiviteter forbundet med olieefterforskning og -udvinding i den grønlandske del af Davis Strædet, nærmere bestemt farvandet mellem 62° og 67° N.

Miljøvurderingen er udarbejdet af DCE - Nationalt Center for Miljø og Energi (DCE) og Grønlands Naturinstitut for Råstofdirektoratet, med henblik på at indgå i beslutningsprocessen om at udbyde yderligere licensområder til olieefterforskning i de grønlandske offshore områder af Davis Strædet. På baggrund af eksisterende publiceret og upubliceret litteratur, inklusiv tre tidligere miljøvurderinger udarbejdet i forbindelse med de eksisterende licensblokke, beskriver denne miljøvurdering det fysiske og biologiske miljø, inklusiv beskyttede områder, truede arter, kontaminantniveauer samt udnyttelse af de biologiske resurser. Baseret på denne beskrivelse af den nuværende situation, vurderes de potentielle konsekvenser af olieaktiviteter. Tilvejebringelse af yderlig information vil gøre det muligt, at reducere usikkerheden på vurderinger af de potentielle konsekvenser.

Såfremt der tildeles flere licensblokke, er det planlagt at initiere et undersøgelsesprogram, som skal udfylde identificerede videnshuller og understøtte den miljømæssige planlægning og regulering af olieaktiviteter. Den ny viden vil blive inkluderet i en opdateret miljøvurdering, som skal være et referencedokument for miljøarbejdet og vil erstatte denne midlertidige miljøvurdering.

Vurderingsområdet er vist på figur 1.1.1. Dette område kan potentielt blive påvirket af et stort oliespild, forårsaget af aktiviteterne i de forventede licensområder. Afhængig af vind og strømforhold kan olien dog drive til områder udenfor den viste afgrænsning.

Aktiviteterne fra en komplet livscyklus for et oliefelt er kort beskrevet og så vidt muligt vurderet, med vægt på de aktiviteter og hændelser som erfaringsmæssigt giver de væsentligste miljøpåvirkninger. Men da der ikke er erfaringer med udvinding af olie i Grønland, er vurderinger af aktiviteter i denne forbindelse ikke konkrete, men bygger på erfaringer fra andre områder med så vidt muligt sammenlignelige forhold. Der er især trukket på den meget omfangsrige litteratur om det store oliespild i Prince William Sund i Alaska i 1989, den norske miljøvurdering af olieaktiviteter i Barentshavet (2003) og på Arktisk Råds "Arctic Oil and Gas Assessment". Endvidere er der inddraget viden fra det nylige store undersøiske olieudslip i den Mexicanske Golf (2010), om end erfaringerne herfra endnu er begrænsede.

På grund af barske vejrforhold og udbedt havis i de nordlige og vestlige dele af vurderingsområdet forventes olieefterforskningsaktiviteterne, at være vanskeliggjort i vinterperioden samt i det tidlige forår (ca. december – april). Men såfremt en egentlig olieproduktion påbegyndes, forventes der at pågå aktiviteter året rundt.

## Miljøet

### Det pelagiske miljø

De fysiske forhold i vurderingsområdet er kort beskrevet med fokus på oceanografi og isforhold. Den sydlige del af området er normalt isfrit året rundt, med udtagelse af de mest vestlige dele. Den nordvestlige del af vurderingsområdet er sædvanligvis isdækket fra omkring februar til april. Af og til forekommer der isbjerge i området, hyppigst senvinter og forår. Isfjelde ses dog sjældent nord for Fyllas Banke. Dette skyldes strømforhold, bathymetri og den lange afstand til produktive isbræer.

Offshore-bankerne i Sydvestgrønland hører til blandt de vigtigste karakteristika for havmiljøet i vurderingsområdet. En høj vandgennemstrømning over disse forholdsvis lavvandede områder forårsager en kraftig opstigning af næringsrigt vand, som skaber basis for en langvarig høj primærproduktion. Bankerne er sædvanligvis helt eller delvis isfrie (løst drivis) året rundt, med undtagelse af Store Hellefiskebanke i den nordlige del af vurderingsområdet. Den høje primærproduktivitet på bankerne opretholdes i op til flere måneder længere end på dybere offshore lokaliteter. En anden vigtig egenskab for området er overgangszonen, hvor arktiske og tempererede havstrømme mødes. De fysiske processer der er forbundet med frontzonerne påvirker planktonorganismerne på forskellig vis, herunder næringstilgangen og dermed niveauet for primær- og sekundærproduktion samt planktonfordelingen. Desuden adskiller havvand fra de mere kystnære områder sig fysisk og kemisk fra det mere oceaniske vand, idet det opblandes med ferskvand fra oplandet.

Vurderingsområdet er beliggende indenfor det subarktiske område. Det pelagiske miljø i offshore områderne er dårligt undersøgt, men ud fra oplysninger fra fiskebankerne samt andre områder i Grønland, er det pelagiske miljø i vurderingsområdet karakteriseret ved lav biodiversitet - men ofte talrige og tætte koncentrationer af de tilstedeværende populationer, en relativ simpel fødekæde fra primærproducenter til topprædatorer og nogle få arter der spiller en nøglerolle i det økologiske system. Den mest markante økologiske begivenhed i det marine miljø er forårsopblomstringen af fytoplankton, som udgør primærproducenterne i fødekæden. Disse græsses af zooplankton, inklusiv de vigtige Calanus vandlopper (primært *C. finmarchicus*), som udgør nøglearter i det marine økosystem.

### Bentisk fauna og flora

Den bentiske makrofauna konsumerer en betydelig del af den tilgængelige primærproduktion og udgør til gengæld vigtige fødeemner for fisk, havfugle og havpattedyr. Der findes kun få makrofauna studier fra vurderingsområdet og generelt mangler der viden om den rumlige og tidsmæssige variation i samfundsstrukturen, viden fra særlige habitattyper og fra offshore områderne. Makroalgerne findes langs kystlinjen, tilknyttet hård bund, og kan forekomme på mere end 50 m dybde. Biomassen og produktionen af litorale og sublitorale makroalger kan være betydelig og dermed vigtig for de højere trofiske niveauer i fødekæden. De kan fungere som substrat for fastsiddende organismer, yde beskyttelse mod prædation, udtørring, strøm og bølgeslag eller som direkte føde emne. I det aktuelle område er viden om makroalgernes diversitet meget begrænset og makroalgernes artssammensætning, biomasse, produktion og rumlig variation er stort set ukendt.

### Fisk
Fiskefaunaen i offshore områderne, inklusiv fiskebankerne, er domineret af bundlevende arter, så som hellefisk, helleflynder, rødfisk, havkat samt andre ikke-kommercielle arter. For hellefisk, der udgør en meget vigtig kommerciel fiskeriresurse, antages det at det primære gydeområde ligger indenfor vurderingsområdet og er væsentlig for bestands-rekrutteringen også udenfor området (Nordvestgrønland og Canada). Tobis forekommer i tætte stimer på fiskebankerne og udgør vigtigt bytte for visse fisk, havfugle og bardehvaler. I det kystnære område gyder tre vigtige arter: torsk, lodde og stenbider. Lodde er vigtig som bytte for større fisk, havfugle, havpattedyr samt for mennesker. Både torsk og stenbider (rogn) udnyttes på kommercielt basis. Fjeldørred er også en vigtig art i det kystnære område og er genstand for meget lystfiskeri. Andre arter som udnyttes i mindre skala, kommercielt eller ikke-kommercielt, er havørred, helleflynder og havkat.

### Havfugle
Havfugle kolonier er talrige i vurderingsområdet, om end de typisk er mindre i størrelse sammenlignet med nordligere kolonier i Vestgrønland. I alt er 20 arter kendt som almindelige ynglefugle fra området og den højeste tæthed af kolonier findes i skærgårdsområdet mellem 63° and 66°N, på trods af at dette område ikke er systematisk gennemsøgt for ynglefugle. To arter hører til blandt de mere sjældne ynglefugle i Grønland, nemlig lunde og atlantisk lomvie, og disse er listet som henholdsvis ”næsten truet” og ”udryddelsestruet” på den grønlandske rødliste.

For 13 arter er deres vigtighed for vurderingsområdet klassificeret som ”høj” på en national eller international skala, grundet antallet af ynglefugle, fældefugle eller overvintrende fugle (Tab. 4.7.1). Vurderingsområdet er særlig vigtigt som overvintringsområde for havfugle. Området udgør en stor andel af åbentvandsområdet i Sydvestgrønland, som huser et stort antal overvintrende havfugle fra Rusland, Island, Svalbard og Canada i perioden oktober-maj. Det er estimeret at mere end 3,5 millioner fugle overvintre alene i det kystnære område. De mest talrige arter er polarlomvie, almindelig ederfugl, kongeederfugl og søkonge. Et ukendt, men stort, antal havfugle migrerer desuden gennem eller overvintrer i offshore områderne.

### Havpattedyr
Havpattedyr udgør en signifikant komponent af det marine økosystem. Fem arter af sæler forekommer i vurderingsområdet, blandt hvilke grønlandssæl er talrig i hele området gennem det meste af året, mens spættet sæl er opført som ”kritisk udryddelsestruet” på den grønlandske rødliste. Den nordlige del af vurderingsområdet overlapper med den sydlige del af et vigtigt overvintringsområde for hvalros. Blandt hvalerne, er der flere bardehvaler som periodevist forekommer relativt hyppigt i vurderingsområdet, herunder vågehval, finhval, pukkelhval og sejhval. Området er en del af deres fourageringsområde om sommeren og fordelingen af hvalerne er ofte korreleret med de primære fødeemner: lodde, krill og tobis. Grønlandshval migrerer gennem området i januar-februar måned, på vej mod fourageringsområder og muligvis yngleområder umiddelbart nord for vurderingsområdet. Flere tandhvaler er også almindelige i området, herunder marsvin, grindehval, døgling og hvidnæse. De sydlige overvintringsområder for hvidhvaler og narhvaler strækker sig desuden ind i den nordlige del af vurderingsområdet. Isbjørn forekommer i den vestlige del af området vinter og forår, afhængig af og knyttet til Vestisens udbredelse i Davis Strædet.

### Fangst og udnyttelse

Menneskelig udnyttelse af de naturlige resurser er udbredt i hele området; fritidsfangst og erhvervsfangst i mindre skala er udbredt i det kystnære område, mens et betydeligt kommercielt fiskeri foregår udenskærs. Da det meste af det kystnære område normalt er isfrit året rundt, er fangstmulighederne også gode det meste af året, om end der er fangstforbud i visse perioder. Havfugle er blandt de vigtigste resurser og bliver skudt i et betydeligt antal. Polarlomvie og ederfugl er de mest eftertragtede arter og i 2008 blev henholdsvis 35.000 og 11.000 fugle rapporteret skudt i vurderingsområdet. Sæler bliver også skudt/fanget i stort antal. Skindene bliver solgt og klargjort til det internationale marked på et garveri i Sydgrønland, mens kødet konsumeres lokalt. Den vigtigste art er grønlandssæl og der rapporteres årligt en fangst på ca. 30.000 dyr i vurderingsområdet. Hvalros, hvidhval og narhval nedlægges vinter og forår i den nordlige det af området og er reguleret af kvoter. Desuden nedlægges marsvin, vågehval, finhval og pukkelhval i området, hvoraf fangsten af de to førstnævnte udgør langt den største andel. Vågehval, finhval og pukkelhval er underkastet fangstkvoter, bestemt af IWC. Isbjørn skydes fåtalligt i den nordlige del af vurderingsområdet og reguleres ligeledes af kvoter.

Det kommercielle fiskeri repræsenterer det vigtigste eksporterhverv i Grønland og i 2009 udgjorde det 88 % af Grønlands eksportindtægt (1.7 milliard DKK). Hellefisk, rejer og krabber er de primære arter der udnyttes kommercielt i vurderingsområdet og de årlige fangster udgør en stor andel af de totale fangster i Grønland. Torskefiskeriet er vokset indenfor det seneste årti, men rekrutteringen til bestanden er meget ustabil. Sammenlignet med tidligere (1960'erne), er de nuværende fangster af torsk ubetydelige; i 2009-10 var der helt lukket for udenskærsfiskeri efter torsk i vurderingsområdet. I det kystnære område pågår et mindre fiskeri, som fritidsfangst eller kommerciel fangst, af arter som stenbider, havkat, rødfisk, torsk, fjordtorsk, lodde, fjeldørred og laks.

Turisme er en voksende industri i Grønland og udgør nu det tredjestørste erhverv på landsbasis. Det samlede antal gæster i 2008 var 82.000 (eller 250.000 overnatninger), hvoraf størstedel besøgte vurderingsområdet og især Nuuk. Desuden bidrager krydstogtskibe med et større og større antal besøgende. Det kystnære område er meget væsentlig aktiv for turistindustrien.

### Klimaændringer

Klimaændringer kan påvirke det marine økosystem markant, specielt i arktiske egne. Ændringer i fordelinger og tætheder af nøglearter på forskellige trofiske niveauer, kan få drastiske konsekvenser for den økosystemstruktur, som de nu er en del af. Fangst og fiskeri vil højst sandsynligt blive påvirket. For nogle populationer vil klimaændringer virke som en ekstra stressfaktor, på linje med f.eks. jagt, og medføre en højere følsomhed overfor oliespild. Andre populationer kan blive hyppigere og mere robuste overfor oliespild, som en konsekvens af klimaændringer. Endelig er det sandsynligt at artssammensætningen vil ændre sig, eftersom nogle arter forsvinder og andre kommer til som konsekvens af en nordlig forskydning i udbredelse.

### Kontaminanter

Viden om baggrundsniveauer for kontaminanter, så som kulbrinter og tungmetaller, er væsentlig for at kunne vurdere sårbarheden og de miljømæssige konsekvenser af olieaktiviteter.

Niveauet af visse kontaminanter, herunder organoklorider, er stadig højt i Grønland på grund af langtransport af stofferne til Arktis. Niveauet er særlig højt i de øverste trofiske niveauer, såsom hos hvaler og isbjørne. Desuden er nye persistente forurenende stoffer nu blevet målbare, såsom bromerede flammehæmmere. Med undtagelse af havneområder er niveauet af olieforbindelser, inklusiv PAH'er, relativt lavt og regnes som værende baggrundsværdier.

Vores nuværende vide om kontaminanter i marine organismer i Grønland, inklusiv vurderingsområdet, er dog stadig begrænset. Det gælder særligt sammenhængen mellem kontaminantbelastning og potentielle biologiske effekter, inklusiv subletale sundhedseffekter og funktionsnedsættelser. Mere viden om artsspecifik sensitivitet og om brugbare moniteringsstrategier er også tiltrængt.

## Vurdering af aktiviteter

Nærværende vurderinger bygger på viden om arternes nuværende fordeling, deres tolerance og tærskelværdier overfor olierelaterede aktiviteter, samt på de eksisterende klimatiske forhold. Klimaændringer forventes imidlertid at ændre meget på miljøet i vurderingsområdet i de kommende årtier og det er derfor ikke givet, at konklusionerne er gældende for fremtidige forhold. Samtidig er en stor del af vurderingsområdet dårligt undersøgt og ny viden kan derfor også ændre på konklusionerne.

## Efterforskning

Efterforskningsaktiviteter er midlertidige, de varer typisk nogle år og vil for det meste være spredt ud over de tildelte licensområder. Hvis der ikke lokaliseres olie, der kan udnyttes, ophører aktiviteterne helt. Findes der olie, vil aktiviteterne overgå til udvikling og udnyttelse af oliefeltet (se nedenfor).

De væsentligste påvirkninger fra efterforskningsaktiviteter kan være forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, boring i havbunden og helikopterflyvninger) fra selve boreprocessen og udledninger. Alvorlige påvirkninger kan undgås med forebyggende tiltag, som f.eks. ved at undgå aktiviteter i særligt følsomme områder eller perioder.

De arter i området som er mest sensitiv overfor støj fra seismiske undersøgelser er bardehvalerne (vågehval, finhval, sejhval og pukkelhval) og tandhvaler som kaskelot og døgling. Disse risikerer at blive bortskræmt fra vigtige opholdsområder om sommeren. En fordrivelse eller forskydning i udbredelse af hvalerne vil påvirke tilgængeligheden for fangerne, såfremt de oprindelige opholdsområder var vigtige fangstområder. Narhval, hvidhval, grønlandshval og hvalros er også sårbare overfor seismisk støj, men deres forekomst i området overlapper kun i mindre grad med de seismiske undersøgelser.

Da seismiske undersøgelser kun er midlertidige, er risikoen for langtidspåvirkninger på populationer, forårsaget af enkelte surveys, ret lav. Risikoen er dog til stede, såfremt der udføres flere undersøgelser samtidig, eller hvis undersøgelserne foregår i det samme kritiske område i lange perioder eller i adskillelige år i træk (kumulative effekter). Særlige 3D-seismiske undersøgelser, der typisk foregår i begrænsede områder, kan give anledning til mere markante midlertidige påvirkninger.

Indenfor fiskeriet, er risikoen for påvirkninger af seismisk støj størst for hellefisk. Disse risikere midlertidigt (dage eller uger) at blive kortskræmt og kan resultere i mindre fangst på fiskepladserne. Selvom det præcise gydeområde for hellefisk er usikkert, må det anbefales at undgå seismiske undersøgelser i deres gydeperiode (tidlig vinter). Fiskeriet af rejer og krabber vil sandsynligvis ikke påvirkes.

Støj fra boreplatforme er også midlertidige, men lokalt mere permanent end seismiske undersøgelser. De mest sårbare arter i vurderingsområdet er hvaler og hvalros. Såfremt alternative habitater er tilgængelige for hvalerne, forventes der ikke nogen negativ effekt af aktiviteten, men hvis flere platforme opererer samtidig i et område, er der risiko for kumulative effekter og bortskræmning selv fra alternative habitater.

Boremudder og –spåner der bliver udledt på havbunden vil påvirke bundfaunaen. I vurderingsområdet forventes kun lokale effekter af udledningerne, såfremt de mest miljøvenlige typer af boremudder benyttes. Prøveboringer i de mest sårbare områder bør dog helt undgås. Der skal foretages basisundersøgelser på borestederne før boringerne, med henblik på at dokumentere og vurdere om unikke samfund eller arter, så som koldtvandskoraller eller svampehaver, vil være i risiko ved en øget sedimentation. Undersøgelser efter boringer skal dokumentere at der ikke er specifikke effekter.

Efterforskningsboringer er energikrævende processer og vil medføre store udledninger af drivhusgasser. Blot en enkelt boring vil forøge det grønlandske bidrag betydeligt.

Endelig vil der være risiko for oliespild ('blow-out') i forbindelse med en efterforskningsboring (se nedenstående).

Uacceptable miljøpåvirkninger ved efterforskningsaktiviteter undgås bedst ved nøje planlægning baseret på grundige miljøundersøgelser, brug af "Best Available Technique" (BAT) og "Best Environmental Practice" (BEP) og ved at følge forsigtighedsprincipper og internationale standarder (OSPAR), f.eks. ved at undgå aktiviteter i de mest følsomme områder og perioder.

## Udvikling og produktion

Aktiviteterne ved udvikling, produktion og transport er langvarige (årtier) og der er adskillelige aktiviteter, som potentielt kan medføre alvorlige miljøpåvirkninger.

Generelt vil påvirkningerne afhænge af antallet af aktiviteter, deres indbyrdes afstand i det aktuelle område samt deres varighed. I denne sammenhæng er det vigtig, at vurdere risikoen for kumulative effekter.

### Udledninger

Boringerne vil fortsætte under udvikling og produktionsfasen og boremudder og spåner vil blive produceret i meget større mængder end i efterforskningsfasen. Udledninger bør minimeres mest muligt, ved at genbruge og tilbageføre materialerne og kun udledning af miljøvenlige kemikalier (f.eks. dem som ifølge OSPAR er klassificeret som 'grønne' og 'gule'), der er blevet testet for giftighed og nedbrydning under arktiske forhold, bør tillades. Brugen af "sorte" kemikalier er forbudt i Grønland og de "røde" kemikalier kan kun benyttes hvis der tildeles dispensation. Ikke-giftige udledningerne kan ændre fordelingen af kornstørrelser på havbunden og påvirke bundfaunaen i nærheden af udledningsstederne.

De udledninger som imidlertid giver størst årsag til bekymring, er produktionsvand (som er vand der pumpes op sammen med olien) som kan indeholde rester af olie. Nyere undersøgelser indikerer at selv små mængder af olie kan påvirke fugle, fisk og primærproduktionen. Den mest oplagte måde at undgå sådanne effekter, er at rense produktionsvandet bedre inden det udledes, eller endnu bedre at pumpe vandet tilbage i produktionshullet, som det er praksis i Lofoten-Barentshavet.

Udledninger af ballastvand medfører en risiko for at introducere ikke-hjemmehørende eller invasive arter. Derfor skal ballastvand behandles og udledes efter særlige regler. Dette er endnu ikke et stort problem i Arktis, men risikoen vil stige i takt med klimaændringer og den mere intensive trafik af tankskibe som opstår ved et producerende oliefelt.

Udvikling af et oliefelt og produktionen af olie er meget energikrævende og aktiviteten vil bidrage markant til Grønlands udledning af drivhusgasser. Et af de store norske oliefelter udleder i dag således mere end dobbelt så meget $CO_2$ som hele Grønland tilsammen.

#### Støj

Støj fra boringer og positionering af maskinel, som vil fortsætte i udvikling og produktionsfasen, kan potentielt føre til permanente tab eller forskydninger af vigtige sommerhabitater for hvalerne, særligt hvis flere produktionsfelter er aktive samtidig. Støj fra skibe (inkl. isbrydere) og helikoptere, nu mere permanente end i efterforskningsfasen, kan påvirke både havpattedyr og havfugle. De mest sårbare arter i vurderingsområdet er de kolonirugende havfugle, grønlandshval, narhval, hvidhval, vågehval, finhval, marsvin og hvalros – arter som muligvis forbinder støj med negative begivenheder, så som jagt. Traditionelle fangstområder kan også blive påvirket. Brug af faste flyveruter og –højder vil minimere påvirkningerne fra helikopterstøj.

#### Placering af installationer

Placering af offshore installationer og etablering af infrastruktur kan lokalt påvirke artssamfund på havbunden og der er en risiko for at ødelægge vigtige fourageringsområder - hvalros er sårbar, om end de hovedsageligt forekommer i den nordlige del af vurderingsområdet. Fourageringsområder for overvintrene kongeederfugle på fiskebankerne (særligt Fyllas Banke) er også følsomme. Installationer i land kan lokalt påvirke ynglende fugle, hindre fjeldørreder vejen til visse elve, ødelægge den kystnære flora og fauna, samt påvirke det æstetiske indtryk af det uberørte landskab. Sidstnævnte kan få betydning for turismen.

En særlig påvirkning af fiskeriet er de sikkerheds/afspærringszoner (typisk 500 m) som etableres rundt om midlertidige eller permanente offshore installationer. Disse vil få en betydning, i de områder hvor der fiskes intensivt efter hellefisk og rejer.

Oplyste installationer og flares (gasflammer) kan tiltrække havfugle når det er mørkt og der er en risiko for at specielt ederfugle og måske søkonger kolliderer med installationerne.

### Kumulative effekter

Der vil være en risiko for kumulative effekter når flere aktiviteter foregår samtidigt eller i forlængelse af hinanden. Eksempelvis har seismiske undersøgelser et stort potentiale for at forårsage kumulative effekter. Kumulative effekter kan også forekomme i kombination med andre menneskelige aktiviteter, så som jagt, eller i kombination med klimaændringer.

Påvirkninger fra udvikling og produktionsfasen kan begrænses mest muligt ved at kombinere detaljerede miljøundersøgelser (for at lokalisere sårbare økosystem komponenter) med nøje planlægning af placeringen af installationer og transportruter. Ligeledes skal BEP, BAT og internationale standarder (f.eks. OSPAR og HOCNF) implementeres, for at reducere udledninger i havet og til atmosfæren.

## Oliespild

Det miljømæssige mest kritiske uheld der kan ske ved de ovennævnte aktiviteter er et stort oliespild. Et oliespild kan ske under selve boringen ('blowout') eller ved uheld i forbindelse med opbevaring eller transport af olien. Store oliespild er forholdsvis sjældne, fordi de tekniske løsninger og sikkerhedsforanstaltninger til stadighed forbedres. Risikoen er imidlertid altid tilstede.

Modellering af oliespildsscenarier er ikke udført for det nærværende vurderingsområde i Davisstrædet.

Store oliespild kan potentielt påvirke alle niveauer af det marine økosystem, fra primær-producenter til topprædatorer. Det kan udgøre en trussel på populations- og måske endda artsniveau og påvirkningerne kan vare i adskillelige årtier, som det er dokumenteret for Prince William Sundet i Alaska. For nogle populationer kan dødeligheden i nogen udstrækning være kompensatorisk, idet den delvist erstatter naturlig dødelighed, mens den for andre populationer hovedsageligt vil være additiv i forhold til den naturlige dødelighed. Nogle populationer kommer hurtigt på fode igen, mens det for andre kan gå meget langsomt, afhængig af deres livsstrategi og populationsstatus. Arter der er sårbare overfor olie og som samtidig udsættes for fangst, kan påvirkninger fra olien reduceres ved af forvalte fangsten på en mere restriktiv og bæredygtig måde. Mangel på effektive afværgeforanstaltninger i isdækkede farvande og den ofte afsides beliggenhed, vil forværre den kritiske situation ved et oliespild.

For dette vurderingsområde er offshore områderne opdelt i otte områder, som hver især er klassificeret i forhold til deres sårbarhed overfor oliespild. Analysen er baseret på arternes eller artsgruppernes hyppighed, arts- eller bestandsspecifikke sårbarhedsværdier overfor olie, estimerede opholdstider for olien (oil residency), resurse udnyttelse og enkelte andre parametre. Gennem alle årstider er de mest kystnære offshore områder, cirka svarende til kontinentalsoklen, blandt de mest sårbare områder. Disse er meget vigtige for migrerende og overvintrende havfugle, som fiskeområder for rejer og krabber og som fourageringsområde for bardehvaler. Om foråret og om vinteren klassificeres desuden det sydvestlige hjørne af vurderingsområdet som meget sårbar overfor oliespild. Det skyldes primært et intensivt hellefisk fiskeri og at der i marts og april måned findes yngleområder for klapmyds langs kanten af vestisen.

En sammenligning af årstider, baseret på absolutte sensitivitetsværdier og gennemsnitsværdier for alle offshore områder, viser at vinteren er den mest sårbare periode, tæt efterfulgt at forår og efterår, mens sommeren er mindst sårbar overfor oliespild. Den primære grund til denne forskel er de store forekomster af migrerende/overvintrende havfugle gennem forår, vinter og efterår. Havfugle er generelt meget sårbare overfor olie, særligt alkefugle og havænder.

Det kystnære område i vurderingsområdet er særlig sårbart, fordi olien her kan påvirke områder med høj biodiversitet. Sårbarheden skyldes også at olien kan blive fanget i bugter og fjorde, hvor høje og giftige koncentrationer af olie kan opstå. Der vil være risiko for negativ påvirkning af gydende fisk som lodde og stenbider om foråret, fjeldørred som samles foran elvene og mange havfuglepopulationer - både om sommeren, i trækperioder og særligt om vinteren hvor havfugle fra mange steder i Nordatlanten samles i Sydvestgrønland. Langtidspåvirkninger kan forekomme i det kystnære område, såfremt olien indlejres i sedimentet, mellem sten, i muslingebanker eller i klippesprækker. Fra sådanne olieaflejringer kan olien langsomt sive og forårsage en kronisk forurening der kan vare ved i årtier. I Prince William Sund i Alaska har sådanne olieaflejringer haft negative langtidseffekter for de fugle der udnytter de forurenede kyster og nogle arter er endnu ikke kommet på fode igen. Det kystnære område er også meget vigtigt for de lokale fiskere og fangere og i tilfælde af et oliespild, kan deres aktiviteter blive markant påvirket af forbudszoner og ændrede fordelingsmønstre blandt fangstdyrene. Turistindustrien vil også blive negativ påvirket af et oliespild i det kystnære område.

I den nordlige og vestlige del af vurderingsområdet er vinteren og foråret en kritisk periode pga. Vestisens udbredelse. Ved et oliespild i isfyldt farvand vil olien indledningsvist blive fanget mellem isflagerne og i små hulrum på isflagernes underside. Isen vil i første omgang være med til at begrænse udbredelsen af et oliespild, men da isen holder på olien kan den også transportere den over lange afstande (uden væsentlig nedbrydning) og kan således påvirke miljøet, f.eks. havfugle og havpattedyr, langt fra det oprindelige udslip. Olien kan også blive fanget langs iskanten eller i israndzonen, hvor der kan forekomme store og sårbare koncentrationer af primærproduktion, havfugle eller havpattedyr.

Generelt forebygges oliespild bedst ved nøje planlægning og brug af standardiserede sikkerhedsprocedurer (HSE), forsigtighedsprincipper (BEP, BAT) og internationale standarder (OSPAR). Den foreliggende viden om oliespilds adfærd og skæbne i isdækkede farvande er dog begrænset og den tilgængelige teknologi til bekæmpelse af olie i isdækket farvand er endnu utilstrækkelig.

#### Primærproduktion og zooplankton

Det vurderes, at påvirkningerne på primærproduktion og zooplankton fra et overfladespild i det åbne hav vil være lav i vurderingsområdet på grund af den store udbredelse i tid og rum af disse forekomster. Der er imidlertid en risiko for en negativ påvirkning (nedsat produktion) på primærproduktionen lokalt og forårsperioden med algeopblomstring vil være den mest sårbare periode.

Erfaringer fra olieudslippet fra Deepwater Horizon i den Mexicanske Golf i 2010, hvor store og spredte undersøiske lommer af olie forekom på forskellig dybde, kan muligvis ændre på konklusionen om primærproduktion og zooplankton, såfremt et lignende stort undersøisk olieudslip skulle ske i vurderingsområdet. Det er dog endnu for tidligt at drage konklusioner på baggrund af uheldet i den Mexicanske Golf, idet den tilgængelige videnskabelige information herfra endnu er begrænset. Det er dog givet, at et stort undersøisk olieudslip på størrelse med det i den Mexicanske Golf, må forventes at have større påvirkninger end et overfladesplid, for primærproduktionen, zooplankton og fiske/reje-larver.

### Fisk og krebsdyr larver

Generelt er æg og larver fra fisk og krebsdyr mere sårbare overfor olie end de voksne individer og bestandene kan potentielt blive påvirket med reduceret rekruttering og efterfølgende konsekvenser for bestandsstørrelser og fiskeriudbytte i en årrække. Atlantisk torsk er særlig sårbar, fordi dens æg og larver kan være koncentreret i de øverste 10 m af vandsøjlen, hvorimod f.eks. larver af rejer og hellefisk normalt går dybere og derfor er mindre udsat overfor skadelige koncentrationer af olie på havoverfladen. Et meget stort undersøisk udslip med store lommer af olie fordelt i vandsøjlen, kan dog eksponere æg og laver overfor olie i store områder og dybdeintervaller og kan potentielt påvirke rekrutteringen og bestandsstørrelsen af arter som rejer, hellefisk, krabber og tobis.

### Bundfauna

Bundlevende organismer som muslinger og krebsdyr er sårbare overfor oliespild, om end der ikke forventes nogen effekter på det åbne hav, med mindre olien synker til bunden. På lavt vand (< 10-15 m) kan høje toksiske koncentrationer af olie nå havbunden, med mulige konsekvenser for den lokale bundfauna og de arter der udnytter disse, særligt almindelig ederfugl, kongeederfugl, havlit, remmesæl og hvalros. Et stort undersøisk olieudslip vil også kunne påvirke bunddyrene på dybt vand.

### Voksne fisk

Der forventes ikke påvirkninger fra et overfladespild på voksne fisk i det åbne hav. Et stort undersøisk 'blow-out' vil derimod godt kunne ramme pelagiske og bundlevende fisk langt til havs, enten direkte eller indirekte gennem fødekæden. Hellefisk vil være udsat på begge måder, idet de bevæger sig op fra havbunden for at søge føde i de pelagiske vandmasser. Situationen er mest kritisk for det kystnære område, hvor store og toksiske koncentrationer af olie kan opbygges i beskyttede bugter og fjorde og resultere i høj dødelighed blandt fiskene (se ovenstående).

### Fiskeriet

Et oliespild på det åbne hav vil primært påvirke fiskeriet gennem midlertidige forbudszoner, som skal forhindre fangst af kontaminerede fisk. Varigheden af sådanne forbudszoner vil afhænge af varigheden af olieudslippet, vejret og andet. Udenskærsfiskeriet efter hellefisk er stort i vurderingsområdet og eventuelle forbudszoner vil sandsynligvis også omfatte canadiske fiskeområder vest for vurderingsområdet. Dette skyldes, at hellefisk kan bevæge sig over store afstande på forholdsvis kort tid og der er således risiko for, at kontaminerede fisk (med afsmag – "tainted") fanges langt fra det oprindelige olieudslip.

Vurderingsområdet er også et af de vigtigste fiskeområder i Grønland for rejer og krabber. Forbudszoner kan ligeledes medføre betydelige økonomiske tab for dette fiskeri.

Oliekontaminerede kyster vil også medføre nedlukning af fiskeriet i kortere eller længere periode. Der er eksempler på mange måneders fiskeforbud som konsekvens af oliespild, særligt hvis olien er indlejret i sedimentet eller strandkanten. Det kommercielle kystnære fiskeri går primært efter stenbider og lokale bestande af torsk, mens lodde primært fanges til privat forbrug.

### Havfugle

Havfugle er meget sårbare overfor olie i det marine miljø, idet de normalt tilbringer meget tid på havoverfladen, hvor de fleste oliespild sker og hvor olien typisk spredes. Sårbarheden er knyttet til deres fjerdragt, som blot ved meget små mængder olie mister deres isolations- og opdriftsevne. Kontaminerede fugle dør som oftest af underafkøling, sult, drukning eller pga. forgiftning. I vurderingsområdet er det kystnære område særligt sårbart, fordi der forekommer store koncentrationer af fugle det meste af året. En betydelig del af disse fugle, inklusiv ynglefugle, fældefugle og overvintrende fugle, er knyttet til habitater i den yderste skærgård. Et olieberedskab er vanskeliggjort i sådanne områder pga. den afsides beliggenhed, en kompleks kystmorfologi og ofte barske vejrbetingelser. De mest sårbare arter er de havfugle med en langsom reproduktionsevne, et karaktertræk for mange alkefugle, mallemukker og havænder. Arter som polarlomvie, søkonge, ederfugle og havlit overvintrer i vurderingsområdet i stort tal, idet området er en del af et internationalt vigtigt overvintringsområde (åbentvandsområdet i Sydvestgrønland) for havfugle fra hele Nordatlanten.

Om efteråret og om vinteren er nogle arter af havfugle fra vurderingsområdet også i risiko for olieforurening længere til havs, inklusiv fiskebankerne, om end fuglene på det åbne hav sædvanligvis er mere spredte end i det kystnære område. Nogle af de vigtige arter er mallemuk, ride, lunde, søkonge, polarlomvie, tejst og kongeederfugl. Blandt disse er kongeederfugl den mest sårbare art, idet den samles i store tætte flokke på fiskebankerne om vinteren (Fyllas Banke og Store Hellefiskebanke). Et stort oliespild i disse områder kan decimere population.

### Havpattedyr

Isbjørne og sælunger er blandt de mest sårbare havpattedyr overfor den direkte kontakt med olie og kun en begrænset eksponering kan være dødelig, idet olien påvirker pelsens isolationsevne. Sælunger er meget relevante for vurderingsområdet (se nedenstående), mens isbjørne forekommer i varierende grad, afhængig af pakisens udbredelse i Davisstrædet.

Hvaler, sæler og hvalrosser kan påvirkes af oliespild på havoverfladen. Bardehvalerne kan få barderne indsmurt i olie og derved indtage olien med deres føde. Det kan påvirke filtreringsevnen eller føre til forgiftning og skader i maveregionen. De risikerer også at indånde oliedampe og at få olie i øjnene. I hvilken grad havpattedyr aktivt kan undgå at komme i kontakt med en oliepøl og samtidig hvor skadelig olien er for de ramte individer, er usikkert. Observationer indikerer imidlertid, at i det mindste nogle arter ikke opfatter olie som en trussel og er gentagne gange set svømme direkte ind i en oliepøl.

Arter af havpattedyr som kunne blive ramt af et oliespild i vurderingsområdet kunne være remmesæl, klapmyds, ringsæl, spættet sæl, grønlandshval, narhval, hvidhval, isbjørn, marsvin, hvalros, døgling og kaskelothval. Spættet sæl er særlig sårbar fordi den er truet i Grønland, samt klapmyds fordi yngleområderne findes i den østlige pakis i Davisstrædet. Havpattedyr som fouragerer i området om sommeren inkluderer grønlandssæl, klapmyds, ringsæl, spættet sæl, finhval, pukkelhval, vågehval, sejhval, marsvin, hvidnæse, døgling, kaskelothval og grindehval. Blåhval forekommer sjældent i vurderingsområdet, men er sårbar pga. den meget lille population.

#### Afværgeforanstaltninger

Risikoen for uheld og de miljømæssige konsekvenser kan minimeres ved brug af høje sikkerhedsforanstaltninger, ved at undgå de mest sårbare perioder og områder, ved at implementere effektive beredskabsplaner med adgang til passende udstyr og ved brug af sensitivitetsatlas, hvor de mest sårbare områder er identificeret.

### Videnshuller og nye undersøgelser

Der er generelt mangel på information om økologiske komponenter og processer i Davisstrædet. En foreløbig identifikation af vidensbehov og videnshuller i forhold til en miljømæssig forvaltning og regulering af kommende olieaktiviteter i Davis Strædet er at finde i kapitel 12. For at forvalte kommende olieaktiviteter behøves der mere viden for at kunne a) vurdere, planlægge og regulere aktiviteterne således at påvirkninger minimeres mest muligt; b) identificere de mest sårbare områder og herunder, at opdatere de eksisterende sensitivitetsatlas for oliespild; c) etablere baseline viden til brug i studier før og efter et eventuelt stort oliespild.

# Imaqarniliaq kalaallisooq

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Nalunaarusiaq Råstofdirektoratimiit piniarneqarsimavoq suliarineqarlunilu Danmarks Miljøundersøgelser-nit (DMU) aamma Pinngortitaleriffimmit (GN).

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## Avatangiisit

### Immap ikerani avatangiisit

Nalilersuiffimmi pissutsit atuuttut naatsumik nassuiarneqarput oceanografi sikullu pissusii salliutillugit. Tamatuma kujasinnerusortaa nalinginnaasumik ukioq kaajallallugu sikuuneq ajorpoq, avannamut kippasinnerusortaa eqqaassanngikkaanni. Nalilersuiffiup avannarpasinnerusortaa februarip missaaniit aprilimut sikuusarpoq. Ilaanneeriarluni tamaani iluliaqartarpoq, pingaartumik ukiuunerata naajartornerani upernaakkullu. Ilulissalli Fyllas Bankip avannaani qaqutigoortuupput. Tamatumunnga pissutaapput immap sarfai, itissutsit assigiinnginnerat aammalu sermit iigartartut ilulialiornerusut tamaannga ungasissumiinnerat.

Kujataata avataani avasissup ikkannersui nalilersuiffimmi pissutsinut assingunerpaapput. Tamakkua ikkannerit sakkortuumik sarfartuunerat pissutaalluni imaq inuussutissaqarluartoq tamakkunani annertuumik pikialaartinneqarpoq taammalu sivisuumik annertuumillu pinngorarnermik pilersitsilluni. Ikkannersuit sikoqartaratilluunnit sikuisattuusarput, Store Hellefiskebanki, nalilersuiffiup avannarpasinnerusortaaniittoq eqqaassanngikkaanni. Ikkannersuarni annertuumik pinngorartitsineq avataani itinerusuni pinngoratitsinermut naleqqiullugu qaammatinik arlalinnik sivisunerusarpoq. Pissuseq tamaani pingaarutilik alla tassaavoq immap issittumiitup immallu kissalaarnerusup naapiffiat. Tamaani aporaaffiusoq tappiorarnartunut assigiinngitsunik, ilaatigut nerisassat takkussorneratigut taamalu pilersitsinerup siulliup tulliatalu qanoq annertutiginerannut planktoneqarneranullu sunniuteqartarpoq. Aammalumi imaq tarajoq sinerissap qanittuaniittoq sananeqaatimigut akuugaanermigullu avataata imaanit immikkoortinneqartarpoq, taannami nunamit qanitaminiit imermik akoorneqartarmat.

Nalilersuiffigineqartoq issittorsuup kujatinnguaniippoq, subarktiskiusumiilluni. Avasissumi immap ikerani avatangiisit naammattumik misissorneqarnikuunngillat, kisiannili paasissutissat Kalaallit Nunaata eqqaani ikkannersuarni aalisarfiusuneersut tunngavigalugit nalilersuiffimmi immap ikerani avatangiisit ikittuinnarnik assigiinngisitaartunik uumasoqarput – tamakkuali amerlaqalutillu eqimmattorsuusarput, taamalu nerisareqatigiinneq minnerpaaniit nerisunut pingaarnernut ta-kisuujunani, artit amerlanngitsut uumasoqatigiinnermi aalajangiisuunerullutik. Immami uumasoqatigiinnermi pisartoq malunnarnerpaaq tassaavoq upernaakkut tappiorarnartut naasuusut, nerisareqatigiinnermi toqqammaviusut, amerleriarujussuartarnerat. Tamakkua tappiorarnartunit uumasuusunit nerisarineqartarput, ilaatigullu kingunnit Calanus-init (pingaartumik C. finmarchicus) tassaasut immami uumasoqatigiinnermut pingaarutilerujussuit ilaat.

### Bentisk fauna aamma flora

Bentiske makrofauna-p pinngorartut ilarparujussui nerisarpai taamaalillutillu aamma aalisakkanit, timmissanit imarmiunit miluumasunillu imarmiunit pingaaruteqartumik namminneq nerisaallutik. Nalilersuiffimmi mikrofaunamik misissuinerit ikittuinnaapput ataatsimullu isigalugu tamakkua qaqugukkut amerlassutsikkullu allanngoranerannut, avataanilu najortagaannut tunngatillugu ilisimasat amigaatigineqarlutik.  Makroalgit sinerissamiittuupput manngertumik natilimmiuullutik 50 m sinnerlugu itissusilimmiissinnaasarlutik.  Biomassi aammalu pinngoraneq ulittarnerup tinittarnerullu naqqaniittoq taassumalu avatinnguaniittoq annertuujusinnaavoq taammalu nerisareqatigiinnermi pingaarnerpaalluni. Tamakkua mikroalgit uumasuaqqanut immap naqqani nipinngasunut nerisaallutillu nerinianut illersuutaallutillu parnguttoornissamut, sarfamut mallillu qaartarnerannut imaluunniit nerineqarnissamut illersuutaasinnaapput.  Pineqartumi mikrolagit assigiinngisitaarnerannut artinullu katitigaanerannut, biomassimut, pilersitsinermut amerlassutsikkullu allanngorarnerannut tunngatillugu ilisimasat killilerujussuupput ilisimaneqanngingajavillutillu.

### Aalisakkat

Avataasiorfimmi, ikkannersuarnilu aalisakkani natermiut, soorlu qaleralik, nataarnaq, suluppaagaq, qeeraq aalisakkallu artit aningaasarsiutigalugit piniarneqanngitsut amerlanersaapput. Qaleralik aalisarnermut pingaaruteqaqisoq nalilersuiffiup timaani suffisarsorineqarpoq qalerallillu ilanngussortut amerlanersaat aamma tamatuma avataaneersuusarlutik (Kalaallit Nunaata avannaa kitaa Canadalu). Putooruttut amerlasoorsuullutik ikkannersuarniittartut aalisakkanit, timmissanit imarmiunit arfernillu soqqalinnit nerisaalluartuupput. Sinerissap qanittuani artit pingaarutillit pingasut suffisarput: saarullik, ammassat nipisallu. Ammassak aalisakkat annerusut, timmissat imarmiut, miluumasut imarmiut inuillu nerisaattut pingaarutiliuvoq. Saarullik nipisalu (suaat) aningaasarsiutigineqarput. Eqaluk aamma artiuvoq sinerissap qanittuani pingaarutilik sukisaarsaatigalugu aalisarneqarluartartoq. Artit allat annikinnerusumik iluaqutigineqartut, akissarsiutitut imalunniit akissarsiutiginagit, tassaapput immap eqalua, nataarnaq qeerarlu.

### Timmissat imarmiut

Nalilersuiffimi timmissat imarmiut ineqarfippassuaqarput, naak Kitaata avannarpasinnerusuani timmissat ineqarfissuisut annertutiginngikkaluartunik. Katillugit artit 20-it nalinginnaasumik tamaani erniortuusut naluneqanngilaq ineqarfiillu eqimanerpaat sinerissap qerertarpassuiniipput 63˚ aamma 66˚N-p akornanniittuni, naak tamanna peqqissaartumik timmissanik piaqqiortunik misissuiffigineqarsimanngikkaluartoq.  Artit marluk kalaallit Nunaanni timmissat qaqutigoornerpaat ilagaat, tassalu qilanngat appallu sigguttuut, taakkua kalaallit rødlistianni nalunaarsorsimapput ”ulorianartorsiungajalluinnartutut” aamma ”nungutaasinnaasutut”.

Artinut 13-inut nalilersuiffimmiittunut tunngatillugu Kalaallit Nunaannut nunanullu allanut pingaarutaat nalilerneqarpoq ”pingaartorujussuusoq”, timmissat piaqqiortartut amerlassusiat, isasartut ukiisartullu pissutigalugit (Tab. 4.7.1). Nalilersuiffigineqartoq timmissat imarmiut uki-isarfiattut pingaarutilerujussuuvoq. Tamassumami ilarujussua Kalaallit Nunaata kujata kitaani sikuneq ajortumut, timmissat imarmiut amerlasoorsuit Ruslandimeersut, Islandimeersut, Svalbardimeesut Canadameersullu oktoberimiit majimut ukiisarfiata ilagaa.  Missiliorneqarpoq timmissat 3,5 millionit sinnerlugit tamatuma sinerissamut qaninnerusortaannaani ukiisartut. Amerlanerpaat tassaapput appat siggukitsut, mitit, mitit siorakitsut appaliarsuillu.

Timmisat imarmiut amerlasoorsuit, qanorli amerlatigineri ilisimaneqanngitsut, avataa tamanna inger-laarfigisarluguluunnit ukiivigisarpaat.

### Miluumasut imarmiut

Miluumasut imarmiut imaani uumasoqatigiinnermi malunnaateqartumik ilaapput. Puisit assiginngitsut tallimat nalilersuiffimmiipput, ilaatigut aataat amerlasoorsuullutik tamanna tamakkerlugu ukiup annersaani puisaasut, qasigiarlu kalaallit rødlistianni "nungutaanissaa aar-lerinarluinnartutut" nalunaarsorsimasoq. Nalilersuiffiup avannarpasinnerusortaa aarrit ukiivigisartagaannut pingaarutilimmut ilaavoq.  Arfernut ilaapput soqqallit arlallit piffissap ilaatigut nalilersuiffimmi takkusimaarajuttut, taakkununnga ilaallutik tikaagulliit, tikaagulliusaat, qipoqqaat sejhvalillu. Tamanna neriniarfiannut ilaavoq arferillu takkusimaarfigisartagaat amerlanertigut neriniagaasa pingaarnerit takkusi-maarnerannut atasarpoq: ammassat, isituuaqqat putooruttullu. Arfiviit tamaana ingerlaarfeqaramik januar-februar tamaanaqquttarput immaqalu nalilersuiffiup tamatuma avannannguani erniortarlutik. Arferit kigutilli arlallit tamaani nalinginnaapput, ilaatigut niisat, niisarnat, anarnat aarluarsuillu. Kujasinnerusumi qilalukkat qaqortat qernertallu ukiisarfiat nalilersuiffiup avannarpasinnerusortaanut atavoq.
Kippasinnerusortaani ukiukku upernaakkullu nanoqartarpoq, tassani apeqqutaasarluni kitaata sikuata qanoq Davis Strædemut siaruarsimatiginera.

### Piniarneq iluaquteqarnerlu

Uumasut isumalluutit tamaani tamarmi inunnit iluaqutigineqarput; annikinnerusumik sunngiffimmi piarneq inuussutissarsiutigalugulu pinartuuneq sinerissami tamarmi ingerlanneqarpoq, annertuumilli iluanaarniutigalugu aalisarneq avataasiorluni ingerlanneqarluni. Sinerissap qanittua ukioq kaajallallugu sikuuneq ajormat ukioq tamaat piniarnermut periarfissarissaarpoq, naak piffissap ilaatigut piniaqqusaanngiffeqaraluartoq. Timmissat imarmiut isumalluutinut pingaarnerpaanut ilaapput ikigisassaanngitsunillu pisaqarfiusarlutik. Appat mitillu piumaneqarnerpaapput 2008-milu nalilersuiffimmi 35.000-inik 11.000-inillu pisaasunik nalunaarutaasimallutik. Puisit aamma amerlasuunik pisaqarfiusarput. Amii tunineqartarput Kujataanilu ammerivimmi suliaralugit nunani allani niuerfinnut tuniniagassiarineqartarlutik, neqaalli nammineq nerisarineqartarpoq. Puisini pingaarnerpaavoq aataaq ukiumut 30.000 missiliorlugit nalunaarsuiffimmi pisaralugu nalunaarutigineqartartoq. Aaveq, qilalukkat qaqortat qernertallu ukiukkut upernaakkulllu pisarineqartarput pisassiisarnikkullu killilersorneqarlutik. Niisat, tikaagulliit, tikaagulliusaat qipoqqaallu tamaani pisarineqartarput, siullit taakkua marluk pisaasartunit amerlanersaallutik. Tikaagulliit, tikaagulliusaat qipoqqaallu pisassiissutigineqartarput IWC-mit aalajangerneqartartumik. Nannut amerlanngitsunik, nalilersuiffiup avannarpasinnerusortaani pisaasarput pisassiissutitigut killilersorneqartumik.

Iluanaarniutigalugu aalisarneq Kalaallit Nunaanni inuussutissarsiutini pingaarnerpaavoq, 2009-milu Kalaallit Nunaata nunanut allanut niuernikkut isertitaasa 88 %-iinik (1.7 milliard DKK) isertitsissutaasimalluni. Qalerallit, kinguppaat saattuallu nalilersuiffimmi aningaasarsiutigalugit iluaqutigineqarput Kalaallit Nunaannilu ukiumut pisaasartut tamarmiusut ilarparujussui tamaani pisarineqartarput. Saarullinniarneq ukiuni qulikkuutaani kingullerni annertusiartorpoq, saarulliilli nutaanik ilaartornerat assut allanngorardluni.  Siusinnerusumut (1960-ikkunnut) naleqqiullugu ullumikkut saarullittarineqartartut ikittuarasuupput; 2009-10-mi avataasiorluni saarullinniarneq nalilersuiffimmi matoqqatinneqarpoq. Sinerissap qanittuani annertunngitsumik aalisarneqarpoq, aliikkutaralugu akissarsiutigaluguluunniit, soorlu nipisat, qeeqqat, suluppaakkat, saarulliit, uukkat, ammassat, eqaluit kapisillillu aalisarneqarlutik.

Takornariartitsineq Kalaallit Nunaanni ingerlataavoq annertusiartortoq massakkullu nuna tamaat isigalugit inuussutissarsiutinut annerpaanut pingajuulersimasoq. Takornariat 2008-mi 82.000-isimapput (imalunniit unnuinerit 250.000), taakkualu amerlanersaasa nalilersuiffik, pingaar-tumillumi Nuuk tikeraarsimavaat. Umiarsuillu takornarianik angallassisut takornariat amerliartuinnartut tikittalernerannut ilapittuutaasimapput. Sinerissap qanittua takornariartitsinermut pingaaruteqarluinnartuuvoq.

### Klimap allanngorneri

Klimap allanngornerisa immami uumasoqatigiinneq annertuumik sunnersinnaavaat, minnerunngitsumillu issittumiitut. Artit pingaarnerit sumut agguataarsimanerisa eqimassusiisalu nerisareqatigiinnermi allanngorneri annertoorujussuarmik uumasoqatigiit aaqqissuussimanerannut kinguneqarsinnaapput, taakkununngami ilaasuummata. Piniarneq aalisarnerlu qularnanngilluinnartumik sunnerneqartussaapput. Uumasoqatigiit ilaannut klimap allanngorneri ilungersuatitsinngitsoornavianngillat, soorlu piniarnikkut aamma ilungersuatinneqartartut, taammalu kingunerissallugu uuliaarluernernut suli misikkarinnerulerneq. Ummasoqatigiit allat takkusimanerulersinnaallutillu uuliaarluernermut akiuulluarnerulersinnaapput klimap allanngornerisa kinguneranik. Kiisalu ilimanarpoq artit katitigaanerat allanngorumaartoq, artimmi ilaat tammarumaarmata allallu takullutik siammarsimaffiata avannarpariartornerata kinguneranik.

### Mingutitsissutit

Mingutitsissutinut, soorlu kulbrintinut saffiugassanullu oqimaatsunut, qanoq annertutigisumik akooreernerannut  tunngatillugu uuliasiornermut atatillugu avatangiisinut ajoqusiisinnaanerat sunniutigisinaasaallu eqqarsaatigalugit ilisimasat pingaarutilerujussuupput.

Kalaallit Nunaanni mingutitsissutit ilaat, taakkununnga ilaallutik organoklorider, suli annertujaarujussuupput tamakkua ungasissumiit Issittumut ingerlaartarnerat pissutaalluni. Tamakkua annertunerupput uumasoqatigiinni nerisaqarnikkut qaffasinnerusumik inississimasuni, soorlu arferni nannunilu. Kiisalu mingutitsissutit sivisuumik sunniusimasartut nutaat massakkut uuttorneqarsinnaalersimapput, soorlu ikuallannaveeqqutit bromeriusut. Umiarsualiviit qanittuilu eqqaassanngikkaanni uuliamut attuumasut, PAH-t ilanngullugit, annertugisassaanngillat tamaaneereersutullu isigisariaqarlutik.

Kalaallit Nunaanni uumassusilinni immamiittuni, tassa nalilersuiffik ilanngullugu, mingutitsissutit suli annertugisassaanngillat. Pingaartumik mingutitsineq tamakkualu uumassusilinnut sunniutigisinnaasaat, peqqinnissamut piginnaasanillu annikillissutaasinaasut eqqarsaatigalugit  sunniutigisinaasaat ilannngulugit tassani pineqarput.  Assigiinngitsut tamakkua misikkariffigineqassusiannik aammalu nalunaarsuinermi periaatsinut tulluassusiannut tunngatillugu annertunerusumik ilisimasaqarnissaq pisariaqartinneqarportaaq.

## Ingerlatanik naliliineq

Naliliinerit makkua ullumikkut artit agguataarsimanerannut, uuliamut tunngatillugu ingerlatanut nalinullu killigititanut qanoq tigusisarnerat aammalu klimami pissutsinut atuutunut tunngatillugu ilisimasanik tunngaveqarput. Klimalli allanngorneri nalilersuiffimmi avatangisinik annertuumik allanngortitsiumaartut ilimagineqarpoq, taamaattumik oqaatigineq ajornarpoq naliliinerit ukiuni qulikkuutaani aggersuni aamma atuukkumaarnersut. Aammami nalilersuiffiusup ilarujussua iluamik misissuiffiunikuunngilaq taamaattumillu ilisimalikkat nutaat naliliinernik allanngortitsisinnaapput.

## Ujarlerneq

Ujarlernikkut ingerlatat utaqqiisaannaasarput ukiualunni ingerlagajuttut aammalu akuersissutaateqarfimmi sumi tamaani ingerlanneqarumaartut. Uuliamik iluaqutigineqarsinnaasumik nassaartoqanngippat taava ingerlatat taamaattut univittussaapput. Uuliamilli nassaartoqarpat taava ingerlatat ineriartortitsininngorlutillu uuliaqarfimmik iluaquteqarninngussapput (ataaniittoq takuuk).

Ujarlernikkut ingerlatat sunniutaat tassaasinnaapput ingerlatat nipiliorneri (assersuutigalugu sajuppillatitsisarluni misissuinerit, immap naqqani qillerinerit helikopterpalunnerlu), qillerinermi aniatitsinermilu. Sunniutit annertunerusut pinngitsoorneqarsinnaapput illersuutaasunik iliuuseqarnikkut, soorlu misikkariffiuallaartumi ingerlatsinaveersaarnikkut imaluunniit piffissap ilaatigut ingerlatisannginnikkut.

Artinit tamaaniittunit sajuppillatitsisarluni misissuinerup nipiliortitsineranut arferit soqqallit misikkarinnerupput (tikaagullik, tikaagulliusaaq, sejhval qipoqqarlu) aamma arferit kigutillit, soorlu kigutilissuit anarnallu. Tamakkua aasaanerani najortakkaminnit pingaarutilinnit nujutinneqarsinnaapput. Arferit qimagutitaanerat siammartinneqarneralluunniit piniartunit pisariuminarnerannik akornusiisinnaapput najortuartarsimasaat piniarnermut pingaaruteqartuusimappata. Qilalukkat qernertat, qaqortat, arfiviit aarrillu aamma immami sajuppillatitsisarnikkut nipiliornermit sunneruminartuupput, kisiannili najortagaat annikitsuinnarmik sajuppillatitsisarluni misissuiffimmut ilaavoq.

Sajuppillatitsisarluni misissuinerit qaangiukkumaarmata tamakkua, uumasoqatigiinnut ataasiaanarluni misissuinerit sivisuumik sunniusimanissaat ilimanarpallaanngilaq. Aarlerinarsin-naavorli misissuinerit taamaattut arlallit ataatsikkut ingerlanneqarpata, imaluunniit misissuinerit sivisuumik imaluunniit ukiuni arlalinni ajoqutaasinnaaffimmi ingerlanneqarpata pisut assigiingitsut ataatsimut sunniutaat (kumulative effekter) pilersinnaammata. Misissuinerit immikkut ittut 3D-sajuppillatitsisarluni misissuinerit, amerlanertigut sumiiffinni annikkinnerusuni atorneqartartut, annertunerumik ajoqusiigallarsinnaapput qaangiukkumaartunilli.

Aalisarnermut atatillugu sajuppillatitsisarluni nipiliornerup ajoqusiisinnaanera qaleralinnut annertuneruvoq. Taakkuami tatamitillugit nigortikkallarneqarsinnaapput (ullualunni sapaatip akunneriniluunniit) taamalu aalisarfinni pisakinnerulernermik kinguneqarluni. Qalerallit sumerpiaq suffisarnerat erseqqivissumik tikkuarneqarsinnaanngikkaluartoq suffinerisa nalaani sajuppillatitsisarluni misissuinerit pinaveersarnissaat inassutigineqassaaq (ukiuleqqaasaani). Kinguppanik saattuanillu aalisarneq sunnerneqassagunanngilaq.

Qilleriveqarfinni nipiliorneq aamma qaangiuttussaavoq, najukkalli ilaanni sajuppillatitsisarluni misissuinermit aalaakkaanerusumik ingerlanneqarumaarlutik. Nalilersuiffimmi artit misikkarinnerit tassaapput arferit aarrillu. Arferit nuuffigineqarsinnaasumik najugassaqassappata ingerlatat tamakkua ajortumik kinguneqarnissaat ilimagineqanngilaq, qilleriveqarfiilli arlallit ataatsikkut misissuiffimmi ingerlassappata tamanna kumulative effektinik aammalu arferit nuuffigisinnaasaraluaminnit nujutsinneqarnerannik kinguneqarsinnaasoq aarlerigineqarsinnaavoq.

Maralluk qillerinermi atorneqartoq qillernerlukullu immap naqqanut aniatinneqartut immap naqqata uumasuinut sunniuteqarsinnaavoq. Ilimagineqarpoq nalilersuiffiusumi aniatitsivippiaannarnut sunniuteqarumaartoq qillerinermi maralluit avatangiisinut ajoqutaannginnerusut atorneqarpata. Sumiiffinnili misikkarinneruni misiliilluni qillerisoqarnissaa sapinngisamik pinngitsoorniarluinnartariaqarpoq. Qillerisoqalersinnagu qilleriviusussami tunngaviusumik misissuineqartariaqarpoq tamaani pissutsit aartilluunniit immikkoorluinnartut uppernarsaaser-sornissaat siunertaralugu, artit soorlu immap nillertup koralii imaluunniit svampeqarfiit, annertunerusumik qallersuinermit navianartorsiortineqarnerat annertusisinnaammat. Qillerinerup kingornagut misissuinerit uppernarsassavaat malunnaatilinnik sunniuteqarsimanersoq.

Misissuilluni qillerinerit ingerlataapput nukimmik piariaqartitsisorujussuit tamatumalu kingunerissavaa annertuumik naatisiviup gassiinik aniatitsineq. Qillerinerup ataasiinnarluunniit kalaallit gassinik tamakkuninnga aniatitsinerat malunnaatilimmik annertusitittussaavaa.

Kiisalu misissuilluni qillerinerup uuliamik aniasoornikkut uuliakoorsinnaaneq ("blow-out") aarlerinartoraa (ataaniittoq takuuk).

Ujarlernermi akuerineqarsinnaanngitsunik avatangiisinik sunniinerit pinaveersaarneqarsinnaapput avatangiisinik misissuinerit tunngavigalugit peqqissaartumik pilersaarusiornikkut "Best Available Technique" (BAT) aamma "Best Environmental Practice" (BEP) malillugit mianersortumik ingerlatsigaanni nunallu assigiinngitsut piumasaqaataat (OSPAR) malillugit suligaanni, assersuutigalugu sumiiffinni misikkarissuni piffissanilu aalajangersuni.

## Ineriartortitsineq tunisassiornerlu

Ineriartortitsineq tunisassiornikkullu ingerlatat nalilersoruminaatsuupput sumiiffissaat qanorlu annertutiginissaat ilisimaneqanngimmat. Sunniutinut nalinginnaasumik ingerlatat qassiunerat, qanoq tamaani imminnut ungasitsiginerat qanorlu sivisutigisumik ingerlanneqarnerat apeqqutaasussaavoq. Tassunga atatillugu pingaartuuvoq ataatsimoortumik sunniutissaasa nalilersorneqarnissaat.

Piiaanermut, tunisassiornermut assartuinermullu atatillugu ingerlatat sivisuujusarput (ukiunik qulikkuutaartunik sivisussusillit) aammalu ingerlatat arlaqartut ajorluinnartumik avatangiisinik sunniisinnaapput.

### Aniatitsinerit

Ineriartortitsinerup tunisassiornerullu nalaanni qillerinerit ingerlassapput aammalu maralluk qillerinermut atorneqartoq qillernerlukullu ujarlenerup nalaaniit annertunerujussuarmik aniatinneqassallutik. Aniatitat sapinngisamik annikillisarneqartariaqarput, atoqqittarnerisigut aammalu piiarnerlukut uterartinnerisigut taamaallaallu kemikaliat avatangiisinut ajoqutaanngitsut aniatinnerisigut (assersuutigalugu "qorsuit" "sungaartullu"), issittumi toqunartoqarneri arrortikkuminarnerilu misiligarneqareersimasut kisimik atorneqartariaqarput. Kemikalianik ”qernertunik” atuinissaq Kalaallit Nunaanni inerteqqutaavoq kemikaliallu ”aappaluttut” taamaallaat atorneqarsinnaapput immikkut akeritissimagaanni. Aniatitat toqunartuunngitsut immap naqqani aserorternerit angisusiisa agguataarsimanerat allanngortissinnaavaat aammalu aniatitsiviusup qanittuani uumasut natermiut sunnersinnaallugit.

Aniatitalli isumakuluutigineqarnerusut tassa tunisassiornermi imeq atorneqartoq (uuliamut ilanngullugu pumperlugu qallorneqartoq) uuliaminernik akoqarsinnaammat. Misisuinerit nutaanerusut maluginiarpaat uuliamineerannguit timmissat, aaalisakkat pinngorartullu sunnertaraat. Sunniutit taamaattut pinngitsoortinnissaannut periusissaq piukkunnarnerpaaq tassaavoq erngup tunisassiornermi atorneqartup pitsaanerusumik saleqqaarlugu iginneqartarnissaa, imaluunniit suli pitsaanerussagaluarpoq imeq utertillugu qillikkamut utertinneqartartuuppat, soorlu Lofoten-Barentshavemi tamanna atorneqartoq.

Erngup umiarsuit ballasterisimataata aniatinneqarneranut atatillugu arlerinarpoq uumasut maanimiunngitsut eqqunneqarnisaat aammami maaniittut qerliinnarlugit amerliartortartunik eqqussuissutaasinnaammat. Taamaattumik imeq ballasterineqarsimasoq suliarineqartariaqarpoq peqqussutillu aalajangersut malillugit aniatinneqartariaqarluni. Tamanna suli imatorsuaq Issittumi ajornartorsiutaanngikkaluarpoq. Kisiannii aarlerinartua annertusiartortussaavoq klimap allanngorneri uuliamillu tunisassiorfimmik pilersoqarpat umiarsuit uuliamik assartuutit amerliartornerat peqatigalugu.

Uuliasiorfimmik ineriartortitsineq uuliamillu tunisassiorneq nukissarujussuarmik atuisuupput ingerlatallu taamaattut Kalaallit Nunaata naatitsiviup gassiinik aniatitsineranut annertuumik ilapittuutaasussaapput. Norgemi uuliasiorferujussuit ilaat ataaseq ullumikkut Kalaallit Nu-naata tamarmiusup CO2 –mik aniatitaata marloriaataanik aniatitsivoq.

### Pisorpaluk

Qillerinernit atortullu inissititernerisa nipiliornerat ineriartortitsinerup tunisassiornerullu nalaani ingerlaannartussaavoq, tamannalu arferit aasami najortagaasa annaaneqarnerannik tamakkualuunniit illikarnerannik kinguneqarsinnaavoq, pingaartumik tunisassiorfiit arlallit ataatsikkut ingerlanneqassappata. Umiarsuit (sikunik aserorterutit ilanngulugit) helikopterillu nipiliornerat ujarlernerup nalaaniit atamaarnerulersussaasoq maluumasunik imarmiunik timmissanillu imarmiunik sunniisinnaavoq. Artit nalilersuiffimmi eqqoruminarnerit tassaapput timmissat amerlasoorsuullutik piaqqiortartut, arfiviit, qilalukkat qernertat, qaqortat, tikaagulliit, tikaagulliusaat, niisat aarrit – artit nipip ulorianartumik nassataqartarneranik ilisimasallit, soorlu aallaaniarnermiit. Qangaanilli piniarfiusartut aamma sunnerneqarsinnaapput. Timisartut aalajangersukkut qutsissutsikkullu aalajangersukkut timmisarnerisigut helikopterip nipiliornerisa sunniutaat annikillisinneqarsinnaapput.

### Atortoqarfiit inissinneqarnerat

Imaannarmi atortoqarfiit sumut inissinneqarnerat atassuteqaatinillu pilersitsinerup qanittumi immap naqqata uumasui sunnersinnaavai neriniarfiillu pingaarutillit aserorsinnaallugit – aaveq taama eqqoruminartuuvoq, naak taanna nalilersuiffiup avannarpasinnersaani naapitassaanerugaluartoq. Mitit siorakitsut ukiisut neriniarfii ikkannersuarniittut (pingaartumik Fyllas Bankimi) aamma misikkarissuupput. Nunami atortulersuutit tamaani timmissat erniortut sunnersinnaavaat, eqaluit kuunnut aalajangerssumut ajornissaat mattussinnaallugu, sinerissap qanittuani naasut uumasullu aserorsinnaallugit, aammalu nunap alianaatsuunera sunnernerlussinnaallugu. Kingulleq taanna takornariaqarnermut pingaarutiliuvoq.

Aalisarnermut immikkut sunniuteqartussat tassaapput isumannaatsuunissaq pillugu matusat/tikeqqusaanngitsut (500 m-eriugajuttut) imaannarmi atortuugallartut ataavartulluunniit eqqaanni pilersinneqartartut. Tamakkua annertuumik qaleralinniarluni kinguppanniarlunilu aalisarfiulluartunut sunniuteqartussaapput.

Atortulersuutit qaammaqqutillit ikumasullu (gassi ikumasoq) timmissanit imarmiunit taartillugu qaninniarneqartarmata, pingaartumik mitit, immaqalu appaliarsuit tamakkununnga qaalluitsisarnissaat aarleqqutigisariaqarpoq.

**Pissutsit arlallit ataatsimut sunniutaat (Kumulative effekter)**
Kumulative effektit uuliasiorfinni ingerlatanit tamanit (inunnit pisunik klimallu allanngornerinik ilallugit) pisut, ingerlatat qanoq annertutiginissaat ilisimatinnagu assut nalilersoruminaapput. Sunniutit suunissaannut apeqqutaassaaq ingerlatat qanoq annertutiginerat, ingerlatat qassiunerat tamakkualu qanoq sivisutigisumik ingerlanissaat.  Naliliinissaq tamakkua ilisimalernissaannut utaqqittariaqassaaq.

Ineriartortitsinerup tunisassiornerullu sunniutaat killilersimaaneqarsinnaavoq sukumiisumik avatangiisinik misissuinerit (uumasoqarfiit eqqoruminarnerusut sunnerneqarnerannik paasiniaanerit) tunngavigalugit atortoqarfinnik assartuillunilu aqqutinik pilersaarusiornikkut. Taamatuttaaq BEP, BAT aamma nunat allat immamut silaannarmullu aniatitat millisinniarlugit maleruaqqusaat (assersuutigalugu OSPAR aamma HOCNF) atulersinneqartariaqarput.

## Uuliaarluerneq

Avatangiisit eqqarsaatigalugit ingerlatani qulaani eqqartorneqartuni ajutoorneq ajornerpaaq tassaavoq annertoorsuarmik uuliaarluerneq.  Uuliaarluerneq qillerinerup nalaani pisinnaavoq (”blow-out”) imaluunniit uuliamik toqqortuiffimmi assartuinermiluunniit pisinnaalluni. Anertoorsuarmik uuliamik aniasoornerit qaqutigoortutut oqaatigisariaqarput, teknikikkummi aaqqiissutissat isumannaallisaanikkullu pissut-sit nutarterneqartuarmata. Taamali pisoqarsinnaanera aarlerinartuarpoq.

Davis Strædemi nalilersuiffimmut tunngatillugu uuliamik aniasoqarpat qanoq pisoqarnissaanut tunngatillugu pisuusaartitsinermik modellit atorlugit misiliisoqarsimanngilaq.

Uliaarlluerujussuarnerup immaqa uumasoqatigiiffiit tamaasa sunnersinnaavai, pinngoratitsivinniit nerisareqatigiinnermi qullerpaanut. Tamanna uumasoqatigiinnik artinillu sunniinissamut, ilami immaqa uumasoqatigiinnik ataatsinik, ukiuni qulikkuutaani arlalinni atuussinnaasumik aarlerinartorsiutaavoq, soorlu Alaskami Prince William Sundet-imi uppernarsarneqartoq. Uumasoqatigiit ilaannut tunngatillugu toqusartut taarserneqarsinnaasarput, nalinginnaasumik toqusarnermik taarserneqarluni, uumasulli ilaannut tunngatillugu nalinginnaasumik toqusarnermut ilasaataasinnaalluni. Uumasut ilaat sukkasuumik siumut saaqqittarput, allalli arriitsuararsuarmik qaangiiniartarlutik qanoq uumariaaseqarnerat uumasoqatigiillu qanoq atugaqarnerat tassani apeqqutaalluni. Artit uuliamit eqqoruminarnerusut piniarneqartuusullu uuliamit sunnerneqarnerat annikillisinneqarsinnaavoq pisaasartut killilersuiffiunerusumik ikiliartuutaanngitsumillu aqutsivigineqarneratigut. Pitsaasunik immami sikuusartumi pinarveersaartitsisinnaannginneq avinngarusimasumiikkajunnerallu uuliaarluerneqartillugu ajornerusumik kinguneqartitsisarpoq.

Nalilersuiffiusoq tamanna immikkoortunut arfineq pingasunut avitaavoq uuliaarluernermit qanoq navianartorsiortinneqarsinnaanerat tunngavigalugu immikkoortitikkanik. Misissuineq artit arteqatigiikkuutaalluunniit qanoq tamaaniittigisarnerat, artit imaluunniit uumasoqatigiit uuliamit sunneruminarnerat, uuliap qanoq sivisutigisumik sumiiffigisinnaasaanik (oil residency) isumalluutinik atuinermik aammalu apeqqutinik ataasiakkaanik allanik tunngaveqartinneqarpoq.

Ukiup qanoq ilineratigulluunniit avataani sumiiffiit, tasaanerusut nunaviup tunngaveqarfia, eqqoruminarnerpaanut ilaapput. Tamakkuami timmissanut imarmiunut ingerlaanut ukiisunullu pingaarutilerujussuupput, kinguppannik saattuanillu aalisarfiullutik aammalu arfernit soqqalinnit neriniarfiullutik. Upernaakkut ukiuuneranilu nalilersuiffigineqartup kujammut kimmut isua uuliaarluernermit assorsuaq navianartorsiortikkuminartutut nalilerneqarpoq. Tamatumunnga pissutaavoq annertoorujussuarmik qaleralinniarfiunera aammalu martsimi aprilimilu natsersuarnit kitaata sikuata sinaava erniorfiummat.

Ukiup qanoq ilinerisa sanilliussuunneranni misikkarissutsimut uuttuutit piviusut aammalu agguaqatigiissitsinerit tunngavigalugit tamanut tunngatillugu ingerlanneqartut takutippaat ukiuunera ajoqusiiffigissallugu ajornerpaasoq, upernaaq ukiarlu qanittuararsuarmik tulleralugit, aasarli uuliaarluernermit taama eqqoruminartiginani. Taama assigiinngisitaarnermut pissuterpiaavoq timmissat imarmiut amerlasoorsuullutik ingerlaartut/ukiisut upernaakkut, ukiukkut ukiakkullu tamanna najortarmassuk. Ataatsimut isigalugu timmissat imarmiut uuliaarluernermit navianartorsiortikkuminartorujussuupput, pingaartumik appakkut mitikkullu (havænder).

Nalilersuiffiusumi sinerissap qanittua immikkut eqqoruminartuuvoq assigiinngitsorpassuarnik kangerlunni iterlannilu uumasoqarfiusoq uuliap uniffigisinnaammagu uuliap toqunartuinik eqiteriffinngorlugu. Aalisakkat suffisut, soorlu ammassat nipisallu upernaakkut, eqaluit kuuit paavini katersuuttartut timmissalu imarmiorpassuit ajoquserneqarsinnaapput – aasakkut, ingerlaarnermik nalaani pingaartumillu ukiukkut Atlantikup avannaani Kalaallit Nunaatalu kitaani kujataani timmiarpassuit katersuuffigisartagaanni. Sinerissap qanittuani sivisuumik sunniusima-sinnaavoq uulia kinnerni ujaranngortuni, ujaqqat akornanni, uiloqarfinni qaarsullu quppaani unissimappat. Uuliaarluerfinni taamaattuni uulia arriitsuinnarmik aniarusaarsinnaavoq ataavartumillu mingutitsilersinnaalluni ukiunik qulikkuutaanik arlalinnik sivisussuseqarsinnaasumik. Alaskami Prince William Sund-imi uuliaarluernerit taamaattut timmissat najortagaat suli ulloq manna tikillugu iluarsisimanngillat. Sinerissap qanittua tamaani aalisartunut piniartunullu pingaarutilerujussuuvoq, uuliaarluerneqarpallu ingerlataat malunnartumik sunnerneqarsinnaapput inerteqquteqarfitsigut piniakkallu najortakkaminnik allanngortitsinerannit. Takornariaqarnertaaq sinerissap qanittuani uuliaarluernermit ajoqusernegarumaarpoq.

Nalilersuiffiup avannarpasinnerusortaa kippasinnerusortaalu ukiuunerani upernaakkullu kitaata sikoqartarnera pissutigalugu isumakulunnarneruvoq. Sikulimmi uuliaarluertoqarneratigut uulia sikut akorninut sikullu ataani ilullisimanernut unerarsinnaavoq.  Aallaqqaammut sikup uuliaarluerneq siaruatsaaleqqaassavaa, uuliali sikumut nipinngammat sumorsuaq sikumit angallanneqarsinnaavoq (imatut nungukkiartorani) taamaattumillu avatangiisit, soorlu immap timmiai miluumasullu imarmiut uuliaarluerfiusumit ungasissorujussuarmiittut sunnernerlussinnaallugit. Uulia aamma sikup sinaavani sinaaqarfianiluunniit uninngatinneqarsinnaavoq pinngorarfissuarmi pinngorarnermut ajoquseruminartumi, timmissanut imarmiunut miluumasunullu imarmiunut ajoqutaalerluni.

Ataatsimut isigalugu uuliaarluerneq pitsaanerpaamik pinaveersaarneqarsinnaavoq pilersaarusiorluarnikkut periaatsinillu isumannaallisaataasunik aaqqissuussanik atuinikkut (HSE), mianersortumik pissuseqarnikkut (BEP, BAT) aammalu nunani allani peqqussutit (OSPAR) malinneqarnerisigut. Immami sikuusumi uuliaarluernerup pissuserisartagaanut tunngatilluguli ilisimasat massakkut pigineqartut killeqarput sikuusumilu uuliaarluernerup akiorneqarnissaanut teknologi pigineqartoq ullumikkut suli naammanngilaq.

### Pinngorarneq uumasuaqqallu tappiorarnartut

Naliliineqarpoq imaannarmi immap qaavani uuliaarluernerup sunniutaa pingorarnermut uumasuaqqanullu tappiorarnartunut annertuujussaanngitsoq tamakkua annertoorujussuarmut siaruarsimanera amerlassusiallu eqqarsaatigigaanni. Ajortumilli sunniuteqarsinnaanerat (pinngorarnerup minnerulernissaa) sumiiffinni aalajangersuni upernaakkut algenileruttorfiani, ajoquseruminarnerpaaffimmi ajoqutaasinnaanera isumakulunnartuuvoq.

Mexico Golf-imi 2010-mi Macodo-brønden-imi uuliamik aniasoornermit, immap iluani itissutsini assigiinngitsuni uuliaminertarujussuit sumorsuaq siaruarfigisaannit, misilittakkat malillugit immaqa pinngorarnermut  uumasuaqqanullu tappiorarnartunut tunngatillugu naliliineq allanngortittariaqarsinnaavaa, taamatut ittumik nalilersuiffimmi uuliamik aniasoorneqassagaluarpat. Massakkulli Mexicanske Golf-imi ajutoorneq tunngavigalugu inerniliinissaq piaarpallaarpoq, tassami tassanngaanniit ilisimatuutut paasissutissiissutit suli annertunngeqimmata. Qularutissaanngilarli immap naqqani Mexico Golf-imi aniasoornersuartut angitigisumik aniasoorneqassagaluarpat ilimagisariaqartoq tamanna immap qaavani aniasoornermit annertunerusumik pinngorarnermut, uumasuaqqanut tappiorarnartunut aamma aalisakkanut tukerlaa-nut/kinguppaallu piaraannut ajoqusiineq annertunerujussuussagunartoq.

### Aalisakkat peqquillu piaraat tukerlaat

Ataatsimut isigalugu suaat peqquillu piaraat tukerlaat inersimasuninnganit uuliamut misikkarinnerupput, aammalu uumasoqatigiit ilaartortuunerat appassutaasumik akornuserneqarsinnaavoq tamannalu ikilinermik kinguneqarsinnaalluni ukiuni arlalissuarni aalisarnikkut pisakinnerulernermik kinguneqartumik. Saarullik Atlantikormioq eqqoruminartorujussuuvoq suaat piaraallu tukerlaat immap qaava 10 m angullugu itissusilik najortaramikku, akerlianilli kinguppat qalerallillu piaraat tukerlaat  itinerusumiittarlutik taamalu immap qaavani minguttitamiit ajoquserneqarsinnaanerat annikinnerulluni. Immap iluani aniasoorujussuarnikkut itissutsini assigiinngitsuni annertoorsuanngorluni unerartoq suannut tukerlaanullu itissutsini assigiinngitsuni sunniisinnaavoq peqarneranullu, soorlu kinguppannik, qaleralinnik, saattuanik putooruttunillu, sunniisinnaalluni.

### Immap naqqata uumasui

Uumasut natermiut uillut peqquillu uuliaarluernermit eqqoruminartuupput, imaannarmili imatut sunniuteqarnissaa ilimagineqanngilaq uulia immap naqqanut kivinngippat. Ikkattumi (< 10-15 m) toqunartut uuliamiittut immap naqqanut pisinnaapput tamaani naasunut, immap natermiunut uumasunullu tamaaniittunut tamakkualu iluaqutaanerannut sunniuteqarnerlussinnaallutik, pingaartumik miternut siorartuunut, miternut siorakitsunut, allernut, ussunnut aavernullu. Immap naqqaniit annertoorsuarmik aniasoornikkut itisuup naqqani uumasut aamma sunnerneqarsinnaapput.

### Aalisakkat inersimasut

Imaannarmi immap qaavanut aniasoorneq aalisakkanut inersimasunut sunniuteqarnissaa ilimagineqanngilaq. Akerlianilli immap naqqani aniasoorujussuarneq ”blow-out” aalisakkat ikerinnarmiut natermiullu avasiinnarsuarmiittut eqqorsinnaavai, toqqaannartumik imaluunniit nerisareqatigiinnikkut. Qalerallit taakkuninnga marlunnit sunnerneqarsinnaapput, taakkumi immap naqqaniit qaffarterlutik ikerinnarmi nerisassarsiortarput. Sinerissalli qanittua aarlerinarnerpaavoq, uuliaminerujussuit toqunartullu tassanngaanneersut iterlanni kangerlunnilu unissinnaammata aalisakkat annertuumik toqorarnerannik kinguneqartumik (qulaaniittoq takuuk).

### Aalisarneq

Imaannarmi uuliaarluernerup siullermik aalisarneq eqqussavaa utaqqiisaagallartumik aalisarfigeqqusaanngitsutigut, taakkua pilersinneqassapput aalisakkanik mingutsinneqarsimasunik pisaqarnissaq pinngitsoortinniarlugu. Taamatut matuneqarsimasut qanoq sivisutigisumik matoqqanissaannut apeqqutaavoq uuliap anianerata qanoq sivisutiginera, silap pisusii allallu. Avataasiorluni qaleralinniarneq nalilersuiffiusumi annertoorujussuuvoq aalisarfigeqqusaanngitsulersuisoqassagaluarpallu nalilersuiffiup kitaani Canadami aalisarfiit aamma ilaatinneqartussaassapput. Tamatumunnga pissutaavoq qaleralik ungasissorsuarmut piffissaq sivisunngitsoq atorlugu nikerartarmat taamalu aalisakkat mingutsinneqarsimasut (tipittut – ”tainted”) uuliaarluerfimmit ungasissorujussuarmi pisarineqarsinnaallutik.

Nalilersuiffittaaq Kalaallit Nunaanni kinguppannik saattuanillu aalisarfiit pingaarnerpaat ilagaat. Aalisarfigeqqusaanngitsulersuinerup aamma aalisarnerup aningaasarsiornikkut annertuumik annaasaqarnera kingunerisinnaavaa.

Sinerissami uuliamik mingutsinneqarsimasut sivisunerusunik sivikinnerusunilluunniit aalisaqqusinnginneq kingunerisinnaavaa. Assersuutissaqarpoq uuliaarluerneq pissutaalluni qaammaterpassuarni aalisaqqusiunnaaneqartarmat, pingaartumik uuliakoq immap naqqanut sissamullu nipissimatillugu. Sinerissap qanittuani inuussutissarsiutigalugu aalisarneq pingaartumik najukkani saaqullinniarneruvoq, ammassalli nammineq atugassatut annerusumik pisarineqartarluni.

#### Timmissat imarmiut

Timmissat imarmiut immami uuliaarluernermit eqqornerlukkuminartorujussuupput, piffissammi annersaa immap qaaniittarput uuliaarluerfioqqajaanerpaasartumi uuliallu siaruarterfigisartagaani. Meqqoqarnerat ajoquseruminarnerannut pissutaavoq, ilami uuliamininnguugaluartulluunniit meqquisa oqorsaataanerat puttalatitsinerallu aserorsinnaavaa. Timmissat mingutsinneqartut amerlanertigut qiullutik, perlerlutik, ipillutik toqunartulluunniit pissutigalugit toqusarput. Nalilersuiffiusumi sinerissap qanittua eqqornerlukkuminarnerpaavoq, ukiormi kaajallangajallugu tamaani timmiarpassuaqartarpoq. Timmissat tamakkua ilarpassui, piaqqiortut, isasartut ukiisartullu ilanngullugit najugannaaqarput qeqertarpassuaqarfimmi. Uuliaarluernissamut sillimaniarneq taamaattuni ajornakusoortorujussuusarpoq, alimasippallaarneq, sinerissap ilusaa silarlukkajunneralu ilaatigut pissutaallutik. Timmissat imarmiut eqqornerlunneqarsinnaanerpaat arriitsumik kinguaassiortuupput, tassaallutik appat ilaqutaallu, appaliarsuit, mitit allerillu nalilersuiffiusumi amerlasoorsuullutik ukiisartut, tamannami nunanit assigiinngitsuneersunik timmissanut imarmiunut ukiiffiuvoq pingaarluinnartoq (Kalaallit Nunaat kitaa sikuuneq ajortoq) timmissanit nunanit Atlantikup avannaaneersunit tamanit najorneqartarami.

Timmissat imarmiut ilaat nalilersuifimmeersut ukiakkut ukiuuneranilu avasiinnarmi, ikkannersuit aalisarfiit ilanngullugit, uuliaarluernissaat aarlerinartuuvortaaq naak timmissat imaannarmiittut sinerissap qanittuaniittunit siamasinnerusaraluartut. Artinut pingaatunut tamakkununnga ilaapput malamuit, taateraat, qilanngat, appaliarsuit, appat siggukitsut mitillu siorakitsut. Taakunannga mitit siorakitsut aarlerinarnerpaapput, amerlasoorsuullutik eqimaqalutik ikkannersuarni aalisarfinniittaramik (Fyllas Bankimi, Store Hellefiske Bankimi).

Tamaani uuliaarluerujussuarneq timmissanik taakkuninnga nungutsingajalluinnarsinnaavoq.

#### Miluumasut imarmiut

Nannut puisillu piaraat miluumasuni imarmiuni uuliamut atuunnissamut aarlerinartorsiornerpaapput, tassami annikitsuinnarmilluunniit uuliaarluerneq toqussutigisinnaagamikku, tassa uuliap meqquisa oqorsaataanerat aserortarmagu. Puiseeqqat nalilersuiffimmi nalinginnaasorujussuupput (ataaniittoq takuuk), nannulli tamaaniittarnerat allanngorarpoq, tassani Davisstrædip qanoq sikoqarnera apeqqutaasarluni.

Arferit, puisit aarrillu immaap qaavani uuliaarluernermit sunnerneqarsinnaapput. Arferit soqqallit soqqaat uuliaarluersinnaapput aammalu nerisaminnut ilanngullugu uuliamik iioraasinnaallutik. Tamanna soqqaasa nakkartitsissutitut atorneranik allannguisinnaavoq, toqunartortorluni naakkullu ajoquteqalerluni toqussutaasinnaalluni. Aammalumi uuliap aalaa najuussorsinnaavaat isimikkullu uuliaarluersinnaallutik. Miluumasut imarmiut uuliaarluernermik namminneerlutik qimatserisinnaanersut aammalu uulia uumasunut tamakkununnga mingutsitsisoq qanorpiaq ajorusiitigisarnersoq erseqqissumik ilisimaneqanngilaq. Takuneqartartulli tunngavigalugit malunnarpoq artit ilaasa uulia aarlerinartutut isiginngikkaat aammalu uuliaarluernermut pulaqaqattaartartut takuneqartarlutik.

Miluumasut imarmiut nalilersuiffimmi uuliaarluernermit eqqorneqarsinnaasut tassaapput ussuit, natsersuit, natsiit, qasigissat, arfiviit, qilalukkat qernertat, qaqortat, nanoq, niisa, aaveq, anarnaq aamma kigutilissuaq. Qasigiaq

Kalaallit Nunaanni immikkut ulorianartorsiortuuvoq, aamma natsersuaq erniorfii Davisstrædip kangisinnerusuani sikuni eqingasuni erniorfeqaramik. Miluumasunut imarmiunut tamaani aasakkut neriniartartunut ilaapput aataat, natsersuit, natsiit, qasigissat, tikaagulliusaat, qipoqqaat, tikaagulliit, sejhvalit, niisat, aarluarsuit, anarnat, kigutilissuit niisarnallu. Tunnulik qaqutigut tamaanga nalilersuiffiusumut takkuttarpoq, eqqornerlukkuminartuuvorli tunnullit ikittuinnaammata.

#### Pinngitsoortitsiniarluni iliuutsit

Ajutoorsinnaaneq avatangiisinullu kinguneqarnerlussinnaaneq annikillisinneqarsinaapput isumannaallisaanikkut annertuumik iliuuseqarnikkut, tassa piffissat sumiiffiillu ajoqusiiffiusinnaanerusut atornaveersaarnerisigut, sillimaniarnikkut iliuusissat sunniuteqarluartut atorneqarnerigisut aammalu atortunik tulluartunik atuinikkut aammalu suut navianartorsiortikkuminarnerusut nalunaarsorsimaffiannik atuinikkut.

### Ilisimasat amigaataat misissuinerillu nutaat

Økologiimut tunngatillugu Davisstrædimi paasissutissat amigaataapput. Avatangiisinut tunngatillugu aqutsinermi Davis Strædemilu uuliasiornikkut ingerlataalerumaartunut tunngatillugu aqutsineq killilersuinerlu pillugit ilisimasanik pisariaqartitsineq ilisimasanillu amigaateqarneq kapitali 12-imi takuneqarsinnaavoq. Uuliasiornermut atatillugu aqutsivigineqarnissaanni annertunerumik ilisimasaqarnissaq pisariaqartinneqarpoq makkua isumagineqassappata; a) naliliineq, pilersaarusiorneq ingerlatat sunniutaanerlussinnaasut sapinngisamik annikitsuutinnissaat siunertaralugu killilersuiffigisinnaajumallugit; b) sumiiffiit ajortumik eqqorneqarsinnaasut suusut paasilluarumallugit, aammalu uuliaarluernermut misikkarissutsimut takussutissatut nunap assiliaq pigineqartoq nutartersinnaajumallugu, c) annertoorsuarmik uuliaarluernerup siornagut kingornagullu atugassanik ilisimasanik tunngaviusussanik pilersitsiumalluni.

# 1 Introduction

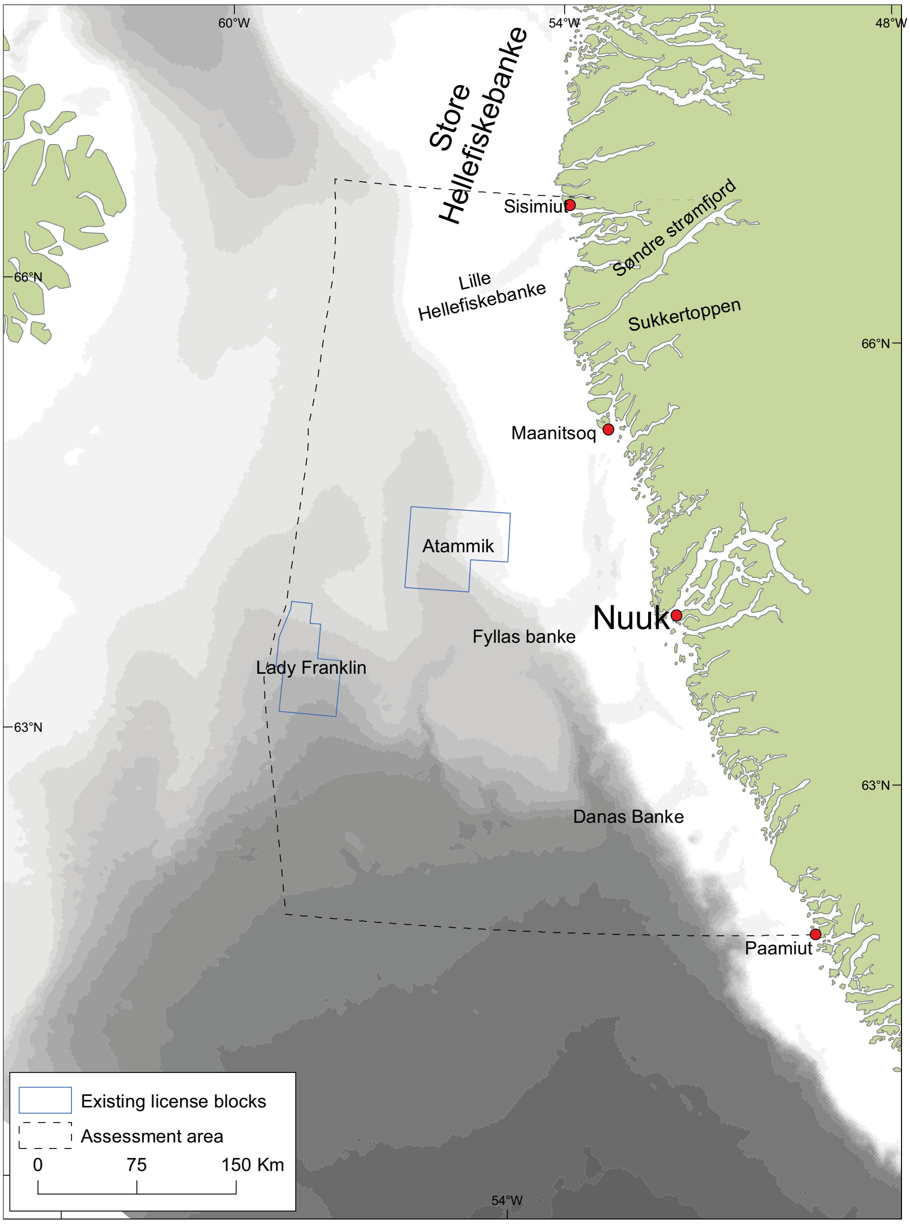
This document comprises a preliminary Strategic Environmental Impact Assessment (SEIA) of expected hydrocarbon activities in the eastern Davis Strait between 62° and 67° N (Fig. 1.1.1). It has been developed in cooperation with the Bureau of Minerals and Petroleum (BMP), DCE -Danish Centre for Environment and Energy (DCE) and the Greenland Institute of Natural Resources (GINR).

The SEIA provides an overview of the environment in the licence area and adjacent areas and identifies major potential environmental impacts associated with expected offshore oil and gas activities. The SEIA will also identify 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 on general restrictive or mitigative measures and monitoring requirements that must be dealt with by the companies applying for oil licences. The SEIA can be updated when new information becomes available. It is important to stress that an SEIA does not replace the need for site-specific Environmental Impact Assessments (EIAs). The latter is required by law whenever companies conduct site-specific activities that potentially can affect the environment.

The present SEIA is based on existing published and unpublished sources. This includes previous environmental impact notes for the eastern Davis Strait (Anon 2004a, b, c), the environmental oil spill sensitivity mapping (Mosbech et al. 2000) and similar impact assessments of oil activities in the Disko West area and in the Baffin Bay region (Mosbech et al. 2007, Boertmann et al. 2009). Also the recent assessment from the Lofoten-Barents Sea area in Norway (Anon 2003b) has been drawn upon for comparison of potential impacts, because the environment there is comparable to West Greenland waters in a number of respects. 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 Mexican Gulf in 2010 (more than 800,000 tonnes, the largest peace-time marine oil spill ever) has also been drawn upon, although the scientific information available on effects is still limited at this point.

Finally, an important issue in this context is climate change. This may affect both the physical and the biological environment; for example, the ice cover of Davis Strait area is expected to be reduced, which again will impact the ecology and particularly wildlife dependent on the ice, such as polar bears. Most of the data used for this SEIA has been sampled 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 those at present.

**Figure 1.1.1.** The assessment area, existing licence blocks (issued 2002/2005) and the surrounding areas in Southwest Greenland, including main cities and important shallow-water shelf banks.




## 1.1 Coverage of the SEIA

The offshore waters and coastal areas between 62° to 67° N in eastern Davis Strait (approximately from Paamiut to Sisimiut, Fig. 1.1.1) are in focus, as this is the region which potentially can be most affected by oil activities, particularly from accidental oil spills. This focus area will be referred to as the 'assessment area'. An SEIA has been produced for the area north of 67° N (Mosbech et al. 2007) and another one is being prepared for the area south of 62° N (South Greenland).

The present assessment area extends over waters of two municipalities: Sermersooq and Qeqqata. Four main cities are located within the area, Sisimiut, Maanitsoq, Nuuk and Paamiut, counting roughly 5,500, 2,800, 15,500 and 1,900 people, respectively. In addition, seven settlements are found between 62° to 67° N (from north to south: Sarfanngiut, Kangerlussuag, Kangaamiut, Napasoq, Atammik, Kapisillit and Qeqertarsuatsiaat), with altogether approx. 1,600 inhabitants (Greenland Statistics 2010, www.stat.gl).

## 1.2 Abbreviations and acronyms

AMAP = Arctic Monitoring and Assessment Programme
APNN = Department of Fisheries, Hunting and Agriculture
EIA = Environmental Impact Assessment
BAT = Best Available Technique
bbl = barrel of oil
BEP = Best Environmental Practice
BMP = Bureau of Minerals and Petroleum, Greenland Homerule Government
BTX = Benzene, Toluene and Xylene components in oil
CI = confidence interval
CRI = Cuttings Re-Injecting
CV = Coefficient of Variance
DCE = Danish Centre for Environment and Energy
DMI = Danish Meteorological Institute
DPC = Danish Polar Centre
DDT = dichlorodiphenyltrichloroethane (a synthetic insecticide)
EIA = Environmental Impact Assessment
EPA = Environmental Protection Agency
FPSO = Floating Production, Storage and Offloading unit
GBS = Gravity Based Structure
GEUS = Geological Survey of Denmark and Greenland
GINR = Greenland Institute of Natural Resources
gww = grammes, wet weight
HBCD = hexabromocyclododecane (brominated flame retardants)
HSE = Health, Safety and Environment
ICES = International Council for the Exploration of the Sea
IWC = International Whaling Commission
LRTAP = Convention on Long-Range Transboundary Air Pollution
MARPOL = International Convention for the Prevention of Pollution from Ships
MIZ = Marginal Ice Zone
NAO = North Atlantic Oscillation
NERI = National Environmental Research Institute, Denmark
NOW = North Water polynya
OHC = organohalogen contaminants
OSPAR = Oslo-Paris Convention for the protection of the marine environment of the Northeast Atlantic
PAH = Polycyclic Aromatic Hydrocarbons
PCB = Polychlorinated Biphenyls
PBDE = polybrominated diphenyl ethers
PLONOR = OSPARs list over substances which Pose Little Or No Risk to the Environment
PNEC = Predicted No Effect Concentration
POP = Persistent Organic Pollutants
ppm = parts per million
ppb = parts per billion
PTS = permanent elevation in hearing threshold shift
rms = root mean squared
SEIA = Strategic Environmental Impact Assessment
TBBPA = tetrabromobisphenol (brominated flame retardants)
TBT = tributyltin (antifouling agent)
TPH = Total Petroleum Hydrocarbons
TTS = temporary elevation in hearing threshold
USCG = United States Coast Guard

VEC = Valued Ecosystem Components
VOC = Volatile Organic Compounds
WGC = West Greenland Current
WSF = Water Soluble Fraction
ww = wet weight.

# 2 Summary of petroleum activities

*David Boertmann (AU)*

Utilisation of an oil/gas field develops through several phases, which to some degree 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

## 2.1 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 generally is much lower in water than in air, causing the strong noise created by seismic surveys to travel very long distances, potentially disturbing marine animals. Regional seismic surveys (2D seismics) are characterised by widely spaced (over many kilometres) 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 sesmic surveys. For example, a company carrying out site surveys used a single airgum (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.

## 2.2 Exploration drilling

Exploration drilling follows the seismic surveys. Offshore drilling takes place from drill 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, the jack-up rigs, which are built to stand on the seabed. It is assumed that the drilling season in the waters of Davis Strait is limited to approximately May – November, depending on the year and exact location, due to the presence of ice and harsh weather conditions during winter and spring. Drilling requires the disposal of cuttings and drill mud. In the strategic EIA of the Lofoten-Barents Sea area it is assumed that approximately 450 $m^3$ cuttings are produced and approximately 2,000 $m^3$ mud is 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 tons of drilling mud. Energy consumption is very high during drilling, resulting in emissions of combustion gases such as $CO_2$, $SO_2$ and NOx.

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).

## 2.3 Drilling mud and cuttings

Drilling muds are used to optimise drilling operations. Muds were previously oil-based (OBM), but due to the 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, resulting impacts on the benthic communities.

## 2.4 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 commercial. 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.

## 2.5 Other exploration activities

One activity that may have environmental impact during the exploration phase is helicopter transport, which is associated with 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 different chemicals, occasionally including radioactive compounds.

## 2.6 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 (GBS) or onshore (APA 2003). From the production facility crude oil subsequently has to be transported by shuttle tankers to a trans-shipment terminal, most likely in eastern Canada.

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.

## 2.7 Produced water

Produced water is by far the largest 'by-product' of the production process. On a daily basis 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 millions $m^3$ 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 to the major part of the oil pollution during normal operations, e.g. in Norway up to 88 %.

Produced water has usually been discharged to the sea after a cleaning process which reduces the amount of oil to levels accepted by the authorities (in the North Sea sector of Norway, for example, 40 mg/l or 30 mg/l as recommended by OSPAR). 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. But long-term effects of the releases of produced water have not been studied, and several uncertainties have been expressed concerning, for example, the 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, discharges will be further reduced, e.g. by the discharge policy in the Lofoten-Barents Sea area (Anon 2003b), where produced water will be re-injected except during a 5 % 'off-normal' operation time (Anon 2003b).

## 2.8 Air emmissions

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 the energy producing machinery (for drilling, production, pumping, transport, etc.). For example, the drilling of a well may produce 5 million $m^3$ exhaust per day (LGL 2005). But also flaring of gas and trans-shipment of produced oil contribute to emissions. The emissions consist mainly of greenhouse gasses ($CO_2$, $CH_4$), NOx, VOC and $SO_2$. The 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 tonnes in 1999 (STF 2000), and the drilling of the three exploration wells in 2010 in the Disko West area resulted in the emission of 105,000 tonnes 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.

## 2.9 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 1 million bbl will depart, within a 5-day cycle, from a highly productive field off Disko Island. Something similar could be expected for the eastern Davis Strait.

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

## 2.10 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 largest 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.

# 3 Physical environment

*Michael Dünweber (AU)*

The assessment area forms part of the Davis Strait and is situated within what is normally referred to as the sub-Arctic region in the marine environment, defined as the marine areas where the upper water layers are of mixed polar and non-polar origin (Dunbar 1954). The Davis Strait is a semi-enclosed oceanic basin that separates western Greenland and Baffin Island, the largest island in the Canadian Arctic Archipelago. In the north it is connected to the Arctic Ocean through Baffin Bay and the Nares Strait. In the south it is connected to the Labrador Sea. In terms of hydrography, the area is characterised by sub-Arctic waters from the North Atlantic (average July temperature higher than 5° C) in the southern part and the high-Arctic waters of Baffin Bay (average July temperature below 5° C) in the northern part.

The shelf comprises the rather shallow waters (depths less than 100m) in the northeastern corner to more than 2000m (down to 2,500 metres) in the southwestern corner. This shelf includes several large shoals or banks e.g., Fyllas Banke, Sukkertop Banke and Store Hellefiskebanke, typically ranging between 20 and 100m in depth. The shelf is traversed by deep troughs, which separate the fishing banks. At its narrowest point, a ridge up to approximately 600m deep extends between Greenland (at Holsteinborg, Sisimiut) and Baffin Island (at Cape dyer).

On a large scale, the metrological and oceanographic conditions of Davis Strait are quite well known. Recent descriptions are found in (Buch et al. 2005, Myers et al. 2009), however the majority are focused on the Baffin Bay area with short descriptions of the Davis Strait (Tang et al. 2004, Dunlap & Tang 2006). More detailed descriptions on hydrography are found for offshore areas prepared by the Danish Meteorological Institute and Bureau of Minerals and Petroleum (DMI and BMP, respectively) (Nazareth & Steensboe 1998, Buch 2000, Karlsen et al. 2001, Buch 2002, Hansen et al. 2004, Ribergaard 2010). An early impact assessment report by NERI for the Fyllas Banke is found in Mosbech et al. (1996b) and an oil sensitivity atlas for the coastal zones of West Greenland by Mosbech et al. (2004a) and (2004b).

## 3.1 Weather and Climate

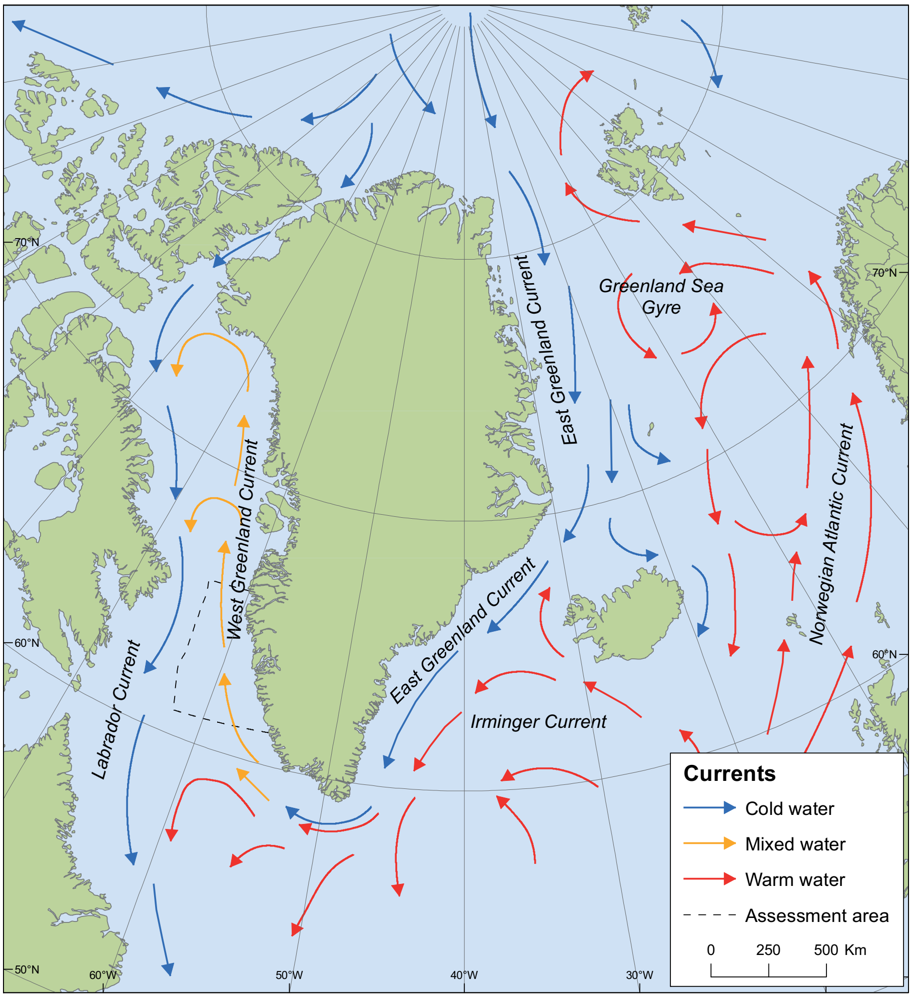
The weather in this region is determined by the North American continent and the North Atlantic Ocean, namely the North Atlantic Oscillation (NAO). NAO exerts a dominant influence on the winter-time temperatures of surface air and sea temperatures in the Arctic. When the NAO is positive, enhanced westerlies flow across the Atlantic and intensify the North Atlantic Current, which is deflected to the east of Greenland. This results in low intensities of the cold, south-flowing East Greenland Current and the warm, north-flowing Irminger current (derived from the North Atlantic Current), producing cold conditions in the Arctic region. When the NAO is negative, the conditions are almost the opposite, with low inflow of North Atlantic Waters coupled with an intensified East Greenland Current and Irminger Current giving warm Arctic temperatures (Buch 2002, Ribergaard 2010). However, the Greenland Inland ice and the steep coasts of Greenland also have a fundamental impact on the weather local to the area. Many Atlantic depressions develop and pass near the southern tip of Greenland and frequently cause very strong winds off West Greenland. Also more local phenomena such as fog or polar lows are 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 of local wind patterns can be found in the sensitivity atlas of the West Greenland region prepared by NERI (Mosbech et al. 2004b).

## 3.2 Oceanography

### 3.2.1 Currents

Along West Greenland the West Greenland Current flows with two principal components. Closest to the shore the surface layer (0-150 m) from the East Greenland Current (with cold Polar Sea water) moves northward. On its way, this water is diluted by run-off water from the various fjord systems, e.g. Godthåbsfjorden (Kangersuneq). The other component (depth layer of 150-800 m) is from the North Atlantic Current deriving from the Irminger Sea. This relatively warm and salty water can be traced all the way along West Greenland from Cape Farewell to Thule/Qaanaaq (Fig. 3.2.1).

**Figure 3.2.1.** Major sea surface currents in the northern Atlantic.



Along the Greenlandic west coast the current patterns tend to follow the bathymetry along the coast (Ribergaard et al. 2004). Southeast 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 East Greenland Current component loses its momentum on the way northward, and at the latitude of Fylla Banke (64º N) there is no longer a strong and solid current. A great proportion of the mass is deflected westward towards Canada where it joins the Labrador Current. Further north the deflection towards west continues resulting in a further weakening of the current (Buch 2000).

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 62º N and 67º N are usually ice free during winter time. Mixing and heat diffusion of the two layers (The Polar and Irminger Currents) are important factors in determining temperature conditions in the assessment area. Years where the East Greenland Current and Irminger Current are strong will often be cold years (Nazareth & Steensboe 1998, Buch 2000, 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. These climatic variabilities can be related to shift in the NAO index from negative to positive values during the period 1970-2000, resulting in colder climate (Buch et al. 2005). However, over 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). High melt rates from the inner Godthåbsfjord glacier suggest increased input of freshwater to the West Greenland basin, presumably affecting the marine ecosystem and the fjord and marine water exchanges (Rysgaard et al. 2008 and references therein). The warmer climate in the Arctic during the last decade may partly be a result of the change in the NAO index from positive to negative. However, there is a profound increase of 0.4º C per decade (1966-2003) in Arctic surface air temperature, which deviates from that of natural expected variations (McBean et al. 2005).

### 3.2.2 Hydrodynamic discontinuities

Hydrodynamic discontinuities are areas where different water masses meet with sharp boundaries and steep gradients between them. They can be upwelling events where cold nutrient water is forced upwards to the upper layers, fronts between different water masses and ice edges (inclusive the marginal ice zone). Upwelling often occurs along the steep sides of the shelf banks driven by the tidal current and therefore usually alternates with downwelling. Model simulations north of the assessment area predict that that most frequent upwelling occurs west of the banks, both north and south of the Disko Bay entrance and at the slopes of Store Hellefiskebanke (Mosbech et al. 2007 and references therein).

### 3.2.3 The coasts

The coastal zone between 62º-68º N is dominated by bedrock shorelines with many skerries and archipelagos. In sheltered areas small bays with sand or gravel are found between the rocks. Sandy beaches are found in the Marraq-Sermilik area and in the vicinity of the Frederikshåb Isblink glacier, where there are extensive sandy beaches and barrier islands (Mosbech et al. 1996b).

## 3.3 Ice conditions

Sea ice of the following main types occurs in the Davis Strait: 'Storis', which is mainly multi-year drift ice of polar origin carried to Southwest Greenland by the East Greenland Current; and the 'West ice', which is mainly first-year drift ice formed in Baffin Bay and the Davis Strait. Sea ice is normally present in the Davis Strait from November to mid-summer. However, the waters south of Nuuk are normally free of sea ice but occasionally covered for a short period of time in late winter. During the spring and early summer months, multi-year sea ice can drift into the area (Nazareth & Steensboe 1998, Buch 2000, Karlsen et al. 2001, Buch 2002, Hansen et al. 2004). The Davis Strait experiences strong annual variability in sea ice extent and concentration, primarily driven by wind and current patterns, and low winter temperatures. The variability in distribution of the sea ice is primarily determined by the annual North Atlantic Oscillation (NAO) index, 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 (Buch 2000, 2002, Heide-Jørgensen et al. 2007b).

The assessment area is influenced by the warm West Greenland Current, which is an offshoot of the Gulf Stream. The warm, north-flowing West Greenland Current creates open water in winter along the Southwest Greenland coast, and inhibits ice formation close to the Greenland West coast as far as to 67º N (Nazareth & Steensboe 1998, Buch 2000, 2002, Hansen et al. 2004). This warm flowing current has such an impact in the area that it usually results in earlier breakup of the sea ice in the eastern part than in the western part of the Davis Strait. During winter and early spring West ice is conveyed south along Baffin Island to Davis Strait and Labrador Sea. At the end of the freeze-up season, first year sea ice usually dominates in the eastern part of the Davis Strait, while the western and central parts of the Davis Strait are dominated by thicker first year sea ice mixed with smaller parts (1-3 tenths) of multi-year sea ice. The northwestern part from Fyllas Banke is usually free of West ice from early May until early January and the southeastern part is free from mid-April until late January (Nazareth & Steensboe 1998).

Sea ice cover has decreased in the Arctic during the past 20 years (Parkinson 2000), both in thickness and extent (Rothrock et al. 1999). This has occurred much faster than would be expected from natural climate variations (Vinnikov et al. 1999). Observations based on satellite data from 1979-2007 show 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). In recent years sea ice has shown high year-to-year variability or reduced extent for limited time periods in Disko Bay (Hansen et al. 2006), depending on atmospheric cooling (Buch 2000, 2002, Tang et al. 2004). Evidence exists of increased volumes 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). The extent to which the increased freshwater input from the fjord systems affects the characteristics of the West Greenland Current is currently unknown.

### 3.3.1 The West Ice and drift patterns

The 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 effects of the cold south-flowing Baffin Island Current. Ice starts to form in the open water in the northern Baffin Bay in September when the amount of West Ice (first year ice) in the Davis Strait and Baffin Bay is at the lowest level. In the following months, ice cover increases steadily from north to south reaching a maximum in late winter, usually in March, after which it decreases (Nazareth & Steensboe 1998, Buch 2000, 2002, Hansen et al. 2004). The relatively warm West Greenland Current delays sea ice formation in the eastern Davis Strait and results in an earlier breakup of the sea ice than in the western parts. There is therefore always more ice cover in the western than in the eastern half of Baffin Bay (Fig. 3.3.1). The Baffin Island Current conveys large amounts of sea ice from Baffin Bay to the Davis Strait and Labrador Sea, especially during the winter and early spring months. During this period sea ice normally covers most of the Davis Strait north of 65° N, but not areas close to the Greenland coast. Here, a flaw lead (open water or thin ice) of varying widths often appears between the shore and the offshore parts of the fast- and drift ice as far north as latitude 67° N. South of 65°- 67° N, sea ice-free areas dominate throughout the year. The eastern part of the Davis Strait, south of Disko Island, is free of sea ice during this period (Fig. 3.3.1 and 3.3.2), whereas drifting ice dominates to the west and north. The area northwest of the Fyllas Banke area is normally free of West Ice from early May until early January (Valeur et al. 1996, Nazareth & Steensboe 1998).

Small amounts of multi-year ice of Arctic Ocean origin drift to the western parts of the area from Lancaster Sound or Nares Strait; however, the multi-year ice from these waters does not usually reach the West Greenland shores. At the end of the freeze-up season, first-year ice in the thin and medium categories dominates in eastern parts (up to about 100 km from the Greenland coast). The western and central parts of the Davis Strait are dominated by medium and thick first-year ice categories, mixed locally with small amounts (1-3 tenths) of multi-year ice (Nazareth & Steensboe 1998) (Fig. 3.3.1).

The local drift is to some extent controlled by the major surface current systems, the West Greenland Current and Baffin Island Current; however, the strength and direction of the surface winds also affect the local drift of sea ice, especially in the southern waters.

Under normal conditions the multi-year sea ice (Storis) drifts to the Cape Farewell area in December/January depending on the low pressure system of the North Atlantic Ocean. In spring and summer, the low pressure system normally weakens and the Storis drift into Northeastern Labrador Sea or North-westward along the West Greenland coast. However, on average Storis drifts north of 63º N every second year, but the amount and presence of the Storis varies between these years. Storis has never been observed north of 63º N earlier than late February (Hansen et al. 2004).

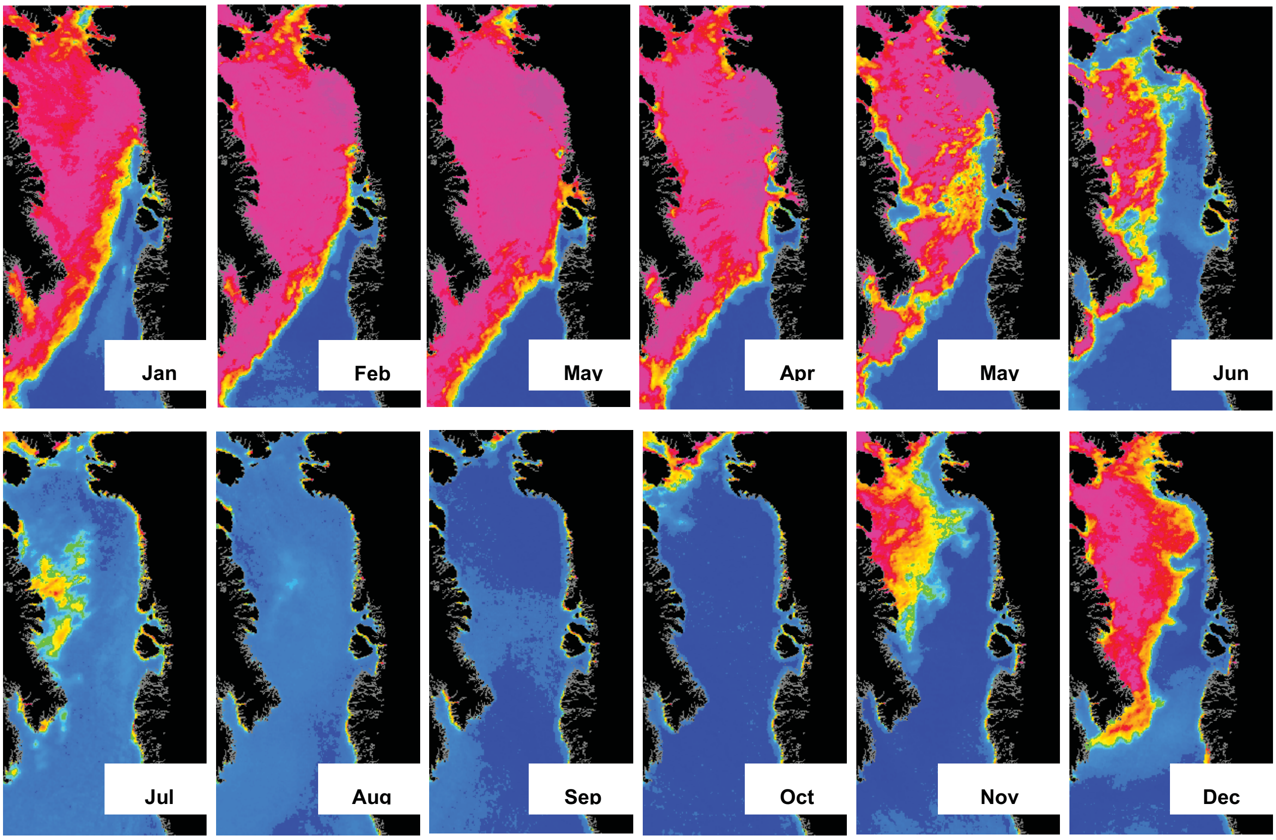


**Figure 3.3.1.** The monthly sea ice cover in 2010, January - December. Red and magenta indicate the very dense ice (8-10/10), while yellow indicates somewhat looser ice. The loosest ice (1-3/10) is not recorded. Images based on Multichannel Microwave Radiometer (AMSR and SMMR) and processed by the Technical University of Denmark (DTU) with support from the European Space Agency (ESA)'s PolarView project.

The size of the common ice floes near the marginal ice zone in the Davis Strait are less than 100 metres as a result of melting and breakup by waves. These floes are often consolidated, forming extensive areas without any open water. The dominant size of ice floes range from large floes of about 1 km wide to vast floes larger than 10 km (Nazareth & Steensboe 1998).

A sea ice drift pattern was studied north of the assessment area in April 2006 by Mosbech et al. (2007 and references therein). In April 2006 two satellite transmitters were deployed on the sea ice, west of Nuussuaq Peninsula. Their purpose was to track the movements of the drift ice. One was tracked until June, when it had moved approximately 500 km in total (entire length of track line), but overall it had only moved 66 km towards the southwest. The second transmitter was only tracked for a couple of days, when it moved 21 km towards the south (Mosbech et al. 2007). No specific sea ice drift patterns were observed during that study which suggest further experiments are required on this subject in the future.

### 3.3.2 Icebergs

Icebergs differ from sea ice in many ways:

- They originate from land
- They produce freshwater on melting
- They are deep-drafted, with appreciable heights above sea level
- They are always considered as an serious local hazard to navigation and offshore activity

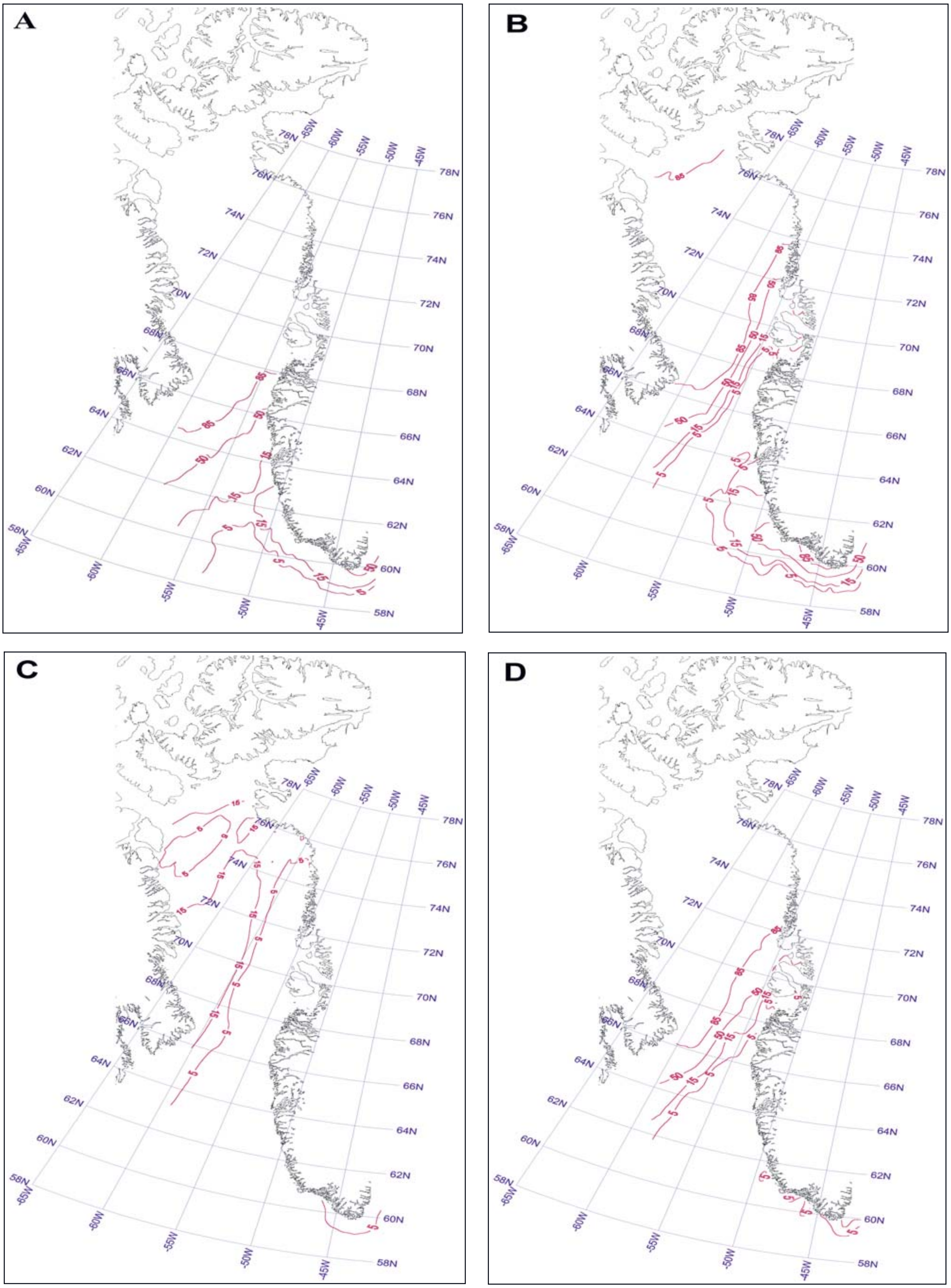
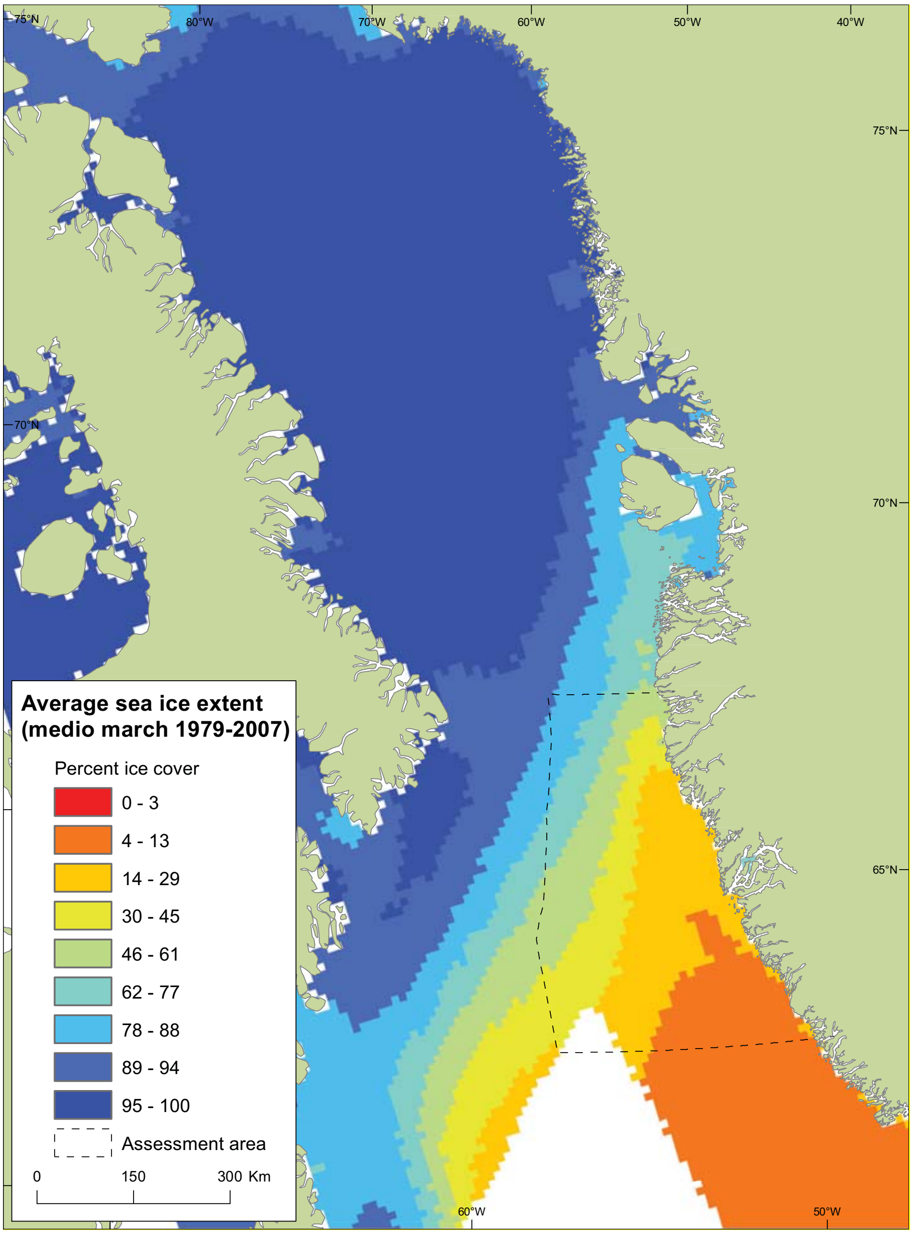



**Figure 3.3.2.** Probability of sea ice in West Greenland waters based on data from the period 1960-96. (A) March 1st (B) June 4th (C) September 3rd and (D) December 3rd. Based on data from the Danish Meteorological Institute (DMI) and Canadian Ice Service – Environment Canada (CIS).

**Figure 3.3.3.** Average sea ice extent as percentage ice cover in West Greenland waters based on data in the period 1979-2007 (medio March). Blue colours indicate highest percentage ice cover while red indicates lowest percentage cover. White has no data value. 'High' ice cover is encountered west of Disko Island while low ice cover is found south of Sisimiut in March (Data sources: Ocean and Sea ice (EUMETSAT).




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 has been 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; however, the productive glaciers which produce the most and the largest icebergs are Jakobshavn Isbræ (Ilulissat), Disko Bay western Greenland and Ittoqqortoormiit, eastern Greenland. In general, icebergs occur in West Greenland waters between 60° and 72° N, with some exceptions, e.g. low iceberg concentrations off Sisimiut. In Disko Bay, hundreds of icebergs are present throughout the year (Fig. 3.3.4) (Valeur et al. 1996, Karlsen et al. 2001).

Most of the icebergs found near assessment area are formed from East Greenland glacial outlets. Large annual variation in the number and size of the icebergs rounding Cape Farewell and transported all the way up to Nuuk and Maniitsoq with the West Greenland current (Nazareth & Steensboe 1998, Buch 2000, Karlsen et al. 2001). Occasionally, 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 ocean areas (Karlsen et al. 2001).

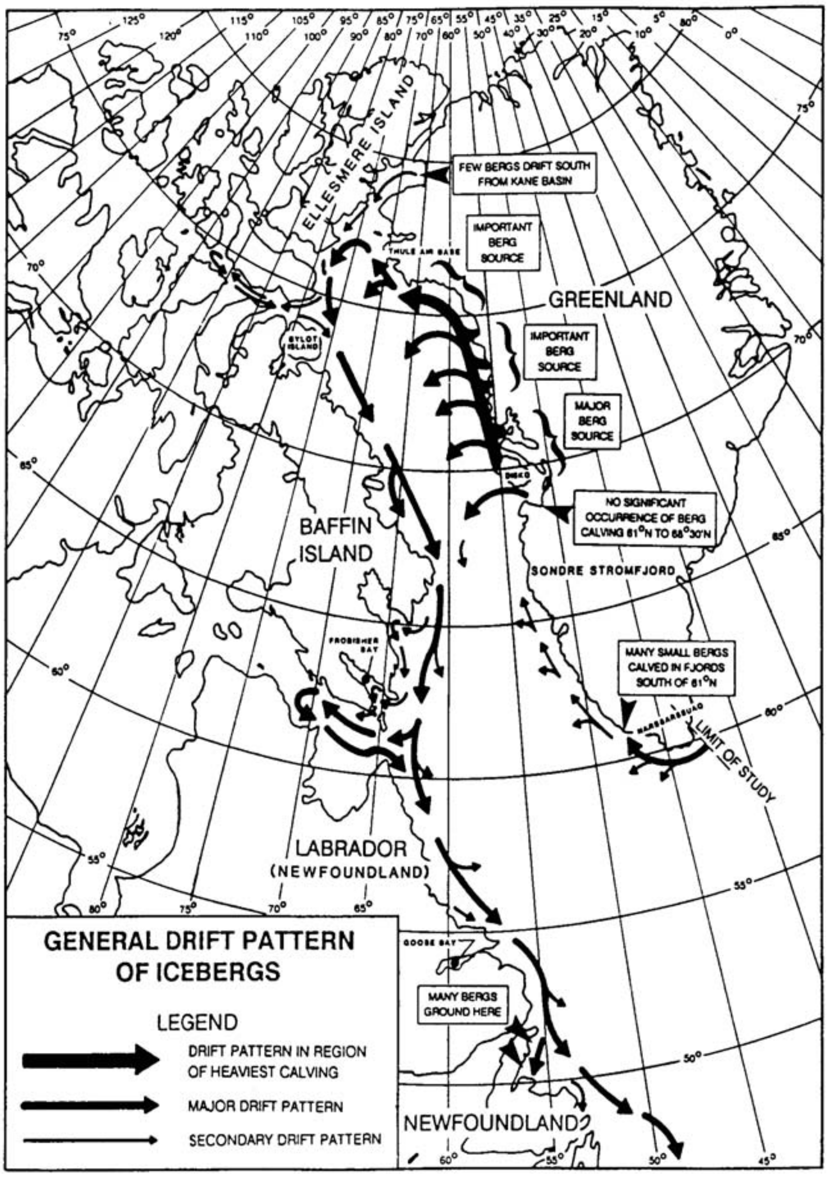
#### Iceberg drift and distribution

On a large scale the basic water currents and drift of icebergs in the Davis Strait are fairly simple. There is a north-flowing current along the Greenland coast (West Greenland current) and a south-flowing current along Baffin Island and the Labrador coast (Baffin Island current), giving an anti-clockwise drift pattern (Fig. 3.3.4). However, branching of the general currents causes variations, and these can have a significant impact on the iceberg number and their residence time. Thus, the distribution of icebergs in the area 63º to 68º N is influenced both by the north going West Greenland current and the south going Baffin Island current and the interaction between them. Thus, the iceberg drift mainly responds to the surface circulation of these two current patterns (Karlsen et al. 2001).

Most of the icebergs found near the Fyllas Banke area are from the East Greenland glaciers. Occasionally, East Greenland icebergs under the effects of wind and the absence of the Irminger Current (part of the West Greenland Current) drift westwards across the southern Davis Strait to the coast of Labrador and Baffin Island. There, they join the main stream drifting southwards.

Distribution and density of icebergs are also controlled by the presence of multi-year sea ice (Storis), since icebergs drifting within the Storis are prone to lower melting rates and less deterioration from wave/swell action (Karlsen et al. 2001, Hansen et al. 2004). The bathymetry is another factor determining the variability of icebergs south of the Fyllas Banke area, since the continental slope being particularly steep makes it a shallow water region. This underlying bathymetry formats eddies (i. e. a circular and counter current motion from the main water flow) creating instability in the Irminger Current, resulting in westward branching of the current. Therefore, the largest north-going icebergs will probably ground before reaching into certain shallow areas or branch off to the western side of the Fyllas Banke area (Nazareth & Steensboe 1998, Hansen et al. 2004).

**Figure 3.3.4.** Major iceberg sources and general drift pattern in the West Greenland Waters. Data source: US National Ice Center (NIC).




A study in the late 1970s on iceberg masses that occur on the western coast of Greenland observed low iceberg mass (0.3-0.7 million tonnes, max.: 2.8 mil. tonnes) in the area between 64° and 66° N compared with iceberg masses north and south of the area (Nazareth & Steensboe 1998 and references therein). The year-to-year variability in distribution of multi-year sea ice and the presence of the Irminger current in the Davis Strait therefore concurrently determine the amount and size of icebergs reaching the assessment area.

Studies of the iceberg distribution at the Fyllas Banke area in summer 2000 by Karlsen et al. (2001) were predominantly of bergy bits and growlers types, mostly entering the area from southerly to northeasterly directions. More than 200 icebergs were observed during the summer period and presumably represent a normal seasonal iceberg conditions. Other studies of the iceberg distribution on the west coast of Greenland are from the late 70'ties, and summarized in later reports (Valeur et al. 1996, Karlsen et al. 2001).

The majority of icebergs from Jakobshavn Isbræ, Disko Bay are carried northward to northeastern Baffin Bay and Melville Bay before heading southward. Most of the icebergs from Baffin Bay drift southward in the western Davis Strait, joining the Labrador Current further south; although some may enter the eastern Davis Strait instead. Icebergs produced in Disko Bay or Baffin Bay will generally never reach the Greenland shores south of 68° N.

### 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 from 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 tonnes, with a maximum mass of 8.0 million tonnes. Average draft was 60-80 m and maximum draft was 138 m. In between 64° N and 66° N, average masses were between 0.3 and 0.7 million tonnes with maximum mass of 2.8 million tonnes. Average draft was 50-70 m and maximum draft was estimated to be 125 m. The largest icebergs north of 66° N were found north and west of Store Hellefiskebanke. The average iceberg mass was about 2 million tonnes with a maximum mass of 15 million tonnes. It is worth noting that many icebergs are deeply drafted and, due to the bathymetry, large icebergs will not drift into shallow water regions (Valeur et al. 1996, 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 into 'small' pieces, and thresholds in the mouths of the glacier fjords. The measurements of iceberg drafts north of 62°N indicate that an upper limit for a draft of 230 m will only very rarely be exceeded; 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. The large icebergs originating in Baffin Bay are expected to have a maximum draft of about 250-300 m (Valeur et al. 1996, Karlsen et al. 2001).

# 4 Biological environment

## 4.1 Primary productivity

*Michael Dünweber (AU)*

### 4.1.1 General context

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

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

Development of the phytoplankton (microscopic algae) bloom in spring gives a peak in the primary production in the water column and is the single most important event determining the productive capacity of Arctic marine food webs. The time of the onset of the spring phytoplankton bloom (i.e. spring bloom) varies each year according to the duration of the winter sea ice cover, oceanography and meteorological conditions. The spring bloom develops when the water column is stabilised and retreat of the sea-ice cover and solar input penetrates into the water column. The spring bloom quickly depletes the surface layers (the euphotic zone) of nutrients, inhibiting primary production for some time.

### 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 over time, and their distribution varies according to oceanographic and climatic conditions. However, at sites where nutrients are continuously brought to the uppermost water layers, e.g. 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. There is limited knowledge on sea-ice communities in the assessment area, but see section 4.5 for the information available.

### 4.1.3 The spring phytoplankton bloom in Davis Strait

The spring phytoplankton bloom (i.e. spring bloom) usually begins in Southwest Greenland in late March/early April. In the ice-covered areas timing of its onset is determined by withdrawal of the Davis Strait pack ice (the West Ice). However, most of the southeastern part of the assessment area generally has open water all year around due to the warm West Greenland Current. In the southwestern part of the assessment area the sea ice retreats in March and the northern part usually has open water April-May. Sea ice is therefore generally not considered a limiting factor for initiation of the spring bloom in the assessment area.

A multidisciplinary ecological survey programme (2005-2009) is presented in the annual 'Nuuk Basic' reports, presenting sampling from the inner Godthåbsfjord to Fyllas Banke, southwest Greenland (Juul-Pedersen et al. 2008, Rysgaard et al. 2008, Juul-Pedersen et al. 2009) and described in detail for the year 2006 (Arendt et al. 2010). The following biological descriptions focus mainly on the Fyllas Banke area, which is an area of key importance in the assessment area. Based on measurements of phytoplankton concentration for 2010, elevated values occur in March and early April with peak sea surface concentrations in late April and early May (see also Fig. 4.1.1). Phytoplankton biomass then decreases throughout the summer, usually associated with the pycnocline. In late summer in August there is usually a minor secondary bloom peak.

High concentrations of chlorophyll a (chl *a*) were frequently measured at the outer Fyllas Banke. A high integrated phytoplankton biomass (chl *a* converted to carbon) in the central parts of Fyllas Banke was measured to 4857mg C $m^{-2}$ in the upper 50 m (Arendt et al. 2010). High chl *a* biomass was also found in another shallow water area at Store Hellefiskebanke, northeast of the assessment area. The shallow banks keep the phytoplankton in the photic zone where net growth is possible. Strong tidal mixing may also feed the upper layers with nutrients (i.e. upwelling), which boosts the bloom even more. Upwelling areas are, for example, found at the fishery banks in South and West Greenland e.g. Fyllas Banke and Store Hellefiskebanke. Upwelling areas may, besides enhanced production, also retain copepods, which again are utilised by fish larvae (Simonsen et al. 2006). Therefore, the bank areas are important for increased primary productivity and carbon cycling caused by nutrient-rich upwelling events from wind and tidal motions in the Davis Strait.

### 4.1.4 Productivity at polynyas and shear zones

Polynyas are predictable open-water areas in otherwise ice-covered waters in winter and spring. Part of the assessment area has open water all year around, and thereby acts much like a polynya; although always open to the south. In polynyas primary production starts much earlier than in ice-covered areas, which means they often are preferred feeding areas for marine mammals and seabirds. However, the mere presence of open water makes polynyas attractive for resting seabirds and for mammals that are dependent on open waters for breathing. Many migrating seabirds also use polynyas as staging grounds on their way to breeding grounds further north.

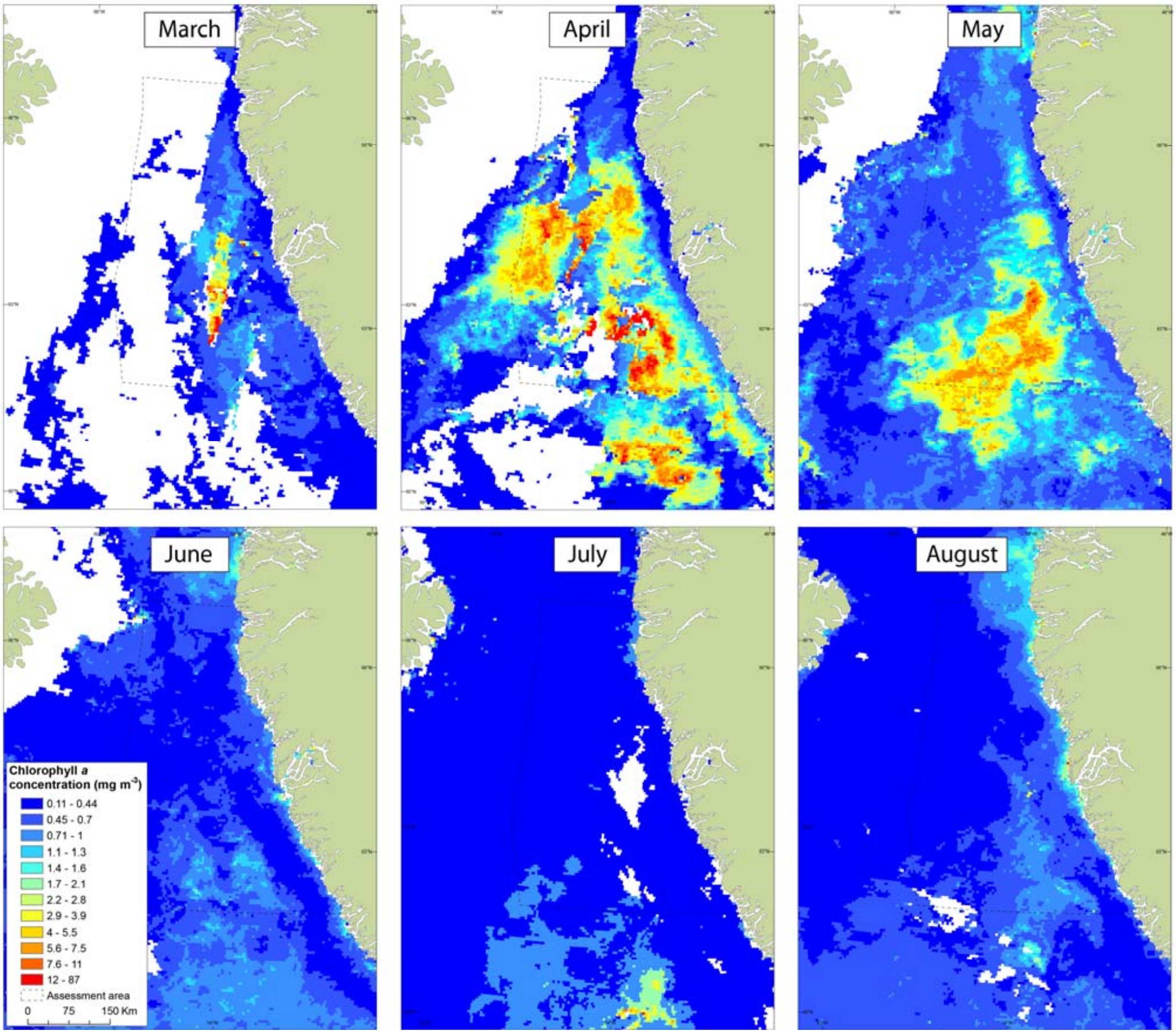



**Figure 4.1.1.** Monthly progressions in sea surface chlorophyll *a* (chl *a*) concentrations (mg $m^{-3}$) from March to August 2010. Data are presented as a monthly average from MODIS level 3 aqua. The colours indicate chl *a* concentrations, blue areas are very low and red is high chl *a* concentration and white indicate ice cover or no data values. The spring bloom in 2010 seems to start in March at Fyllas Banke. Productivity peaks in April and May and occurs then more widely over the shelf break and in neighbouring offshore areas. Following a period of low surface chl *a* in the assessment area in July a post bloom occurs at the coast in August (e.g. at the mouth of Godthåbsfjorden). Data is from the Oceancolor homepage, NASA.

Shear zones are where the solid coastal ice meets the dynamic drift ice. Cracks and leads with open waters are frequent in this type of area and may attract marine mammals and seabirds. When the West ice reaches the coasts, although this occurs rarely in the assessment area, a shear zone is usually present.

## 4.2 Zooplankton

*Michael Dünweber (AU)*

### 4.2.1 General context

Zooplankton has an important role within 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. little auk (*Alle alle*), 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 the *Calanus* copepods, play a key ecological role in supplying the benthic communities with high quality food with their large and fast-sinking faecal pellets (Juul-Pedersen et al. 2006). Thus, vertical flux of faecal pellets sinking down to the seabed sustains diverse benthic communities such as bivalves, sponges, echinoderms, anemones, crabs and fish (Turner 2002, and references therein).

### 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 form of lipids, which are used for overwintering at depth and to fuel reproduction the following spring (Lee et al. 2006, Falk-Petersen et al. 2009, Swalethorp et al. 2011). Most of the higher trophic levels rely on the lipids accumulated in *Calanus* mainly as wax esters. These can be transferred through the food web and incorporated directly into the lipids of the consumer through several trophic levels. For instance, lipids originating from *Calanus* can be found in the blubber of beluga and sperm whales, which feed on fish, shrimps and squid (Smith & Schnack-Schiel 1990, Dahl et al. 2000) and in the bowhead whale (*B. mysticetus*) and northern right whales (*Eubalaena glacialis*), which feed mainly on *Calanus* (Hoekstra et al. 2002, Zachary et al. 2009). Consequently, many biological activities – e.g. spawning and growth of fish – are synchronised with the life cycle of *Calanus*. In larvae of the Greenland halibut (*Reinhardtius hippoglossoides*) and sandeel (*Ammodytes* sp.) 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 biomass of ingested prey (Simonsen et al. 2006).

Vertical distributions of the *Calanus* species are influenced strongly by ontogenetic vertical migrations that occur between the dark winter season and the light summer season. For the most of the light summer season *Calanus* is present in the surface waters. During summer and autumn, *Calanus* begins to descend to deep-water layers for winter hibernation, changing the plankton community structure in the upper water column from *Calanus* 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 considerably higher than in spring. This is a result of shorter generation time and more sustained reproduction as well as relaxed food competition and predation by *Calanus* (Hansen et al. 1999, and references therein). The importance of small non-*Calanus* population in ecosystem productivity can be greater than implied by their biomass alone (Hopcroft et al. 2005, Madsen et al. 2008).

### 4.2.3 Zooplankton in the Davis Strait

Knowledge of zooplankton in the assessment area is based on studies covering a 34-year time series from the 1950s by Pedersen & Smith (2000) and recent studies covering most of the southwestern coastal zone (Pedersen & Rice 2002, Head et al. 2003, Munk et al. 2003, Pedersen et al. 2005, Arendt et al. 2010). The coastal studies in Southwest Greenland clearly corroborate the hypothesis that most of the biological activity in the surface layer is present in the spring and early summer in association with the spring bloom and appearance of the populations of the large copepods *Calanus*. *Calanus* occurrence is widespread in the West Greenland waters, where high biomass values have been recorded across the fishery banks in Southwest Greenland, and is almost exclusively dominated by *C. finmarchicus* (Pedersen et al. 2005, Arendt et al. 2010) (Fig. 4.2.1).

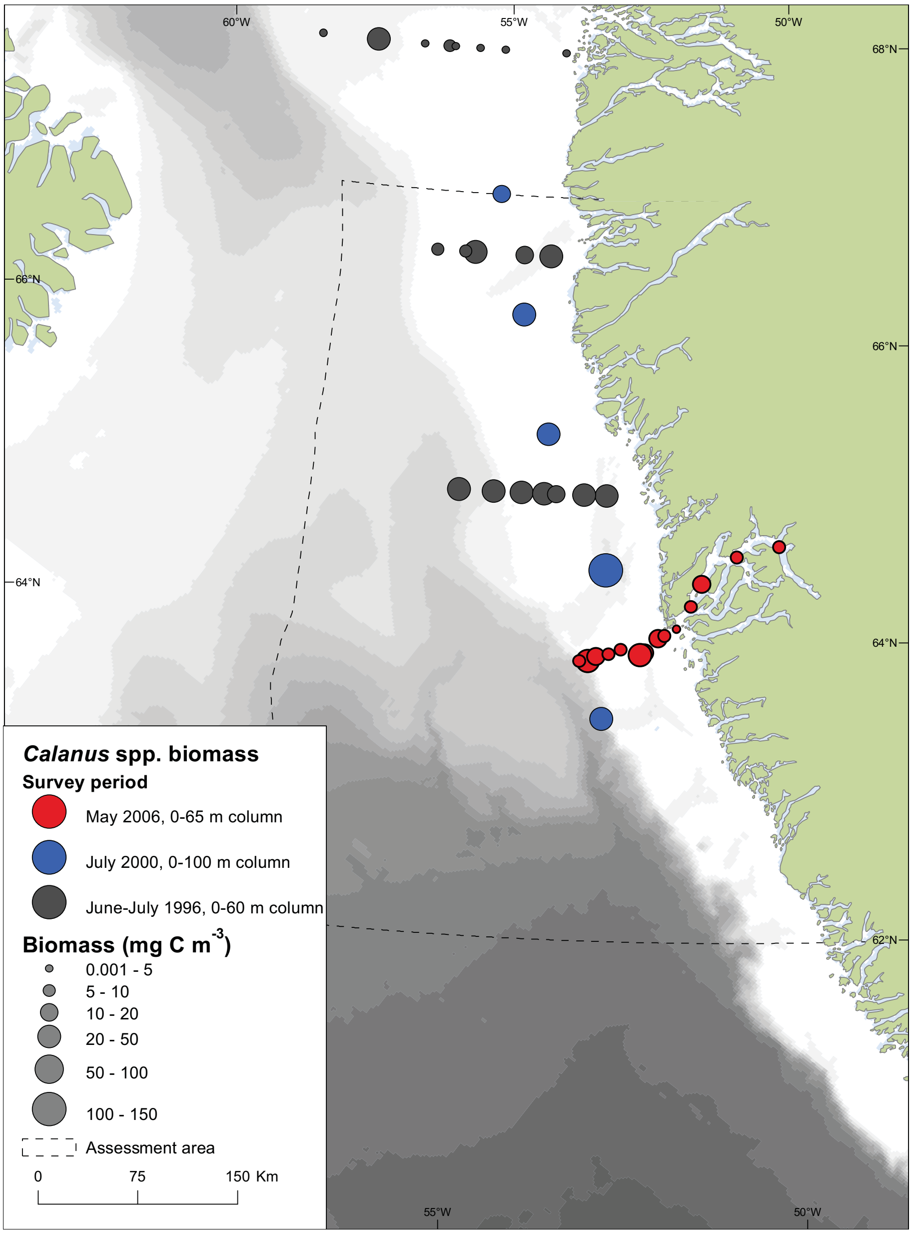



**Figure 4.2.1.** *Calanus* spp. biomass (mg C m$^{-3}$). The coloured dots represent biomass values from different studies; red dots: from May 2006 in the 0-65 m column (Arendt et al. 2010), blue dots: from July 2000 (Pedersen & Smidt 2000) at 0-100 m, dark grey dots: from June-July 1996 (Munk et al. 2003) at 0-60 m column. The biomass values of *Calanus* spp. summer and an autumn period show higher biomass values east and west of the fishery banks. Seasonal descent of *Calanus* towards winter hibernation is presumed to have begun in July-August. Note: Biomass values are calculated based on different length-carbon regressions and using different sampling gear e.g. net types vary between studies.

In general, abundance of *C. finmarchicus* increases as you move from the Arctic region and further south to the sub-Arctic. This is because the drift of *C. finmarchicus* into the assessment area by means of the West Greenland current has strong implications for their distribution, life cycle and production, and for the succeeding link in higher trophic transfer, e.g. Atlantic cod (*Gadus morhua*). Transportation of *C. finmarchicus* from the North Atlantic into the South and West Greenland waters can, depending on food availability, outnumber the true Arctic *C. glacialis* and *C. hyperboreus* by a factor of three throughout the year (Pedersen et al. 2005, and references therein). *C. glacialis* and *C. hyperboreus* have a higher fat content.

There is a lack of knowledge of zooplankton from the offshore parts. It is assumed that the zooplankton community in the assessment area is similar to that found in the coastal area in Southwest Greenland; however, there is expected to be a difference in biomass with lower density offshore than inshore/coastal areas, e.g. the Fyllas Banke area.

### 4.2.4 Zooplankton dynamics in the coastal areas

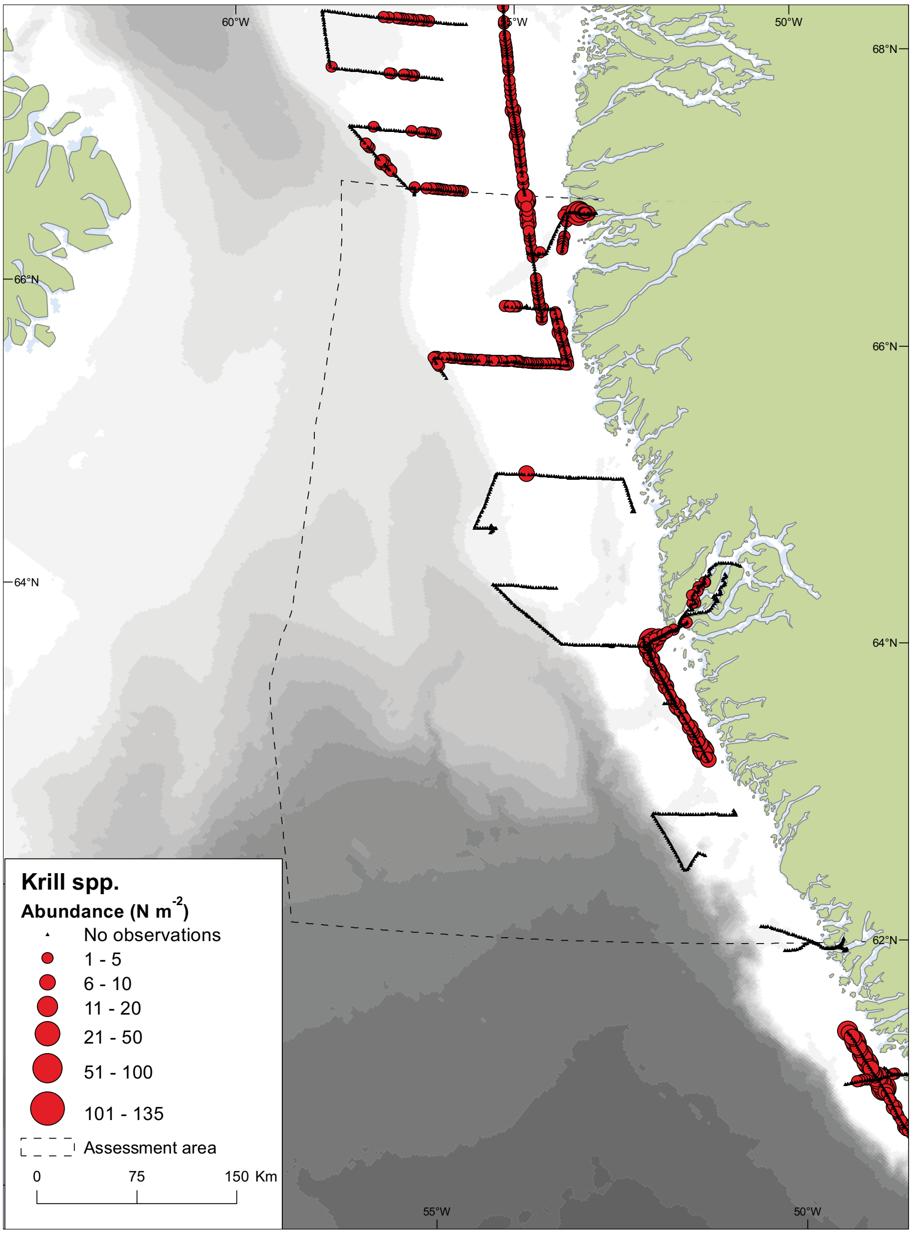
High occurrence of zooplankton species linked to the fishery banks, e.g. Fyllas Banke, are controlled by the hydrographic characteristics of the area and associated predator-prey interactions (Pedersen & Smidt 2000, Pedersen & Rice 2002, Pedersen et al. 2002, Ribergaard et al. 2004, Buch et al. 2005, Pedersen et al. 2005, Bergstrøm & Vilhjalmarsson 2007, Arendt et al. 2010, Laidre et al. 2010). The frontal system occurring at the banks and the upwelling of deeper nutrient rich waters enhances the productivity of the plankton communities in those areas.

A model simulation by Pedersen et al. (2005) describing the linkages of hydrographical processes and plankton distribution demonstrated across the fishery banks (64-67º N) of the Southwest coast of Greenland that wind fields and tidal currents were important, creating temporally retention areas of the plankton. High copepod abundances, mainly *Calanus* spp. coincide with high chl *a* values just east and west of the banks. This agrees with model description of upwelling, which occurs mainly west and to a lesser extent east of the banks, increasing the plankton productivity in the bank areas. Munk et al. (2003) found a close link of plankton distribution with hydrographical fronts, and apparently specific plankton communities were established in different areas of the important fishery banks of West Greenland. Ichthyo- (fish) and zooplankton communities differed in species composition in the north-south distribution of polar versus temperate origin. It seems that flow of major currents and establishment of hydrographical fronts are of primary importance to the structure of plankton communities in the West Greenland shelf area, influencing plankton assemblage and the early life of fish.

### 4.2.5 Higher trophic levels – large zooplankton and fish larvae

Large zooplankton species such as the krill species (*Meganyctiphanes norvegica*) were examined in September 2005 by the Greenland Institute of Natural Resources (GINR) (Bergstrøm & Vilhjalmarsson 2007) as well as in association with large baleen whales in West Greenland (Laidre et al. 2010). Krill were found in scattered aggregations in most of the area (Fig. 4.2.2).

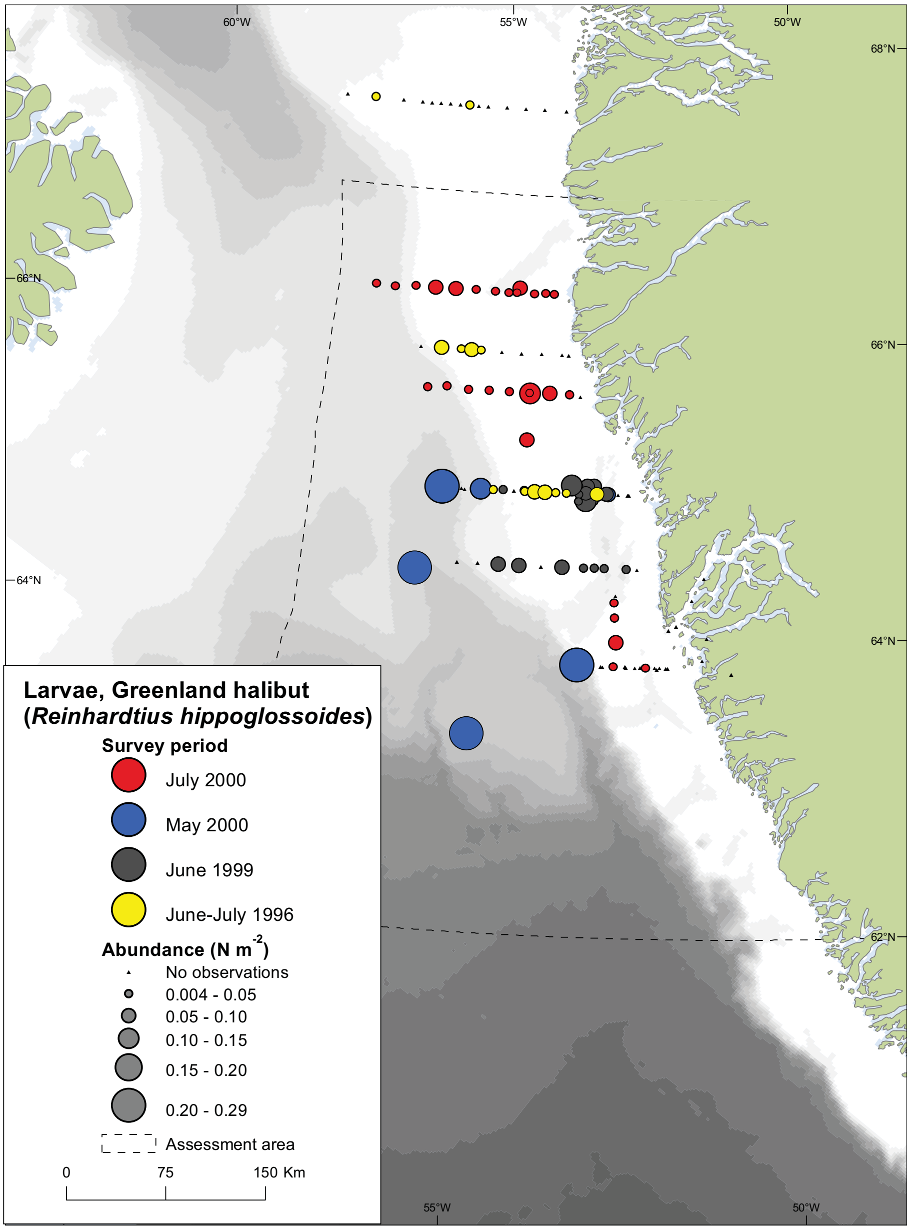
Figure 4.2.2. Krill abundance (N m$^{-2}$) from acoustic measurements from September 2005 in the 0-50 m column (Bergstrøm & Vilhjalmarsson 2007). High krill abundance, mostly *Meganyctiphanes norvegica*, is evident near the coastal areas.




Fish larvae are important components of plankton, and movements and behaviour have been studied for some of the commercially utilised species. Pedersen & Smidt (2000) analysed fish larvae data sampled along three transects during summer in West Greenland waters over 34 years. Peak abundance fish larvae were also observed in early summer in association with the peak abundance of their plankton prey.

Recently, several surveys have investigated the horizontal distribution of fish larvae (Born et al. 2001, Munk et al. 2003, Simonsen et al. 2006) in relation to oceanography and their potential prey along West Greenland (Fig. 4.2.3, 4.2.4, 4.2.5). They document that the important sites for the development of fish larvae are the banks and the shelf break, where the highest biomass of their copepod prey is also located (Simonsen et al. 2006).

**Figure 4.2.3.** Greenland halibut (*Reinhardtius hippoglossoides*) larvae abundance (N m$^{-2}$). The coloured dots represent abundance values from different studies; red, blue, dark-grey and yellow dots: from surveys in May-July 1996-2000 (Munk et al. 2000, Munk et al. 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). There are indications of relatively high abundances offshore compared with inshore/coastal areas.




Greenland halibut larvae concentrations in the upper water column are relatively high south of 68° N, while within the major part of the assessment area they are low in June-July, based on Figure 4.2.3. Other fish larvae that have been studied include sandeel (*Ammodytes* spp.), which were very numerous particularly on some of the banks (Fig. 4.2.4) (Pedersen & Smidt 2000).

In 1996-2000 studies on fish larvae in West Greenland waters were carried out (Munk et al. 2000, Munk et al. 2003, Munk pers. comm., and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). These studies did not find the sandeel larvae concentrations as reported by Pedersen & Smidt (2000). They found large interannual variation in abundance of polar cod larvae and confirmed the distribution of Greenland halibut larvae as reported by Pedersen & Smidt (2000) (Fig. 4.2.3, 4.2.5). Recurrent concentrations areas of fish larvae were not located, and generally there seems to be large variation in distribution and abundance of fish larvae between years. Although planktonic organisms are supposed to move with the currents there seem to be retention areas over the banks, where plankton is concentrated and entrapped for periods (Pedersen et al. 2005).

**Figure 4.2.4.** Red dots indicate sandeel (*Ammodytes* sp.) larvae abundance (N $m^{-2}$) June-July from 1950 to 1984 (Pedersen & Smidt 2000). A relatively high abundance of sandeel was found at Fyllas Banke.

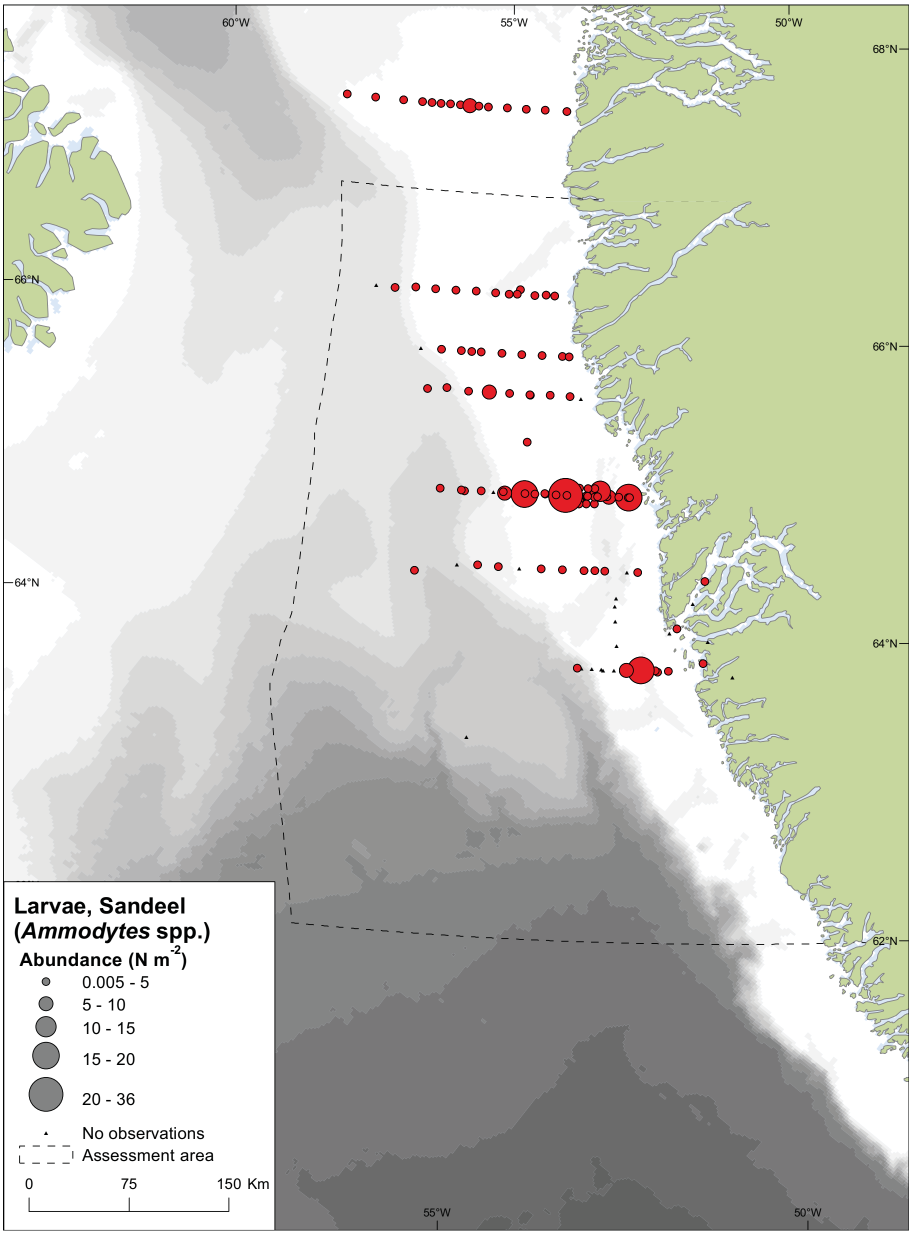
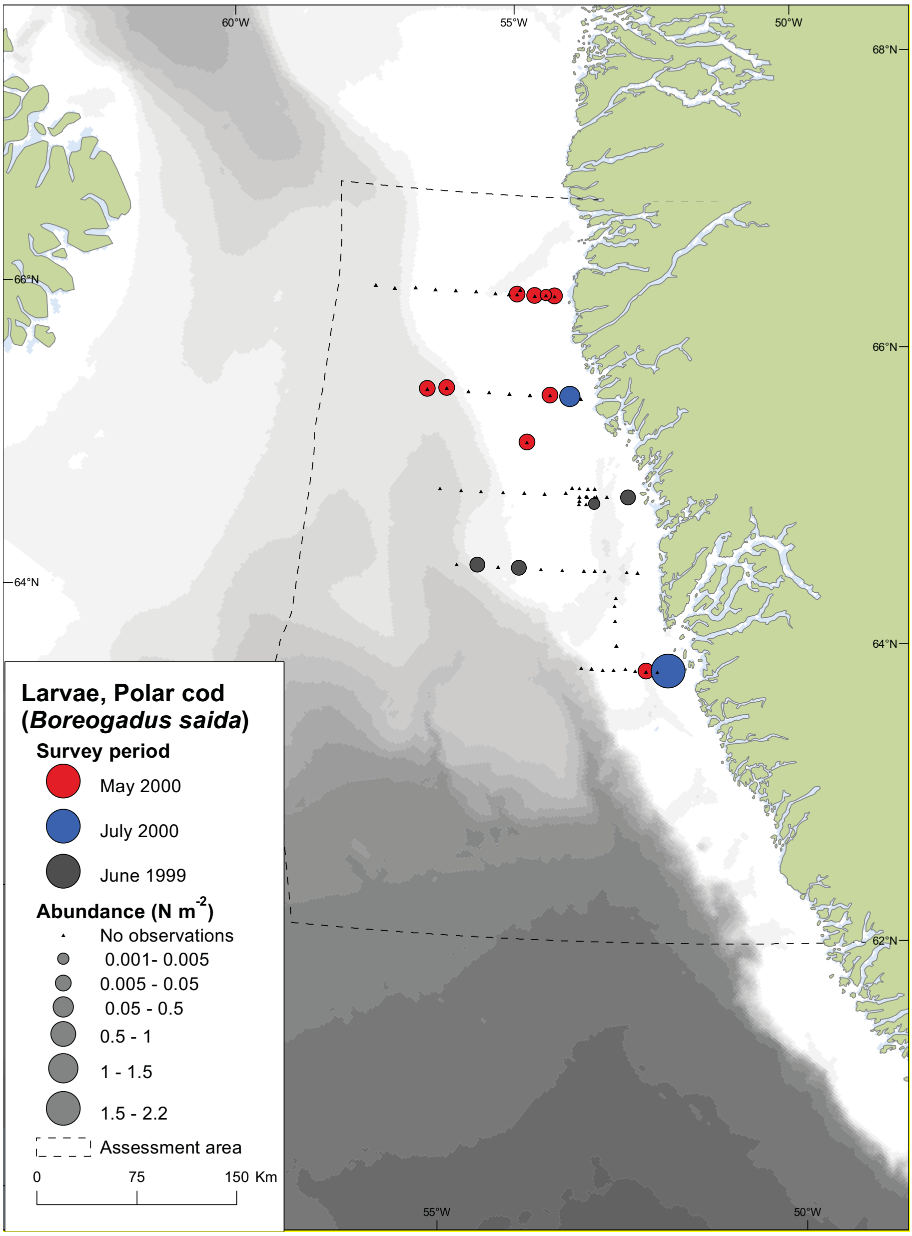


**Figure 4.2.5.** Juvenile polar cod (*Boreogadus saida*) abundance (N $m^{-2}$). The coloured dots represent abundance values from different studies; red, blue and dark grey dots: from surveys in May-July 1996-2000 (Munk et al. 2000, Munk et al. 2003, Munk pers. comm. and REKPRO-data from C. Simonsen and S.A. Pedersen pers. comm.). The juvenile polar cod from different studies in summer and an autumn period all indicate relatively high abundance in the coastal areas and east and west of the fishery banks.




## 4.2.6 Knowledge gaps

Variability in the physical forcing of the Atlantic inflow and the freshwater runoff from ice sheets determines the physical gradients and thereby the geographical distribution of the plankton communities. The dynamics between the physical environment and the variability in the fishery resources in West Greenland waters are not fully understood. Thus, a better understanding on 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 plankton community distribution and the specific adaptations of these communities to physical and chemical gradients are still unknown. To date, no annual surveys have been conducted on primary and zooplankton production with the hydrography in the assessment area (except at the mouth of Godthåbsfjorden, in: Arendt et al. 2010). If addressed, model predictions which include variability in ocean temperature, seasonal timing of food and production, spawning stock biomass, larval drift, species interactions (cannibalism), for each individual in focus should improve our understanding and allow the distribution and recruitment for fish and shellfish to be predicted.

Vulnerability of plankton to anthropogenic impacts should be linked even more to local environmental conditions that influence the pelagic food web, such as temperature, water circulation and ice occurrence in order for the ecological impact of future environmental disturbances associated with climate change and increased human activities (e.g. oil exploration) to be understood.

### 4.2.7 Zooplankton sensitivity to oil

In connection with hydrodynamic discontinuities, i.e. spring blooms, fronts, upwelling areas or the marginal ice zone, high biological activity in the surface waters can be expected. Anthropogenic impacts, e.g. oil pollution, might also influence productivity.

Exposure experiments performed on natural plankton communities (Hjorth et al. 2007, Hjorth et al. 2008) and copepods (Hjorth & Dahllöf 2008, Jensen et al. 2008b, Hjorth & Nielsen 2011) with pyrene (as a proxy for crude oil) have shown reductions 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 in relation to 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 the most by pyrene exposure and sensitivity increased in warmer water in contrast to *C. Glacialis*, which may be partly due to buffering from lipid stores. Pyrene had no effect on development time for the two first non-feeding nauplii stages but clearly prolonged development time from nauplii stage III onwards when they begin to graze on phytoplankton. This was most pronounced at the lowest temperature (0º C), which suggests that the effects of pyrene exposure would be more severe during a spring phytoplankton bloom (~0º C in the upper 50m), since reduced grazing on phytoplankton would potentially lead to lower incorporation of phytoplankton into lipids with more being left ungrazed to sedimentate to the benthic community. The different responses to pyrene exposure in relation to food uptake, production and development time of the two species and higher water temperatures will not only affect them on a species level but will affect the Arctic food chain through a regime-shift to a less lipid-rich energy flux. Temperature stimulates *C. finmarchicus* more than *C. glacialis*, but the former is also more sensitive to oil. Vulnerability of plankton to anthropogenic impacts should be linked even more to local environmental conditions that influence the pelagic food web, such as temperature, water circulation and ice occurrence. The impacts of human activity are likely to vary according to season, location and biological activity. High biological activity in surface waters can be expected in connection with hydrodynamic discontinuities, i.e. spring blooms, fronts, upwelling areas and 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 within the pelagic food web in the upper 50m. In late summer after *Calanus* have migrated down to where they overwinter above the seabed biomass of grazers in surface waters is low (Dünweber et al. 2010) and biological activity is lower or concentrated at the pycnocline, ecological damage from an oil spill on plankton communities can be assumed to be less severe (Söderkvist et al. 2006).

## 4.3 Macrophytes

*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 a direct impact of oil contamination as seen after the Exxon Valdez spill (Peterson et al. 2003). However, some shorelines are highly impacted by natural parameters such as wave action and ice scouring, and such shorelines will therefore naturally sustain a relatively lower production or may appear as barren grounds. So, 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 is scarce and has mainly been conducted as floristic studies. Marine macroalgae were collected on different expeditions to Greenland during the 19$^{th}$ century, and were identified and described by Rosenvinge (1893, 1898). In addition, Christensen (1975, 1981) worked in the Nuuk area and an investigation of marine ecology in the littoral zone (ECOTIDE) has been initiated in Kobberfjord close to Nuuk. A check-list and distribution of the marine algae of Greenland for the east and west coast separately was compiled by Pedersen (1976) (Table 1). Moreover, a recent study assessed the extension and production of kelp belts along Greenland's West coast, from Nuuk to north of Qaanaaq (Krause-Jensen et al. 2011)

### 4.3.1 General context

The marine macroalgae are found along shorelines with hard and stable substratum, such as stones, boulders and rocky coast. The vegetation is distinctly divided in 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 sea water 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, however, grows below the low water mark within water depths with sufficient light. In the Arctic, the length of the ice-free period is an important controller of the light reaching the sea floor and the depth range of the kelp belt increases from north towards south along Greenland's coast parallel to 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 water depths of about 20 m (Krause-Jensen et al. 2011), while they occur deeper than 50 m in South Greenland and around Disko (Wegeberg et al. 2005, Hansen et al. 2012a).

The coastal zone of the assessment area normally has open water year round but may be impacted by drift ice. This ice as well as the marked seasonal changes in light regime and low water temperatures call for efficient adaptative 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 as in, e.g., the littoral zone, as well as to ensure 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 exerts a high physical impact factor on the macroalgal vegetation because of ice scouring. The mechanical scouring of floating ice floes prevents especially perennial fucoid species establishing in the littoral zone, which is the zone mostly influenced by the ice dynamics. Even though the assessment area is an open water region (Mosbech et al. 1996b) pack ice from Baffin Bay and East Greenland may impact exposed coast lines, which then may be subject to the phenomenon of opportunistic green algae development.

Perennial species from the littoral zone do tolerate temperatures at or close to freezing, and might survive at an ice foot, when this phenomenon occasionally occurs in the assessment area, and the ice foot melts without disrupting the vegetation. It was shown for Fucus distichus 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 intertidal zone when exposed to rain and snow during low tide and when sea water mixes with fresh and melt water during seasons with high water run off from land. Low tolerance to hyposaline conditions may result in bleaching (strong loss of pigments) or increased mortality, which suggests that hyposalinity may impact on the photosynthetic apparatus, as shown for kelp species at Spitsbergen (Karsten 2007).

Substratum characteristics are also important for the distribution and abundance of macroalgal vegetation, and only hard and stable substratum can serve as a 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 substratum the algal material drifts and clusters result 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 results in shading. Along the coasts of the calm fjords around Nuuk in the assessment area loose-lying macroalgae of brown and green algae was observed by Christensen (1981).

Sea urchins (Strongylocentrotus droebachiensis) are the most forceful 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 by 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 on 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 will probably affect the macroalgal vegetation, primarily due to a longer season with less ice and thereby a longer season for growth. A change in northward distribution of species is therefore an scenario expected to be coupled to oceanic warming (Müller et al. 2009). Furthermore, a study of climate forcing on benthic vegetation in Greenland (Krause-Jensen et al. 2011) suggests that depth range, abundance and growth of subtidal vegetation belts will expand in correlation to a warmer climate; but the study also concluded that those species with the most northern distribution responded negatively to warming. In addition, melting of inland ice caps leads to an increase in freshwater runoff, which may result in lowered salinity and increasing water turbidity (Borum et al. 2002, Rysgaard & Glud 2007), having a negative impact on the local macroalgae 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* PC Silva 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 to be recovering (NOAA 2010). In contrast, no major effects on shallow sublittoral macroalgae were observed in a study conducted by Cross et al. (1987). It was discussed that this might be due to a similar lack of impact on the herbivores as well as 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

A checklist and distribution of the marine macroalgal species in the assessment area are presented in Table 1 based on Pedersen (1976) and Andersen et al. (2005). Caution should be taken in interpreting the species distribution as the species list is a positive list, which means that the species was registered if it was collected and identified.

183 macroalgal species (excl. the bluegreen algae, Cyanophyta) are listed for Greenland according to the compiled checklist from 1976 (Pedersen 1976). Due to taxonomic and nomenclatural changes the number presently equals 137 species; 37 red algal species, 66 brown and 37 green. Within the assessment area 34 red algae, 51 brown and 33 green have been recorded.

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.

On sea floors with soft sediment, as in some places in the fjords around Nuuk, loose-lying macroalgae, or macroalgae attached to small stones and shells, may occur. These drifting algae masses are often dominated by *Desmarestia aculeata* and other filamentous brown algae. In areas of the fjords with enriched waters the green algae *Enteromorpha* spp. may be substantial (Christensen 1981).

In addition, in the shallow soft bottom areas of some of the inner branches of the Nuuk fjord system, meadows of eelgrass cover the sea floor and reach high abundances (Krause-Jensen et al. 2011).

Another interesting feature in the fjords of Nuuk is the sole registration of the geniculate coralline red algae *Corallina officinalis* in Greenland (Christensen 1975).

In proximity to Nuuk, in the assessment area, sea floor covered by coralline red algae (Fig. 4.3.1) is observed (M. Blicher, pers. comm.). Both encrusting coralline red algae on stones and the loose-lying, branched forms, rhodliths, are present. The processes leading to rhodolith accumulations are poorly understood, but the rhodoliths are most likely derived from branches breaking off from branched encrusting coralline red algal species or developed as branched, crusts overgrowing a pebble or a mussel/shell, which may act as a nodule (Freiwald 1995).

Such areas dominated by encrusting coralline red algae as well as rhodoliths are reported from a couple of other localities in Greenland; in the Disko Fjord and close to Qaqortoq. The locality in Qaqortoq is of the same type as those identified close to Nuuk, i.e. stony sea floor with encrusting coralline red algae and rhodoliths intermixed (AM Mortensen, pers. comm.). In Disko Fjord relatively large rhodoliths with diameters of up to 13 cm (Düwel & Wegeberg 1990, Thormar 2006) are accumulated on a soft and muddy bottom.

The occurrence of coralline red algal dominated habitats seems to be closely correlated to the presence and frequency of sea urchins. According to Bulleri et al. (2002) grazing by sea urchins plays a fundamental role in establishing and maintaining areas dominated by encrusting coralline red algae and hence rhodoliths. The grazing down of foliose macroalgae by the sea urchins leaves the calcite incrusted red algal species with available substratum and optimal light conditions. Thereafter, as investigated in temperate regions, the coralline red algae covering the available substratum may prevent recruitment of erect macroalgae, maintaining the alternative habitat (Bulleri et al. 2002).

**Figure 4.3.1.** Stones at the sea bottom covered by encrusting coralline red algae and loose-lying, branched forms, rhodoliths, intermixed. A number of sea urchin, *Strongylocentrotus droebachiensis*, are apparent. (Photo: Martin E. Blicher).

The sea urchin, *Strongylocentrotus droebachiensis,* occurs frequently in the coralline red algal dominated area (Fig. 4.3.1) (ME Blicher, pers. comm.) and is considered as very dominant in Kobberfjord in the assessment area (Blicher et al. 2009).

In general, the existing knowledge of macroalgal diversity is very limited, and macroalgal species composition, biomass, production and spatial variation are largely unknown in the assessment area. Therefore, important or critical shoreline intervals cannot be identified based on the available information. In addition, at present only limited research addresses the littoral zone and no research has been conducted on subtidal macroalgal community interactions in the assessment area. Hence, the knowledge of biodiversity/abundance of macroalgal associated fauna or mapping of macroalgal /faunal interactions including grazing by, e.g., sea urchins, is lacking.

Therefore, it is suggested that investigations are preformed to provide data and further information on:

- Diversity and spatial variation of the marine flora and associated fauna in the littoral and sublittoral zones
- Macroalgal and associated faunal biomass as well as species specific coverage or number
- Benthic primary production

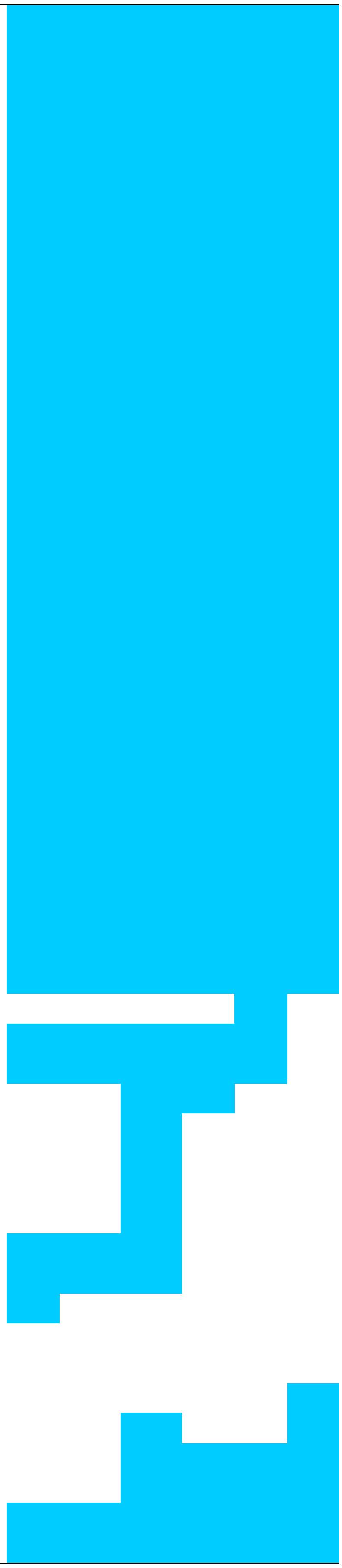
Studies of this nature would provide robust data for mapping and modelling the littoral and sublittoral ecology of the Davis Strait coast of Greenland. This would optimise the advisory and assessment capability for shoreline protection and clean-up in relation to oil activities, as well as evaluation of subsequent rehabilitation of an oil impacted coast.

**Table 4.3.1.** Distribution of macroalgal species in the assessment area based on Pedersen (1976). Binomial names follow Pedersen (2011).

| **Latitude (°N)** | ***62*** | ***63*** | ***64*** | ***65*** | ***66*** | ***67*** |
|---|---|---|---|---|---|---|
| *Cyanophyta* | | | | | | |
| *Calothrix scopulorum* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Rivularia atra* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Gloeocapsopsis crepidinum* | | | ■ | | | |
| *Pseudophormidium battersii* | | | ■ | | | |
| *Chroococcopsis amethystea* | ■ | ■ | | | | |
| | | | | | | |
| **Rhodophyta** | | | | | | |
| *Scagelothamnion pusillum* | | | | ■ | ■ | ■ |
| *Porphyra "njordii"* | | | ■ | ■ | | ■ |
| *Ceramium sp.* | | | ■ | ■ | ■ | ■ |
| *Peyssonellia rosenvingii* | | | ■ | ■ | ■ | ■ |
| *Rhodophysema elegans* | | | ■ | ■ | ■ | ■ |
| *Bangia fuscopupurea* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Clathromorphum compactum* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Coccotylus truncatus incl. Coccotylus brodiaei* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Devaleraea ramentacea* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Euthora cristata* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Fimbrifolium dichotomum* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Hildenbrandia rubra* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Lithothmanion glaciale* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Lithothamnion tophiforme* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Meiodiscus spetsbergensis* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Membranoptera denticulata* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Palmaria palmata* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Pantoneura fabriciana* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Phycodrys rubens* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Phymatolithon tenue* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Ptilota serrata* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Polysiphonia arctica* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Polysiphonia stricta* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Porphyra umbilicalis* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Rhodocorton purpureum* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Rhodomela lycopodioides* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Turnerella pennyi* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Wildemania miniata* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Boreophyllum birdiae* | | | ■ | | ■ | |
| *Pyropia thulaea* | | | ■ | | ■ | |
| *Rubrointrusa membranacea* | ■ | ■ | ■ | ■ | ■ | |
| *Corallina officinalis* | | | | ■ | | |
| *Polysiphonia elongata f. schübeleri* | | | ■ | | | |
| *Acrochaetium secundatum* | ■ | ■ | ■ | | | |
| | | | | | | |
| **Phaeophyceae** | | | | | | |
| *Ectocarpus fasciculatus* | | | | | | ■ |
| *Eudesme virescens* | | | ■ | ■ | ■ | ■ |
| *Papenfusiella callitricha* | | | ■ | ■ | ■ | ■ |
| *Saccharina longicruris* | | ■ | ■ | ■ | ■ | ■ |
| *Agarum clathratum* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Alaria pylaiei* | ■ | ■ | ■ | ■ | ■ | ■ |
| *Ascophyllum nodosum* | ■ | ■ | ■ | ■ | ■ | ■ |

*Battersia arctica*
*Chaetopteris plumosa*
*Chorda filum*
*Chordaria flagelliformis*
*Delamarea attenuata*
*Desmarestia aculeata*
*Desmarestia viridis*
*Dictyosiphon foeniculaceus*
*Ectocarpus siliculosus*
*Elachista fusicola*
*Fucus distichus*
*Fucus vesiculosus*
*Halosiphon tomentosus*
*Isthmoplea sphaerophora*
*Laminaria nigripes*
*Laminaria solidungula*
*Laminariocolax aecidioides*
*Laminariocolax tomentosoides*
*Leptonematella fasciculata*
*Lithosiphon filiformis*
*Petalonia fascia*
*Petroderma maculiforme*
*Pleurocladia lacustris*
*Punctaria plantaginea*
*Pylaiella littoralis*
*Rafsia fungiformis*
*Saccharina latissima*
*Saccorhiza dermatodea*
*Scytosiphon lomentaria*
*Sorapion kjellmanii*
*Stictyosiphon tortilis*
*Stragularia clavata*
*Streblonema stilophorae*
*Sphacelorbus nanus*
*Coilodesme bulligera*
*Hincksia ovata*
*Pogotrichum filiforme*
*Coelocladia arctica*
*Dictyosiphon chordaria*
*Pilinia rimosa*
*Ralfsia ovata*
*Omphallophyllum ulvaceum*
*Ralfsia verrucosa*
*Streblonema fasciculatum*

**Chlorophyta**
*Ulva lactuca*
*Enteromorpha intestinalis*
*Prasiola stipitata*
*Pseudopringsheimia confluens*
*Acrosiphonia arcta*
*Acrosiphonia sonderi*



| |
|---|
| *Chaetomorpha capillaris* |
| *Chaetomorpha melagonium* |
| *Chlorochytrium cohnii* |
| *Chlorochytrium dermatocolax* |
| *Cladophora rupestris* |
| *Enteromorpha compressa* |
| *Enteromorpha prolifera* |
| *Gomontia polyrhiza* |
| *Kornmannia leptoderma* |
| *Monostroma grevillei* |
| *Ostreobium quekettii* |
| *Pseudothrix groenlandica* |
| *Percursaria percursa* |
| *Pringsheimiella scutata* |
| *Protomonostroma undulatum* |
| *Rhizoclonium riparium* |
| *Spongomorpha aeruginosa as Chlorochytrium inclusum* |
| *Ulothrix flacca* |
| *Ulothrix speciosa* |
| *Ulvaria spelndens* |
| *Urospora wormskioldii* |
| *Urospora penicilliformis* |
| *Acrochaete flustrae* |
| *Bolbocoleon piliferum* |
| *Derbesia marina* |
| *Rosenvingiella constricta* |
| *Rosenvingiella polyrhiza* |
| *Blidingia minima* |

## 4.4 Benthos

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The benthic habitat has a central role in the marine ecosystem in the Arctic, in terms of elemental cycling, ecosystem function, and biodiversity. The benthic flora is confined to a relatively narrow photic zone extending from the inter-tidal zone to approximately 40 m depth. The biomass and production of perennial kelps can be significant and the large macroalgae create specific habitats with a characteristic associated fauna. 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 different 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. Moreover, there have been attempts to develop commercial exploitation of blue mussels (*Mytilus edulis*), sea urchins (*Strongylocentrotus* sp.) and sea cucumbers (*Cucumaria* sp.).

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, Wlodarska-Kowalczuk et al. 2004, Piepenburg 2005). Therefore the benthic community is often extremely heterogeneous on both local and regional scales.

The coastline in Southwest Greenland (62-67°N) is traversed by numerous fjords, many of them acting as direct links between the inland ice sheet and the ocean. Moreover, many islands are scattered directly off the coast resulting in an extremely long coastline and a variety of shallow benthic habitats. The continental shelf most often extends >100 km offshore. A mix of shallow banks (<50 m) and deep troughs (>300 m) results in a highly complex bathymetry in the shelf area.

### 4.4.1 Fauna

Considering the extremely long coastline of Greenland the number of benthic surveys is 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, Anon 1978, Ambrose & Renaud 1995, Sejr et al. 2000, Sejr et al. 2002, Born et al. 2003, Merkel et al. 2007, Sejr & Christensen 2007, Blicher et al. 2009, Blicher et al. 2011). In the last few years a number of investigations in coastal areas of West Greenland have consistently confirmed that species richness is high in all the investigated areas (Sejr et al. 2010a, Sejr et al. 2010b, Hansen et al. 2012b). However, together these studies only cover a very little part of the extensive sea bottom around Greenland and there are a number of widely distributed habitat types such as gravel and rocky bottom that have not been included because sampling is technically demanding. 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).

### 4.4.2 Benthic fauna in the assessment area

Southwest Greenland (62-67°N) has not received much attention in terms of benthic studies, and consequently our knowledge is limited. However, besides a study of the macrobenthic fauna composition in the Holsteinsborg Deep and the Store Hellefiskebanke (63-68°N) in the 1970s (Anon 1978), a number of recent studies have focused on the benthic habitat in the Godthaabsfjord system (64°N) both in terms of macrofauna species composition and the importance of the benthic habitat in the elemental cycling in the marine ecosystem (Blicher et al. 2009, Glud et al. 2010, Sejr et al. 2010a, Blicher et al. 2011).

In the shelf region between 63 and 68°N (17-548 m depth) a total of 496 macrofauna species were registered at 31 soft bottom localities resulting from very high species richness and large differences in composition between stations (Anon 1978). Including the epifaunal species observed at stations with hard substrates a total number of 760 invertebrate species were registered in the area. A similar pattern was found on a local scale along a fjord-ocean transect in the Godthaabsfjord/Fylla Bank area (64°N). Here, up to >80 species per 0.1 $m^2$ grab sample were reported, and large differences in habitat characteristics between the 9 sampling stations (47-956 m in depth) affected the species composition significantly, resulting in a high total species richness (339 species) (Sejr et al. 2010a). In the two studies, species accumulation curves (i.e. plots of no. of species vs. no. of samples) showed no sign of reaching an asymptote, which suggested the 'true' number of species to be considerably higher than observed. An increase in sampling effort is therefore likely to lead to the observation of new species. These two data sets contributed to a recent pan-Arctic inventory of macro- and megabenthic species including all existing data from Arctic shelf regions. Although a lack of data from Greenland waters was apparent, enough data was available to suggest species diversity in West Greenland to be in the high end compared to other ecoregions in the Arctic (Piepenburg et al. 2010).

In May 2010 another benthic sampling campaign was performed in the near-shore area between 64 and 61°N (Batty et al. 2010). Detailed taxonomic data are not yet available, but the sampling is expected to provide data on benthic biomass, abundance, diversity and species composition as well as the physico-chemical characteristics of the sediment. Visual examinations of the seabed using an underwater drop camera down to 250 m in depth indicated that the sea floor was very heterogeneous. Several substrate types were registered ranging from soft mud and clay to a mix of stones and shells, and clean rock. The species composition of epifauna was obviously influenced by these different physical conditions, and several different epifaunal communities were identified. Due to the reported heterogeneity in the area, it can be expected to host several different assemblages of epi- and endobenthic species.

As regards the functional role of the benthos in the assessment area, recent studies in coastal areas indicate that macrozoobenthos are key both in terms of elemental cycling and ecosystem function. In Kobbefjord (64°N) the annual carbon demand of the dominating species, sea urchins (*Strongylocentrotus droebachiensis,* Fig. 4.3.1) and scallops (*Chlamys islandica*), corresponded to as much as 21-45% of the pelagic primary production (Blicher et al. 2009). Moreover, it is well established that macrozoobenthos stimulate microbial mineralisation of organic material through bioturbation and bioirrigation, and faeces production (Glud et al. 2003, Vopel et al. 2003, Glud et al. 2010). The functional importance of shallow macrofauna was further demonstrated in a study in Nipisat Sound (64°N), a key habitat for wintering eiders. Here it was estimated that eiders consumed a significant fraction of the available macrofauna biomass to balance their costs of living during their wintering. Their energy demand corresponded to as much as 58% of the total annual production of macrobenthos in the area (Blicher et al. 2011).

Thus, the available studies from the assessment area agree with the results from other areas in Greenland, and in the Arctic as a whole, in that the benthic habitat plays a key role in terms of biodiversity and ecosystem function. However, the lack of studies of spatial and temporal variation in community structure, and the lack of data from certain habitat types and from offshore areas make it difficult to draw more detailed conclusions.

One obvious 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. A 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. 2007). In Greenland waters knowledge of coral distribution and abundance has not been systematically studied. However, during trawl surveys conducted in Greenland waters, corals have been found at many locations along the continental slope of Southwest- and Southeast Greenland (ICES 2010a). Recently, a ban against trawling in two areas south of Maniitsoq (64°N) was suggested due to the observations of high abundance of corals.

## 4.5 Sea ice community

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At least part of the assessment area is considered an open water region, so sea ice and thereby sea ice communities may be less important in the area compared with in areas with more extensive sea ice cover north of the assessment area. However, in most winters the western part of the assessment area is covered with pack ice from the Canadian side (Fig. 3.3.2) and sea ice also occurs regularly in the fjords of the assessment area. Thus, the production of these ice communities may be of greater importance in some years, at times when the pelagic and benthic productions are relatively low, especially before the spring bloom of phytoplankton. In addition, the sea ice community is expected to be very vulnerable to oil spills as the ice may catch and accumulate oil in the interface between ice and sea and the oil may penetrate the ice through brine channels, and both these areas represent the spaces occupied by sea ice communities.

The sea ice in the assessment area may be habitat for a specialised ecosystem of bacteria as well as many species of microalgae and microfauna. Within the assessment area, in the fjord Kangerluarsunnguaq (Kobbefjord), just south of Nuuk, Mikkelsen et al. (2008) found that flagellates (prasinophytes, dinoflagellates, cryptophytes) and both centric and pennate diatoms were regular components of the sea ice algal community. Of diatoms especially *Chaetoceros simplex*, a colonial, centric diatom, was dominant (75% of total sea ice algal abundance) during its bloom in March. In the pack ice on the Canadian side of the Davis Strait, Booth (1984) found a total dominance of pennate diatom genera.

Strong patchiness of the sea-ice algae is commonly reported in the Arctic (Booth 1984, Gosselin et al. 1997, Gradinger et al. 1999, Rysgaard et al. 2001, Quillfeldt et al. 2009), caused by heterogeneity of the ice. Changes in ice thickness, crystalline structure, salinity, porosity and density are important for the community structure of sea ice organisms. Sea ice environments are highly dynamic and display large variations in temperature, salinity and nutrient availability. These variations lead to the high degree of horizontal patchiness in microbial sea ice communities (Quillfeldt et al. 2009).

The sea ice algal production in the Arctic has been estimated to reach 5-15 g C $m^{-2}$ $year^{-1}$ depending on sea ice cover season (Gosselin et al. 1997, Quillfeldt et al. 2009). However, Michel et al. (2002) found that ice algae only represented a small fraction of the total algal biomass, <3%, in the North Water Polynia, and Mikkelsen et al. (2008) and Booth (1984) found that the ice algae only accounted for <1% of the pelagic primary production in Kangerluarsunnguaq and western Davis Strait, respectively. In Young Sound, Northeast Greenland, Rysgaard et al. (2001) reached a similar result.

Furthermore, Mikkelsen et al. (2008) tested if the ice algae acted as inocula for initiating the spring bloom of phytoplankton by algal seeding, but, however, obtained no conclusive results. Michel et al. (2002) concluded that ice algal species released into the water column did not appear to play an important role for phytoplankton development. The ice algal community was dominated by pennate diatoms species by up to 85%, and the phytoplankton bloom was very strongly dominated by pelagic species of centric diatoms, which were not present in the ice algal community in the North Water Polynia. Booth (1984) also found that species composition in the sea ice differed significantly from that of the phytoplankton. Therefore, on the other hand, these findings suggest that the sea ice algae constitute a unique and separate community compared with the pelagic phytoplankton.

The present information on sea ice communities in the assessment area is very scarce and focused on primary production. Thus, ecologically important or critical areas for oil spill in the assessment area cannot be identified based on the available information. Further studies, especially on sea ice community structure and interactions, are recommended to fully understand the role of sea ice communities in the eastern Davis Strait ecosystem and to support identification of potential important or critical areas for production in sea ice in the assessment area.

## 4.6 Fish and shellfish

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Many different shellfish and fish species are of common occurrence in the assessment area. Most are demersal i.e. living near the sea bottom. Species among shellfish include coldwater shrimps, snow crabs, scallops, blue mussels and among marine vertebrates the Greenland halibut, salmon, cod, Atlantic halibut, wolfish, redfish, capelin, lumpsucker and other species. The marine shelf is important fishing grounds and is characterised by relatively few dominant species, with strong interactions (Pedersen & Kanneworff 1995).

### 4.6.1 Selected species

**Shrimp, *Pandalus borealis***

*Biology:* The key species, northern shrimp (*Pandalus borealis*) dominates in West Greenland water. 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 strategy called protandric hermaphroditism, which means that the species grow up as males and then go through a transition to female.

Right before the females extrude the eggs the male attaches a spermatophore to the female. On extrusion of the eggs the females carry them on their legs for approximately 6-9 months.

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

*Movements:* The 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 foodweb at night (Horsted & Smidth 1956).

*Breeding distribution:* The shrimps migrate horizontally into the inshore shallow areas in order to spawn (Hjort & Ruud 1938, Horsted & Smidth 1956, Haynes & Wigley 1969, Bergstrom 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, reaching its highest level in 2005 and decreasing since. 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 (Hammeken & Kingsley 2010). Since 2007 the stock has declined in the assessment area as the population of northern shrimp has contracted northwards (Ziemer et al. 2010). The 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 biomass. It would be reasonable to look into the match-mismatch theory for shrimp egg hatching and the peak of 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, the impacts of annual recruitment strength and subsequent population size are unknown. The shrimp larvae have a pelagic phase and the resources will be especially sensitive to oil spill in that season.

*Knowledge gaps:* Early life history of shrimp, including larval drift between offshore and inshore sites and along the west coast, nursery grounds as well as settling and occurrence of benthic stages is unknown or poorly understood in the assessment area. Furthermore, there is a need to understand whether or not there is a link between shrimp recruitment and climate changes 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 dispersal of the northern shrimp stock, moving south (around

1990) and then north (mid-2000s) in West Greenland waters, is poorly understood. Whether this movement was caused by increased predation affected by the return of cod in southern Greenland, increased bottom temperatures or other factors is unknown. The food web interaction between northern shrimp and their prey and predators is also poorly understood.

#### Snow crab, *Chionoecetes opilio*

*Biology:* 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 there are two exceptions (Paul & Paul 1997, Burmeister 2002). Snow crab mainly inhabits grounds of mud or sand-mud substrate at depths from 30 to 1,400 m, where bottom temperature remains –1.5 to 4°C year round (e.g., Squires 1990, Dawe & Colbourne 2002). Snow crab may be physiologically constrained to these temperatures as its energy budget becomes negative outside of the range due to reduced feeding and rising metabolic costs (Foyle et al. 1989, Thompson & Hawryluk 1990).

As with 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 in autumn at a carapace width (CW) 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 congeners (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 occurs 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 benthic stage.

*Distribution:* The most northerly record of snow crab is from Greenland, where the species is distributed along the west coast between 60°C 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, 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. tagging data, Burmeister & Sainte-Marie 2010). Early life history of snow crab including larval drift between offshore and inshore sites, nursery grounds, settling and occurrence of benthic stages is unknown or poorly understood in the assessment area. Genetic analysis showed that snow crab in West Greenland waters differ significantly from those in western part of Davis Strait (Atlantic Canada), whereas no difference was found between inshore and offshore site subpopulations within this 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, the impacts of annual recruitment strength and subsequent population size are unknown. In contrast to pelagic fish and crustaceans, benthic stage snow crabs are observed not to migrate over larger distances in Greenland, but are believed to be stationary. Change in habitats through chemical pollution is therefore of particular interest in relation to 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 has led to the suggestion that exposure time isthat likely to be longer for species intimately associated with sediment and pollution might play a larger role in crab population decline (Moles & Stone 2002).

*Knowledge gaps:* Early life history of snow crab including larval drift 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 that is widely distributed in the north Atlantic including Baffin Bay, Davis Strait and Labrador Sea and inshore areas along the entire west coast of Greenland and inshore areas at eastern Canada. The main spawning ground is assumed to be located in the central part of the Davis Strait south of the sill between Greenland and Baffin Island where spawning takes place in early winter. The assumption is based on development of ovaries (Jørgensen 1997, Gundersen et al. 2010) and observation of eggs (Smidt 1969). Most sampling has been conducted at depths down to about 1,500 m but no females in spawning conditions have ever been observed and it is possible that spawning takes place at depths greater than 1500 m, probably around 62°30'N - 63°30'N. From the spawning grounds eggs and larvae drift through the assessment area with the West Greenland Current towards the settling areas. Early stage eggs are found between 240-640 m (Smidt 1969) and larvae are primarily found at 13-40 m (Simonsen & Gundersen 2005). The pelagic stage lasts more than six months (Smidt 1969). The larvae settle in August-

September when they have reached a length of about 6-8 cm. Store Hellefiske Bank, Disko Bay and Disko Bank west of Disko Island are well documented settling and nursery areas (Smidt 1969, Stenberg 2007) but larvae are also brought into the Baffin Bay by the West Greenland Current and to the East Coast of Canada (Bowering & Chumakov 1989) by a branch of the West Greenland Current that flexes towards west at the sill between Greenland and Baffin Island. This drift pattern has been strongly supported by observations of egg and larvae and by models simulating the drift of Greenland halibut eggs and larvae (Stenberg 2007). Elsewhere in the Northwest Atlantic spawning has only been observed sporadically in the Baffin Bay and inshore in the Northwest Greenland fjords (Simonsen & Gundersen 2005) and along the east coast of Canada (Bowering & Brodie 1995). The Greenland halibut populations in the Davis Strait, Baffin Bay, inshore areas in Northwest Greenland and the east coast of Canada area are therefore believed to be recruited from the spawning stock in the Davis Strait.

*Migration:* Tagging studies from eastern Canada (Bowering 1984) and West Greenland (Boje 2002) and recent unpublished data from Greenland Institute of Natural Resources together with studies based on survey data (Jørgensen 1997) show that Greenland halibut gradually migrates towards greater depth and towards the presumed spawning area as they grow, reaching the spawning area as adults. One- and to some extend two-year-old fish feed on zooplankton in the water column while older fish feed on shrimps, fish and squids that are taken either at the sea bottom or during irregular feeding migrations into the water column (Jorgensen 1997).

*Sensitivity* and *impacts of oil spill:* The assessment area includes the main spawning ground for Greenland halibut in the Northwest Atlantic and recruitment to important fishing grounds in the Davis Strait, Baffin Bay, eastern Canada and inshore waters in Northwest Greenland and Canada is dependent on recruitment from this area. Eggs and larvae that drift slowly though the assessment area (Simonsen et al. 2006, Stenberg 2007) at depths of 13-40 m are very vulnerable to oil if exposed to a large subsurface plume. In such a case, effects on 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 heavy economic losses due to problems arising in the marketing of the products. Strict regulation and control of the fisheries in contaminated areas are 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. 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 a higher probability of surviving (Kjørsvik 1994). In Greenland Atlantic cod spawns in spring (April-May). The eggs and later the larvae drift with the currents and the larvae settle in the autumn at lengths 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 fiords; and III) Icelandic spawning grounds where the offspring are occasionally transported in significant quantities with the Irminger current to Greenland waters. The Icelandic offspring generally settle off East and South Greenland, whereas 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 in bottom trawls (Greenland Institute of Natural Resources, unpublished data). The feeding behaviour of Greenland lumpsucker is unknown, but due to its 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 to sperm whales in the area, as seen elsewhere (Kapel 1979, Martin & Clarke 1986).

*Distribution:* The common 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 about lumpsucker migrations and dependency on other ecosystem components, it is unclear how the species would respond to climatic changes.

*Sensitivity and impacts of oil spill*: Given the dependency of 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 lumpsucker was estimated as moderate in an environmental oil spill sensitivity atlas for the coastal zone in the area just south (60-62°N) of the assessment area (Mosbech et al. 2004b), and similar conclusions should apply in this case.

**Salmon**, ***Salmo salar***

*Biology and distribution:* Atlantic salmon migrates 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 abundance seems to peak in the autumn from August to October. In West Greenland the northern distribution 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:* 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 (Sorensen & Simonsen 1988, Hedeholm et al. 2010).

*Biology:* Sometime during autumn to spring capelin migrates 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 spawns typically when 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 themisto (Hedeholm 2010). Typical of Arctic food chains, these fatty prey result in capelin also having a high energy content (Hedeholm 2010), which makes it high quality prey to various apex predators such as cod (Hedeholm 2010), harp seals (Kapel 1991), whales and various seabirds (Friis-Rødel & Kanneworff 2002, Vilhjalmsson 2002) .

*Sensitivity and impacts of oil spill:* Key locations for capelin include spawning beaches. These are present in large numbers in most of the fjords in the assessment area from the heads of the 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.

#### Sandeel, *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 swim into the water column to feed. Most of the feeding occurs during spring and summer. 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.

*Distribution:* During a large sandeel survey in 1978, exploring the potentials for a commercial fishery in Southwest Greenland, the highest sandeel concentrations were found at the western and southern edge of Store Hellefiskebanke (just north of the assessment area), at the southern edge of Toqqusaq Banke (just north of Fyllas Banke), at Fyllas Banke and Fiskernæs Banke (Andersen 1985). During a benthic cruise in 2009 very high densities of sandeels (on average 9 indv. $m^{-2}$) were found at Store Hellefiskebanke (J. Hansen, unpubl.), but no sampling was done within the assessment area. Information about the occurrence of sandeel larvae is available from zooplankton surveys conducted in June-July in the period 1950 - 1984 (Pedersen & Smidt 2000). The larvae were found throughout most of the shelf in the assessment area, with the highest abundance at Fyllas Banke, Sukkertoppen Banke and Lille Hellefiskebanke (see also section 4.2.5 and Fig. 4.2.4).

*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. As several important sandeel locations are known from the shelf area, there is no question that the assessment area is a critical area for sandeels in West Greenland. Earlier studies indicated that sandeels off West Greenland spawned during the summer (Andersen 1985), but more recent studies have found abundant young larvae during summer (Munk et al. 2003, Simonsen et al. 2006), indicating mean hatching dates around 1 May. Given the expected large biomass of sandeels in some parts of the assessment area, and their central role as prey for a variety of species, impacts on sandeels have the potential to indirectly affect a large part of the ecosystem.

#### 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 (Moller 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 this has decreased since to approximately 84 million individuals in 2009 (Nygaard & Jørgensen 2010), equivalent to a 25-fold decrease in abundance in 15 years.

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

*Biology:* Three species of wolffish live in the waters off 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 the southern Labrador and USA. Survey indices indicate that the biomass of American plaice in West Greenland water is low compared to the 1980s (Nygaard & Jørgensen 2010).

**Thorny skate, *Amblyraja radiata***

Thorny skate is 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).

## 4.7 Seabirds

*David Boertmann, Flemming Merkel, Anders Mosbech, Kasper Johansen & Daniel Clausen (AU)*

Seabirds are an important component in the marine ecosystem of the assessment area. The numbers of breeding seabirds are, however relatively low compared to the coasts further north in Greenland, in Disko Bay, Upernavik and Qaanaaq Districts. The huge breeding colonies found there, do not occur in the Davis Strait assessment area (Boertmann et al. 1996). However, the assessment area is an extremely important winter quarter for seabirds from the entire North Atlantic (Boertmann et al. 2004).

Seabirds constitute an important resource to the Greenlanders and seabird hunting is a popular spare time activity. There are also full time hunters in the assessment area, who sell their products incl. seabirds on the local open-air markets. The seabird hunting is described in chapter 5. The most hunted species are thick-billed murre (*Uria lomvia*), common eider (*Somateria mollissima*) and black-legged kittiwake (*Rissa tridactyla*).

The bird hunt is regulated by the governmental order on protection and hunting of birds, the most recent one was issued on 8 March 2009.

### 4.7.1 Breeding seabirds

Most of the breeding seabirds are colonial breeders and many breeding colonies are found dispersed along the coast of the assessment area (Fig. 4.7.1 and 4.7.2). Colonies vary in size (from a few pairs to more than 20,000 individuals) and in species composition, from holding only a single species up to ten different species. The seabirds usually forage relatively close to the breeding sites, however, two species may potentially undertake much longer foraging trips, although not studied within the assessment area. In Qaanaaq, thick-billed murres have been recorded to fly more than 100 km to find food (Falk et al. 2000) and the northern fulmar (*Fulmarus glacialis*) is known to undertake exceptional long foraging trips lasting several days (e.g., Falk & Møller 1997).

A total of 20 species of seabirds are known to breed regularly along the coasts of the assessment area. Of these most are more or less colonial, breeding on steep sea-facing cliffs or on low islets (Boertmann et al. 1996). The only seabird not breeding in distinct colonies is the Arctic skua (Tab. 4.7.1). In addition, a number of species breed at freshwater habitats or on sheltered coasts.

**Table 4.7.1.** Overview of birds associated with the marine environment of the assessment area. b = breeding, s = summering, w = wintering, m = migrant visitor, c = coastal, o = offshore. "Importance of study area to population" indicates the significance of the assessment area in a national and international context as defined by Anker-Nilssen (1987).

| Species | Occurrence | | Distribution | Red-list status in Greenland (Boertmann 2007) | Importance of study area to population |
|---|---|---|---|---|---|
| Great northern diver | m/s | spring, summer, autumn | c | near threatened (NT) | medium |
| Red-throated diver | b/m/s | spring, summer autumn | c | least concern (LC) | medium |
| Fulmar | b/s/w | year-round | c & o | least concern (LC) | low |
| Great shearwater | s | July-October | o | least concern (LC) | low |
| Great cormorant | s/w | year-round | c | least concern (LC) | high |
| Mallard | b/w | winter | c | least concern (LC) | high |
| Common eider | b/s/m/w | year-round | c | vulnerable (VU) | high |
| King eider | w | Oct.-May | c | least concern (LC) | medium |
| Long-tailed duck | b/m/w | year-round | c | least concern (LC) | medium |
| Red-breasted merganser | b/m/w | year-round | c | least concern (LC) | high |
| Harlequin duck | m/w | year-round | c (rocky shores) | near threatened (NT) | high |
| Arctic skua | b | summer | c | least concern (LC) | low |
| Black-legged kittiwake | b/s/w | year-round | c & o | vulnerable (VU) | high |
| Herring gull | b | summer | c | not evaluated (NA) | low |
| Glaucous gull | b/s/w | year-round | c & o | least concern (LC) | medium |
| Iceland gull | b/s/w | year-round | c & o | least concern (LC) | high |
| Great black-backed gull | b/s/w | year-round | c & o | least concern (LC) | medium |
| Lesser black-backed gull | b | April-Sept. | c | not evaluated (NA) | medium |
| Arctic tern | b | May-September | c | near threatened (NT) | low |
| Thick-billed murre | b/w | year-round | c & o | vulnerable (VU) | high |
| Common murre | b/w | year-round | c & o | endangered (EN) | high |
| Razorbill | b/w | year-round | c & o | least concern (LC) | high |
| Atlantic puffin | b/w | year-round | c & o | near threatened (NT) | high |
| Black guillemot | b/w | summer | c | least concern (LC) | high |
| | | winter | c & o | | |
| Little auk | w | September-May | o | least concern (LC) | low |
| White-tailed eagle | b/w | year-round | c | vulnerable (VU) | high |

It should be noted that the breeding colonies shown in Figures 4.7.1 and 4.7.2 represent only a minimum of the true number of colonies present. For some species the number of small colonies could easily be twice as many. Especially the extensive archipelago between 63° and 66° N holds a huge potential for seabird colonies and this area has not been thoroughly surveyed. Furthermore, some colony information may be outdated. Extensive survey activity is currently conduced in the archipelago north and south of Nuuk (GINR, L. M. Rasmussen, unpubl.).

### 4.7.2 Summering seabirds

The shelf waters of the assessment area are also utilised by non-breeding seabirds. Numerous individuals from breeding populations all over the North Atlantic – mainly black-legged kittiwakes and northern fulmars (*Fulmarus glacialis*) – move into the Greenland waters in summer. Also included here are great shearwaters (*Puffinus gravis*) breeding in the southern hemisphere. In coastal areas other non-breeding seabirds utilise the region in summer – ducks arriving from breeding sites in Canada and inland Greenland to assemble and moult along the outer coast and in some fjords. Harlequin ducks (*Histrionicus histrionicus*) are found at remote rocky islands, while long-tailed ducks (*Clangula hyemalis*) and red-breasted mergansers (*Mergus serrator*) moult in shallow fjords and bays (Boertmann & Mosbech 2001, 2002).

### 4.7.3 Inland birds

Inland birds, breeding in freshwater habitats also utilise the marine waters, mainly in winter and during migration. These comprise mallards (*Anas platyrhynchos*), long-tailed ducks, red-breasted mergansers, harlequin ducks, red-throated divers (*Gavia stellata*) and great northern divers (*Gavia immer*) (Tab. 4.7.1). As mentioned above some of the ducks may also breed at sheltered coasts, while divers often find their food in the marine environment, performing regular flights between inland breeding sites and the coast.

The white-tailed eagle (*Haliaeetus albicilla*) is also relevant to this assessment as it too is associated with the marine environment.

### 4.7.4 Wintering seabirds

As mentioned above, the waters of the assessment area constitute very important winter quarters for seabirds. This is due to the fact that sea ice usually does not occur in winter – the region is often referred to as the 'Open Water Area' because the harbours are navigable throughout the year. Seabirds from Russia, Iceland, Svalbard and Canada assemble here October-May (Boertmann et al. 2004, Boertmann et al. 2006) and it is estimated that more than 3.5 million birds winter along the coasts of the Open Water Area. To this figure an unknown, but probably very large number (several million) of little auks (*Alle alle*) should be added (Boertmann et al. 2004).

The seabird wintering sites in the assessment area are therefore of high international importance. The most numerous species in winter are common eider, king eider (*Somateria spectabilis*), thick-billed murre and the large gull species. The distribution of the wintering seabirds was surveyed in the coastal area of West Greenland in 1999 (Merkel et al. 2002, Boertmann et al. 2004).

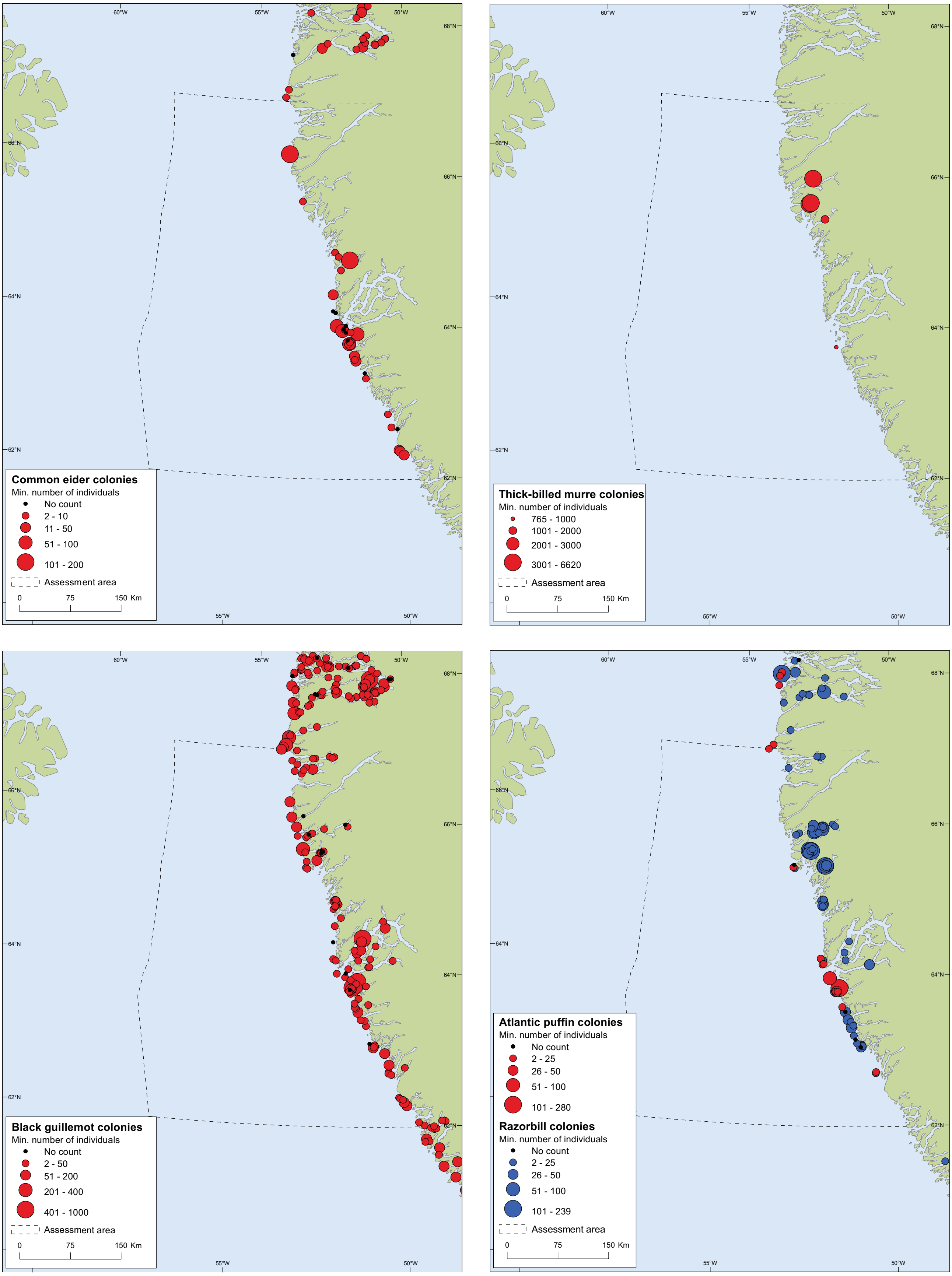



**Figure 4.7.1.** Distribution of seabird breeding colonies of common eider, thick-billed murre, black guillemot, Atlantic puffin and razorbill in the assessment area. Maps are based on data from AU and GINR (the Greenland Seabird Colony Register, 2010), however, survey coverage is not complete and colony information may be outdated.

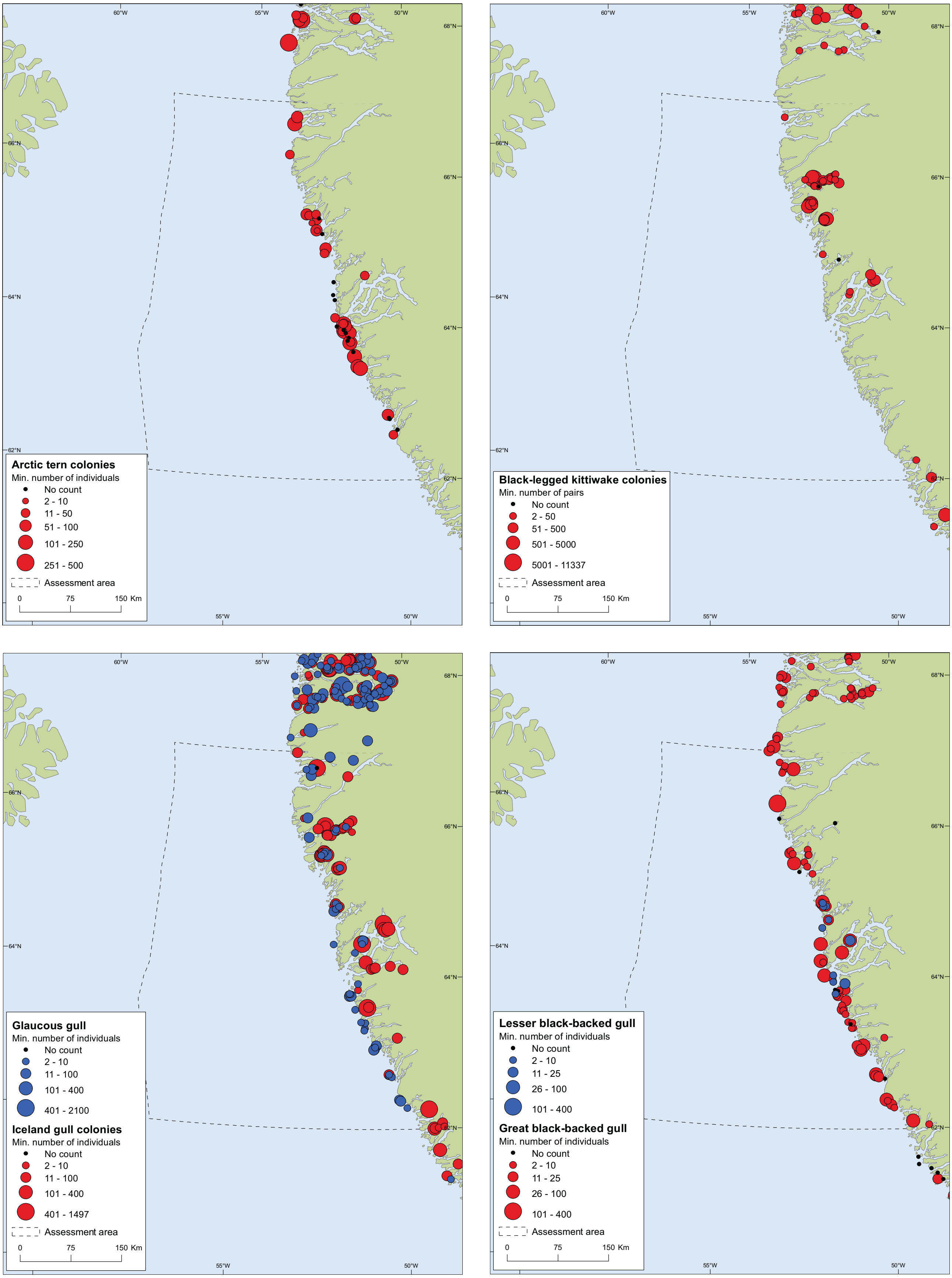



**Figure 4.7.2.** Distribution of seabird breeding colonies of Arctic tern, black-legged kittiwake, glaucous gull, Iceland gull, lesser black-backed gull and great black-backed gull in the assessment area. Maps are based on data from AU and GINR (the Greenland Seabird Colony Register, 2010), however, survey coverage is not complete and colony information may be outdated.

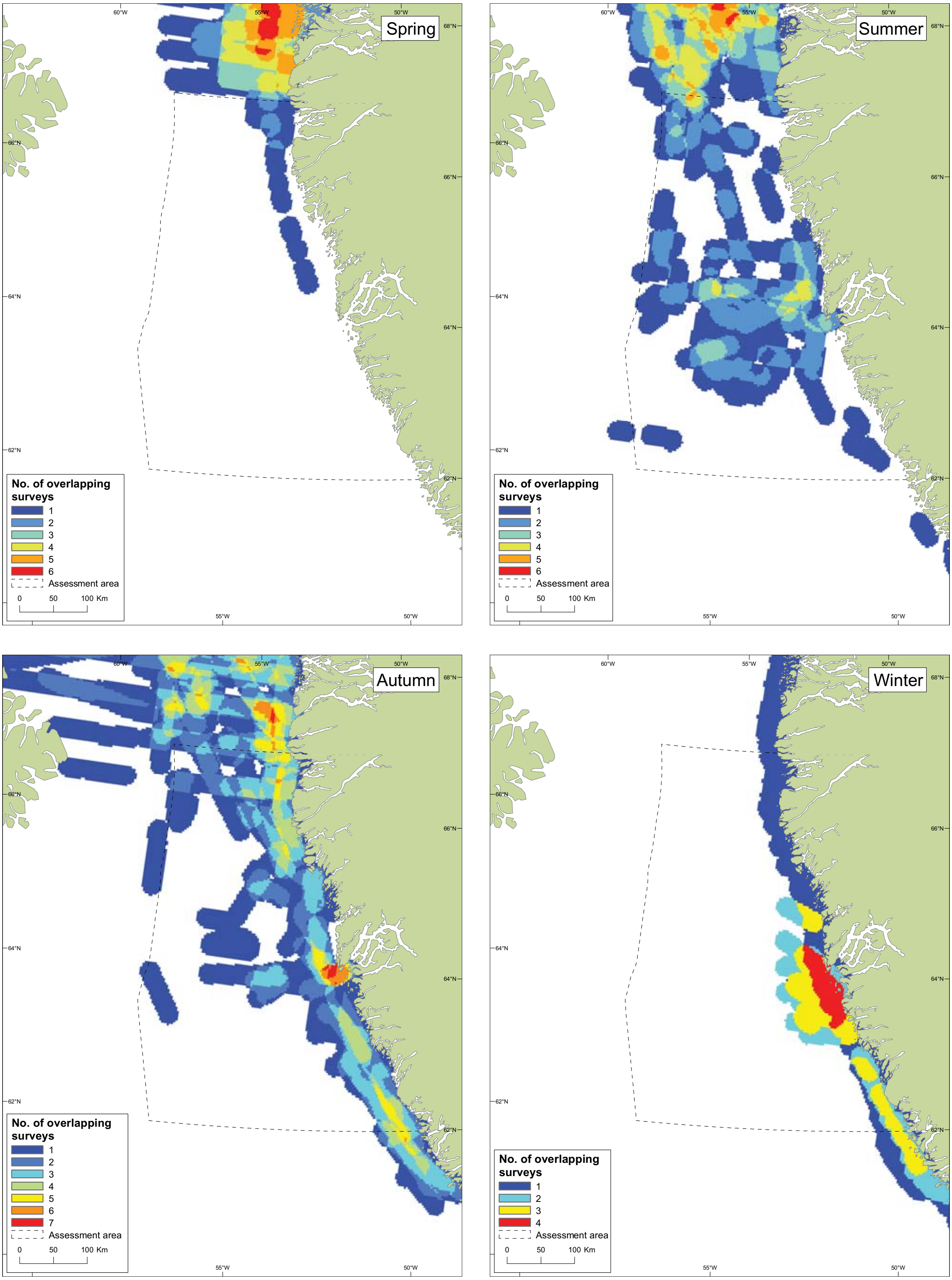



**Figure 4.7.3.** At-sea distribution of survey effort in the assessment area, shown as the number of overlapping ship- and aerial surveys conducted during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar). White areas represent areas with no survey activity. The figures do not include all surveys conducted in the assessment area, only what was available in two shared AU/GINR survey databases at the time of data extraction, corresponding to 25 ship surveys (1988-2010) and 3 aerial surveys (1996-2009).

Knowledge on habitat use of the wintering seabirds and the factors governing their distribution is generally poor, especially for the offshore area. Despite the unknowns it is evident that, seen in a North Atlantic perspective, the waters off West Greenland are very important for seabirds (Barrett et al. 2006).

### 4.7.5 Selected species

A number of seabird species important for the assessment area are briefly described in the following pages. For some species, the at-sea distribution is shown for different seasons of the year, based on available ship and aerial survey data collected in the period 1988-2010. At the time of data extraction this corresponded to 25 ship surveys (1988-2010) and 3 aerial surveys (1996-2009). Seabird densities were calculated as follows. The original survey transects were split into 3 km segments, and for each segment a density was calculated on the basis of the number of birds of the particular seabird species observed, the length of the segment, and an effective search width estimated separately for each survey and species by means of distance sampling methods (Buckland et al. 2001). Survey by survey the densities were interpolated to 3x3 km raster grids by inverse distance weighting (power 2, radius 15 km), and the densities shown on the maps represent the mean value in an overlay analysis of these grids  (divided into four seasons). Densities were calculated only within a 15 km buffer around the survey transects. Note that the number of overlapping surveys varies markedly between seasons and areas (Fig. 4.7.3).

**Northern Fulmar**, ***Fulmarus glacialis***

The number of breeding fulmars in the assessment area is very low, probably no more than a few hundred pairs, and, moreover, the few colonies seem to be unstable in time and space (Boertmann et al. 1996).

In the offshore areas fulmars are numerous and occur almost everywhere, except for in winter when only few are present (Fig. 4.7.4). They usually avoid areas with high ice coverage. Concentrations are linked to foraging areas and such may occur at ice edges, upwelling areas and areas with commercial fisheries.

The fulmar has a favourable conservation status in Greenland and it is not included on the Greenland Red List (Boertmann 2007, listed as of 'Least Concern' (LC)).

Fulmars have medium sensitivity to oil spills both on an individual level and a population level. Breeding colonies are among the most sensitive areas, because fulmars often rest on the water surface here. Recurrent offshore concentration areas are not known, but may occur e.g. at upwelling areas.

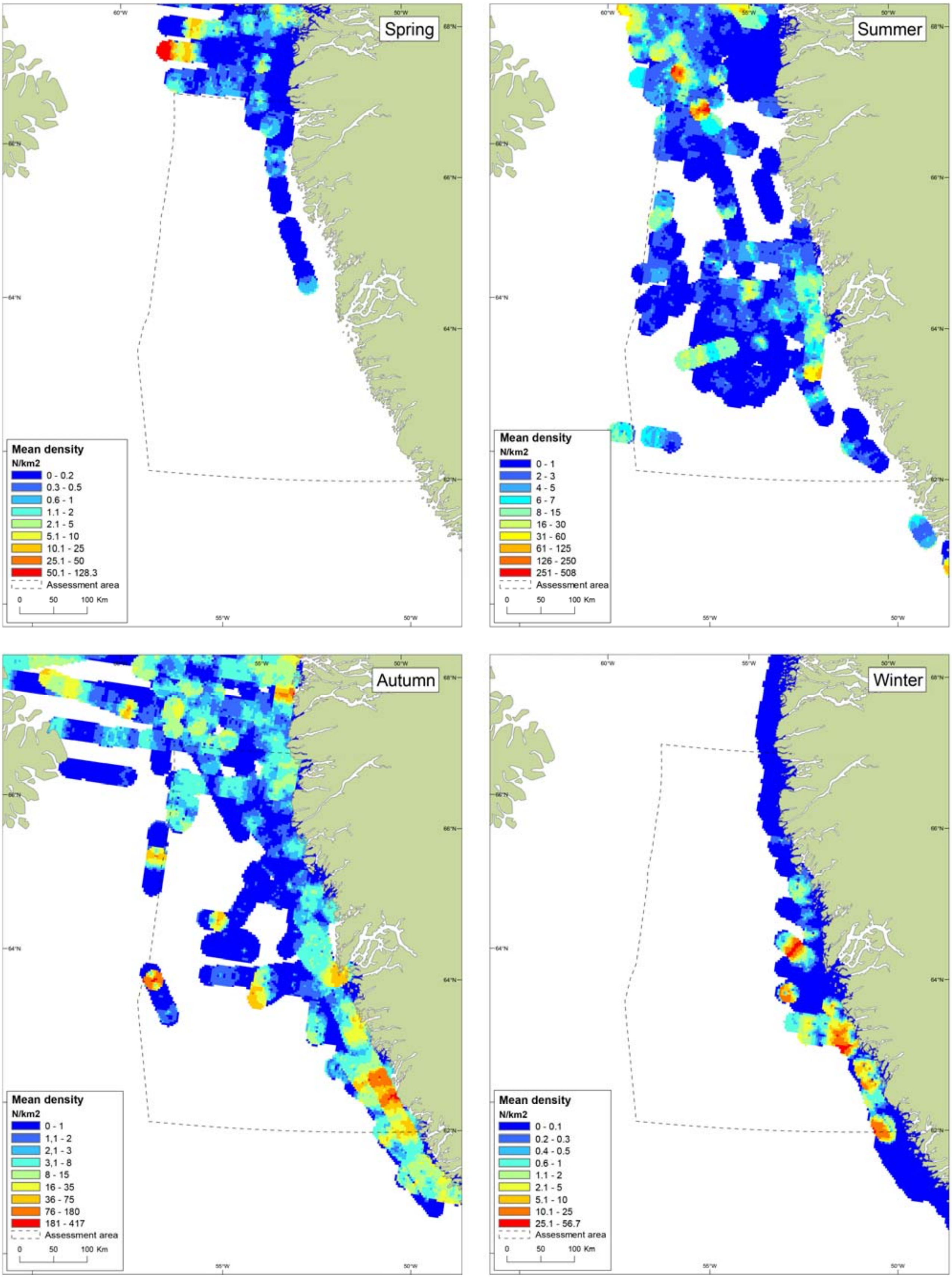



**Figure 4.7.4.** At-sea distribution of northern fulmar in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons.

**Great shearwater**, ***Puffinus gravis***

This is a visitor form the southern hemisphere where it breeds on the islands of Tristan da Cunha. The birds migrate in the southern winter to the northern hemisphere's summer, where they stay, mainly on the Grand Banks and the West Greenland banks until September.

They occasionally occur in high densities in the assessment area (Fig. 4.7.5), although their numbers seems to vary a great deal from one year to another.

High numbers of moulting birds with reduced flying abilities have been reported (Salomonsen 1950) and such concentrations will be highly sensitive to oil spills.

The great shearwater is listed as Least Concern (LC) in Greenland (Boertmann 2007) and is also considered as of Least Concern (LC) on the international red list (IUCN 2010).

**Great Cormorant**, ***Phalacrocorax carbo***

The cormorant breeds in small colonies usually with less than 100 pairs. Within the region these are found in the northern half, with Evighedsfjorden as the most important area. In 1995 the population numbered about 160 pairs (Boertmann & Mosbech 1997), but this is probably much higher today. At least the population has expanded to the south and coverage now includes the Godthåbsfjord (AU unpubl.).

The outer coast of the assessment area is an important winter habitat for cormorants, including breeding birds from areas further north in West Greenland (Lyngs 2003). A significant part of the entire Greenland population is found within the assessment area (Boertmann et al. 2004).

The cormorant population in Greenland is probably isolated from other populations. It has a favourable conservation status, and it is listed as Least Concern (LC) on the Greenland Red List (Boertmann 2007).

The population has a relatively low sensitivity to oil spills due to the many dispersed colonies and a high recovery potential. Furthermore, cormorants spend relatively little time on the sea surface, as they do not rest on the water like other seabirds. This has to do with their plumage not being 'waterproof'.

**Mallard**, ***Anas platyrhynchos***

The mallard breeds mainly in freshwater habitats, but also at sheltered marine shores. However, in winter the mallards are dependent on the marine environment. They assemble in shallow coasts and where they would be very sensitive to oil spills.

The conservation status is favourable and the species is listed as Least Concern (LC) on the Greenland Red List (Boertmann 2007). The Greenland population constitutes a distinct and endemic subspecies.

Although sensitive to oil spills, the Greenland mallard population would probably recover quickly from increased mortality. This appears to be the case when the mallard population occasionally suffers from high winter mortality due to harsh winters.

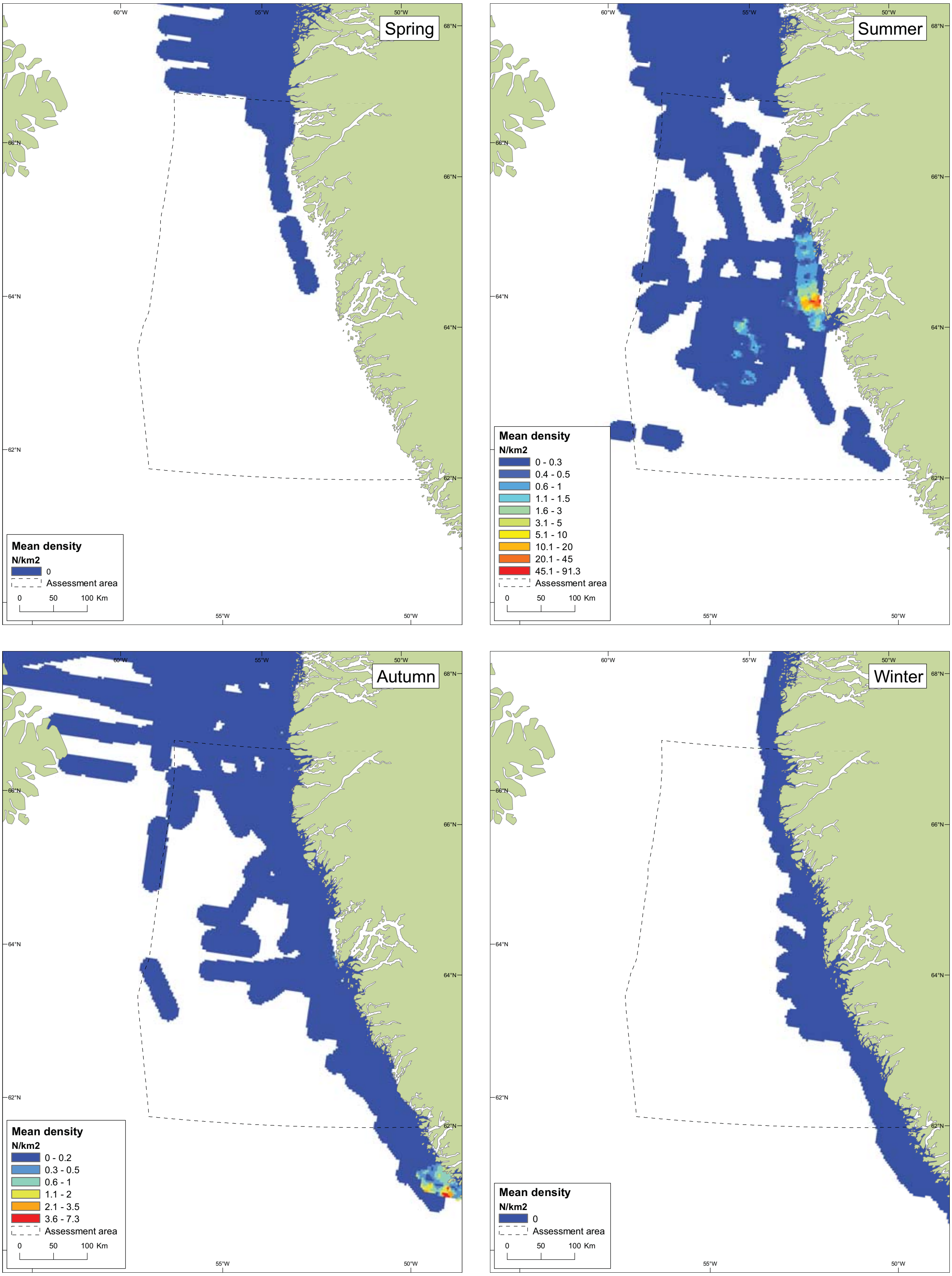



**Figure 4.7.5.** At-sea distribution of great shearwater in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons.

### Common eider, *Somateria mollissima*

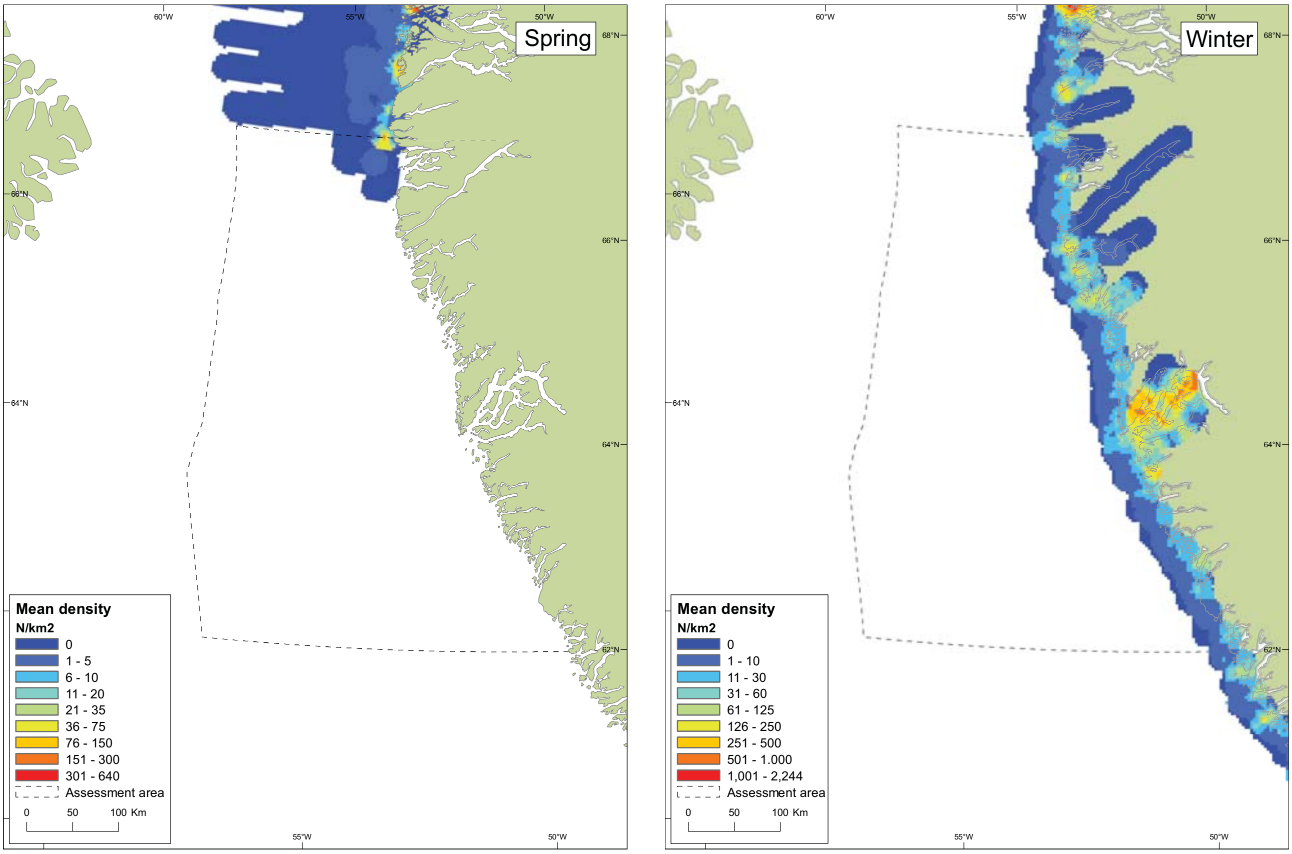
This duck is closely associated with the marine environment. It breeds both dispersed and in colonies on low islands and feeds in shallow coastal waters throughout the assessment area (Fig. 4.7.1).

Males assemble in moulting concentrations in remote fjords and archipelagos when the females have brooded the eggs for some time. Females (failed breeders) follow the males somewhat later and most birds moult within 100 km from the breeding site (Mosbech et al. 2006b). The flight feathers are moulted simultaneously, which means that the birds become flightless for about three weeks. After moulting the eiders migrate to wintering areas in the open water region of Southwest Greenland (Lyngs 2003, Mosbech et al. 2007).

Total number of breeding birds in the assessment area is unknown, but numbers probably amount to some thousand pairs (L. M. Rasmussen, pers. comm.). The population declined considerably during the 1900s due to non-sustainable harvest (Gilliland et al. 2009). But recently, after hunting in the spring was prohibited, population recovery has been evident in the district of Ilulissat and Upernavik, where active management and monitoring using local stakeholders has been applied. An annual population increase of ~15% has recently been estimated for these breeding areas (Merkel 2008, 2010a). Recent surveys in the central part of the assessment area indicated a similar population increase (Rasmussen 2010, 2011).

The common eider population in West Greenland until recently had an unfavourable conservation status due to the decline. It was therefore listed as 'Vulnerable' (VU) on the Greenland Red List (Boertmann 2007). However, this status now seems out-dated.

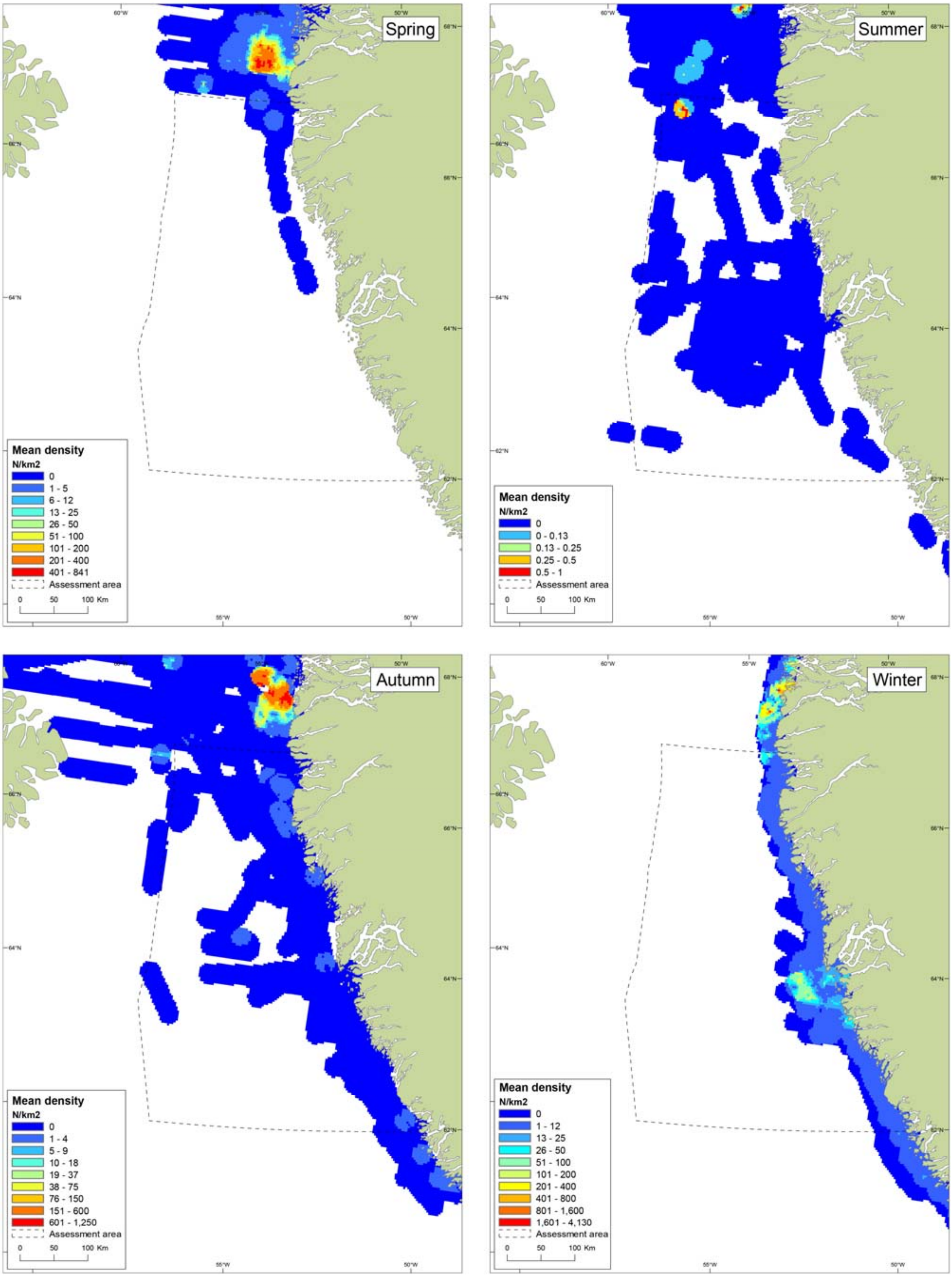
Breeding colonies, moulting areas and staging areas during migration and wintering are sensitive, as large number of birds may stay on the water in such areas. Especially during winter, the density of common eiders is high in the coastal zone of the assessment area (Fig. 4.7.6), as large numbers of breeding birds from Northwest Greenland and eastern Canada spend the winter in Southwest Greenland (Lyngs 2003, Mosbech et al. 2006b). In 1999 the winter population of common eiders was estimated to 460,000 birds in Southwest Greenland, of which a large proportion occurred within the assessment area (Merkel et al. 2002). Presumably the winter population has increased considerably since then. Particularly the fjords and bays around Nuuk are important wintering areas (Merkel et al. 2002, Blicher et al. 2011).




**Figures 4.7.6.** At-sea distribution of common eider in the assessment area based on available ship survey and aerial survey data from 1988 - 2010. Only the coastal zone is well covered and only during winter (Merkel et al. 2002). Note also that the density scale varies between seasons.

### King eider, *Somateria spectabilis*

The king eider is mainly a winter visitor to the assessment area, although a few may occur also in summer. The birds arrive from breeding grounds in Canada and moulting grounds in NW Greenland during October. The most important winter area is the Store Hellefiskebanke just north of the assessment area (Fig. 4.7.7). But wintering king eiders are also found along the coasts and on some of the offshore banks of the assessment area, especially Fyllas Bank. In winters with heavy ice conditions birds are forced to leave Store Hellefiskebanke and seek alternative winter habitats within the assessment area. An aerial survey in March 1999 (Merkel et al. 2002) resulted in an estimate of 153,000 king eiders in Southwest Greenland, of which a large proportion occurred in the assessment area (Merkel et al. 2002). Satellite tracking of king eiders confirms that a part of the population use the assessment area in winter (Fig. 4.7.8) (Mosbech et al. 2006a).




**Figures 4.7.7.** At-sea distribution of king eider in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and 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.

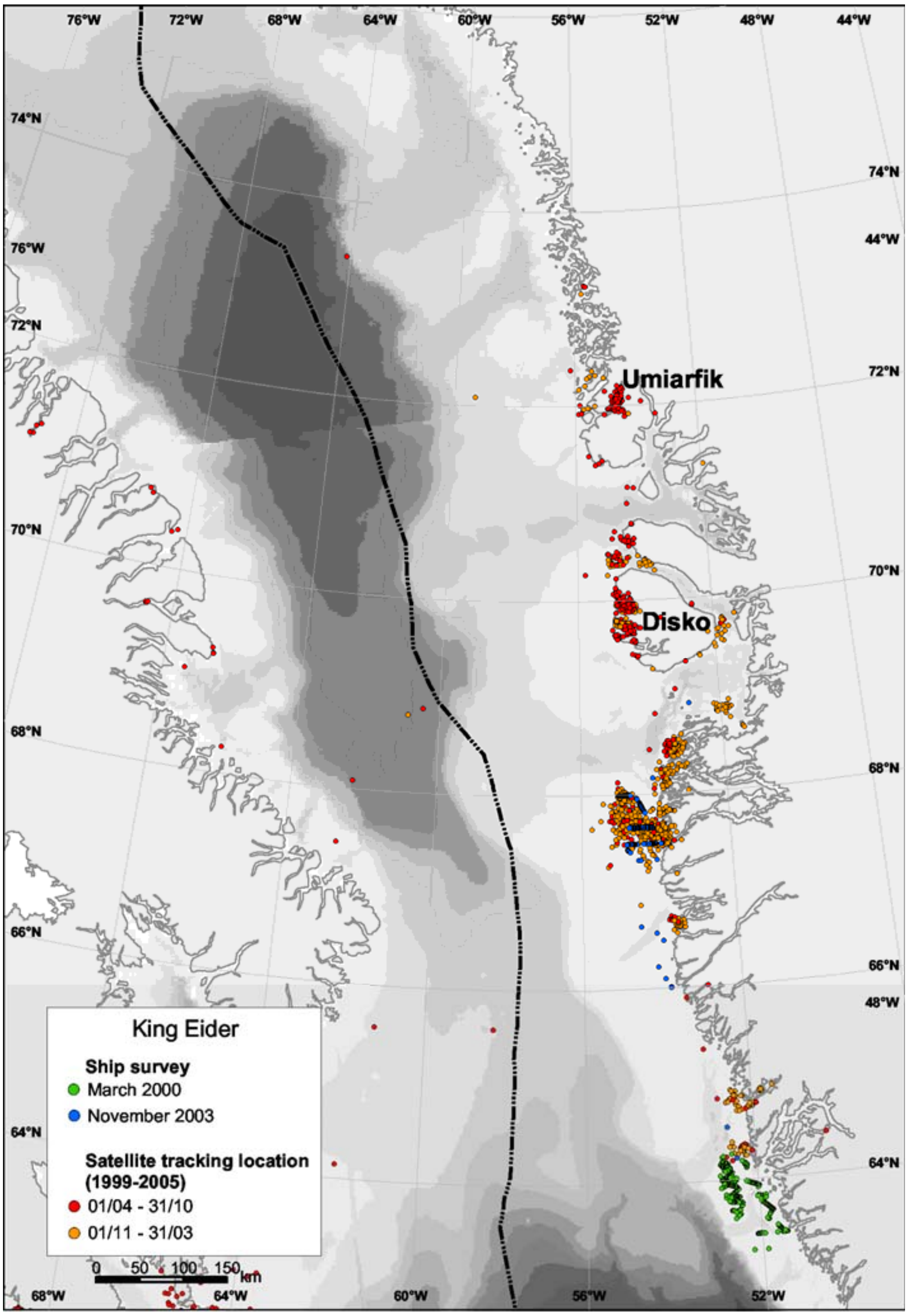



**Figure 4.7.8.** King eider satellite tracking locations from year round tracking of birds implanted at moulting localities in Umiarfik and the fjords at the west coast of Disko and at a breeding locality in Arctic Canada outside the map. The scattered dots in the central Baffin Bay and on Baffin Island are from bird migrating to and from breeding localities in Arctic Canada west of the map border. Observations from two ship based surveys are also indicated on the map. The importance of the waters west of Disko Island, Store Hellefiskebanke (at c. 68° N) and Fyllas Banke (at c. 64° N) is apparent. Based on AU/GINR data and Mosbech et al. (2006a).

King eiders have been recorded in very large flocks (>30.000 indvs.) in leads in the drift ice and such concentrations are very sensitive to oil spills, as a large fraction of the entire population may be exposed to oil.

The king eider is listed as Least Concern (LC) on the Greenland Red list (Boertmann 2007). However, this applies to the breeding population in Arctic Canada, which are the birds that moult and winter in West Greenland. The global status of the king eider is also Least Concern (LC) (IUCN 2010).

**Long-tailed Duck, *Clangula hyemalis***

This duck breeds scattered along sheltered coasts, and there are no major concentrations of moulting birds known from the assessment area. But in winter the ducks, at least from Iceland and Northeast Greenland, winter in the assessment area together with local birds (Lyngs 2003, A. Mosbech unpubl.). 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. 4.7.9). A high density area was located in the coastal zone west of Nuuk where 13,000 birds were present (Merkel et al. 2002).

Wintering long-tailed ducks are sensitive to oil spills and in high density areas, as in the case west of Nuuk, many birds may be exposed.

The long-tailed duck is listed as Least Concern on the Greenland red List (Boertmann 2007).

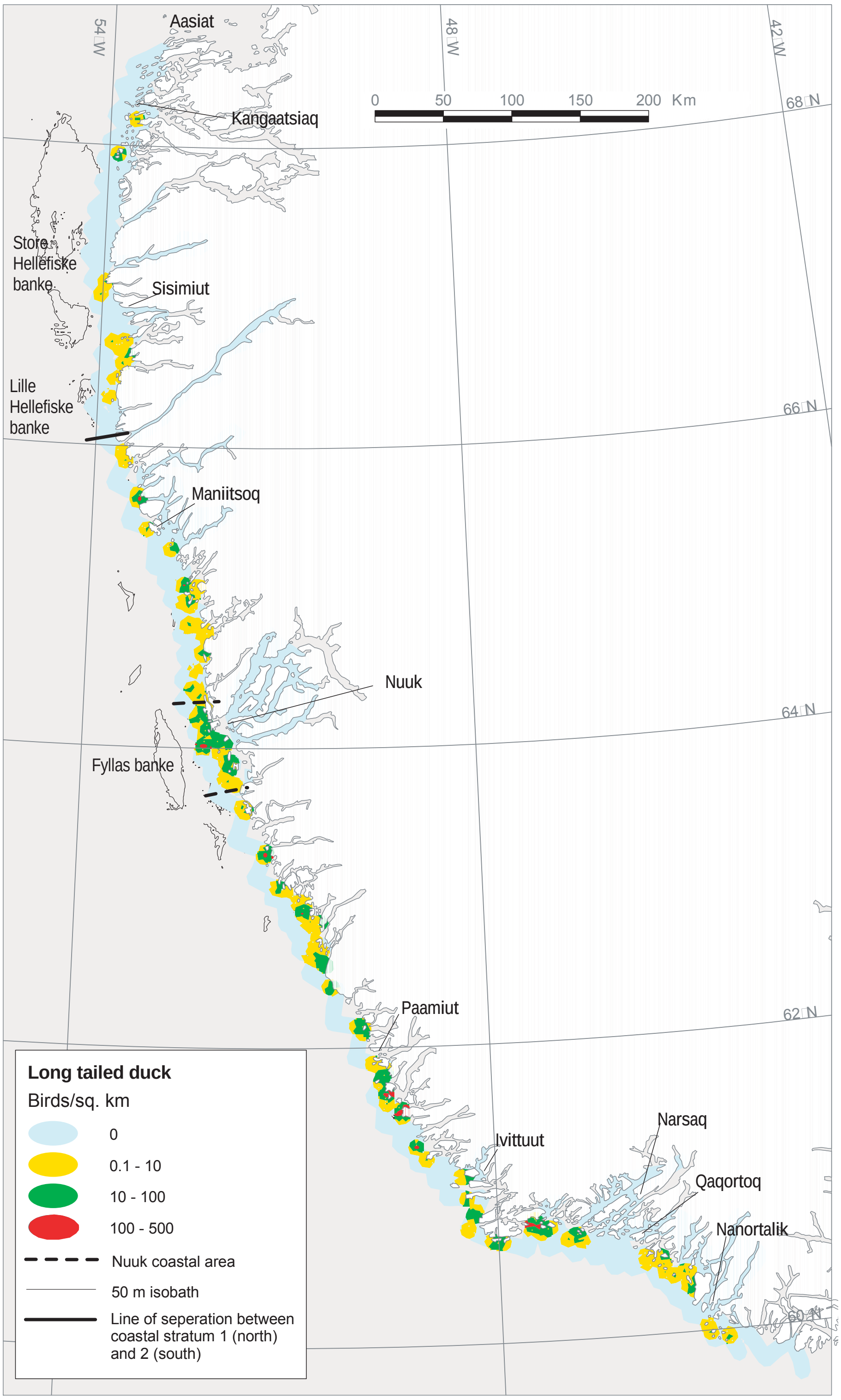



**Figure 4.7.9.** Distribution and inter-polated densities of long-tailed duck in Southwest Greenland based on aerial surveys in February/March 1999 (Merkel et al. 2002).

## Harlequin duck, *Histrionicus histrionicus*

The harlequin duck breeds at inland rivers. However, they also occur in marine habitats: non-breeding individuals and post-breeding males assemble from July at exposed rocky coasts and skerries and in winter all birds are found in these extreme habitats. A few non-breeding birds may stay at these coasts also before the moulting period.

The breeding population in Greenland is low, numbering probably only a few thousand pairs. However, Canadian birds also use the Greenland coasts for moulting and wintering (Robert et al. 2008) explaining why the number of birds along the outer coast – estimated at 5,000-10,000 birds – is higher than the Greenland population can muster (Boertmann 2008a, Robert et al. 2008).

In July 1999 the population of moulting birds was surveyed from aircraft (Fig. 4.7.10) and the resulting estimate was 5,000-10,000 males (Boertmann & Mosbech 2002, Boertmann 2003, 2008a). The winter population has not been surveyed, but is estimated at roughly more than 10,000 birds (Boertmann et al. 2006).

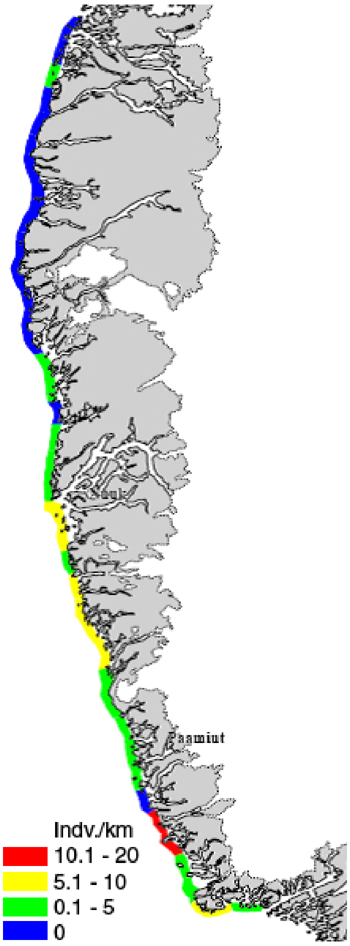



**Figure 4.7.10.** The density of moulting harlequin ducks recorded in July 1999 expressed as the number of birds recorded per km surveyed coastline (Boertmann & Mosbech 2002). The moulting period is July to September.

The moulting and wintering birds are very sensitive to marine oil spills due to their preference for exposed habitats along the outer coastline (Fig. 4.7.10). The highest concentrations of moulting birds within the assessment area was in 1999 found just south of Nuuk, while the distribution of the wintering birds is not known (Boertmann & Mosbech 2002, Boertmann 2003).

Due to the small breeding population, harlequin duck is listed as Near Threatened (NT) on the Greenland Red List (Boertmann 2007).

## Red-breasted merganser, *Mergus serrator*

This is a breeding bird in fjords and on sheltered coasts. Especially moulting birds assemble in high concentrations in some fjords, where they are sensitive to potential oil spills (Boertmann & Mosbech 2001). However, the known moulting sites are far from the outer coast where it is unlikely that oil spills from Davis Strait can reach. Winter concentrations may also be sensitive, but no knowledge on this is at hand.

The red-breasted merganser is listed as Least Concern (LC) on the Greenland Red List (Boertmann 2007). The population is probably isolated from neighbouring populations in Iceland and Canada.

## Black-legged kittiwake, *Rissa tridactyla*

This small gull is a numerous breeder in the assessment area, with the breeding colonies centred in Maniitsoq district (Fig. 4.7.2). The most recent survey of the breeding population in Greenland lists 35 occupied colonies holding approximately 34,000 breeding pairs (Labansen et al. 2010) within the assessment area. The breeding colonies are usually found in the fjords, and the birds often forage in the open sea, performing daily migrations in and out of the fjord. Breeding birds arrive to the colonies in the period March to May and leave again during August when the chicks are fledged.

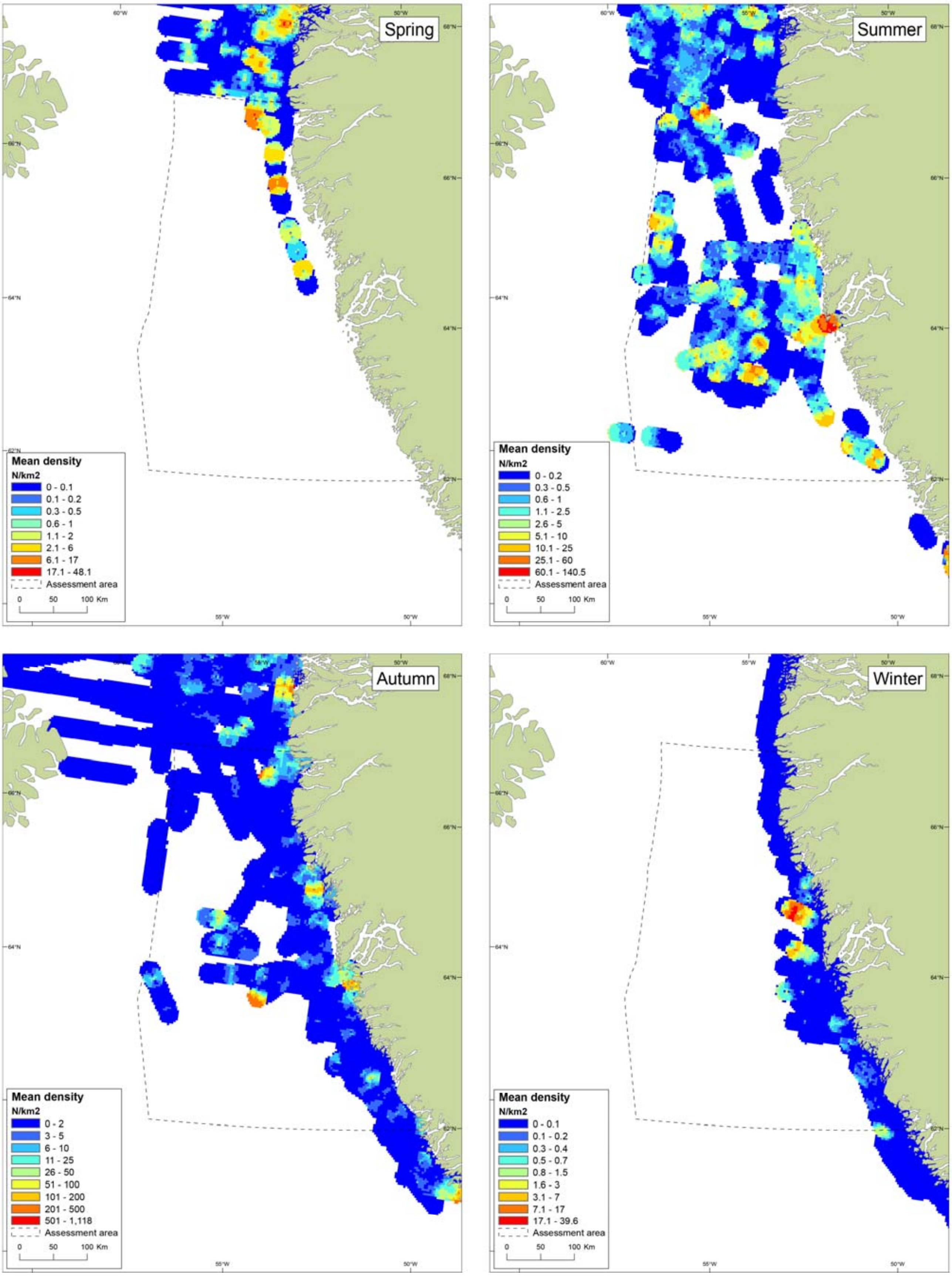



**Figure 4.7.11.** At-sea distribution of black-legged kittiwake in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons.

Kittiwakes are abundant in the shelf waters of the assessment area (Fig. 4.7.11) and many of these are non-breeding birds from populations breeding elsewhere in the North Atlantic (Lyngs 2003). Kittiwakes spend the winter in offshore parts of the North Atlantic, and at least some occur in the Davis Strait, but very few were observed during the winter surveys in 1999 (Merkel et al. 2002).

Kittiwakes are most vulnerable to oil spills at breeding colonies where large numbers of birds often assemble on the sea surface. There may also be concentrations at feeding areas, e.g. in the marginal ice in spring and early summer or at upwelling sites, but these are not predictable in time and space.

Due to a substantial decrease in the breeding population (Labansen et al. 2010), the kittiwake is listed as Vulnerable (VU) on the Greenland Red List (Boertmann 2007).

**Ivory gull**, ***Pagophila eburnea***

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 probably means that a large proportion of the northeast Atlantic population of the ivory gull moves through the assessment area in 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 North East 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. Ivory gulls can probably therefore also be present in the assessment area around this time or slightly later.

The ivory gull is of high conservation concern (Gilg et al. 2009, Gilg et al. 2010), being listed as near threatened (NT) on the international Red List (IUCN 2011), as vulnerable (VU) on both the Greenland and the Svalbard red lists (Boertmann 2007, Kålås et al. 2010), and as endangered by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC).

**Iceland gull**, ***Larus glaucoides***

This gull is the most abundant of the large gulls in the assessment area. Numerous breeding colonies are found there, on steep cliffs and small islands (Fig. 4.7.2).

The assessment area is also an important winter habitat for this gull, and both local breeding birds and birds from northern areas assemble here (Lyngs 2003, Boertmann et al. 2006).

Iceland gulls are most sensitive to oil spills at the breeding colonies. These colonies, however, are generally small and the population is spread widely along the coasts and population sensitivity is therefore relatively low compared to other much more concentrated seabirds.

The Iceland gull has a favourable conservation status in Greenland and is listed as Least Concern on the Greenland Red list (Boertmann 2007). The Greenland population constitutes a distinct and endemic subspecies.

**Glaucous gull**, ***Larus hyperboreus***
This gull is widespread in the region, but generally not as numerous as the Iceland gull (Fig. 4.7.2). It breeds in colonies often together with other colonial seabirds and both on steep cliffs and on low islands.

In winter, glaucous gulls are numerous along the coasts of the open water region, as birds from Svalbard and possibly also Canada assemble here (Lyngs 2003, Boertmann et al. 2004).

Glaucous gulls are most sensitive to oil spills at the breeding colonies. These colonies, however, are generally small and the population is spread widely along the coasts and therefore population sensitivity is relatively low compared to other much more concentrated seabirds.

The glaucous gull has a favourable conservation status in Greenland, and is listed as Least Concern on the Greenland Red list (Boertmann 2007).

**Great black-backed gull**, ***Larus marinus***
This gull is common and widespread along the coasts of the assessment area (Fig. 4.7.2). It breeds both in colonies and as dispersed as pairs – usually on small islands.

In winter, the entire population of Greenland great black-backed gull is found along the coasts of the open water area in Southwest Greenland.

The conservation status is favourable and the population is probably increasing, at least it has extended the range northwards in recent decades. It is listed as Least concern (LC) on the Greenland red list (Boertmann 2007).

**Lesser black-backed gull**, ***Larus fuscus***
The lesser black-backed gull has immigrated to Greenland within the past 30 years (Boertmann 2008b) and it is now a relatively common breeder in the assessment area (Fig. 4.7.2). It is usually found in small colonies among other gull species on small islands. The lesser black-backed gulls are migratory, leaving Greenland for the winter.

This species in not assessed on the Greenland Red List, but as it is increasing, both in range and number, its conservation status is favourable.

**Arctic tern**, ***Sterna paradisaea***
Relatively few breeding colonies of Arctic tern are present in the assessment area, compared with on more northern coasts of West Greenland, and long extents of coastline are completely without breeding terns (Fig. 4.7.2).

Arctic terns are highly migratory, wintering in the southern hemisphere (Egevang et al. 2010). They arrive to the breeding colonies during May/early-June and leave again during August/September. They spend most of the time in coastal waters close to breeding colonies. Terns feed on fish and crustaceans by plunge diving, and they usually do not rest on the water surface, making them less exposed than other seabirds to marine oil spills.

The West Greenland Arctic tern population had at least until 2001 an unfavourable conservation status and was decreasing due to excessive egg collecting. This activity was banned in 2001. It was therefore listed as Near Threatened (NT) on the national Greenland Red List, a listing which may be outdated now (Boertmann 2007).

**Black guillemot, *Cepphus grylle***

This auk is the most widespread of the breeding colonial seabirds in the assessment area (Boertmann et al. 1996). There are colonies in most fjords, bays and coasts, and their numbers range from a few pairs to several hundreds (Fig. 4.7.1). The total breeding population within the assessment area is unknown, but numbers at least several thousand pairs. During the breeding time they primarily stay in coastal waters, but in winter they disperse over the shelf and are often found in waters with drift ice (Mosbech & Johnson 1999).

Black guillemots are more or less migratory and birds from further north in Greenland move to the assessment area for the winter. 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 (Fig. 4.7.12) (Merkel et al. 2002).

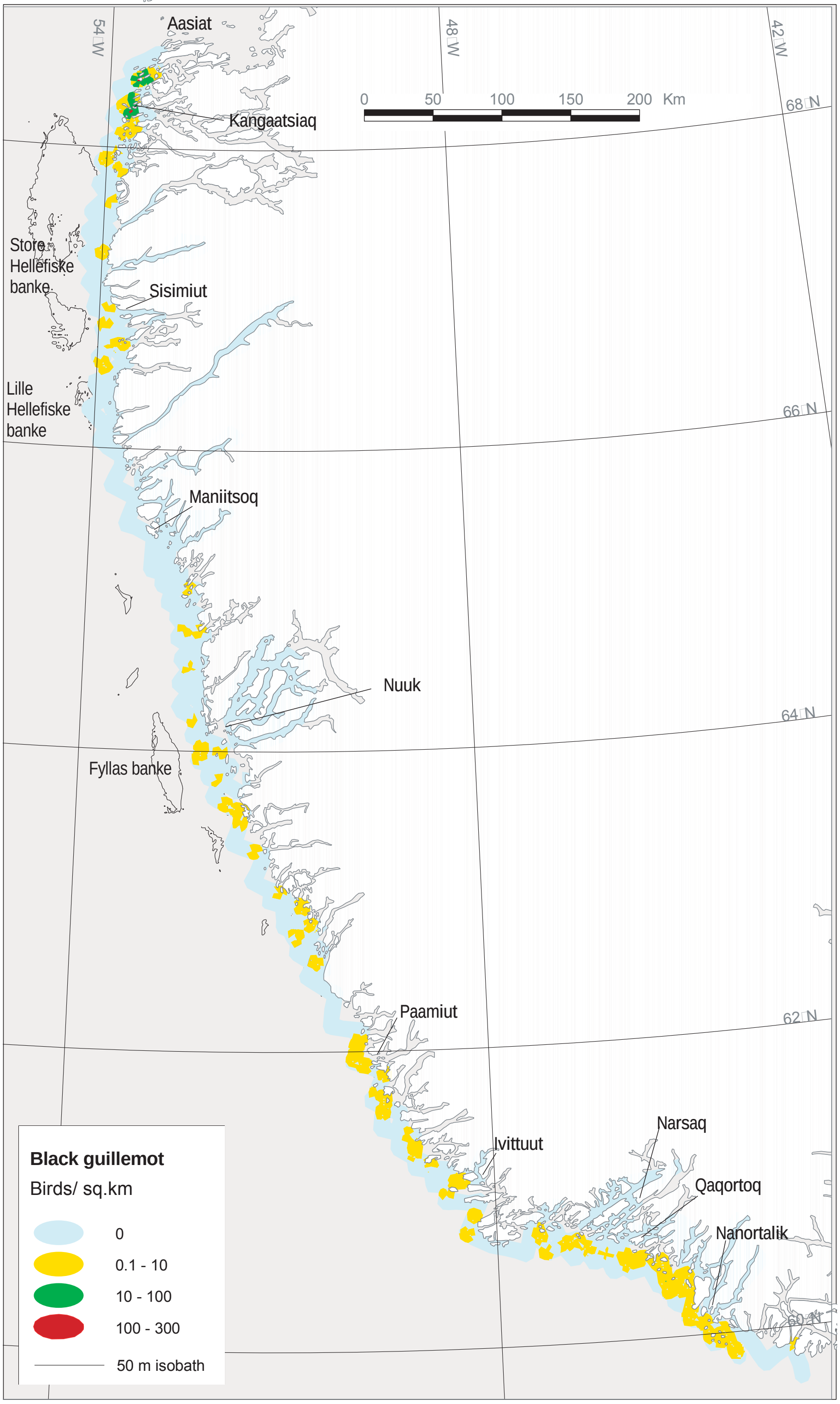
The black guillemot population in Greenland has a favourable conservation status and is listed as Least Concern (LC) on the Greenland Red List (Boertmann 2007).

Vulnerable concentrations occur mainly in the summer time near the breeding colonies. However, due to the wide dispersion of the colonies black guillemot sensitivity on a population level is relatively low.

**Thick-billed murre, *Uria lomvia***

This auk is a relatively numerous breeder in the assessment area. However, the breeding sites are few and very localised: One colony in Nuuk and three in Maniitsoq (Fig. 4.7.1). The most recent surveys sum up to 15,100 indviduals present in the breeding colonies within the assessment area (GINR & AU unpubl. data).

**Figure 4.7.12.** Distribution and interpolated densities of black guillemot in Southwest Greenland based on aerial surveys in February/March 1999 (Merkel et al. 2002).




In winter thick-billed murres from all over the North Atlantic congregate in the open water area and the population then is assessed at >1.5 million birds (Merkel et al. 2002, Boertmann et al. 2006), making it the most numerous seabird in the assessment area during winter (Fig. 4.7.13), except for the little auks, which potentially may occur in higher numbers.

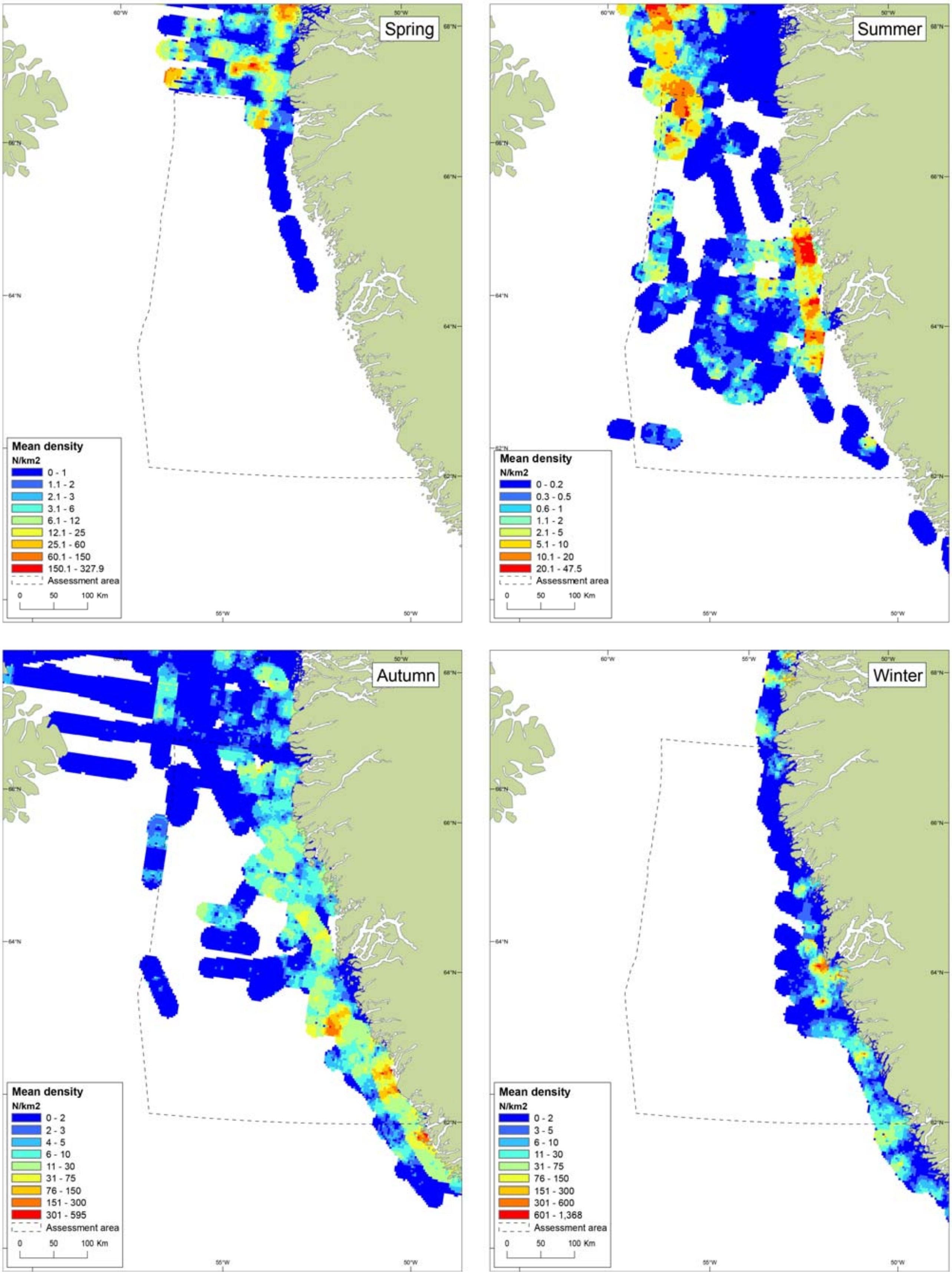



**Figure 4.7.13.** At-sea distribution of thick-billed murre in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons.

Murres spend very long time on the sea surface and only come on land in the breeding season. When the chicks are approximately three weeks old and far from fully grown or able to fly, they leave the colony in company with the adult male and swim/drift to offshore waters. The male then sheds all flight feathers and becomes flightless for some weeks and starts migration southwards by swimming. This swimming migration goes through the assessment area in late summer and early autumn (Fig. 4.7.13).

The West Greenland murre population has an unfavourable conservation status because it is decreasing. This decline is mainly ascribed to non-sustainable harvest and more recently perhaps also chronic oil spills caused by trans-Atlantic shipping in the winter quarters in Newfoundland waters (Falk & Kampp 1997, Wiese et al. 2004).

Murres are very sensitive both to oil spills and disturbance at the breeding colonies, where large proportions of the total population can be impacted by a single incident. Vulnerable offshore concentrations occur at feeding grounds, but they are highly vulnerable especially during the period of flightlessness and swimming migration.

Due to the population decline the thick-billed murre is listed as Vulnerable (VU) on the Greenland Red List (Boertmann 2007).

**Common murre, *Uria aalge***

The common murre is only found breeding at one site in the assessment area (Boertmann et al. 1996), in the colony of thick-billed murres southwest of Nuuk. The highest number recorded there in recent years is approximately 75 birds.

The species is listed as endangered on the Greenland Red List, as the population in other colonies to the south of the assessment area has decreased (Boertmann 2007).

**Razorbill, *Alca torda***

The razorbill is a widespread breeding bird in the assessment area. Several colonies holding from five to 300 individuals are found both in the fjords and at the outer coasts. The main part is found in Maniitsoq district (Fig. 4.7.1).

Razorbills are migratory and recent studies indicated that Greenland razorbills move to the waters off eastern North America for the winter (AU, unpubl.).

Razorbills' behaviour and sensitivity towards oil spills are similar to murres and black guillemots. However, the breeding population is much more dispersed than the thick-billed murres, with numerous small colonies along the coasts, so razorbills are likely to display better recovery potential. The conservation status of the razorbill in Greenland is favourable, and it is listed as Least Concern on the Greenland Red List (Boertmann 2007).

**Atlantic puffin, *Fratercula arctica***

The breeding population of puffins in the assessment area is concentrated at the mouth of Godhåbsfjord. Here approximately eight colonies hold about 1,000 birds. There are a few more small colonies within the assessment area, both north and south of Nuuk.

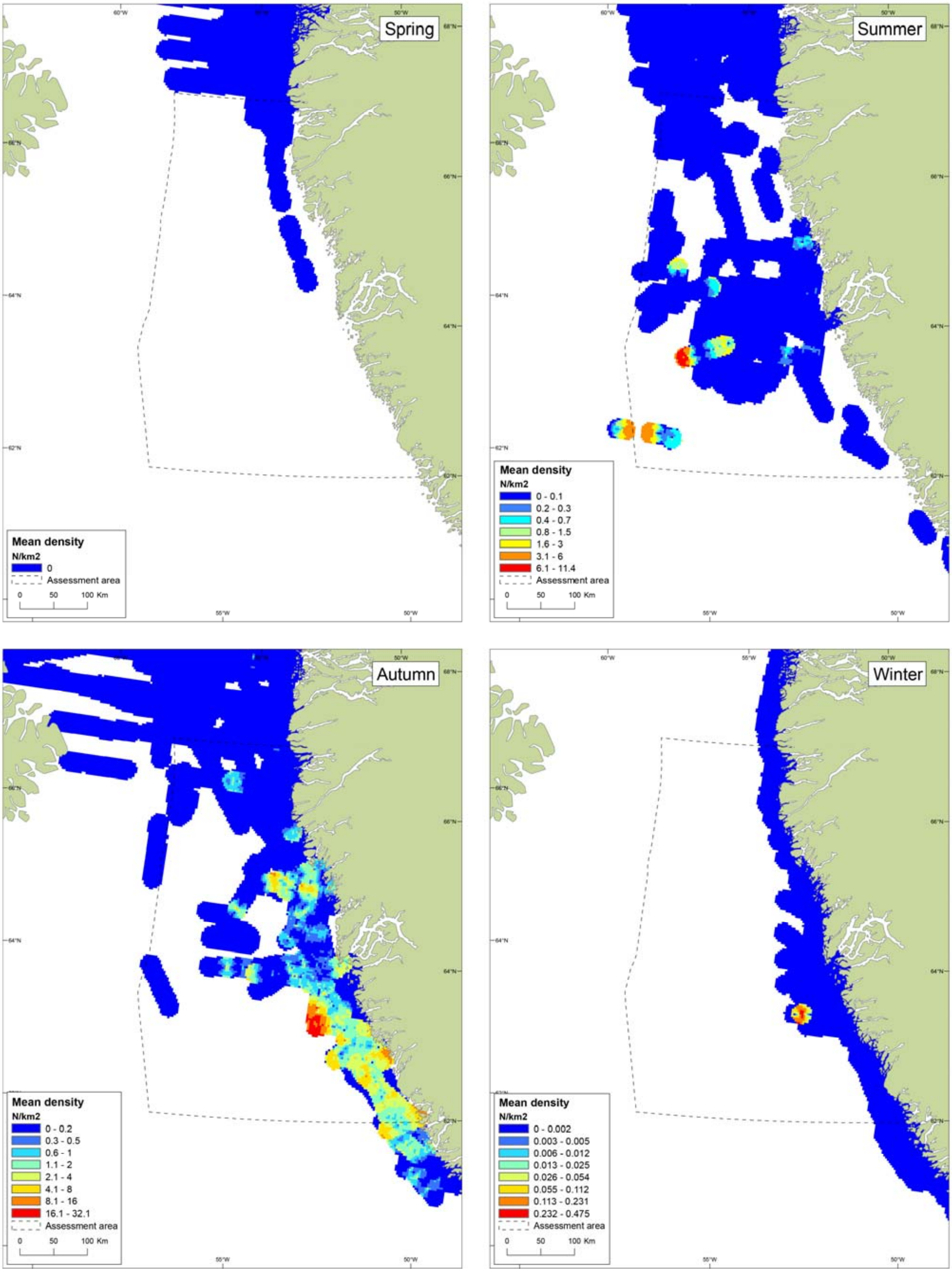



**Figure 4.7.14.** At-sea distribution of puffin in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons.

The puffins are migratory, but their whereabouts in winter are unknown, although recoveries of ringed birds indicate the waters off Northeast Canada (Lyngs 2003). In the autumn high numbers of puffins have been recorded in offshore waters of the southern part of the assessment area (Fig. 4.7.14) and these birds are probably birds from breeding colonies outside Greenland (Iceland, Norway) (Boertmann in press).

Several colonies further north in West Greenland have decreased and the Greenland puffin population was therefore assessed as Near Threatened (NT) on the Greenland Red List (Boertmann 2007).

Puffins are highly sensitive to oil spills both on individual level and on population level (Boertmann et al. 1996, Boertmann in press) and they are most vulnerable at the colonies where high numbers can be assembled on the water.

#### Little auk, *Alle alle*

This is the smallest of the auks, but the most numerous of the seabirds in the North Atlantic. It does not breed within the assessment area, but is a numerous autumn/winter visitor (Fig. 4.7.15). However, the species is difficult to survey due to the size and the knowledge on winter abundance distribution is therefore inadequate (Boertmann et al. 2004).

Little auks are very sensitive to oil spills and large winter concentrations may suffer from high mortality if hit by oil spills.

The Greenland population is assessed as Least Concern (LC) on the national Red List (Boertmann 2007).

#### White-tailed eagle, *Haliaeetus albicilla*

The white-tailed eagle is a resident species along the coasts of the assessment area (Fig. 4.7.16). Pairs breed scattered in archipelagoes and fjords and the total Greenland breeding population in 1990 was estimated at 150-170 pairs (Kampp & Wille 1990). The population today is probably of the same size, but information is lacking.

Although not a seabird, white-tailed eagles take their food from the marine environment, mainly fish and birds, and may become exposed to oil spill by contact with the water and from ingesting contaminated food. Several bald eagles (a close relative to the white-tailed eagle) were killed (estimated approximately 250) by the oil after the spill in Prince Williams Sound in 1989 and the population here recovered within 6 years (Bowman et al. 1997). However the density of eagles in Prince William Sound is much higher than in West Greenland, indicating that a recovery from oil induced mortality in Greenland would be much slower, and that the eagle population is more vulnerable.

Due to the small population the white-tailed eagle is listed as Vulnerable (VU) on the Greenland Red List (Boertmann 2007). The population is isolated from other populations and thereby particularly sensitive to increased mortality.

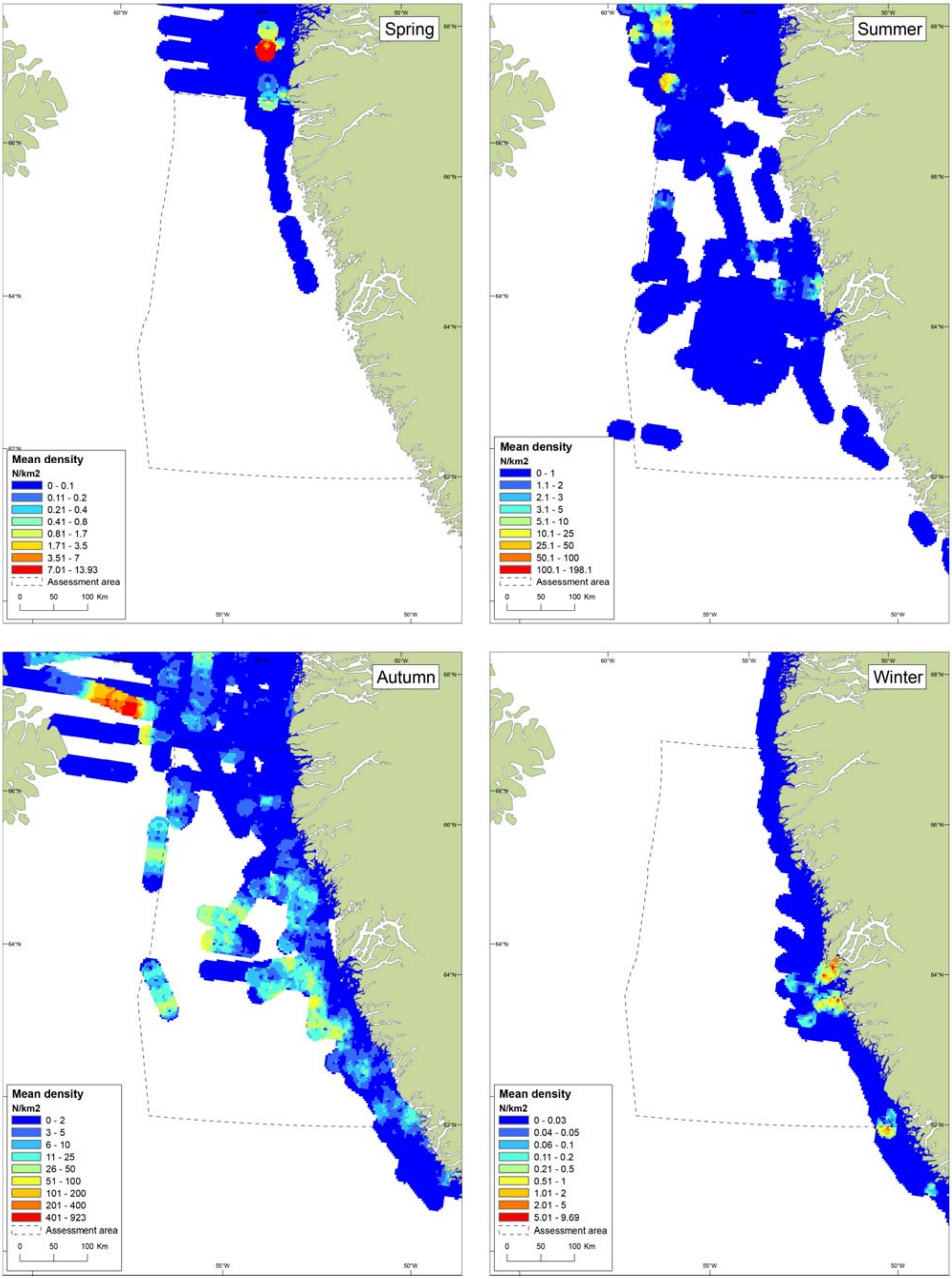
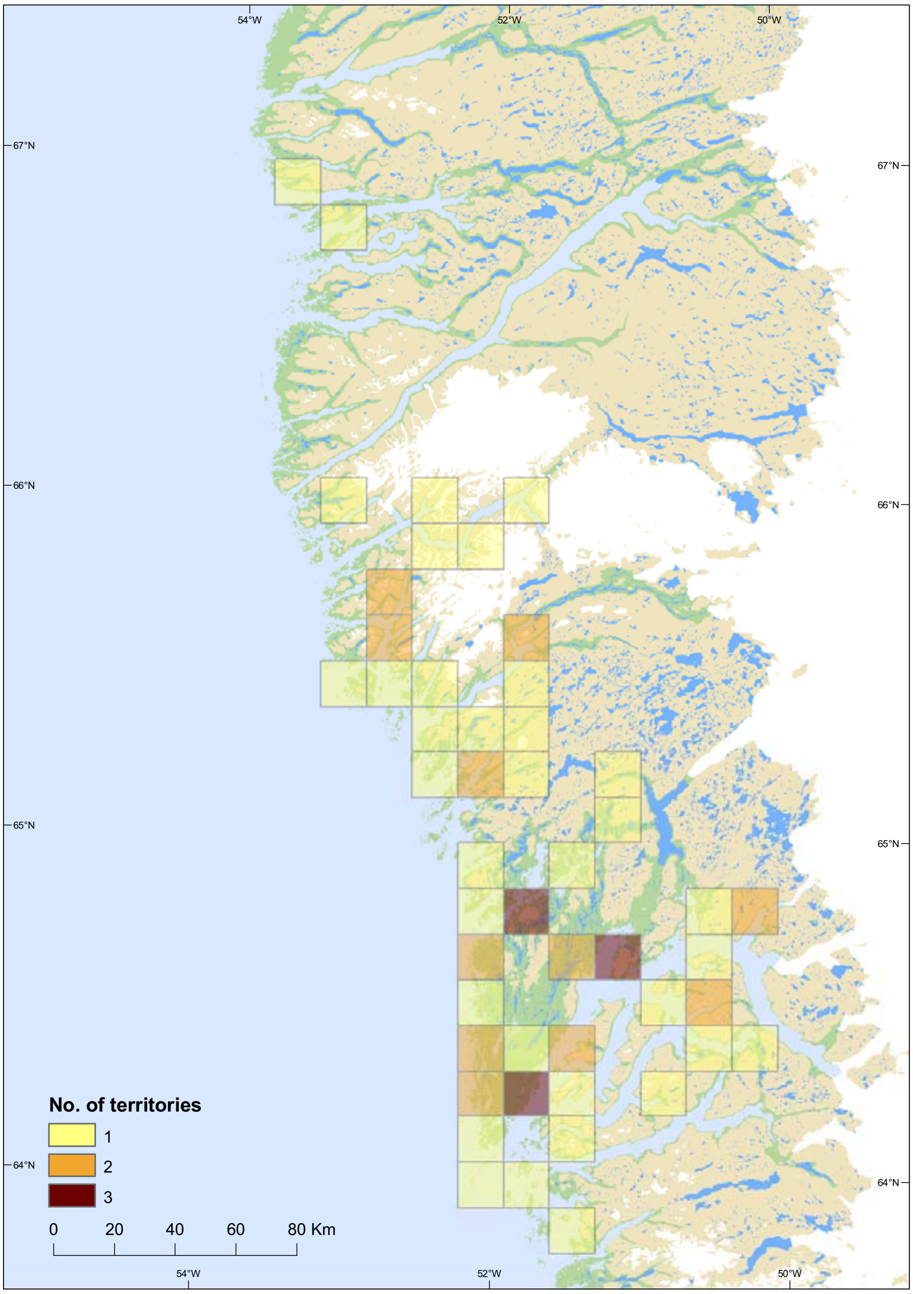



**Figure 4.7.15.** At-sea distribution of little auk in the assessment area during spring (Apr-May), summer (Jun-Aug), autumn (Sep-Dec) and winter (Jan-Mar) based on available ship survey and aerial survey data collected in 1988 - 2010. Note that survey coverage and density scale varies between seasons.

**Figure 4.7.16.** Density of white-tailed sea eagle territories within a 15x15 $km^2$ grid around Nuuk and northwards (Johansen et al. 2008). A similar or even higher density of territories is found south of this map along the coasts of the southern part of the assessment area.




## 4.8 Marine mammals

### 4.8.1 Polar bear and walrus

*Erik W. Born (GINR)*

**Polar bear, *Ursus maritimus***

*Distribution:* Based on the recapture or harvest of previously tagged animals and studies of movement of adult female polar bears with satellite collars, the Davis Strait (DS) subpopulation of polar bear occurs south of 66° N in the Labrador Sea, eastern Hudson Strait and in the sea ice covered areas of Davis Strait south of Cape Dyer on East Baffin Island and the entrance to Kangerlussuaq/Søndre Strømfjord in West Greenland (Obbard et al. 2010 and references therein).

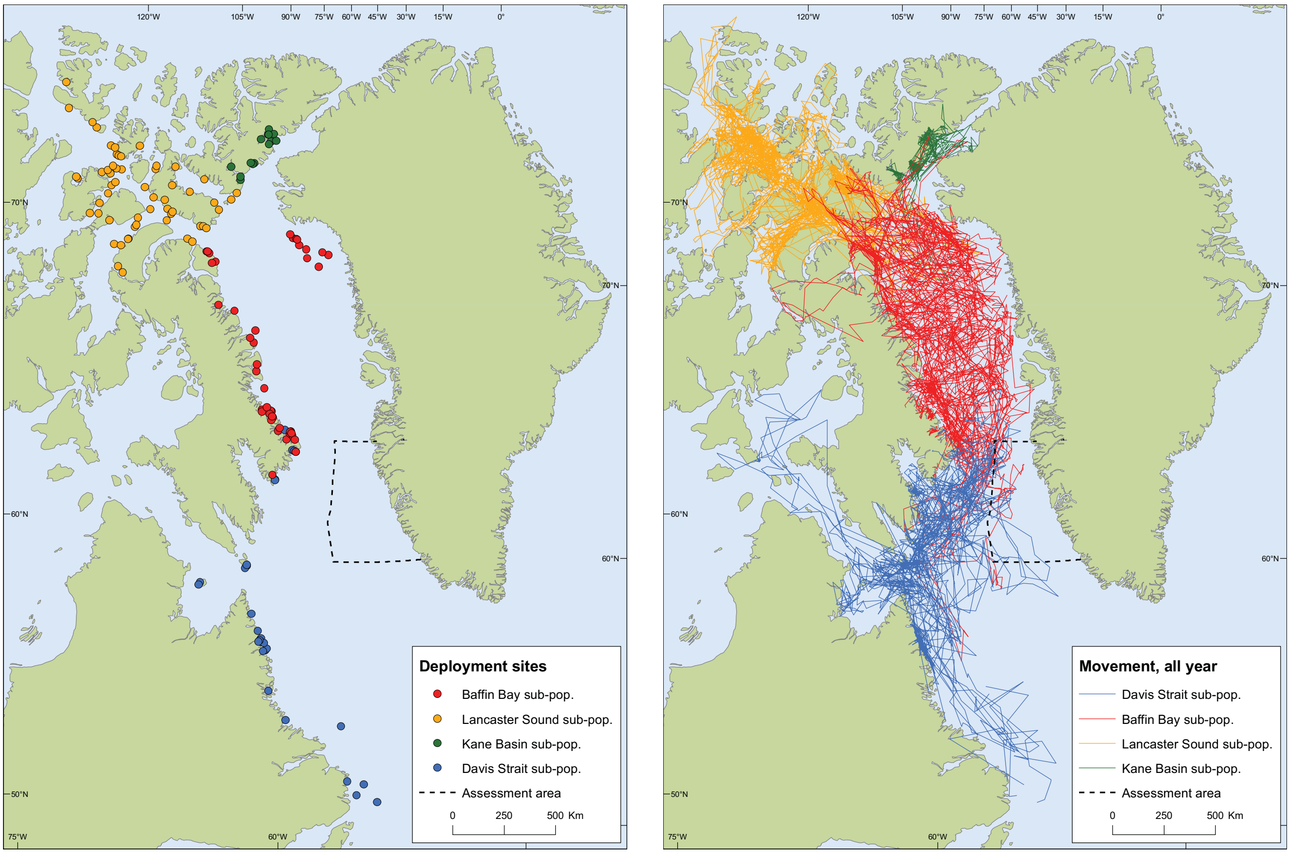



**Figure 4.8.1.** Left: Locations where adult female polar bears were instrumented with satellite transmitters (1991-1995) given by sub-population (Davis Strait, Baffin Bay, Lancaster Sound and Kane Basin). A total of 29 bears were instrumented in the Davis Strait subpopulation (blue) and their movements tracked during 1991-2001. The identification and delineation of the various sub-populations based on hierarchal cluster analyses is described in Taylor *et al.* (2001). Unpublished data: Nunavut Wildlife Management Division, University of Saskatchewan, Canadian Wildlife Service, Greenland Institute of Natural Resources.
Right: Track lines showing the overall movement during 1991-2001 of polar bears instrumented with satellite transmitters in the Davis Strait-Baffin region and adjacent areas. A certain degree of overlap between the different sub-populations is apparent. Unpublished data: Nunavut Wildlife Management Division, University of Saskatchewan, Canadian Wildlife Service, Greenland Institute of Natural Resources.

A genetic study of polar bears (Paetkau et al. 1999) indicated significant differences between bears from the Davis Strait and neighbouring Baffin Bay. The Davis Strait subpopulation of polar bears range in the 'seasonal-ice' ecoregion (Amstrup et al. 2007, 2008), with the ice-free period extending from approximately August through November. Annual ice cover in Davis Strait is highly variable and ice breakup has become earlier since 1991 (Stirling & Parkinson 2006).

Satellite telemetry conducted in the period 1991-2001 showed that polar bears from the DS subpopulation range the offshore pack ice in the Davis Strait (Mosbech et al. 2007). The movement of the bears instrumented with satellite-radios indicated an overall tendency to occur on the fast ice and in the shear zone between fast ice and pack ice along eastern Baffin Island. However, in December-June there is an overlap between the distribution of some polar bears from the Davis Strait subpopulation and the assessment area.

The extent of the pack ice in the Davis Strait varies from year to year (see chapter 3). So does the position of the Davis Strait whelping patch of hooded seals, *Cystophora cristata* (Bowen et al. 1987). During the period 1974-1984, the location of this whelping patch where polar bears occur (F.O. Kapel, personal communication 1984) varied within an area confined by approx. 55° 45'W – approx. 60° W and approx. 61° 50' N – approx. 63° 15' N (Bowen et al. 1987: 286). It is likely that the number of polar bears occurring at the Davis Strait hooded seal whelping patch during spring also varies from year to year, depending among other factors on ice conditions in the Davis Strait and the ability of the bears to reach the whelping patch from eastern Baffin Island.

In recent years unusual occurrence of concentrations of harp seals (*Pagophilus groenlandicus)* at the eastern edge of the Davis Strait pack ice has been reported. In late January-early February large numbers of harp seals were observed in the pack ice west of the town of Sisimiut (approx. 67° N) (Rosing-Asvid 2008). Hence, variation in the distribution of prey including concentrations of harp seals may also influence the spatial distribution and number of polar bears within the assessment area.

*Number:* The most recent inventory of the Davis Strait subpopulation was completed in 2007 resulting in an estimate is 2,142 polar bears (95% log-normal CI 1811 – 2534) (Obbard et al. 2010).

Amstrup et al. (2007, 2008) incorporated projections of future sea ice in four different 'ecoregions' of the Arctic, based on ten general circulation models by the International Climate Change Panel (ICCP), into two models of polar bear habitat and potential population response. One eco-region encompasses the polar bear habitat with seasonal ice ('the seasonal ice ecoregion') – including the Davis Strait – where sea ice usually is absent during the open water period. One of the models (a deterministic 'carrying capacity model') predicted a 7-10% decrease in the polar bear population in the 'seasonal ice ecoregion' approx. 45 years from now (22-32% decline approx. 100 years from now), whereas the other model (quasi-quantitative 'Bayesian network population stressor model') predicted extirpation of polar bears in this ecoregion – including the Davis Strait – by the mid-2100s.

*Conclusions:* Polar bears from the Davis Strait subpopulation occur within the assessment area during periods with sea ice. Satellite telemetry data from the 1990s indicate that polar bears may occur in the assessment area from November-December until sometime in spring (May-June), depending on annual variability in sea ice cover. It is likely that the distribution and number of polar bears from the Davis Strait subpopulation that occur at the eastern edge of the Davis Strait pack ice to a certain extent are influenced by the location of the Davis Strait hooded seal whelping patch and unusual occurrence of harp seal concentrations.

**Walrus, *Odobenus rosmarus***

*General biology:* The following life history traits are relevant to evaluation of the potential effects on walruses from oil-related activities. An important characteristic of walruses is that they are gregarious year round (Fay 1982, 1985), which means that impacts will concern groups rather than single individuals (Wiig et al. 1996). Walruses are benthic feeders that usually forage where water depths are less than approximately 100 m (Vibe 1950, Fay 1982, Born et al. 2003); although they occasionally make dives to at least 200–250+ m depth, both inshore and offshore (Born et al. 2005, Acquarone et al. 2006). They have an affinity to shallow water areas with suitable benthic food and winter in areas without solid ice - i.e. where there is not 100% sea ice cover (Born et al. 1995 and references therein). In western Greenland such habitat is mainly found between approx. 66° 30' N and approx. 70° 30' N and between the coast and approx. 56° W (Born et al. 1994, Born et al. 1995).

During the mating season (January–April; Born 2001, Born 2003 and references therein) male walruses engage in ritualised visual and acoustical display underwater (Fay et al. 1984, Sjare & Stirling 1996, Sjare et al. 2003).

*Delineation of population:* Genetic analyses indicate that three subpopulations exist in the Baffin Bay-Davis Strait region (Cronin et al. 1994, Andersen et al. 1998, Andersen & Born 2000, Born et al. 2001, Andersen et al. 2009a, Andersen et al. 2009b, NAMMCO 2009): The (1) Eastern Hudson Bay-Hudson Strait, (2) West Greenland-Southeast Baffin Island, and (3) and the northern Baffin Bay stock confined to the North Water Polynya. The studies indicated that (1) walruses in the West Greenland-Southeast Baffin Island and the Baffin Bay populations differ genetically with some likely limited male mediated gene flow between these populations, (2) walruses at Southeast Baffin Island and West Greenland do not differ genetically, (3) walruses from Hudson Strait have some genetic input to this West Greenland-Southeast Baffin Island stock.

A satellite telemetry study during 2005-2008 supported the findings of the genetic studies that walruses in West Greenland and at southeastern Baffin Island constitute the same population, and this population is hunted in both Greenland and Nunavut (NAMMCO 2009, Dietz et al. 2010).

*Distribution:* From October–November until late-May (timing varying from year to year depending on sea ice conditions) walruses from the West Greenland-Southeast Baffin Island stock (NAMMCO 2009) are found in the pack ice approximately 30 to 100 km off the coast between approx. 65° 30' N and approx. 68° 15' N. The main distribution in this region is north of approx. 66° 30′ N; although direct observations, satellite tracking and catch reports indicate that walruses do occur inside the northern part of the assessment area (Born et al. 1994, GINR/NERI unpubl. data).

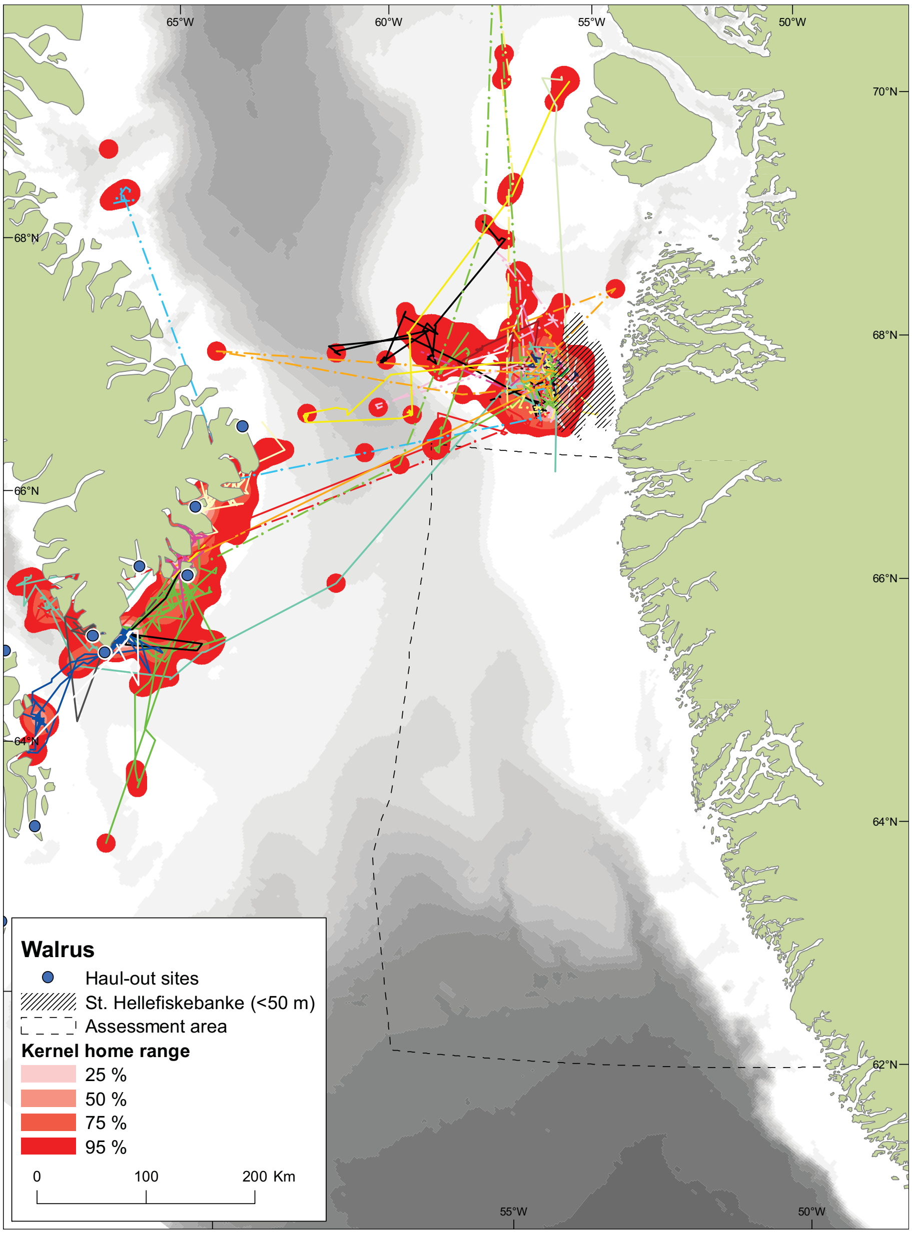
Several systematic aerial surveys conducted during 1981–2008 (Born et al. 1994 and references therein, Mosbech et al. 2007, NAMMCO 2009, Heide-Jørgensen et al. 2010a) showed that winter distribution of walruses off Central West Greenland is similar to that indicated by historical information, with two main concentrations; the shallow water banks between approx. 66° 30' N and approx. 68° 15' N, and the banks along the western coast of Disko Island between approx. 69º 15' and approx. 70º 30' N (*Ibid.*).

On their West Greenland wintering grounds walruses prefer areas with dense pack ice (usually more than 60% ice cover) in <100 m deep waters. Subadults and females with young generally occur closer to the coast than males in areas with less dense ice and shallower water (Born et al. 1994, Dietz et al. 2010). Although larger congregations numbering one to two hundred individuals have occasionally been reported off Central West Greenland (i.e. off Attu-Nassuttoq at ca. 67° 30' N and west of Disko at ca. 69° 45' N; Born et al. 1994), most walruses observed during aerial surveys were either single or in pairs (Born et al. 1994, Dietz et al. 2010, Heide-Jørgensen et al. 2010a). Observations of newborn calves in this area are extremely rare (Born et al. 1994, Born et al. 1995). Recordings of underwater sounds indicate that walruses mate in Central West Greenland (Born et al. 1994).

*Numbers:* The status of the walrus subpopulation in Greenland and the eastern Canadian Arctic was evaluated by the North Atlantic Marine Mammal Commission in 2009 (NAMMCO 2009). The 2006 and 2008 aerial surveys that were dedicated to estimating the abundance of walruses on their Central West Greenland wintering grounds resulted in weighted averages of fully corrected estimates of abundance. The estimate of abundance for the southern wintering ground (i.e. between approx. 65° 30' N and 68° 15' N and between the Greenland coast and approx. 56° W) was approx. 2,400 in 2006 and approx. 2,900 walruses in 2008 (Table 5 in Heide-Jørgensen et al. 2010a). In 2005, 2006, 2007 and 2008 aerial surveys were conducted jointly by Department of Fisheries (DFO, Canada) and the Greenland Institute of Natural Resources (GINR, Greenland) during the 'open water' or ice free season over the walrus summering grounds along Southeast Baffin Island between 62° 10' N and 69° 37' N. In 2007, a boat survey was conducted by DFO, GINR and NERI along the coast of Southeast Baffin Island where walruses from the West Greenland-Southeast Baffin Island stock haul out on land during summer. The purpose was to arrive at an estimate of 'minimum number of walruses alive' in these areas. The highest number recorded was 1,056 walruses obtained on 3-4 September 2007 (NAMMCO 2009). This number has not been adjusted for animals at sea and not present on or at the haul-outs during the survey. Studies of walrus behaviour in other parts of the Arctic indicate that walruses spend an average of approx. 25% to approx. 40% of their time on land (cf. Born 2005). This indicates that several thousand walruses from the West Greenland-Southeast Baffin Island stock can be found during summer along southeastern Baffin Island.

*Movements:* Scattered observations offshore in Davis Strait in March–July suggest that walruses migrate across Davis Strait from western Greenland to eastern Baffin Island during spring (Fig. 4.8.2) (Born et al. 1982, Born et al. 1994). Satellite telemetry during spring of 2005–2008 supports the notion that the majority of walruses that winter in Central West Greenland move west to summer at southeastern Baffin Island (NAMMCO 2009, Dietz et al. 2010).

Figure 4.8.2. Track lines and Kernel Home Range polygons from 31 walruses instrumented with satellite- linked transmitters at Store Hellefiskebanke during March-April 2005-2008 and at Southeast Baffin Island during August-September 2008 (Dietz et al. 2010).




The westward migration occurred between 7 April and 25 May, with the routes across Davis Strait being quite similar and taking place at the shallowest and the narrowest part (approx. 400 km) of the strait. Hence, although the walrus whelping season is protracted (Born 2001) the walruses leave their West Greenland wintering grounds prior to the peak of calving season in late-June (Born 2001). All movements made by the instrumented walruses occurred north and west of the assessment area. However, observations made during seven aerial surveys conducted during 1981-1991 (Born et al. 1994) and in 2006 and 2008 (Heide-Jørgensen et al. 2010a) indicate that occasionally walruses may occur in the shallow waters of the northern part of the assessment area during late winter.

*Sensitivity to oil:* Due to the often highly localised distribution of the walruses close to or within the assessment area, a large proportion of the population may potentially be affected by a single and long-lasting incident – an oil spill or disturbance from permanent infrastructure or construction. An environmental impact assessment of shipping along the Northern Sea Route (the Northeast Passage) concluded that the walrus populations could be negatively impacted by disturbance from ship traffic and oil spills (Wiig et al. 1996).

During haul out walruses are particularly sensitive to disturbance, including sailing, traffic on land, and flying (Born et al. 1995 and references therein). This was for example documented by Born & Knutsen (1990) who, based on fieldwork in Northeast Greenland, concluded that air traffic should not go closer than 5 km to haul out sites. This minimum distance could be tentatively applied to walruses on ice.

The effect of oil spills on walruses has not been studied in the field. However, Born et al. (1995) and Wiig et al. (1996) speculated that if walruses do not avoid oil on the water they may suffer if their habitats are affected by oil and that they, like other marine mammals, can be harmed by both short-term and long-term exposure. Born et al. (1995) pointed to the fact that some features in the ecology of walruses make them more vulnerable to the harmful effects of spilled oil than many other marine mammals:

- Due to the high level of gregariousness in walruses, an oil spill that affects one would be likely to affect at least several individuals.
- Their pronounced thigmotactic behavior on ice and on land makes it likely that oil-fouled walruses will rub oil onto the skin or into the eyes of other individuals.
- Walruses tend to inhabit coastal areas and areas of relatively loose pack ice. Spilled oil is likely to accumulate in just such areas (Griffiths et al. 1987). Walruses therefore have a high risk of being fouled not only in the water but also when they haul out.
- Because they are benthic feeders, walruses may be more likely to ingest petroleum hydrocarbons than most other pinnipeds. Benthic invertebrates are known to accumulate petroleum hydrocarbons from food, sediments and the surrounding water (Richardson et al. 1989). Mortality of several species of benthic invertebrate including bivalve mollusks has been observed as a direct effect of oil spills (North 1967, Percy & Mullin 1975, both fide U.S. Fish and Wildlife Service 1993). Furthermore, sublethal effects on the behaviour, physiology, and productivity of benthic mollusks may result from exposure to petroleum products (Clark & Finley 1977). The implications for walruses may be serious since contaminants in their food are certain to build up in their own tissue. Also, if oil contamination were to reduce the biomass or productivity of the invertebrate communities that sustain walruses there would evidently be some secondary impact on the walruses themselves.
- Walruses are stenophagous and depend on access to mollusk banks in shallow water. Oil spills in certain feeding areas could force walruses to seek alternative food or relocate to other feeding areas. It cannot be assumed that alternative types of food or feeding areas are actually available; thus, such an oil spill scenario could prove detrimental to the walruses.

*Conclusions:* Walruses from the West Greenland-Southeast Baffin Island stock may occur between some time in fall until sometime in May (period likely to depend to a large extent on ice conditions in any particular year) in West Greenland 30 to 100 km off the coast between approx. 65° 30' N and approx. 68° 15' N. Main distribution in this region is between approx. 66° 30' N and approx. 68° 15' N (i.e. Store Hellefiskebanke). Satellite telemetry (2005-2008) and aerial surveys (1981-2008) indicate that only a small fraction of the walruses wintering in these areas may occur within the assessment area. Hence, oil exploration and exploitation activities may potentially only impact a minor (but unknown) fraction of walruses of the West Greenland-Southeast Baffin Island stock when they occur at their West Greenland wintering grounds.

As walruses mainly occur north of the assessment area, the most likely impact of disturbance from oil-exploration inside the northern part of the assessment area will therefore likely be the displacement of relatively few individuals due to underwater noise and masking.

However, the currents that are flowing north at greater depths along the West Greenland coast through the Davis Strait assessment area may bring oil slicks northwards into the important close-by walrus wintering grounds at Store Hellefiskebanke and Disko Banke farther north. In case of fouling of the sea bed < 200 m depth on Store Hellefiskebanke essential walrus foraging areas may be destroyed. In that connection it must be noted that at Southeast Baffin Island there are only few and geographically limited open water areas suitable for wintering walruses compared to the West Greenland 'open water area' over the Store Hellefiskebanke. Furthermore, the extension of shallow water banks along Southeast Baffin Island is much smaller than in West Greenland where walruses occur. Hence, although not known with certainty, it seems plausible that the majority of the West Greenland-Southeast Baffin Island stock of walruses winter at the West Greenland banks between approx. 65° 30' N and approx. 68° 15' N. Therefore, any potential negative impact from oil exploration or exploitation activity in West Greenland would influence this stock comparatively more severely.

### 4.8.2 Seals

*Aqqalu Rosing-Asvid (GINR)*

Five species of seals occur in the assessment area; two species (harp and hooded seals) are migrant seals and their numbers fluctuate significantly with season. Ringed seals maintain breathing holes in annual sea ice throughout the winter. Some ringed seals in the assessment area are likely to live a relatively stationary existence in the glacier fjords, while others enter the area as the pack ice in Davis Strait spreads eastward during winter and spring. The Storis (pack ice from the east coast) might also reach into the assessment area from south and some influx of ringed seals is also likely to come from this front. Bearded seals are also associated with sea ice. They can make breathing holes, but only in relatively thin ice. The seasonal distribution of bearded seals in the West Atlantic is not known in detail, but their numbers increase in the assessment area during winter and spring when especially the Store Hellefiskebanke seems to become an important habitat. Harbour seals spend most of their time close to the coast. The coastal part of the assessment area once had the highest occurrence of these seals in Greenland, but their numbers declined significantly during the 20$^{th}$ century. The species is listed on the Greenland Red List as critically endangered and in 2010 all hunting of harbour seals in Greenland was prohibited.

#### Seals and oil

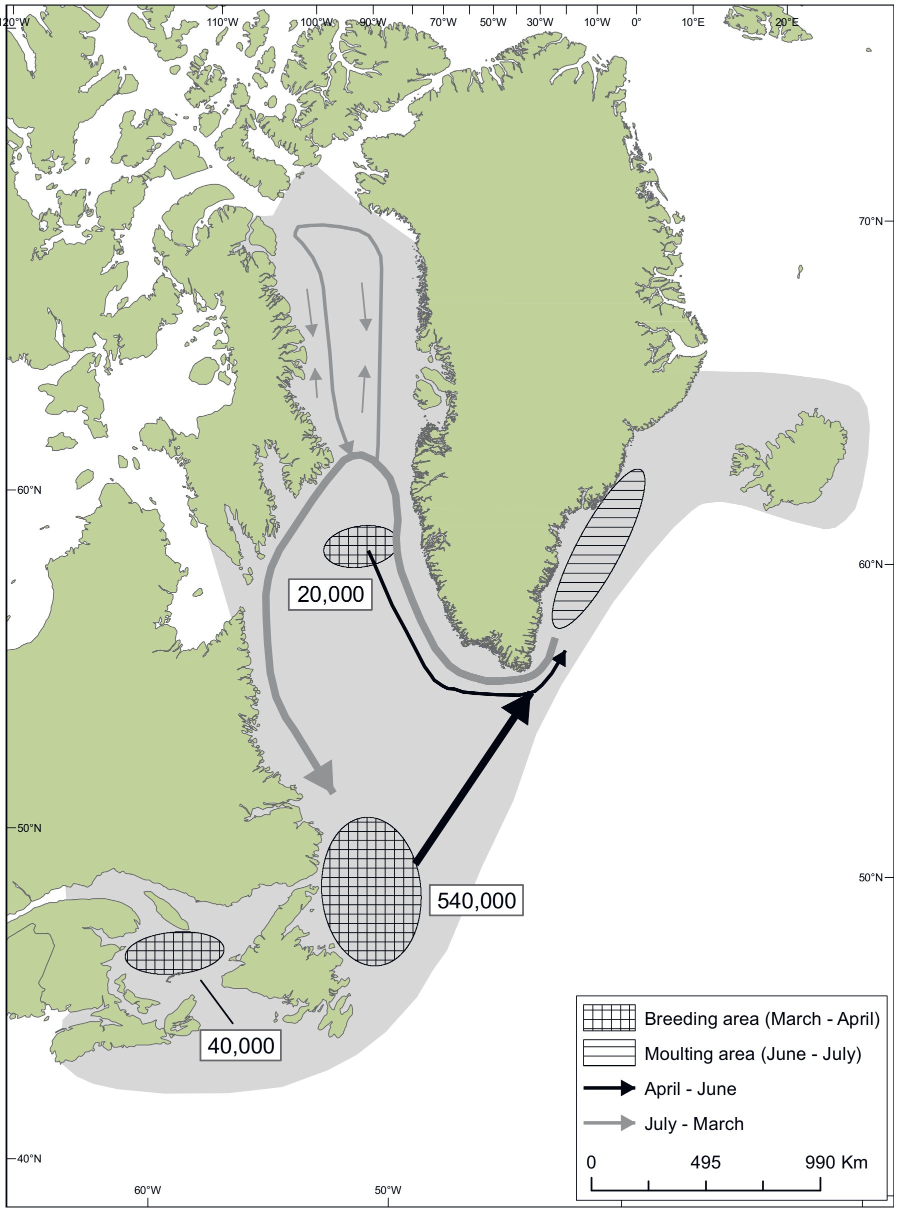
The effects of oil on seals were thoroughly reviewed by St. Aubin (1990) Seals are vulnerable to oil spills as oil can damage the fur, produce skin irritation and seriously affect the eyes as well as the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, the anal and urogenital orifices. In addition, oil can poison seals through ingestion or inhalation. Finally, oil spills can have a disruptive effect by interfering with normal behavior patterns. Effects of oil on seals have the greatest impacts on the pups (St. Aubin 1990 and references therein). Pups are sessile during the weaning period and can therefore not move away from oil spills. They are protected against the cold by a thick coat of woolly hair (lanugo hair) and 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).

**Hooded seal, *Cystophora cristata***

*Distribution and numbers:* Hooded seals are migratory seals (Fig. 4.8.3). The vast majority of the seals from the West Atlantic population whelp in areas near Newfoundland, but part of the population whelp in the Davis Strait. The positions of this whelping patch as well as the number of seals that use this area for whelping change significantly from year to year. The location of the Davis Strait whelping patch also changes during the whelping season as the seals give birth on non-consolidated drifting pack ice. Published locations of whelping hooded seal in the Davis Strait (Sergeant 1974, 1976, 1977, ICES/NAFO 1997 , Kapel 1998) show that some years the hooded seal whelps within the assessment area and some years just outside the area.

The hooded seals give birth in late March-early April and the lactation period is only 4 days (Perry & Stenson 1992). The female mate shortly after the lactation period and the adult seals disperse in early April. The pups will stay a few weeks around their birth place before they also swim away. Most hooded seals from the West Atlantic (both the seals that have been whelping near Newfoundland and in Davis Strait) swim to Southeast Greenland during May-June and moult on the drift ice off east Greenland in June-July. In August-September they swim back to Davis Strait and Baffin Bay where many of them forage throughout the winter regularly diving below 500 m (down to 1500 m (Andersen 2009)). They prey mainly on large fish and squids before they return to the whelping areas in spring.

**Figure 4.8.3.** Distribution of the West Atlantic hooded seals. Numbers are the approximate number of seals associated with each of the three West Atlantic breeding areas in 2005.




The total hooded seal pup production in the Northwest Atlantic (around Newfoundland and in Davis Strait) was estimated to be 116,900 (SE = 7,918, CV = 6.8%) in 2005. This corresponds to a total population of about 592,100 seals (SE=94,800; 95% C.I.= 404,400-779,800) (ICES 2006).

In 1984 the pup production in Davis Strait was estimated to be 19,000 (14,000-23,000) (Bowen et al. 1987), but the estimate in 2005 was only 3,346 (SE = 2,237, CV = 66.8%) (ICES 2006). This change is not believed to reflect a change in overall population size, but merely a shift in distribution, as the hooded seals that whelp near Newfoundland and in Davis Strait are considered to be animals from the same population.

*Conservation status*: The West Atlantic hooded seals are listed as of Least Concern (LC) on the Greenland Red List. The seals are managed internationally through a working group under ICES and NAFO and catches are sustainable (ICES 2006).

*Sensitivity*: Non-whelping hooded seals are not particularly sensitive to oil spills and disturbance. Hooded seals can be affected by oil spills in the same way as all other seals (i.e. tissue damage and poisoning).

*Important and critical areas*: The whelping area in Davis Strait is particularly sensitive to disturbance and pollution during the whelping/breeding season in March-April.

**Harp seal, *Pagophilus groenlandica***

*Distribution and numbers:* Harp seals are migratory seals. The vast majority of the seals from the West Atlantic population concentrate around the whelping areas off Newfoundland in February-April. They give birth on the drift ice in March and they moult in April. After the moult they spread out in the waters between Greenland and Canada and some seals move up along the Greenland east coast (Fig. 4.8.4).

The number of harp seals in the assessment area increases throughout the summer and early autumn, but when the sea ice starts to form they initiate the migration back toward the whelping areas off Newfoundland. Most adult harp seals during summer forage in pods typically consisting of 5–20 individuals. Juvenile seals forage alone, but all ages feed mainly on capelin (*Mallotus villosus*) in the inshore part of the assessment area and on sand lance (Ammodytes spp.) on the Store Hellefiskebanke and probably in other off shore areas too (Kapel 1991) (Kapel 1991)and unpublished data from the Greenland Institute of Natural Resources).

The West Atlantic population that whelps on the ice off Newfoundland in early March is estimated to have increased from around 1.8 million in the early 1970s to about 7-8 million individuals in 2010 (Hammill & Stenson 2010 ). The proportion of seals that enter or pass through the assessment area is unknown and probably also variable, but it might be as high as 50%. The number of seals in the area at any given time is, however, significantly lower. Their number is highest during summer, but the highest concentrations might be found during winter when many seals are seen in a narrow band along the ice edge.

The distribution pattern seems to be changing as many thousands of harp seals in recent years have stayed along the ice edge in the assessment area until few weeks before the whelping off Newfoundland. Some observations of seals whelping in the assessment area have also been made (Rosing-Asvid 2008). Increased competition for food may force the seals to skip the long exhausting migration to areas with fewer polar bears, but climatic changes and periods with less ice around Newfoundland might also trigger whelping in new areas.

*Conservation status*: Harp seal is the most numerous marine mammal in the northern hemisphere and the West Atlantic population is probably at the highest level in historic time. It is listed as of Least Concern on the Greenland Red List.

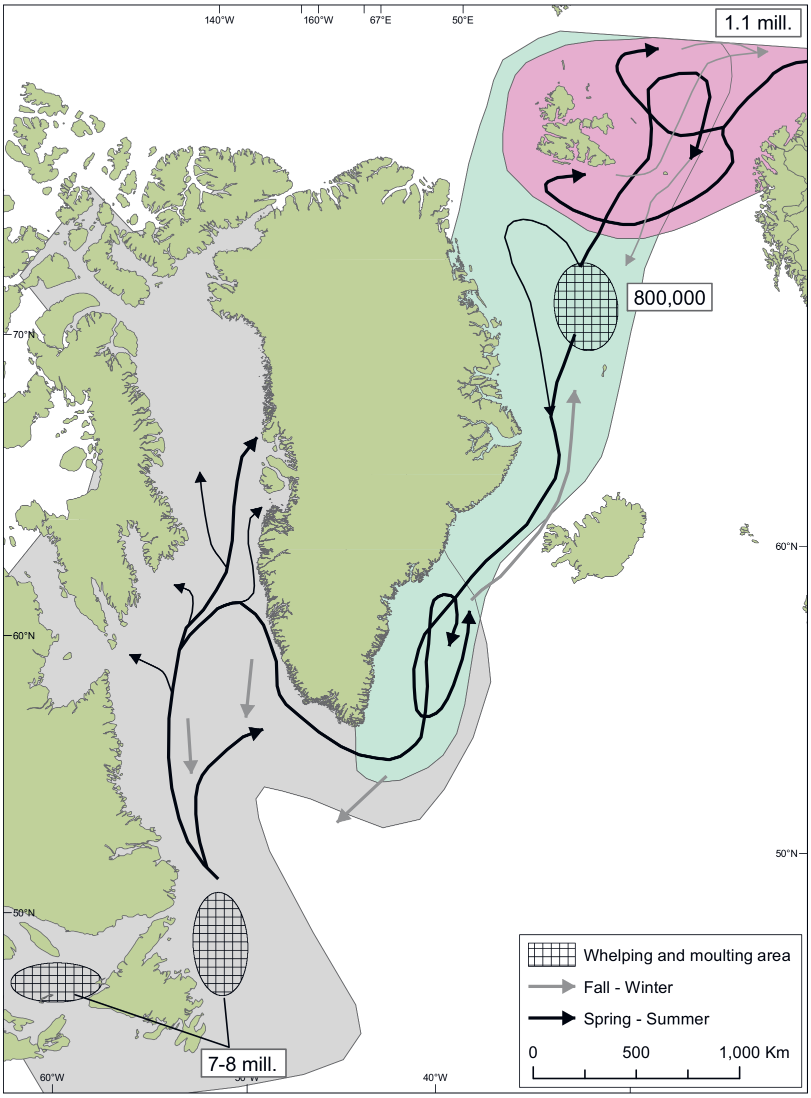



**Figure 4.8.4.** Harp seal distribution and numbers associated with known whelping areas.

*Critical and important habitats*: Harp seals are found in all parts of the assessment area during most of the year and a large fraction of the population migrates through the assessment area during summer and autumn. Highest concentrations are, however, seen along the ice edge during mid-winter.

*Sensitivity*: Non-breeding harp seals are less sensitive to oil spills and disturbance than breeding seals, but they can be severely affected by tissue damage and poisoning.

**Bearded seal, *Erignathus barbatus***

*Distribution and numbers:* Bearded seals are widespread in the Arctic, but only little is known about their numbers and seasonal changes in distribution. Male bearded seals vocalise a lot during the breeding season in spring and individual seals can be recognised by their 'song'. Long-term studies of bearded seal vocalisation show a high degree of site fidelity among male bearded seals (Risch et al. 2007). Seasonal changes in the densities of bearded seals in some areas do, however, indicate that at least part of the population (probably mainly the adult females and young animals) move around. These distribution changes seem to be linked to the seasonal changes in the sea ice conditions. Bearded seals do make breathing holes, but only in relatively thin ice. Seals that summer in areas with thick winter ice therefore either winter in reoccurring leads and polynyas or they follow the pulse of the expanding and shrinking sea ice.

Bearded seals can be found in all the parts of the assessment area and they are seen in the assessment area throughout the year, but the highest concentrations are found on Store Hellefiskebanke during mid-winter and spring when the edge of the Davis Strait pack ice is found in this area (GINR, unpubl. data).

Bearded seals are known mainly to feed on fish and benthic invertebrates found at depths down to 100 m (Burns 1981). The ongoing study in South Greenland shows that some bearded seals also spend considerable time in much deeper water (>300m) and shrimps are found to be the most important prey in this area.

Birth takes place in April–May on drifting ice or near ice edges with access to open water and the lactation period is around 24 days (Gjertz et al. 2000). Some bearded seals are likely to be born in the assessment area each year.

*Conservation status*: The bearded seal is listed as Data Deficient on the Greenland Red List due to lack of knowledge about population boundaries and numbers, but at the same time it is listed as Least Concern, because its uniform and widespread distribution is believed to be a good protection against over-exploitation.

*Sensitivity*: Bearded seals often vocalise, especially during the breeding season in spring (Burns 1981) and may therefore be sensitive to acoustic disturbances (noise). The benthic feeding habits will also make them vulnerable to oil-polluted benthos and bearded seals can be affected by oil spills in the same way as all other seals (i.e.tissue damage and poisoning).

*Critical and important habitat*: Little is known about the bearded seal habitat use in Greenland. Their wide and uniform distribution indicates that they might adapt to several habitats. During winter the ice cover limits the availability of suitable habitats and the Store Hellefiskebanke is therefore likely to have a significant importance to bearded seals that during summer spread out over a much larger area.

### Ringed seal, *Pusa hispida*

*Distribution and numbers:* The ringed seal habitat is all parts of the Arctic that have annual sea ice. They give birth in March-April in lairs dug out in a snowdrift that is covering a breathing hole. Some pups are born on fjord ice in the assessment area and others on the pack ice in the Davis Strait. The extent of whelping as well as the total number of ringed seals in the assessment area is, however, likely to fluctuate significantly depending on the ice and snow conditions. The pups lactate in up to 7 weeks on the fast ice in Canada (Hammill et al. 1991), but it is likely that pups born on the pack ice have a shorter lactation period, probably depending on ice breakup. The moulting period is mainly in June when the seals will spend most of the day basking on the ice. They need to haul out and therefore have to be near ice in this period. Their numbers therefore decline in some of the coastal areas, as some seals move into ice filled glacier fjords and others follow the retreating pack-ice north and westward. When the sea ice expands again during early winter they spread out again. They make breathing holes in the new ice and maintain them throughout the winter. This is mainly done by adult seals that establish territories in ice covered areas, whereas the juvenile seals mainly spend the winter in areas with loose unconsolidated sea ice.

The catches in the assessment area have been around 3,000 animals per year since 2003 (this has been a warm period). Catches were, however, about three times higher during the last cooling period in the 1990s when the pack-ice from the Davis Strait was closer to the coast and the extent of sea ice in the fjords was larger.

*Conservation status*: The ringed seals in general have a favuorable conservation status, because they have a relatively uniform and widespread circumpolar distribution, which prevents overexploitation on an overall population level. Ringed seals are listed as of Least Concern (LC) on the Greenland Red List.

*Sensitivity*: Breeding ringed seals depend on stable sea ice during the 2 months when they give birth and nurse their pups. This stationary behaviour makes them vulnerable to disturbance and particularly to activities that can disrupt the stable ice. However, ringed seals were not particularly shy towards seismic operations in Arctic Canada, where they showed only little avoidance of the ships (Lee et al. 2005). Ringed seals can be affected by oil spills in the same way as all other seals (i.e. tissue damage and poisoning).

**Figure 4.8.5.** Ringed seal lair with pup. Picture of a display in the zoological museum in Copenhagen (Photo Aqqalu Rosing-Asvid).

*Critical and important habitats*: The relatively uniform and widespread circumpolar distribution of ringed seals implies that there are no areas that are critical for the total population. Any disruption of fast ice can, however, have strong influence on local nursing ringed seals in spring.

**Harbour seal, *Phoca vitulina***

*Distribution and numbers:* The harbour seal habitat is the coastal zone. These seals have only inhabited the Greenland waters during the interglacial period and they are relatively few compared to the other Arctic seal species. They concentrate in colonies on land during breeding and moulting, and their link to coastal waters and strong site fidelity toward certain haul-out sites during breeding and moulting have made them vulnerable to hunting. They give birth in June on sandbanks in fjords or on small islands off the coast. Up until the 1950s harbour seals were relatively common in the assessment area, but hunting has driven them to near extinction (Rosing-Asvid 2010 ). In the recent decade only three concentrations of harbour seals have been registered in the assessment area by the Greenland Institute of Natural Resources. One is on the sandbanks near the Kangerlussuaq airport (67°00´N; 50°45´W) where seven harbour seals were seen in 2009. Hunters have reported another concentration of 60-100 seals about 70-80 km upstream the meltwater river, Majoqqaq (65°53´N; 50°38´W). These seals might, however, have moved elsewhere as they have not been observed since 2007. The third location is sandbanks in Alangorlia (63°37´N - 50°32´W) where about 20 seals have been observed in both 2009 and 2010. The winter distribution of these seals is unknown (Rosing-Asvid 2011).

*Conservation status*: Harbour seals are listed as critically endangered on the Greenland Red List.

*Sensitivity*: The known concentrations of harbour seals are two sites in the bottom of deep fjords and one upstream in a river. These areas are not likely to be affected by off shore oil exploration. It is, however, possible (and likely) that unknown colonies of harbour seals exist on remote offshore islands that might be more affected by oil spills.

*Critical and important habitats*: Harbour seals show strong site fidelity to breeding or moulting locations.

### 4.8.3 Whales, dolphins and porpoises (order Cetacea)

*Tenna Kragh Boye, Malene Simon, Fernando Ugarte (GINR) & Kasper Johansen (AU)*

The order Cetacea, which includes whales, dolphins and porpoises, is divided into two sub-orders: Mysticeti (baleen whales) and Odontoceti (toothed whales). As their English name clearly indicates, the main difference between baleen whales and toothed whales is that the former use baleen plates hanging from the roof of their mouths to catch their prey, while the later have 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. Most 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 echolocation clicks used for communication and to gain detailed information about objects ahead of the animal by listening to the reflected echoes (Mellinger et al. 2007). An overview of the frequencies used by the cetaceans present in the assessment area is given in table 4.8.1 and figure 4.8.6.

For the reasons explained above, hearing and sound production are vital for cetaceans and they can be affected by human made noise, including the sounds produced by hydrocarbon exploration and exploitation activities. Potential effects from anthropogenic sound include behavioural changes (e.g. avoidance of the area or disruption of feeding), physical damage (mainly to auditory organs) and masking (obscuring of sounds of interest to the animal by interfering sounds). The sensitivity of cetaceans to anthropogenic sounds from hydrocarbon exploration and development activities is discussed in detail in chapter 10. Cetaceans are also sensitive to oil spills and this is discussed in chapter 11.

**Table 4.8.1.** The frequency range of the most commonly used sound types of 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 |
|---|---|---|---|---|---|
| ***Odontocetes*** | | | | | |
| Harbour porpoise | *Phocoena phocoena* | Click | 120,000 | 150,000 | (Villadsgaard et al. 2007) |
| White beaked dolphin | *Lagenorhynchus albirostris* | Click | 75,000 | 250,000 | (Rasmussen & Miller 2002) |
| | | Whistle | 3,000 | 35,000 | (Rasmussen & Miller 2002) |
| Long-finned pilot whale | *Globicephala melas* | Click | 4,100 | 95,000 | (Eskesen et al. 2011) |
| | | Whistle | 260 | 20,000 | (Rendell & Gordon 1999) |
| Narwhal | *Monodon monoceros* | Click | 24,000 | 95,000 | (Miller et al. 1995) |
| | | Whistle | 300 | 18,000 | (Ford & Fisher 1978) |
| Beluga | *Delphinapterus leucas* | Click | 46,600 | 112,600 | (Au et al. 1985) |
| | | Whistle | 1,400 | 14,000 | (Belikov & Bel'kovich 2006, 2007) |
| 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) |
| N. bottlenose whale | *Hyperoodon ampullatus* | Click | 2,000 | 26,000 | (Hooker & Whitehead 2002) |
| Sperm whale | *Physeter macrocephalus* | Click | 5,000 | 24,000 | (Madsen et al. 2002) |
| ***Mysticetes*** | | | | | |
| Minke whale | *Balaenoptera acutorostrata* | Call / song | 80 | 800 | (Mellinger et al. 2000) |
| Sei whale | *Balaenoptera borealis* | Call / song | 30 | 400 | (Rankin & Barlow 2007) |
| Humpback whale | *Megaptera novaeangliae* | Call / song | 35 | 24,000 | (Payne & Payne 1985) |
| Fin whale | *Balaenoptera physalus* | Call / song | 15 | 30 | (Watkins et al. 1987) |
| Blue whale | *Balaenoptera musculus* | Call / song | 14 | 20 | (Cummings & Thompson 1971) |
| Bowhead whale | *Balaena mysticetus* | Call / song | 100 | 5,000 | (Ljungblad et al. 1982) |

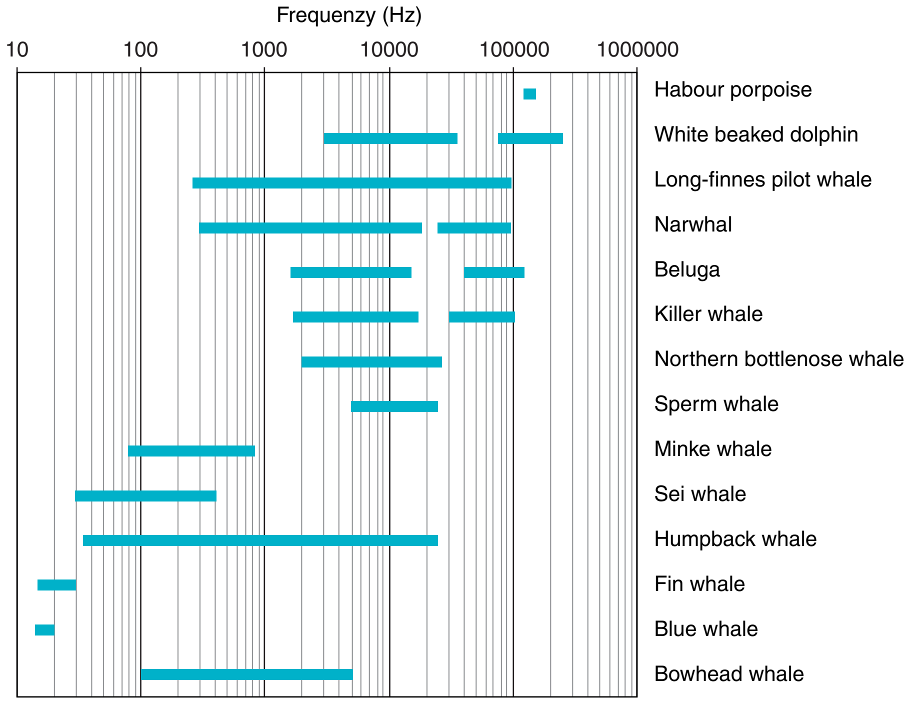



**Figure 4.8.6.** The main frequency range of sounds used by cetaceans in the assessment area. See also Table 4.8.1 for details.

Recent knowledge about the distribution and abundance of cetaceans in the assessment area comes from aerial surveys carried out by GINR in September 2005, April 2006 and September 2007, as well as from passive acoustic monitoring (PAM) moored across the Davis Strait, at the northern edge of the assessment area, recording continuously from October 2006 to September 2008. Additional information about the seasonality, distribution and biology of cetaceans comes from a variety of sources, including scientific studies, catch statistics and observations from marine mammal observers on board seismic surveys.

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. Hunting is explained in more detail in chapter 5.

### 4.8.4 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 bowhead whale (*Balaena mysticetus*) migrates seasonally through the assessment area. The bowhead whale is one of the two species of the right whale family that inhabit the North Atlantic. The critically endangered northern right whale (*Eubalaena glacialis*) may have used the assessment area in the past, but its current distribution in Greenland may be limited to the Cape Farewell area, south of the assessment area.

West Greenland is an important foraging area where baleen whales target dense patches of prey and the distribution of the whales is correlated with certain prey items, such as capelin (*Mallotus villosus*), krill (*Meganyctiphanes norvegica and Thysanoessa sp.*) and sandeels (*Ammodytes sp.)* (Heide-Jørgensen & Laidre 2007, Laidre et al. 2010, Simon 2010). For instance, during a survey focusing on the distribution of cetaceans, krill and capelin in September 2005, 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 the assessment area and one south 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 may be an important link to predict potential changes in distribution and abundance of baleen whales in the assessment area and other areas in Greenland.

Besides prey, sea ice is a limiting factor for the northern distribution of fin whales and this may also be true for other species of rorquals (Simon et al. 2010). Therefore, changes in sea ice coverage are likely to have an effect on the distribution of baleen whales in the assessment area. In the following text we will focus on the biology and occurrence of the different species of baleen whales within the assessment area.

**Fin whale, *Balaenoptera physalus***
The North Atlantic fin whales reach an average length of 19–20 m and an average weight of 45–75 tonnes, which makes them the second largest animal on the planet next to blue whales. 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 an especially large abundance within the assessment area along the 200 m contour (Heide-Jørgensen et al. 2008a, Laidre et al. 2010). In Greenland, fin whales target prey such as sandeels, offshore patches of krill and coastal aggregations of capelin (Kapel 1979). The strong correlation between off shore krill abundance and high density of fin whales indicates that the assessment area is an important fin whale feeding ground (Laidre et al. 2010).

Fin whales are believed to migrate south to unknown breeding grounds during winter, yet passive acoustic monitoring shows that fin whales are present in Davis Strait until end December and the increased fin whale song suggest that mating starts in October-November while the whales are still in the assessment area (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).

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 2007). 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 tonnes) and most abundant baleen whale in Greenlandic waters. They migrate between low lati-

tude breeding grounds and high latitude feeding grounds arriving in Greenland during spring. The population in West Greenland is currently (2007) estimated as larger than 16,609 animals (Heide-Jørgensen et al. 2008b, Heide-Jørgensen et al. 2010d); however large variations in 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 molecular 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 species, 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 within the assessment area and in Northwest Greenland while males tend to migrate to Southwest Greenland (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 icthyophagous of the baleen whales and feed mainly on sandeel and capelin (Kapel 1979). Both IUCN (2008) and the Greenland Red List (Boertmann 2007) places minke whales in the Least Concern category.

#### Humpback whale, *Megaptera novaeangliae*

Humpback whales are about 13 m long and weigh 28 tonnes. They migrate between their low-latitude breeding grounds in the Caribbean and the high-latitude feeding ground in Greenland. They arrive in the assessment area in spring (May) and stay until late autumn (October). However, a minority of individuals skip the migration and overwinter in Greenlandic 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 with a high density humpback whale area 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 has 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 is estimated to 9.4% per year (Heide-Jørgensen et al. 2008 , 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 2007).

#### Sei whale, *Balaenoptera borealis*

Sei whales are on average 14 m long and weigh 20–25 tonnes. 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 and 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 was a high density area 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 as data deficient on the Greenland Red List (Boertmann 2007).

**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 tonnes. Blue whales are globally distributed from the low latitudes to polar waters, where dense pack 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 sandeels 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. Yet several sightings have been reported within the assessment area between 62°-66°N and individuals have been documented to travel between foraging areas in Gulf of St. Lawrence to West Greenland, which suggests 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 2007). In the Central North Atlantic, blue whales are common only around Iceland/East Greenland, when 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 timings of depletions in Norway, Iceland and the Western Atlantic suggest that discrete feeding aggregations exist.

**Bowhead whale, *Balaena mysticetus***

Bowhead whales are long-lived and may be more than 200 years old (George et al. 1999). They reach a length of 14-18 m and a weight 60-100 tonnes. The bowhead whales belonging to the Baffin Bay stock spend most of the year in the Canadian high Arctic around Baffin Island (Heide-Jørgensen et al. 2010b). In winter (January-February) part of the population migrates to West

Greenland to feed on the high densities of Arctic copepods in Disko Bay (Fig. 4.8.7) (Heide-Jørgensen et al. 2006, Laidre et al. 2007, Heide-Jørgensen et al. 2010b). The whales migrating to West Greenland constitute 78% females and besides for feeding the whales may use the area as a mating ground (Heide-Jørgensen et al. 2010b). An unknown number of individuals pass through the assessment area during their migration between Canada and West Greenland. This is further supported by passive acoustic monitoring in Davis Strait with recordings of bowhead whale song from January to June and a clear peak in March-May (Simon 2010).

Extensive commercial whaling of bowhead whales reduced the stock to a level where whaling was no longer profitable at the end of the 19th century (Ross 1993 ) and sightings were rare in West Greenland. However, the stock is now recovering and the whales have returned to the Disko Bay feeding/mating area. The most recent estimate of bowhead whales in Disko Bay is 1229 (95% CI 495-2939) bowhead whales (Heide-Jørgensen et al. 2007a) and the bowhead whale is now listed as *least concern* on the IUCN Red Llist (2008) and as *nearly threatened* on the Greenlandic Red List (Boertmann 2007).

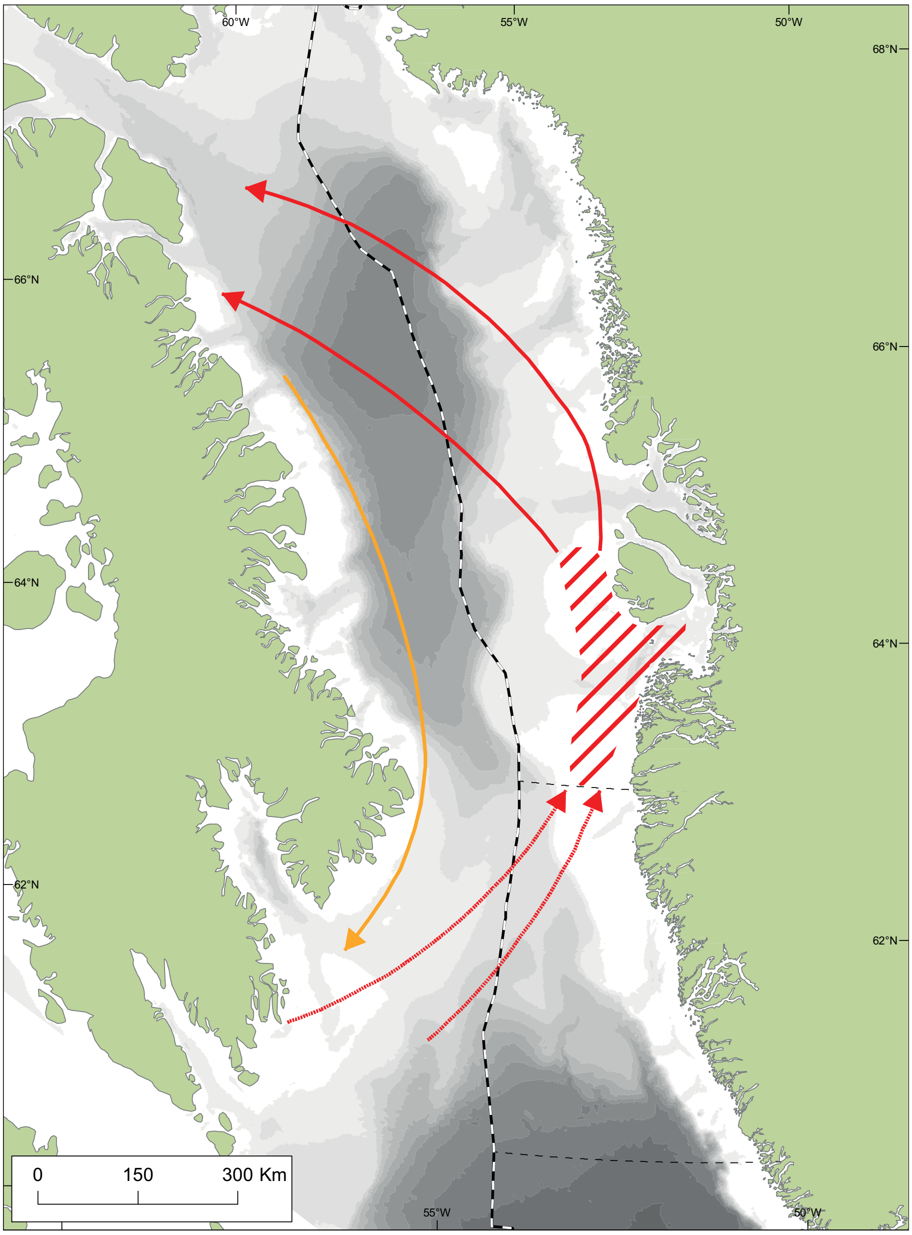



**Figure 4.8.7.** Migration routes for bowhead whales in the Davis Strait and Baffin Bay. In January-February the whales migrate through the assessment area on their way to feeding/mating grounds just north of the assessment area (hatched area).

### 4.8.5 Toothed whales (Odontoceti)

Eight species of toothed whales possibly occur in the assessment area: long-finned pilot whale (*Globicephala melas)*, white-beaked dolphin (*Lagenorhynchus albirostris)* harbour porpoises (*Phocoena phocoena*), narwhal (*Monodon monoceros*) beluga whale (*Delphinapterus leucas*), killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*) and northern bottlenose whale (*Hyperoodon ampullatus*). As for the baleen whales, a change in prey distribution or ice coverage, e.g. due to climatic changes, is likely to cause a change in the toothed whale distribution. The distribution of e.g. the beluga whale depends largely on the distribution of ice coverage, the whale staying close to the edge of the pack ice and moving further north or further west, further offshore if any loosening in the pack ice occurs (Heide-Jørgensen et al. 2009). Hence, changes in ice coverage and in temperature may change the distribution of certain species of toothed whales.

#### Sperm whale, *Physeter macrocephalus*

Sperm whales are the largest of the toothed whales and reach lengths of 18 m and weights of 50 tonnes. Although they are found in all oceans, the species display sexual segregation where females and calves reside in tropical and sub-tropical 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, within the assessment area, in both 2009 and 2010 (GINR, unpubl. data). Echolocation clicks of sperm whales have also been recorded close to the West Greenlandic continental shelf in the Davis Strait (GINR, Unpubl.). Male sperm whales feed both at shallow depths of approximately 117 m and at the sea bottom at depths down to 1860 m, showing that male sperm whales have flexible feeding habits (Teloni et al. 2008). Sperm whales are expected to use the assessment area during ice-free periods in suitable habitat, such as deep-sea waters close to continental slopes and underwater canyons with 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 2007).

#### Long-finned pilot whale, *Globicephala melas*

The long-finned pilot whale occurs in temperate and sub-polar zones, but is according to Greenlandic catch statistics occasionally also found as far North as Upernavik (DFFL, 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 and the largest abundance was found within the northernmost part of the assessment area in Store Hellefiskebanke (Hansen 2010). Groups were also found further South within the assessment area (on Lille Hellefiskebanke and Danas Banke) and Hansen *et al.* (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 & Lastein (1993) suggested that pilot whales from the eastern and western North Atlantic are segregated into two separate stocks. A genetic comparison of long-fined 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), while relative abundance in Newfoundland was estimated at 13,200 individuals in 1980 (Hay 1982). Hence pilot whales are abundant and considered as *least concern* on the Greenland Redlist (Boertmann 2007) 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 within Greenlandic waters is not known, but cod, capelin and sandeels 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 in 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.

White-beaked dolphins are present within the entire range of the assessment area, but the majority is found in South Greenland rather than the Disko area, which appears to represent the northern 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 to constitute 11,800 animals in West Greenland (Hansen 2010). White-beaked dolphins are considered as *not applicable* on the Greenland Red List (Boertmann 2007).

**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 the shore (Jefferson et al. 2008). Killer whales feed on prey varying from small schooling fish to large marine mammals and their high dietary specialisations 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 Antarctic (Pitman & Ensor 2003). Mating between different ecotypes rarely occurs (Pilot et al. 2009). 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 very poorly understood. Yet, Heide-Jørgensen (1988) reviewed published and unpublished information available on killer whales in Greenland and carried out a questionnaire-based investigation of sightings of killer whales. 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 2007). 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 porpoises**, ***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. It is amongst the most abundant whale species in the North Atlantic and also in West Greenland where it occurs 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 range of the entire assessment area from 62°-67°N. 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 to 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 hunting of harbour porpoise in Greenland is sustainable. Hence, harbour porpoises are listed as *data deficient* on the Greenland Red List (Boertmann 2007), but their large abundance in the Northern hemisphere puts them in the *least concern* category on the IUCN Red List (IUCN 2008).

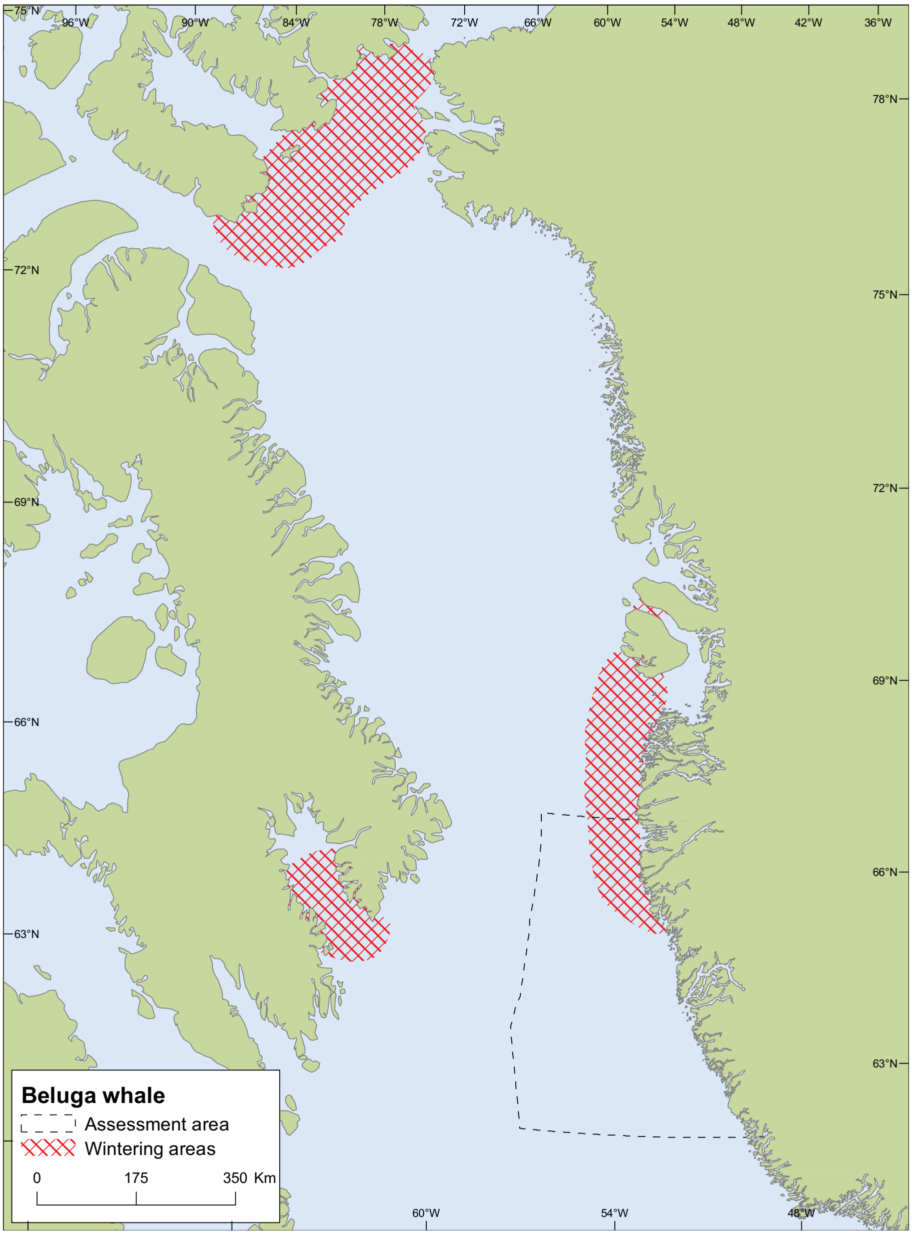
**Beluga whale**, ***Delphinapterus leucas***

Beluga whales reach a length up to 5 metres and a weight of 1,500 kg and although they are born grey they turn white with age. They prey mainly on fish, especially polar cod but also squid and shrimp constitute a part of their diet (Heide-Jørgensen & Teilmann 1994). Beluga whales most often travel in groups of two to ten whales, but larger groups are not uncommon.

Beluga whales only occur in the Arctic and Subarctic region, where they live among the pack ice in leads and polynias during winter and migrate to shallow bays and estuaries during summer (NAMMCO 2008). The beluga whales found in West Greenland during winter spend the summer in the Canadian High Arctic archipelago and tagging with satellite transmitters indicates that only a fraction of the whales travel to West Greenland while the majority most likely reside in the North Water Polynia (Heide-Jørgensen et al. 2003a). The whales that do travel to West Greenland migrate along the North West Greenland coast and arrive at more southern feeding areas South of Disko in December, where they remain scattered on the shallow banks until spring (Heide-Jørgensen et al. 2009). Although beluga whales occur within the northern part of the assessment area they do not have their main distribution in this area. Instead Store Hellefiskebanke just north of the assessment area supports high densities of beluga whales, where only ice coverage seem to be the limiting factor of this species' movements further north or offshore (Heide-Jørgensen et al. 2009). Beluga whales are expected to acquire the major part of their annual food intake in their winter quarters (Fig. 4.8.8).

The wintering whales in West Greenland and the North Water are considered as two different stocks, both of which spend the summer in the Canadian High Arctic (NAMMCO 2008). The latest abundance estimate of the West Greenland stock was calculated in 2006 to constitute 10,595 individuals and the stock is considered substantially depleted (Heide-Jørgensen et al. 2009, NAMMCO 2008). Due to this, beluga whales in West Greenland are considered as *critically endangered* on the Greenland Red List (Boertmann 2007). Yet, on a global scale they are categorised as *near threatened* (IUCN 2008).

**Figure 4.8.8.** Map of known wintering grounds for beluga whales in West Greenland and eastern Nunavut. Summering grounds are in Arctic Canada. Belugas can be found along the whole northwest coast of Greenland during migration between winter and summer grounds. Map modified from Heide-Jørgensen & Laidre (2006).




**Narwhal**, ***Monodon monoceros***

Narwhals are found only in high arctic regions where they feed primarily on Greenland halibut but also on other species of arctic fish and squid (Laidre & Heide-Jørgensen 2005). They undertake seasonal migrations between shallow summer grounds where little or no foraging takes place and their wintering grounds where they feed (Dietz & Heide-Jørgensen 1995, Laidre & Heide-Jørgensen 2005, Dietz et al. 2008). Narwhals are site faithful to summering and wintering grounds and individuals tagged with satellite transmitters have migrated between summering grounds in Arctic Canada and Melville Bay and wintering grounds in Baffin Bay and the northern Davis Strait. Wintering grounds include both deep waters between Greenland and Canada and waters close to the coast of West Greenland (Fig. 4.8.9) (Dietz & Heide-Jørgensen 1995, Dietz et al. 2001, Heide-Jørgensen et al. 2003b, Dietz et al. 2008). They reside in or close to the pack ice during winter and as the ice opens up into large channels in spring the narwhals return to their summering grounds.

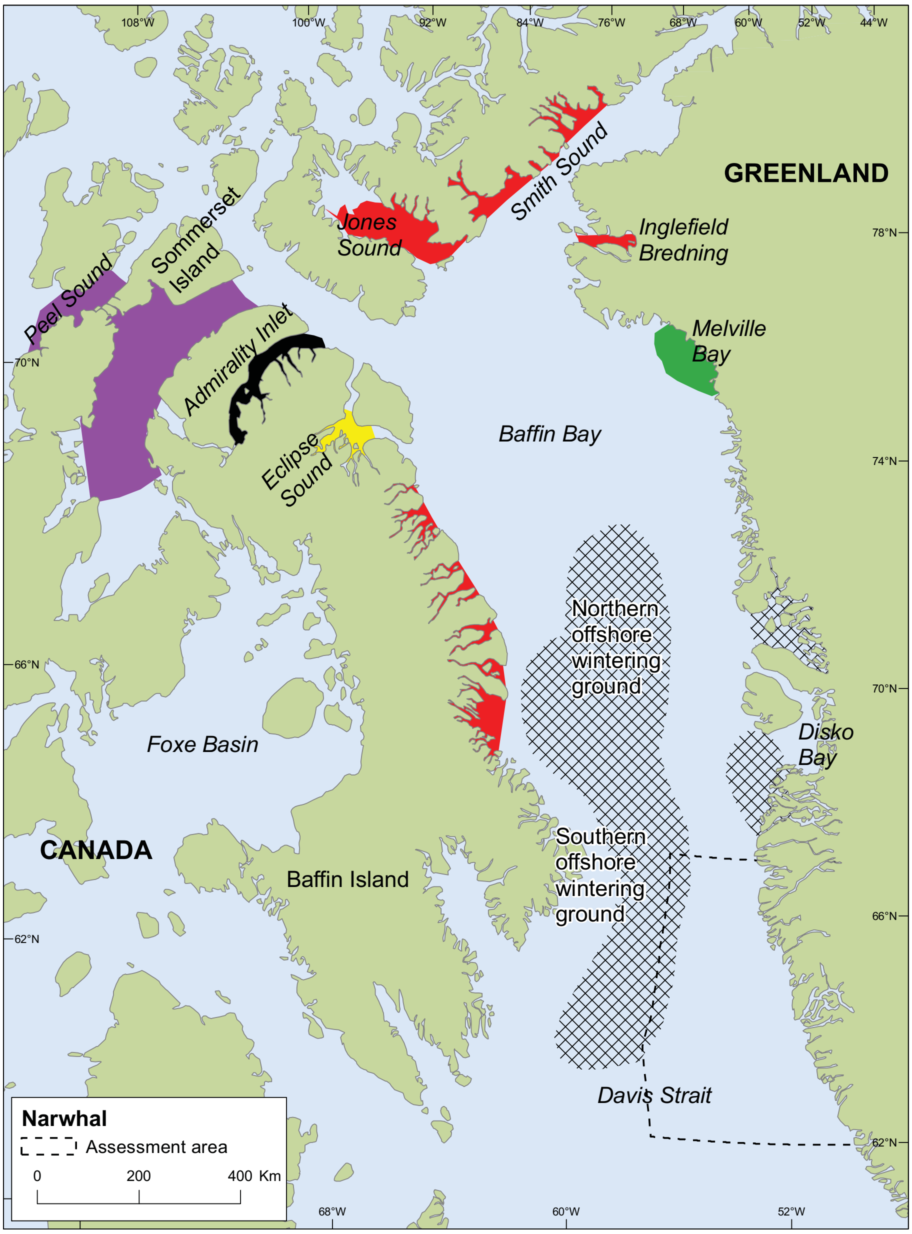



**Figure 4.8.9.** Main summer and winter grounds of narwhals in West Greenland and the Eastern Canadian Arctic. Narwhals can be found along the whole north-west coast of Greenland during migration between winter and summer grounds. Map modified from Heide-Jørgensen & Laidre (2006).

Intense benthic feeding behaviour has been documented for narwhals on their winter feeding grounds and suggests that a major portion of the annual energy intake is obtained on these winter feeding grounds (Laidre et al. 2004, Laidre & Heide-Jørgensen 2005). Hence, the wintering grounds are likely to be the most critically important habitat for narwhals (Laidre et al. 2008). Furthermore, a significant portion of the global population of narwhals winters in the northern Davis Strait and southern Baffin Bay area.

The northern part of the assessment area may overlap with the southern part of narwhal wintering grounds. There are about 18,000 narwhals wintering in the offshore pack ice (Laidre & Heide-Jørgensen 2011). These narwhals can be found at extremely high densities (average 77 narwhals $km^2$ open water in 2008) in leads in dense pack ice (Laidre & Heide-Jørgensen 2011). There were approximately 6,500 narwhals in the wintering ground in West Greenland in 2006 (Heide-Jørgensen et al. 2010c). As mentioned above, the narwhals wintering in or close to the assessment area come from a number of summer grounds in Arctic Canada and North West Greenland. Based on a series of surveys in 2002-2004, it was estimated that more than 60,000 narwhals spend the summer spread over several locations in High Arctic Canada (Richard et al. 2010). The abundances of narwhals in Inglefield Bredning and Melville Bay, Northwest Greenland, in 2007 were 8,368 (95% CI: 5,209–13,442) and 6,024 (95% CI: 1,403–25,860), respectively (Heide-Jørgensen et al. 2010c).

Due to intense hunting in the past, the stocks in Greenland have been under great pressure and narwhals are considered as *critically endangered* on the Greenland Red List (Boertmann 2007). On a global scale, narwhals are subject to differing levels of threats and are placed in the category *near threatened* 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 metre long whale is a deep diving species, diving as deep as 1,400 meters (Hooker & Baird 1999) to forage primarily on squid (e.g. Lick & Piatkowski 1998) but other invertebrates and fish also constitute their diet. They live in groups where especially the males may form long-term associations (Gowans et al. 2001). The bottlenose whales are present in Greenland during summer (Mosbech et al. 2007) and are common in the assessment area. 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 the effect of human activities.

Due to the scarce knowledge on bottlenose whales in Greenland, the species is listed as *not applicable* on the Greenland Redlist (Boertmann 2007). 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).

## 4.9 Summary of Valued Ecosystem Components (VECs)

As part of an environmental impact assessment of an area, the concept of Valued Ecosystem Components (VEC) is sometimes applied. The idea is to identify important ecosystem components, because it is often not possible to evaluate all ecological components individually. VECs can be species, populations, biological events or other environmental features that are important to the human population (not only economically), have a national or international profile, can act as indicators of environmental change, or can be the focus of management or other administrative efforts. VECs can also be important flora and fauna groups, habitats and processes such as the spring bloom in primary production.

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 Davis Strait assessment area. See chapter 9 for a more detailed description of the VEC concept and how it has been applied here.

### 4.9.1 Pelagic hotspots

The shelf bank areas (e.g. Fyllas Banke) and the shelf break are assumed to have increased primary productivity in spring due to nutrient-rich upwelling events from wind and tidal motions in the Davis Strait. There are limited data in the assessment area, in terms of physical measurements on primary productivity, to support this; however, remote sensing data (MODIS, chlorophyll a) showing productivity in the surface layer clearly identifies Fyllas Banke as the location for the initial spring bloom in March. Results from the Nuuk Basic monitoring programme supports this. Productivity peaks in April and May and occurs then more widely over the shelf break and in neighbouring offshore areas.

The enhanced primary production retains zooplankton species such as copepods, which again are utilized by fish larvae. In general, the slopes of the shelf and shelf banks are believed to be important for fish larvae development due to high biomass of their copepod prey. For Greenland halibut, the main spawning ground is assumed to be located in the western part of the assessment area and the eggs and larvae are known to drift through the assessment area towards settling areas further north.

### 4.9.2 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 capelin and lumpsucker. Capelin is an ecological key species, important for larger fish species, whales, seals, seabirds and human use, while lumpsucker support a small-scale commercial fishery on lumpsucker eggs. The benthic macrofauna, such as bivalves and sea urchins, play a key role for benthic feeders, such as common eider, king eider and long-tailed duck.

In addition, the tidal/subtidal zone is very important for seabird hunting and tourism.

### 4.9.3 Demersal fish and benthos

The sea floor and the adjacent parts of the water column support the commercially important fisheries of Greenland halibut, northern shrimp and snow crab. For Greenland halibut, the main spawning ground is assumed to be located in the western part of the assessment area.

In addition, sandeels, which are the most important food for many seabirds and whales, are distributed in high densities in sandy sediments at the shelf banks (e.g. Fyllas Banke). Benthic macrofauna, such as bivalves and sea urchins, also plays a central role for benthic feeders at the shelf banks, such as king eiders, bearded seal and walrus. The sea floor and adjacent parts of the water column are also important for cod, which sustained an important fishery in the past and has the potential of becoming commercially important again.

### 4.9.4 Breeding seabirds

For the common eider, black-legged kittiwake, Iceland gull, black guillemot, common murre, Atlantic puffin and white-tailed eagle the coastal areas and the fjords of the assessment area are important as breeding grounds. The breeding population of common murre and atlantic puffin is small, but significant for the Greenland population.

### 4.9.5 Non-breeding seabirds

Large numbers of migrating, wintering and moulting seabirds from the entire North Atlantic occur in the assessment. Among the most important species are migrating/wintering thick-billed murres, little auks, common eiders, king eiders, long-tailed ducks, black-legged kittiwakes, ivory gulls, great cormorant, white-tailed eagle and moulting/wintering harlequin ducks. Most species are associated with the coastal areas and partly the fjords and the shelf, but some species also utilize the western part of the assessment area, such as little auk, kittiwake and ivory gull.

In addition, thick-billed murre, common eider and black-legged kittiwake are important as quarry species for the hunters in the assessment area.

### 4.9.6 Marine mammals (summer)

From spring to autumn, the assessment area is an important foraging area for several species of cetaceans and seals. Minke whale, fin whale and humpback whale feed on krill, capelin and sandeels in shelf and fjord waters. Harbour porpoise inhabit shelf waters and feed on small fish such as capelin and young cod, as well as squid and krill. Long-finned pilot whale, white-beaked dolphin, sperm whale and northern bottlenose whale prey on larger fish and squid species on deep-sea waters and continental slopes. Harp seals arrive to the area during spring to feed on capelin and sand eel, both offshore and in the fjords. Hooded seals are abundant in late summer and autumn when migrating between moulting grounds in Southeast Greenland and feeding grounds in the Baffin Bay. They feed on large fish and squid in deep waters. The assessment area is important for at least one group of harbour seals, which are critically endangered in Greenland.

All the species mentioned above, with exemption of sperm whale, bottlenose whale and harbour seal are hunted in Greenland and considered an important resource for both economic and cultural reasons.

### 4.9.7 Marine mammals (winter)

Several important species of marine mammals are associated with the northern or western part of the assessment area during winter. These include the walrus, beluga whale, narwhal, polar bear, hooded seal, bearded seal and ringed seal. The main wintering area of these species is located just north and/or west of the assessment area; however, in years with an extensive ice-coverage their distribution overlaps with the assessment area. The bowhead whale migrates through the assessment area in January-February towards foraging areas (and perhaps mating grounds) in the Disko Bay area. Some of the marine mammals that occur during summer may remain during winter in ice-free waters of the assessment area.

To various extents these marine mammals are all hunted in Greenland and considered an important resource for both economic and cultural reasons. At the same time polar bear, narwhal, beluga whale, bowhead whale and walrus are listed as vulnerable, near threatened or threatened in the Greenland Red List.

# 5 Natural resource use

## 5.1 Commercial fisheries

*AnnDorte Burmeister, Helle Siegstad, Nanette Hammeken Arboe, Ole Jørgensen, Anja Retzel, Rasmus Hedeholm, Rasmus Nygaard, Nikoline Ziemer (GINR) & Daniel Clausen (AU)*

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 of 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) and snow crab (45 million DKK) (Statistics of Greenland 2010). Greenland halibut, shrimp, snow crab and cod are the main commercially exploited species within the assessment area. Lumpsuckers, wolffish, redfish and salmon are exploited in the more coastal regions of the area.

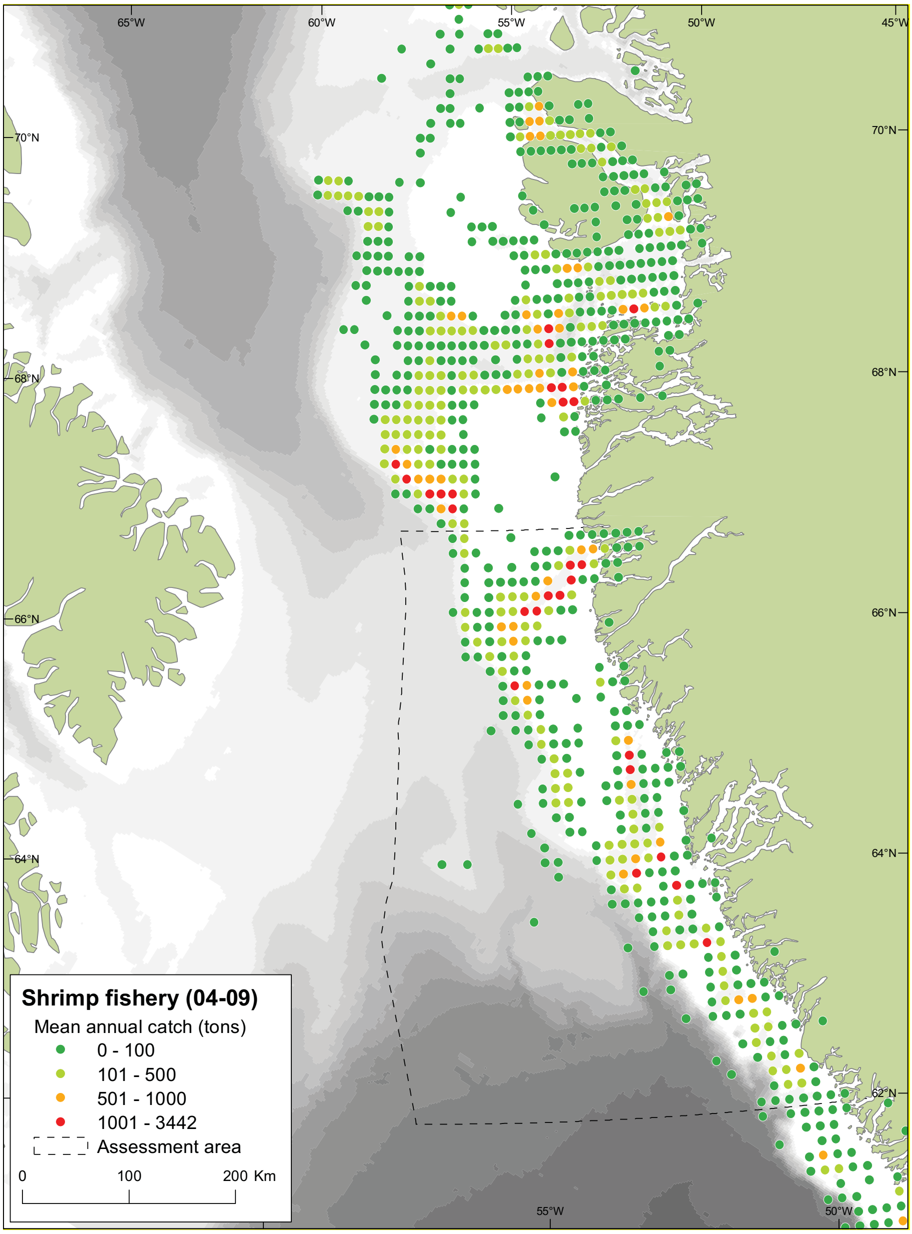
**Shrimp, *Pandalus borealis***

Northern shrimp is caught on the bank slopes and in Disko Bay. The fishery for shrimp began in inshore areas in 1935 as a small-scale fishery and it developed slowly to become a 150,000 tonne fishery. The major part of the catch is taken by large modern trawlers, which process the catches onboard. The fishery extends from 59°30'N to 74°N in West Greenland waters. The annual catch in 2010 was approximately 135,000 tonnes (Hammeken & Kingsley 2010) (Fig. 5.1.1). The assessment area holds very important grounds for the northern shrimp fisheries and between 50% and 70% of the annual catch was taken here from 1990 to the mid2010s. From 2009 the proportion of the annual catch taken from the assessment area has declined from 50% to 20%.

**Snow crab, *Chionoecetes opilio***

Snow crabs are important for 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 tonnes, and the snow crab was at that time the third most important species in terms of total export income for Greenland. The assessment area is the most important snow crab fishing area and crabs are harvested both inshore and offshore, with only a few fjords left unexploited. The fishery is mainly situated along the inner and outer edges of the offshore banks from 62°N to 67°N, but also Holsteinsborg Dyb and Godthaabs Dyb are important fishing sites. Total catches in the assessment area peaked at approximately 9,500 tonnes in 2001 (Fig. 5.1.2). In the succeeding years catch declined substantially to approximately 1,500 tonnes in 2009 (Burmeister 2010).

**Figure 5.1.1.** Distribution and size of northern shrimp catches within and nearby the assessment area. Catch size calculated as the annual average for 2004-2009.



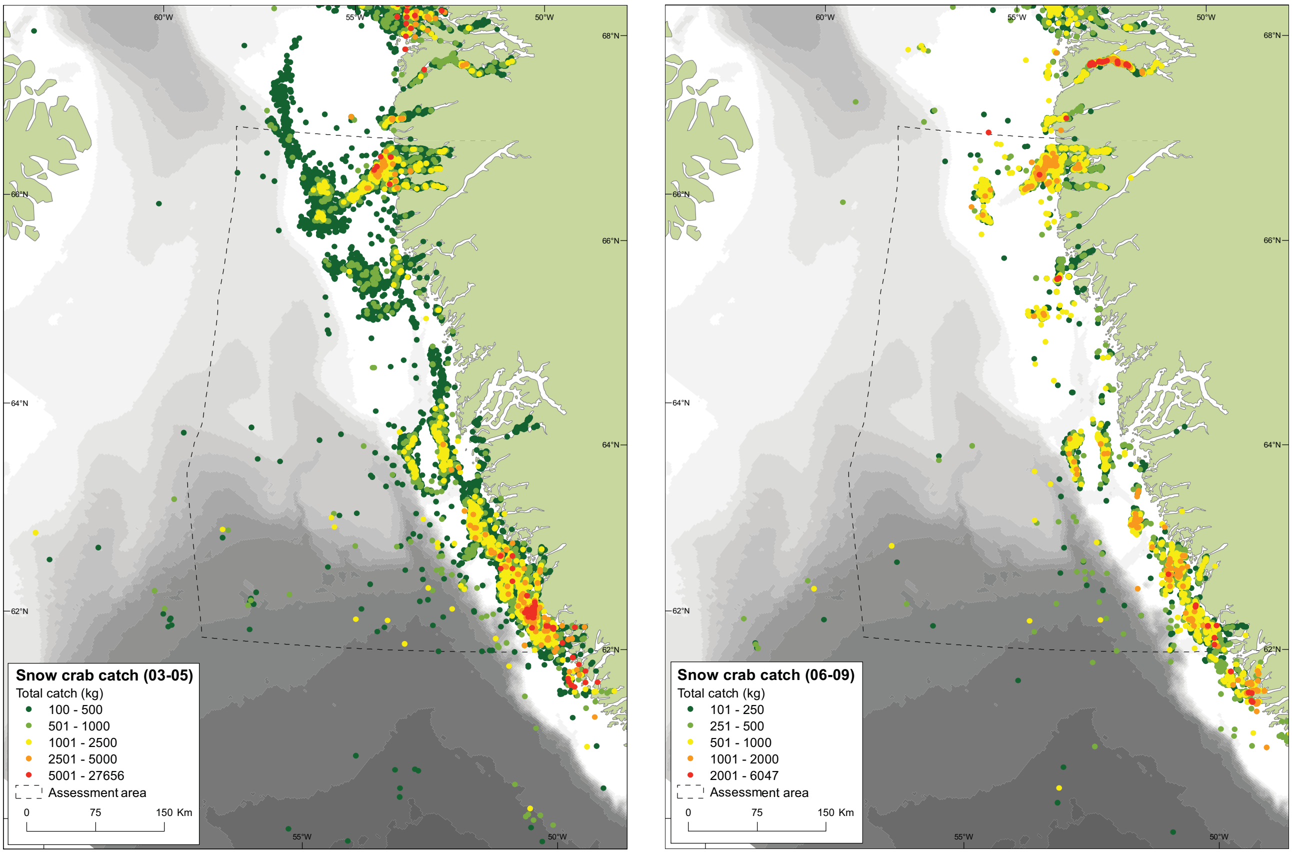



**Figure 5.1.2.** Distribution and size of snow crab catches within and nearby the assessment area in 2003-2005 (left) and 2006-2009 (right). Catches less than 100 kg are not shown.

**Greenland Halibut, *Reinhardtius hippoglossoides***

During the period 2003-2009 annual catches of Greenland halibut in the Davis Strait were about 10,000-12,000 tonnes, but increased in 2010 to about 14,000 tonnes (Jørgensen 2010). Half of the catch ise from Greenland waters (Fig. 5.1.3) and constitutes a significant proportion of the total Greenlandic catch of Greenland halibut. The other half of the catch is taken in Canadian waters close to the Greenland border. In recent years most of the catches in Greenland waters use bottom trawl apart from a very small fishery which uses longlines (about 20 tonnes). The fishery has been distributed in the same way throughout the period (Fig. 5.1.3).

*Greenland halibut inshore exploitation:* Greenland halibut in the inshore areas of West Greenland are considered to be recruited from the offshore stocks of Greenland halibut in the Davis Strait (Riget & Boje 1988). In northern Greenland (north of 67°N) a large inshore fishery with total catches up till 25,000 tonnes (Nygaard et al. 2010) will presumably be affected if the offshore stock collapses. In the assessment area inshore fishery is mainly conducted in Nuup Kangerlua (the Nuuk/Godthåb fjord) and catches peaked in the early 1980s at a level of more than 2,000 tonnes per year. The stock collapsed due to a high fishing mortality and there was no fishery in the fjord until 2009. In 2010 landings from Nuup Kangerlua were at a level of 230 tonnes.

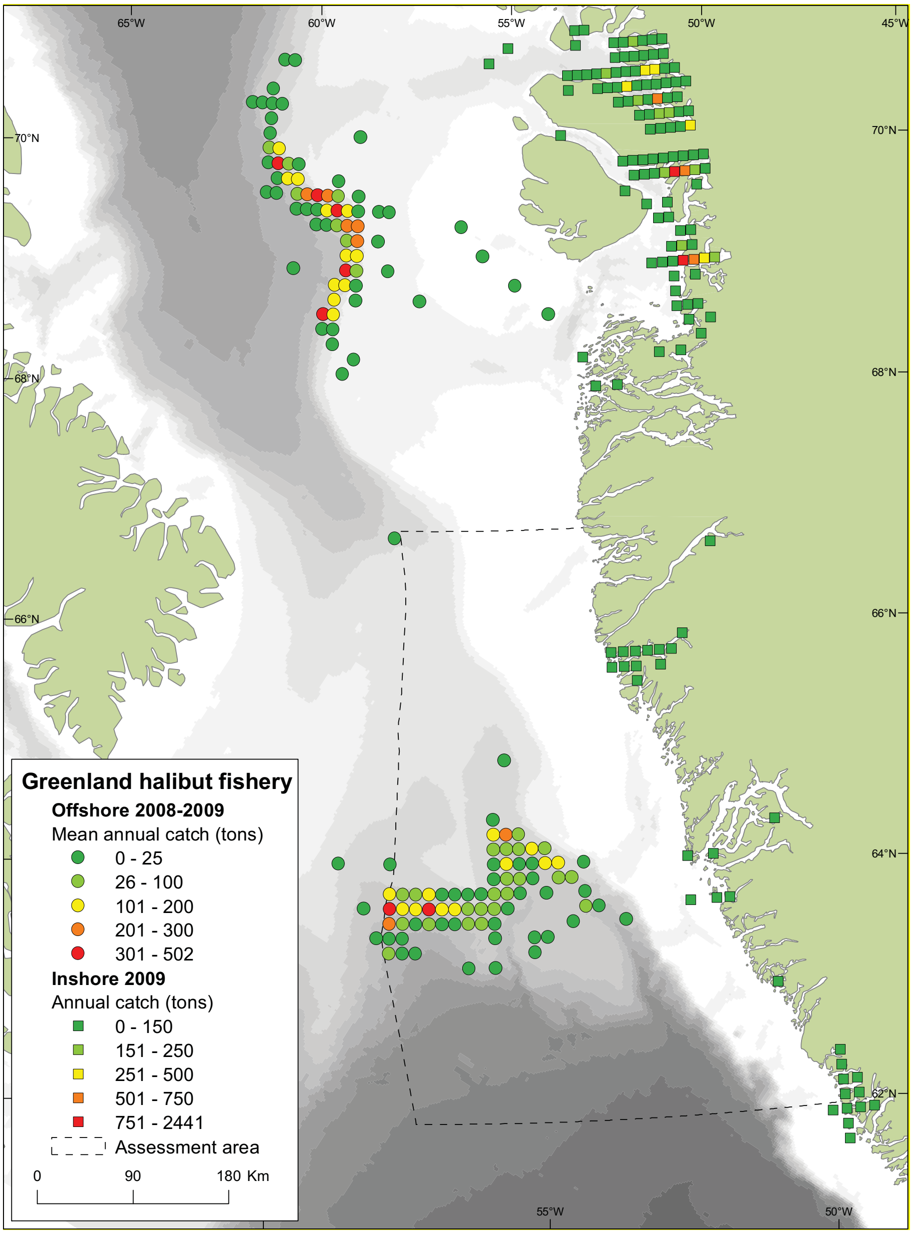
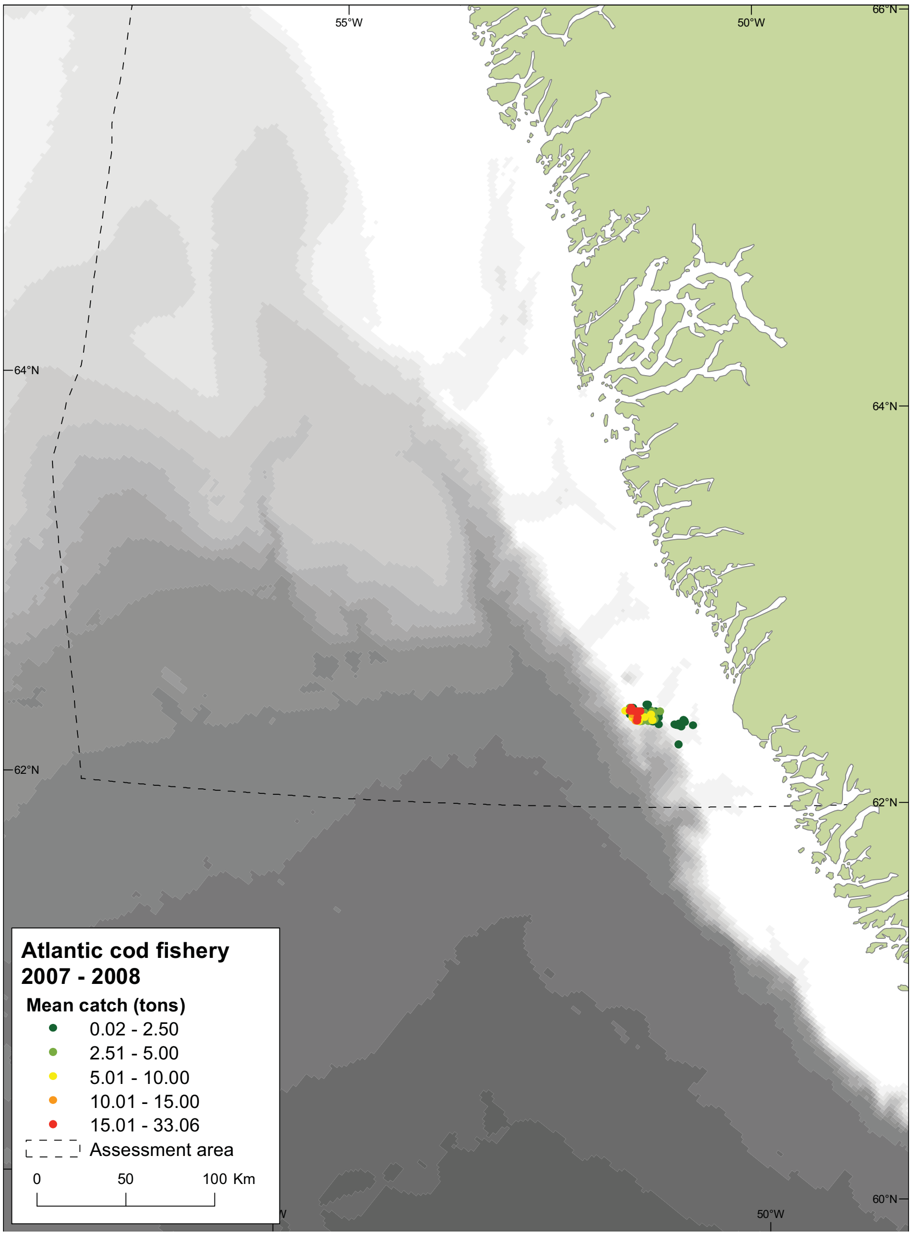



**Figure 5.1.3.** Distribution and size of the Greenland halibut landings from the assessment area. Note that different scales apply to inshore and offshore landings. Inshore catches only shown for 2009, offshore by the annual average for 2008-2009.

### Atlantic cod, *Gadus morhua*

In the assessment area cod fishery has been very important historically. The West Greenland commercial cod fishery started in 1911 in local fjords (Horsted 2000). In the 1920s the offshore fishery developed and total landings increased over the next few decades and then peaked in the 1960s with annual catches of some 350,000-500,000 tonnes. Spawning stock and sea temperature then decreased and in the late 1960s the stock collapsed (Buch et al. 1994). Except for a temporary improvement for cod during 1988-90 the stock remained at a very low level until early in 2000. Since the beginning of this millennium the Atlantic cod stock has improved and large spawning cod have been documented in East Greenland in 2007 (ICES 2010b). In 2008 total catches peaked with 25,000 tonnes, but decreased thereafter (Fig. 5.1.4). In 2009 and 2010 the offshore area in West Greenland was closed for cod fishery.

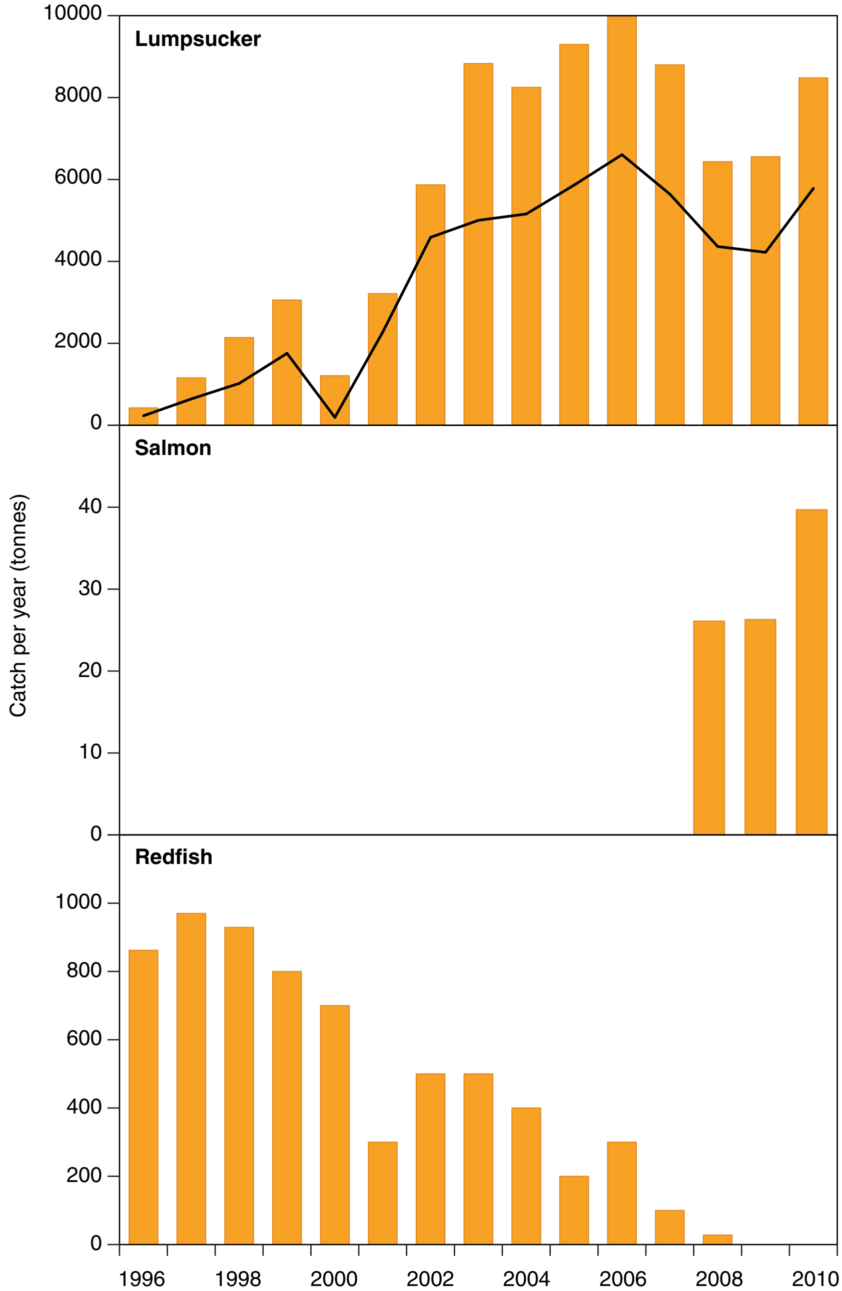
Figure 5.1.4. Distribution and size of the Atlantic cod catches in the assessment area. Catch size calculated as the annual average for 2007-2008. Catch statistics for the inshore fishery were not available. In 2009 and 2010 the offshore area in West Greenland was closed for cod fishery.




**Lumpsucker**, ***Cyclopterus lumpus***

Lumpsucker is caught commercially along the entire Greenland west coast (Greenland Institute of Natural Resources, unpubl. data), with total catches up to 10,000 tonnes in 2006. In the last decade 65% of total catch was caught in the assessment area. The fishery is mainly conducted using gillnets and takes place in spring and early summer when the fish move into shallow coastal waters to spawn. The roe is the commercial product and the amount bought by the local factories in the assessment area varies considerably between years. However, since 2002 total catch has increased considerably to 8,000-10,000 tonnes annually (Fig. 5.1.5a). The same pattern is seen in the assessment area where the majority of the catch is landed.

**Figure 5.1.5.** The total annual catch of lumpsucker, salmon and redfish in West Greenland from 1996 to 2010. The black line for lumpsucker shows the combined catch reported for Pamiut, Nuuk, Maniitsoq and Sisimiut, i.e. the assessment area (data from APNN).




**Capelin**, ***Mallotus villosus***
Capelin is not fished commercially, but caught for local consumption. There have, however, been several trial fisheries targeting roe-bearing females, latest in 2007, but these have been unsuccessful in finding exploitable resources of capelin. In September 2005, an acoustic survey showed considerable concentrations of capelin in several Greenland fjords, including two in the assessment area (Bergstrøm & Wilhjámsson 2006). Especially the Nuuk fjord (64°N) had high concentrations of capelin, whereas only small capelin concentrations were found outside the fjords along the Greenland west coast. However, yearly trawl surveys conducted by the Greenland Institute of Natural Resources along the coast show that capelin migrate to the shelf area, where they presumably spend time from autumn to winter (Friis-Rødel & Kanneworff 2002). No other reliable capelin biomass estimates exist and the current stock status is unknown.

**Salmon**, ***Salmo salar***

The fishery for Atlantic salmon in Greenland waters began in 1960-62 and peaked in the early 1970s at a catch level of more than 2,000 tonnes a year (Jensen 1990). The fishery was quota regulated from 1972, but due to declining stocks NASCO agreed in 1998 that no commercial fishery for salmon should be allowed. Since then, the export of salmon from Greenland has been banned and the fishery has been limited to the amount that can be sold and consumed within Greenland. The coastal fishery constitutes a significant income for a few fishermen in each community. In 2010 reported landings amounted to 40 tonnes (Fig. 5.1.5b). Approximately half of the total catch of salmon in Greenland is caught in the assessment area.

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

Landings of redfish in West Greenland were more than 5,000 tonnes per year prior to the mid-1980s. Since then landings in West Greenland have been below 1,000 tonnes per year and less than 100 tonnes in 2010 (Fig. 5.1.5c). Part of the catch is taken inshore in the West Greenland fjords. Specific catch statistics for the assessment area are not available.

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

Catch statistics are currently not divided into species, but reported as wolffish combined. Wolffish are mainly taken inshore (Nygaard & Jørgensen 2010), partly as bycatch in the longline or gillnet fishery for Greenland halibut and cod and occasionally in crab traps. During the last decade landings of wolffish have increased from less than 100 tonnes to about 1,000 tonnes per year. Atlantic wolffish survey indices from the EU-German survey are very low compared to the mid-1980s. The current advice for Atlantic wolffish is 'No direct fishery'. Spotted wolffish survey indices increased between 2002 and 2008 to a level above average.

**Iceland scallop**, ***Chlamys islandica***

Iceland scallop is caught in shallow waters in the assessment area where currents are strong. Only one fishing boat is active in the fishery and the total catch in 2009 was 511 tonnes.

## 5.2 Subsistence and recreational fisheries and hunting

*Tenna Kragh Boye, Fernando Ugarte, Malene Simon, Erik W. Born, Lars M. Rasmussen, Aqqalu Rosing-Asvid (GINR) & Daniel Clausen (AU)*

Hunting and fishing are an integrated part of Greenlandic culture. Subsistence hunting is still of economic importance and recreational hunting and fishing activities make a significant contribution to private households. In Southwest and South Greenland a lot of the subsistence fishing and hunting of marine mammals and seabirds has gradually developed into recreational activitys.

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 and benefit from subsistence and recreational fisheries.

Many fish species are utilised on a subsistence basis, the most important are spotted wolfish (*Anarchichas minor*), Greenland halibut (*Reinhardtius hippoglossoides*) redfish (*Sebastes* spp.), Atlantic cod (*Gadus morrhua*), polar cod (*Boreogadus saida*), Greenland cod (*Gadus ogac*) and Greenland shark (*Somniosus microcephalus).*

### 5.2.1 Bird hunting

Birds have historically played an important role as a supplement to hunting marine mammals, caribou and to fishing. The most important hunted bird species are thick-billed murre (*Uria lomvia),* common eider (*Somateria mollissima)* and king eider (*Somateria spectabilis),* little auk (*Alle alle)* and black guillemot *(Cepphus grylle)*.

Catches have been reported annually to Piniarneq, the official Greenlandic hunting statistics since 1993, and represent 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. 5.2.1 and 5.2.2). Within the assessment area the number of reported common eider was reduced to from 33,000 to 11,000 from 2000 to 2002, when the hunting season was shortened by approximately two months, and has stabilised around 11,000 birds annually.

Since 1996 the thick-billed murre has been the far most important hunted seabird, followed by common eider. Specific hunting seasons are established by the Department of Fisheries, Hunting and Agriculture and vary between species and region. 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).

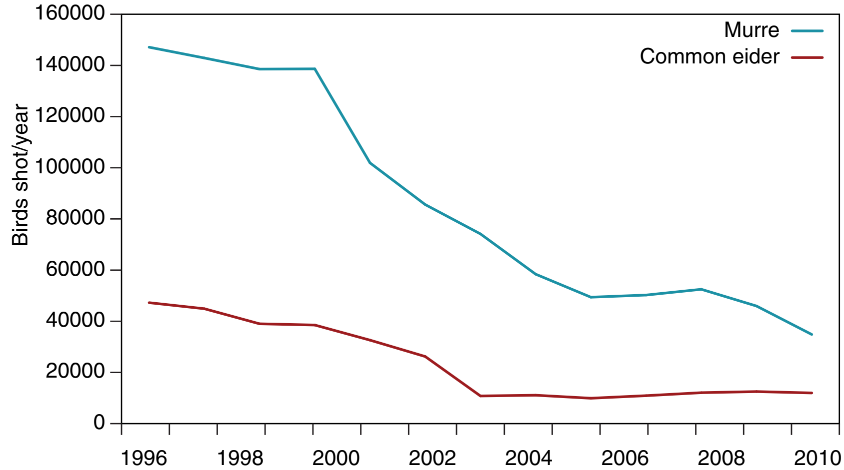



**Figure 5.2.1.** Annual number of murres and common eiders hunted in West Greenland from Paamiut to Sisimiut (the assessment area) in the period 1996-2008. Unpublished data from Piniarneq, Greenland hunting statistics, Department of Fisheries, Hunting and Agriculture, 2011.

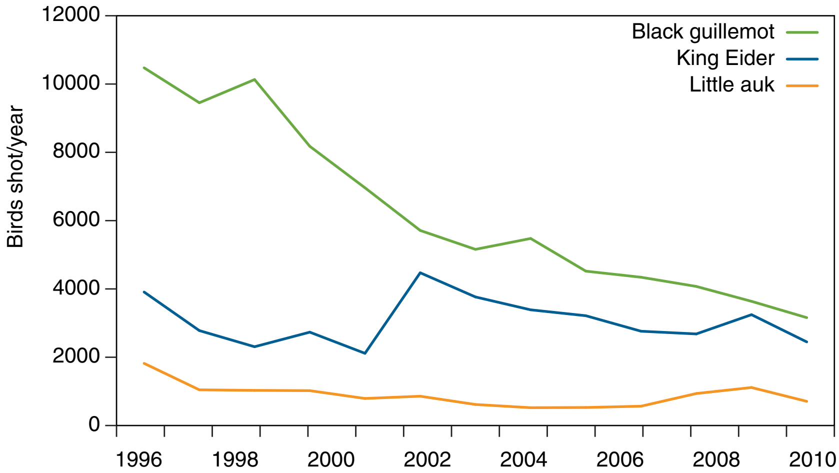



**Figure 5.2.2.** Annual number of king eider, black guillemot and little auk hunted in West Greenland from Paamiut to Sisimiut (the assessment area) in the period 1996-2008. Unpublished data from Piniarneq, Greenland hunting statistics, Department of Fisheries, Hunting and Agriculture, 2011.

### 5.2.2 Seal hunting

Seals are important for both part-time and ful-time hunters in the assessment area. The skins are purchased and prepared for the international market by the tannery in Southwest Greenland, and the meat is eaten locally. In the period 2000-2008 more than half a million seal skins were traded in Greenland. However, in 2008-2009 the market for sealskins collapsed and it is now difficult to sell the skins (Rosing-Asvid 2010).

Harp seals are caught in large numbers (Fig. 5.2.3), especially during summer (Fig. 5.2.4). In winter and early spring most of the West Atlantic harp and hooded seals congregate near the whelping areas off Newfoundland. However, a small fraction of these seals will stay in West Greenland throughout the year.

Hooded seal can also be caught throughout the year, but most catches are made during spring, just prior to and after whelping, when many hooded seals are close to the assessment area, or in the fall when post-moult seals migrate through the assessment area towards their foraging grounds in Davis Strait and Baffin Bay.

The ringed seal are normally associated with sea ice and some live in or near glacier fjords in the assessment area all year. Catches increase during winter and spring. Most catches are juvenile seals, of which some are likely to be seals that have been 'pushed' out of the fjords where adult seals make territories when fast ice starts to form. The assessment area is, however, also likely to have an influx of seals coming from the Davis Strait pack ice when it approaches the coast during winter.

Catches of bearded seals also increase in late winter–spring (March-April) in the northern part of the assessment area when the pack ice comes close to the coast.

#### Annual catch

*Harp seal*: 27-37,000 animals/yr. in recent decades
*Ringed seal:* <4,000 animals/yr since 2004
*Hooded seals:* 400-1,000 animals/yr. in the last decade
*Bearded seal:* About 100-300 seals/year
*Harbour seal: Protected against hunting.*

**Figure 5.2.3.** Catch statistics for seals in the assessment area, 1996-2008 (data from Piniarneq, APNN).

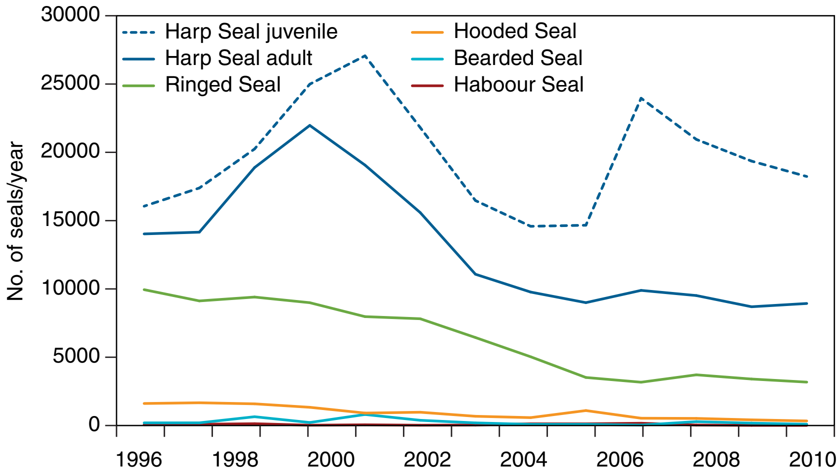
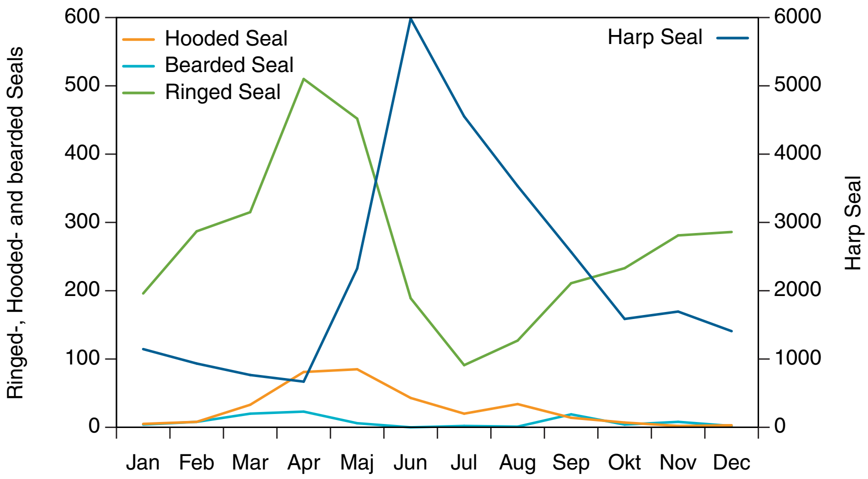



**Figure 5.2.4.** The seasonal distribution of the seal catches in the assessment area in 2008 (data from Piniarneq, APNN).




### 5.2.3 Walrus and polar bear

#### Walrus

Walruses from the West Greenland-Southeast Baffin Island walrus stock are hunted in West Greenland mainly during spring until retreat of the pack ice westwards and the more or less simultaneous emigration of walruses from their West Greenland wintering areas (Born et al. 1994, Born et al. 1995). Walruses from this stock are also hunted along Southeast Baffin Island (Nunavut) mainly during the period May-November (COSEWIC 2006, Stewart 2008) – i.e. when generally are they absent from West Greenland.

Quotas for the West Greenland-Southeast Baffin Island walrus stock in 2007, 2008 and 2009 were 80, 65, 50 animals (Anon 2006a, b), respectively. However, a total of only 43, 28 and 33 walruses were reported landed in West Greenland from this stock in 2007, 2008 and 2009 (Ugarte 2011). The Greenland quota for the West Greenland-Southeast Baffin Island stock of walrus for the period 2010-2012 is 61 landed in each year (Anon 2010b, a).

During the five-year period 1998/99-2002/03 the reported catch of walruses from the same stock on Southeast Baffin Island in the communities Iqaluit, Qikiqtarjuaq, Pangnirtung and Kanngiqtugaapik/Clyde River averaged 27.2/year (sd=11.3, range=15-43, n=5 years). And during the period

2003/04-2007/08 the catch averaged 16.0/year (sd=11.8, range:2-34). This is a minimum estimate of total removals, because in some years landed catches for some of these settlements are not reported. Furthermore, struck-and-lost is not included in the reporting (DFO unpubl. data *in lit.* 2009).

#### Polar bear

Total annual quotas for the harvest from the DS population is 46 for Nunavut, 2 for Greenland, 6 for Nunatsiavut (Newfoundland and Labrador). There is no quota in Nunavik (Quebec). In January of 2006, Greenland established a quota system. An annual quota of 2 bears was established for the Davis Strait population (Obbard et al. 2010).

### 5.2.4 Baleen whales

Minke whales, fin whales, bowhead whales and humpback whales are hunted in West Greenland and annual quotas are set every 5 years by the IWC (The International Whaling Commission) (Tab. 5.2.1). 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).

Apart from a period between 1987 and 2009, humpback whales have been hunted in Greenland for centuries (Fabricius 1780). Six out of the nine humpback whales from the quota of 2010 and 2011 can be taken within, or close to, the assessment area (APNN 2011b). Whale watching focusing on humpback whales is an activity that has grown considerably in Greenland during the last years and is practised both by commercial companies and by locals from private boats (Boye et al. 2010). To avoid conflicts of interest between whaling and whale watching, whalers and tour operators in the Municipality of Sermersooq have agreed to avoid overlap of their activities in time and space (Bergstrom 2010). To minimise disturbance to humpback whales, a voluntary code of conduct for whale watching has been suggested by the Greenland Tourism and Business Council (Boye et al. 2010, Boye et al. 2011)

Bowhead whales have been hunted since the time the Thule Inuit settled in Greenland about 1,000 years ago (Jensen et al. 2008a). European and North American whalers decimated the population in the $17^{th}$-$19^{th}$ centuries and by the start of the $20^{th}$ century the species had become rare in Greenland. In 1927 the species was protected. The population has now recovered to the extent that a quota of two animals per year for the period 2008-2012 has been approved by the IWC. The first bowhead whales were caught in 2009. Bowhead whales are caught in Disko Bay, north of the assessment area.

**Table 5.2.1.** 2011 quotas for the four species of baleen whales and two species of tooth whales caught in West Greenland waters (APNN 2011b).

| 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) | 83 |
| Fin whale (*Balaenoptera physalus*) | 10 | Open | 3 |
| Humpback whale (*Megaptera novaeangliae*) | 9 | 6 | 6 |
| Bowhead whale (*Balaena mysticetus*) | 2 | 0 | 0 |
| Narwhal (*Monodon monoceros*) | 310 | 6 | NA |
| Beluga whale (*Delphinapterus leucas*) | 310 | 41 | NA |

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 2010c). In 2010, the total catch of minke whales reported in zones within the assessment area was 83 individuals: 21 minke whales for the Sisimiut area, 37 for Maniitsoq, 11 for Nuuk and 14 for Pamiut (APNN, unpubl. data). Most minke whale catches within the assessment area (Fig. 5.2.5) 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, bowhead whales and humpback whales can only be hunted using harpoon cannons and explosive penthrite grenades (Anon 2010c). 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 in Disko bay or further south (as mentioned above, bowhead whales are hunted only in Disko Bay). In 2010, three fin whales were caught within the assessment area and two were hunted just south of Disko Island in Qeqertarsuaq and Ilulissat, north of the assessment area. Of the quota of nine humpback whales for each of the years 2010 and 2011, three whales were given to the municipality of Qeqqata and three to Sermersooq, both within or close to the assessment area. Two humpback whales were given to the municipality of Qaasuisup, north from the assessment area and one to Kujalleq, south of the assessment area. Figure 5.2.5 shows the positions of fin whales caught in 1988-2007 and humpback whales caught in 2010. In addition to the hunt, up to approximately five humpback whales are unintentionally caught in fishing gear every year in Greenland.

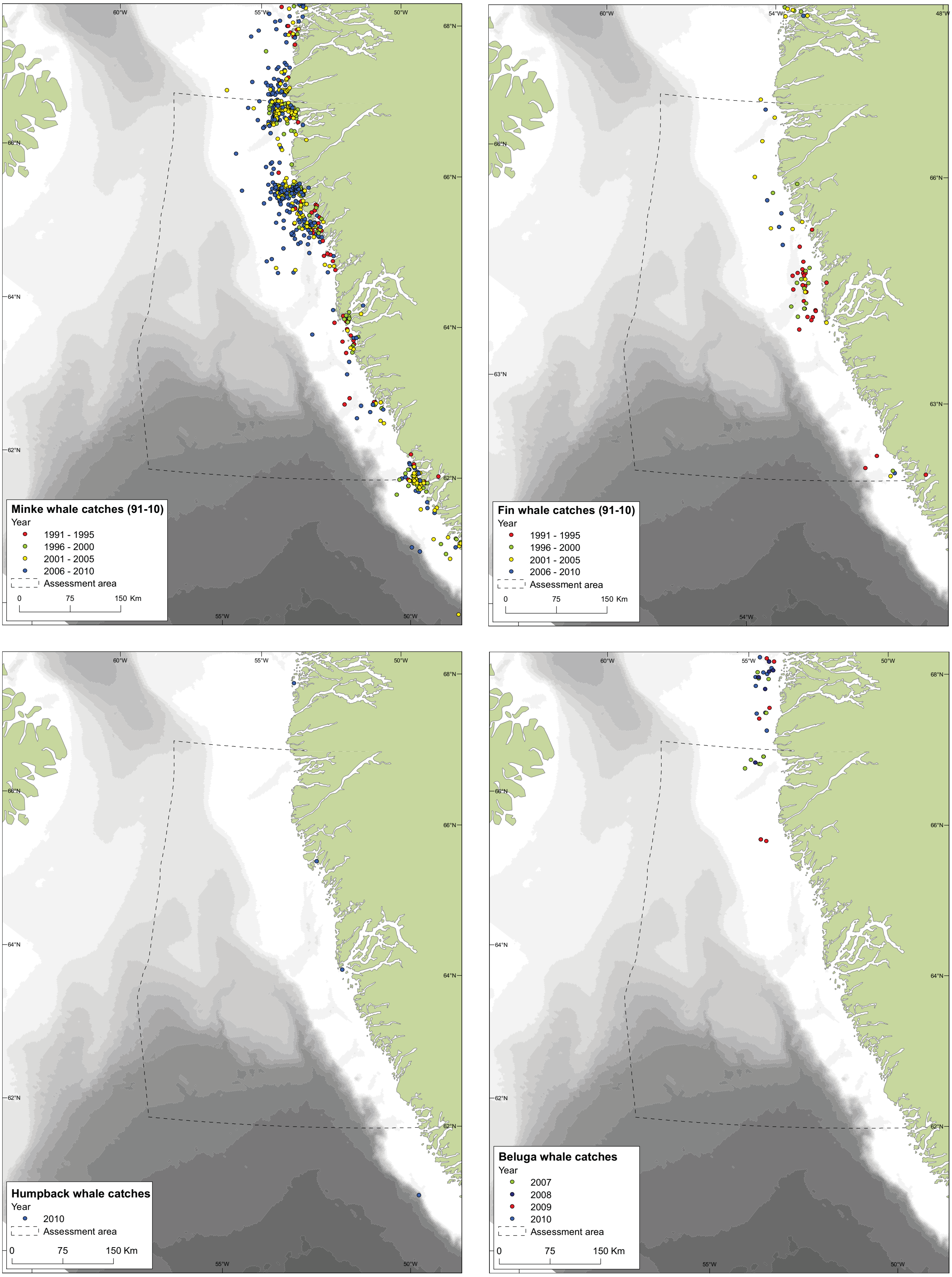



**Figure 5.2.5.** Minke whale, humpback whale, beluga whale and fin whale catches in West Greenland within varying time periods. For belugas, the figure shows only 7 % of the reported catch. The remaining dataset has not yet been geo-referenced (data from APNN).

### 5.2.5 Toothed whales

Catches of narwhals and belugas are amongst the most important for the communities of Northwest Greenland (Heide-Jørgensen 1994). Sisimiut and Maniitsoq, in the northern part of the assessment area, are the southernmost places where narwhals and belugas are regularly caught. Large catches over several decades caused an apparent decline in the population sizes of the two species. In 2004, quotas were introduced by the Government of Greenland. The annual quotas are 310 belugas and 310 narwhals per year (Tab. 5.2.1). With these quotas there is a 70% chance that the population sizes of both species will increase (NAMMCO 2010). For Sisimiut, the quotas for 2011-2012 include two narwhals and 26 belugas per year. For the same period, quotas for Maniitsoq are two narwhals and ten belugas per year (APNN 2011a). Narwhal and beluga are the only toothed whales whose hunt is regulated by quotas in Greenland (Anon 2011b). Figure 5.2.5 shows the positions of beluga catches from 2006-2010.

Harbour porpoise, pilot whales and, to some extent, white beaked dolphins, killer whales and perhaps bottlenose whales are also hunted. 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 is entered into a large database administrated by the Ministry of Fisheries, Hunting and Agriculture. The data presented below comes from this database. A partial validation of killer whale data showed that there are human mistakes in the reporting.

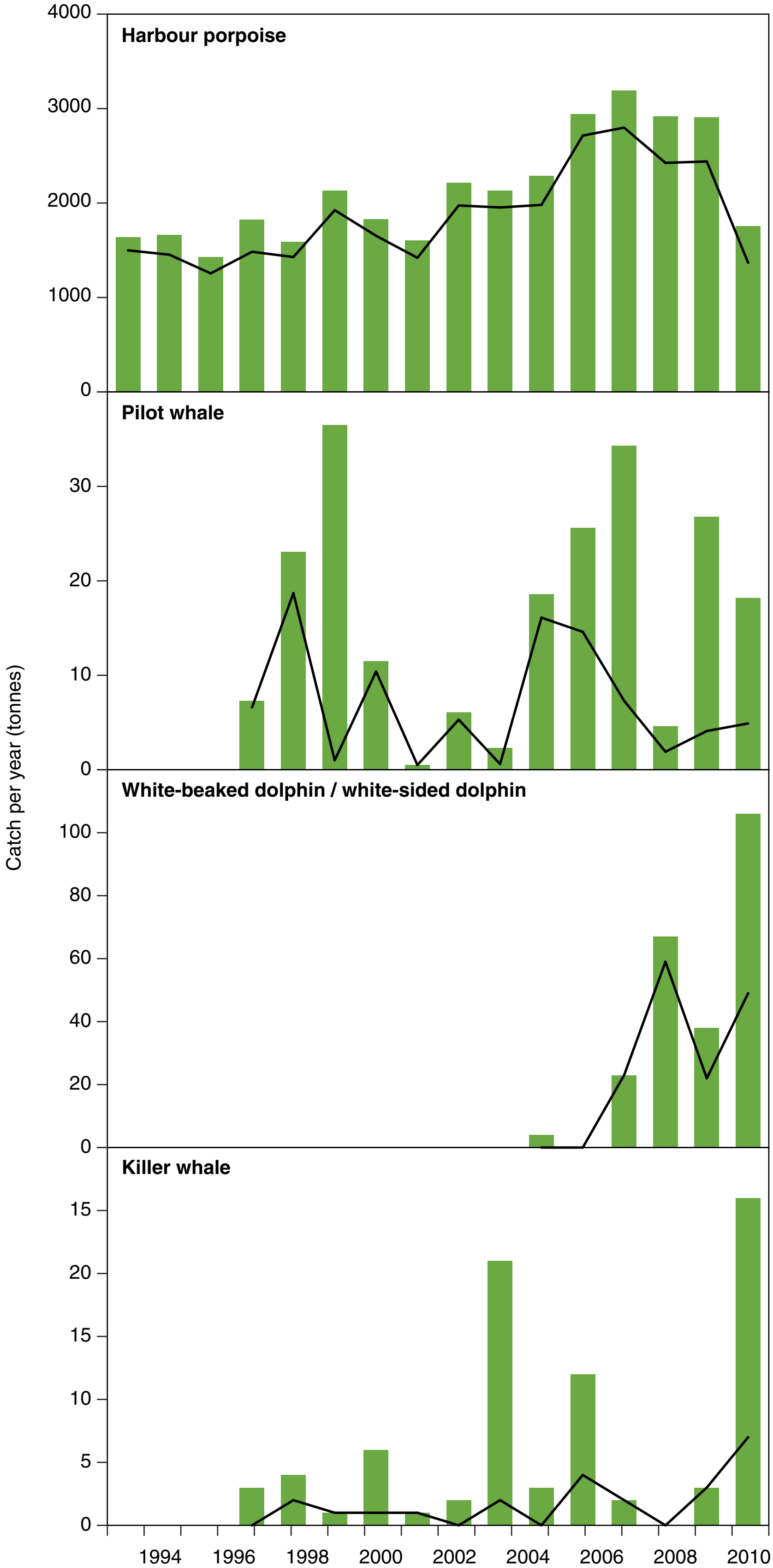
In the period from 1993-2008 an average of 2,271 harbour porpoises were taken annually. Of the 34,064 catches reported from 1993-2008 in West Greenland, 30,443 harbour porpoises (i.e. 89%) were taken within, or close to the assessment area (i.e. between Pamiut and Sisimiut) (Fig. 5.2.6a).

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 and approximately half have been caught within the assessment area (Fig. 5.2.6b).

White-beaked dolphins and white-sided dolphin are not separated in the reporting system. In Greenlandic both species have the same name. 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, 40 dolphins have been caught annually in the period from 2003-2008 (Fig. 5.2.6c). Out of 238 dolphins reported caught in West Greenland from 2003-2008, 153 (i.e. 64%) were caught in the assessment area.

Killer whales are hunted partly for human subsistence and partly to feed sledge dogs. As they are considered as competitors for seal and whale hunters, this is an additional reason for the hunting of killer whales. From 1996-2008 a total of 84 killer whales have been caught in West Greenland and the annual average catch for the entire period was 13, ranging between 0 and 26 killer whales per year (Fig. 5.2.6d). The killer whales have been caught irregularly along the entire West coast from Upernavik in the north to Nanortalik in the south, with 27% of the catches (i.e. 23 animals) taken within the assessment area.

**Figure 5.2.6.** The West Greenland catch (green bars) of harbour porpoise, pilot whale, white beaked dolphin and killer whale. The black line shows the combined catch reported for Pamiut, Nuuk, Maniitsoq and Sisimiut, i.e. the assessment area (data from APNN).



Bottlenose whales are not eaten in Greenland because their blubber causes diarrhea in humans as well as dogs. Nevertheless, a few catches have been reported. It is possible that these reports are mostly mistakes, but until they have been validated we can mention that catches reported from 2006, 2007 and 2008 were two, nine and 21 bottlenose whales, respectively. With the exemption of three, all reports are from the assessment area.

## 5.3 Tourism

*Michael Dünweber & David Boertmann (AU)*

The tourist industry is one of three major sectors within the Greenland economy, and the industry is increasing greatly in importance in the assessment area, both nationally and locally. The most important asset for the tourist industry is the unspoilt, authentic and pristine nature. There are no statistics on the number of tourists and their regional distribution in Greenland available, but hotels report the number of guests they have accommodated and how many 'bed nights' they have sold. Overall figures for Greenland as a whole in 2008 were approximately 82,000 guests and approximately 250,000 'bed nights' (Statistics of Greenland 2010). In the region of mid-Greenland which includes the capital Nuuk, approximately 117,000 bed nights. By far the major part of bed nights were in the assessment area and only 5-10% in Northwest and East Greenland (= former municipalities of Qaanaaq, Upernavik, Uummannaq, Scoresbysund and Tasiilaq).

In addition, cruise ships bring an increasing number of tourists to Greenland. Cruise ships increased from 37 in 2007 to 42 in 2008, where the ship deployment also increased from 148 to 165 in the same period (Statistics of Greenland 2010). According to the Danish Naval Authorities in Greenland, the number of visitors from cruise ships increased from 23,000 in 2006 to 55,000 in 2007 (Fig. 5.3.1). The National Strategy of Tourism 2008-2010 plans a 10% increase per year in the number of cruise tourists (Erhvervsdirektoratet 2007). The cruise ships focus on the coastal zone and they often visit very remote areas that are otherwise almost inaccessible, and seabirds and marine mammals are among the highlights on these trips.

A number of tourists also go to Greenland for outdoor leisure activities (mountaineering, kayaking, etc.) or scientific expeditions (natural history) (Fig. 5.3.2).

### 5.3.1 Tourist activities

Toursim activities are centred in the two main towns of the assessment area, Nuuk and Sisimiut, where there is accommodation and tourist operators are based. The season starts in early spring when there are opportunities for dog sledding (Sisimiut) on land, but the main season is summer (July-August) when it is possible to sail from the towns to attractions such as archeological sites, bird cliffs, whale habitats, glaciers, small settlements, hiking areas and areas with scenic views. In Nuuk the following activities take place (www.greenland.com):

- Whale watch cruises – summer and autumn
- Fishing and hunting, including boat trips with local hunters – mainly in the summer season

- Kayaking in June to August. Kayakers explore the coastal zone and bring equipment and provisions of their own
- Cruise ships, mainly in August and September. Visitors in Nuuk mainly explore the city; sightseeing, museums, art exhibitions and restaurants
- Skiing (cross country and alpine), mainly February to April
- Hiking, climbing and mountaineering. Mainly in the spring and summer season.

Much of the tourist activity within the assessment area takes place in the coastal zone and extensive oil exposure in this area will have serious impact on local tourist activity and the tourist industry.

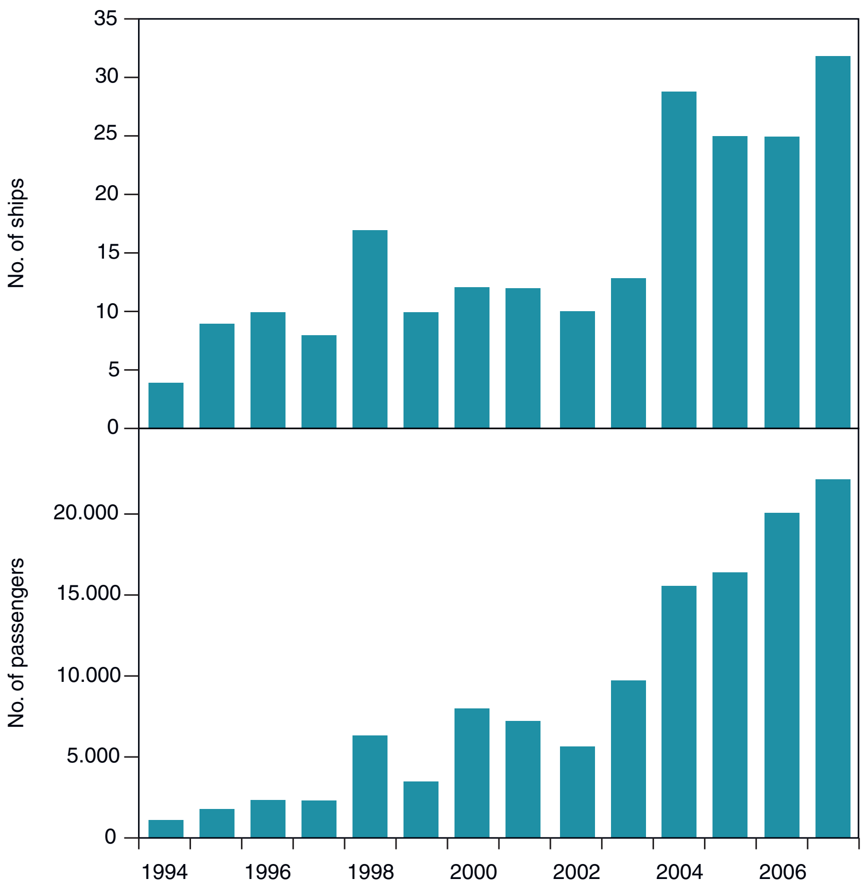



**Figure 5.3.1.** The number of cruise ships (upper graph) and the number of passengers (lower graph) in Greenland, 1994–2007. There is no data on the cruise ship activity available for the assessment area, but the trends are similar (Greenland Tourism, pers. comm.).

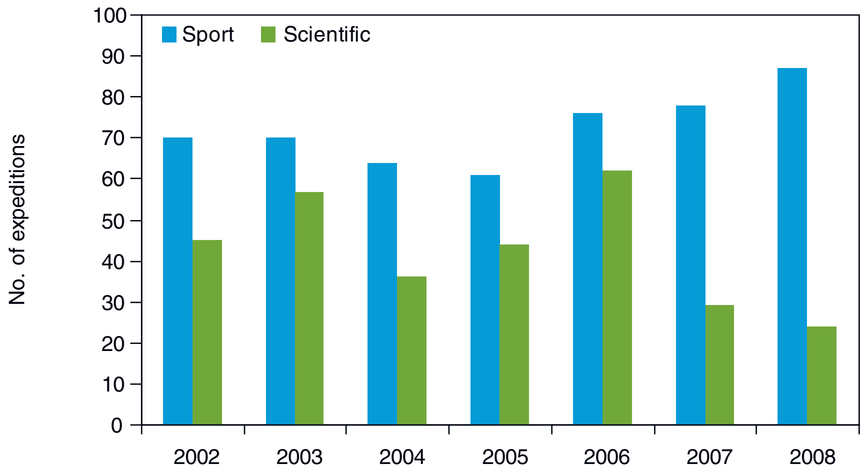



**Figure 5.3.2.** The number of expeditions in Greenland by year. Data provided by the Danish Polar Centre (DPC). It is not possible to filter out the expeditions visiting the assessment area.

# 6 Protected areas and threatened species

*David Boertmann & Daniel Clausen(AU)*

## 6.1 International nature protection conventions

According to the Convention on Wetlands (the Ramsar Convention, http://www.ramsar.org), 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, only one of the Greenland Ramsar sites has so far been protected legally. A single Ramsar site is situated within the assessment area, and that is the fjord Ikkattok and adjacent archipelagoes near Paamiut (Egevang & Boertmann 2001) - see fig. 6.1.1.

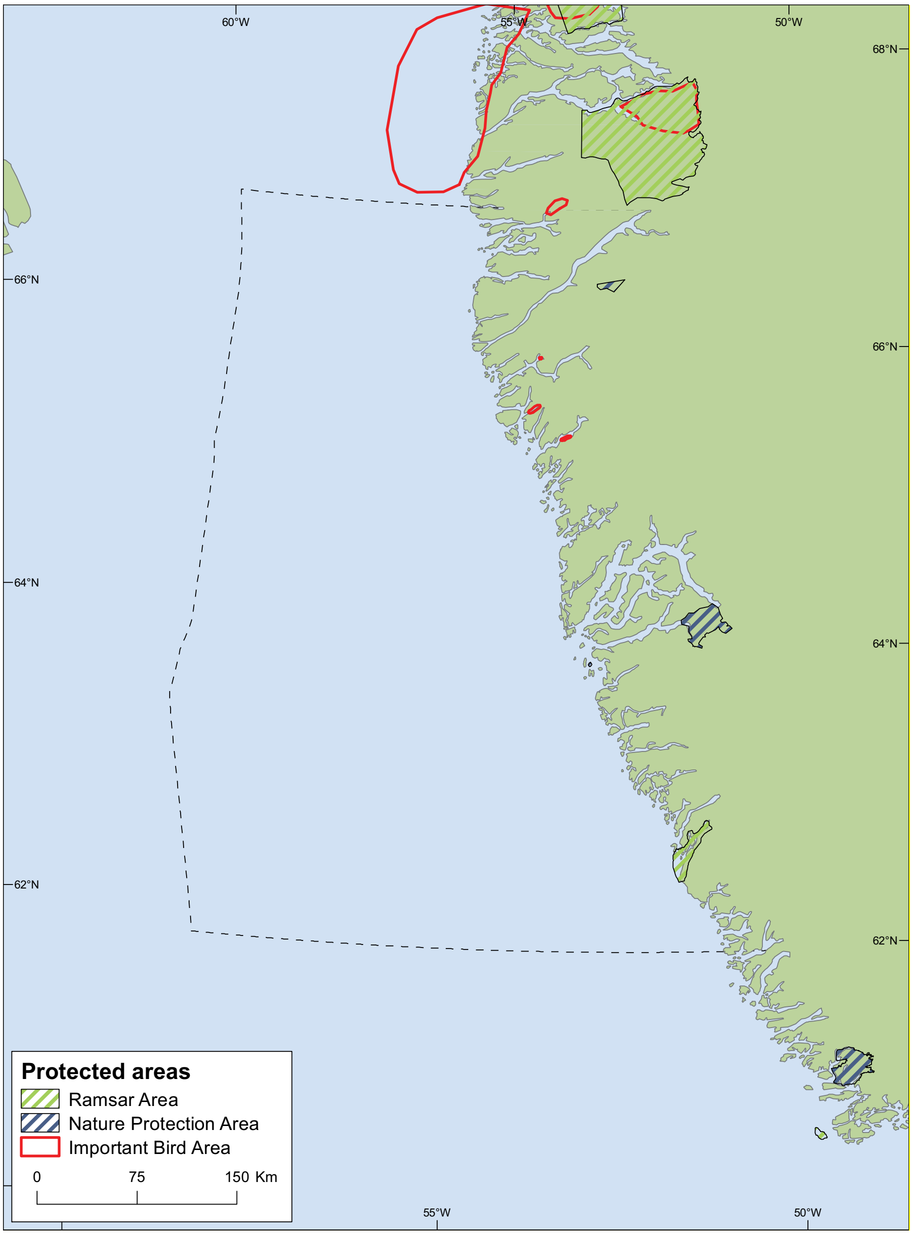



**Figure 6.1.1.** Areas within or near the assessment area protected according the Greenland Nature Protection Law or designated as Important Bird Areas (IBAs) or Ramsar sites.

## 6.2 National nature protection legislation

Only three areas protected according to the Greenland nature protection legislation are located within the assessment area. However, two of these are inland sites and will not be affected by offshore oil activities. The third site is the island of Akilia near Nuuk (Order no. 19 of November 1, 1998), which is close to the outer coast and protected due to geological interest (Fig. 6.1.1).

No sites within the assessment area are protected as seabird breeding sanctuaries according to the Bird Protection Executive Order (No. 8 of March 2, 2009). But this order also states, that in general, all seabird breeding colonies are protected from disturbing activities (*cf.* the maps showing the seabird breeding colonies within the assessment area (Fig. 4.7.1 and 4.7.2). According to the Mineral Extraction Law, a number of areas are designated as 'important to wildlife' and mineral (and hydrocarbon) exploration activities are regulated in order to protect wildlife. There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies. The areas important to wildlife can be found on this link: http://dmugisweb.dmu.dk/rdimportantareas/.

## 6.3 Threatened species

Greenland has red-listed (designated according to risk of extinction) six species of mammals, thirteen species of birds and one species of fish (Tab. 6.3.1) which may occur in the assessment area (Boertmann 2007), although some are rare.

A few species have been categorised as 'Data Deficient' (DD) in the Greenland red list and they may become red-listed when additional information is available. These are bearded seal, harbour porpoise, blue whale and sei whale. Bottlenose whales, listed as 'not applicable' in the Greenland Red List and 'Data Deficient' in the IUCN global Red List may also change status when additional information is available.

**Table 6.3.1.** Species and included in the national red list of Greenland (Boertmann 2007).

| Species | Red list category |
|---|---|
| Harbour seal | Critically endangered (CR) |
| Walrus | Endangered (EN) |
| Bowhead whale | Near threatened (NT) |
| Beluga whale | Critically endangered (CR) |
| Narwhal | Critically endangered (CR) |
| Great northern diver | Near threatened (NT) |
| Greenland white-fronted goose | Endangered (EN) |
| Common eider | Vulnerable (VU) |
| Harlequin duck | Near threatened (NT) |
| Gyr falcon | Vulnerable (VU) |
| White-tailed eagle | Near threatened (NT) |
| Sabines gull | Near threatened (NT) |
| 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) |
| Atlantic salmon* | Vulnerable (VU) |

* local stock spawning in a single river in Godthåbsfjord.

National responsibility species constitute a significant part (20%) of the global population in Greenland, why their global survival are dependent on a favourable conservation status in Greenland. Endemic species or subspecies are also of national responsibility as the total global population is found within Greenland. Those occurring in the assessment area are listed in Table 6.3.2.

**Table 6.3.2.** Species of national responsibility and endemic species (subspecies) occurring in the assessment area.

| **National responsibility species** |
|---|
| Narwhal |
| Walrus |
| Polar bear |
| Light-bellied brent goose |
| Greenland white-fronted goose (endemic subspecies) |
| Brent goose |
| Mallard (endemic subspecies) |
| Common eider |
| White-tailed eagle (endemic subspecies) |
| Iceland Gull (endemic subspecies) |
| Black guillemot |
| Little auk |
| |
| **Species with isolated population in Greenland (endemics not included)** |
| Great cormorant |
| Red-breasted merganser |
| Harlequin duck |
| Harbour seal |
| Harbour porpoise |
| Atlantic salmon (local spawning stock) |

The International Union of Nature Conservation (IUCN 2010)) lists the species, which are globally threatened. See Table 6.3.3 for the species occurring within the assessment area.

**Table 6.3.3.** Species occurring in the assessment area and listed as globally threatened (IUCN 2010).

| Species | Redlist category |
|---|---|
| Ivory gull | Near Threatened (NT) |
| Polar bear | Vulnerable (VU) |
| Fin whale | Endangered (EN) |
| Blue whale | Endangered (EN) |
| Sperm whale | Vulnerable (EN) |
| Narwhal | Near Threatened (NT) |
| Beluga whale | Near Threatened (NT) |

## 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), of which eight are located within the assessment area (Fig. 6.1.1). These areas are designated using a large set of criteria, for example, that at least 1% of a bird population should occur in the area. For further information see the IBA website (http://www.birdlife.org/ action/science/sites/index.html). Some of the IBAs are included in or protected by the national regulations for example as seabird breeding sanctuaries, but many are without protection or activity regulations.

# 7 Contaminants, background levels and effects

*Doris Schiedek (AU)*

Knowledge on background levels of contaminants in areas where hydrocarbon exploration and exploitation are foreseen is important, since it serves as a baseline for monitoring and assessment of potential future contamination of the environment caused by these activities. The occurrence of contaminants in the marine environment and their potential impacts on 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, present knowledge is summarised with focus on studies with relevance for the Davis Strait assessment area.

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). Only data for animals not affected by local pollution sources, i.e. former mine sites are included. 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 with southern areas.

## 7.1 AMAP Monitoring Activities

With 1991 as baseline, 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 number 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 activities 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, e.g. cadmium (Cd), mercury (Hg), selenium (Se). A detailed overview of contaminant levels and temporal trends in the monitored species is given by Schiedek in (Boertmann & Mosbech 2011), which included results from the latest AMAP assessment in 2009 (Muir & de Wit 2010).

In general it can be stated with regard to POPs that the AMAP assessments have revealed levels of organochlorines in Arctic biota generally to be highest in marine organisms belonging to the top trophic level (e.g., great skuas, glaucous gulls, great black-backed gulls, killer whales, pilot whales, Arctic fox, and polar bears). This is particularly true in relation to biomagnification of PCBs and DDT. AMAP activities have also shown a decrease in the levels of some POPs (e.g. PCBs and DDT), resulting from 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, use of new persistent pollutants, currently produced in large quantities, is on the increase (AMAP 2004, Muir & de Wit 2010). These substances have also been detected in animals from Greenland; such as the brominated flame retardants hexabromocyclododecane (HBCD) or tetrabromobisphenol (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), with concentrations of HBCDs in animals from West Greenland generally being lower than in the same species from East Greenland. The same effect has previously been described for other halogenated compounds such as polybrominated diphenyl ethers (PBDEs) (Vorkamp et al. 2007).

Another, more localised source of pollution is mining activity, e.g. the olivine mine at Seqi in Niaqunngunaq (Fiskefjord) north of Nuuk. The nearest settlement is Atammik, at the inlet of the fjord. The mine was in operation between 2005 and 2010. Since 2004, environmental monitoring has been conducted every year in order to assess any impact from mining. During operation increased levels of some elements, particularly chromium and nickel, were measured in lichens, blue mussels and seaweed. Generation and spread of metal-contaminated dust from the roads and the ore-crushing facility was considered the main source of this contamination. Since closure of the mine in 2010, the environmental impact has decreased and is presently considered as being insignificant for the Niaquungunaq fjord system (Søndergaard & Asmund 2011).

### 7.1.1 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 shipping lanes (Sousa et al. 2009). In remote areas such as the Arctic environment, TBT levels are usually low, except close to harbours, e. g. Sisimiut (Villumsen & Ottosen 2006) and 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, though the concentrations are rather low (Jacobsen & Asmund 2000, Strand et al. 2005).

### 7.1.2 Petroleum hydrocarbons and Polycyclic Aromatic Hydrocarbons (PAH)

Petroleum hydrocarbons represent several hundred chemical compounds originating from crude oil e.g. gasoline, kerosene, and diesel fuel. Of primary interest for assessment of the environmental impacts are the aromatic hydrocarbons (i.e., benzene, ethylbenzene, toluene, and xylenes). Another important group is the 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 chapter 10 and 11). Twentythree PAHs are included on the lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency (EPA).

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 performed so far in Greenland, including the assessment area, on PAH levels in biota and sediment (including sediments from offshore areas, municipal waste dumpsites and sites with no known local pollution sources), levels of petroleum compounds in the Greenland environment appear to be relatively low and are regarded as background concentrations (Fig. 7.1.1, PAH concentrations in West Greenland).

The higher PAH concentrations in some areas off the coast of the Nuussuaq Peninsula (Fig. 7.1.1) could probably be attributed to the Marrat oil seep, which has been studied some years ago (Mosbech et al. 2007).

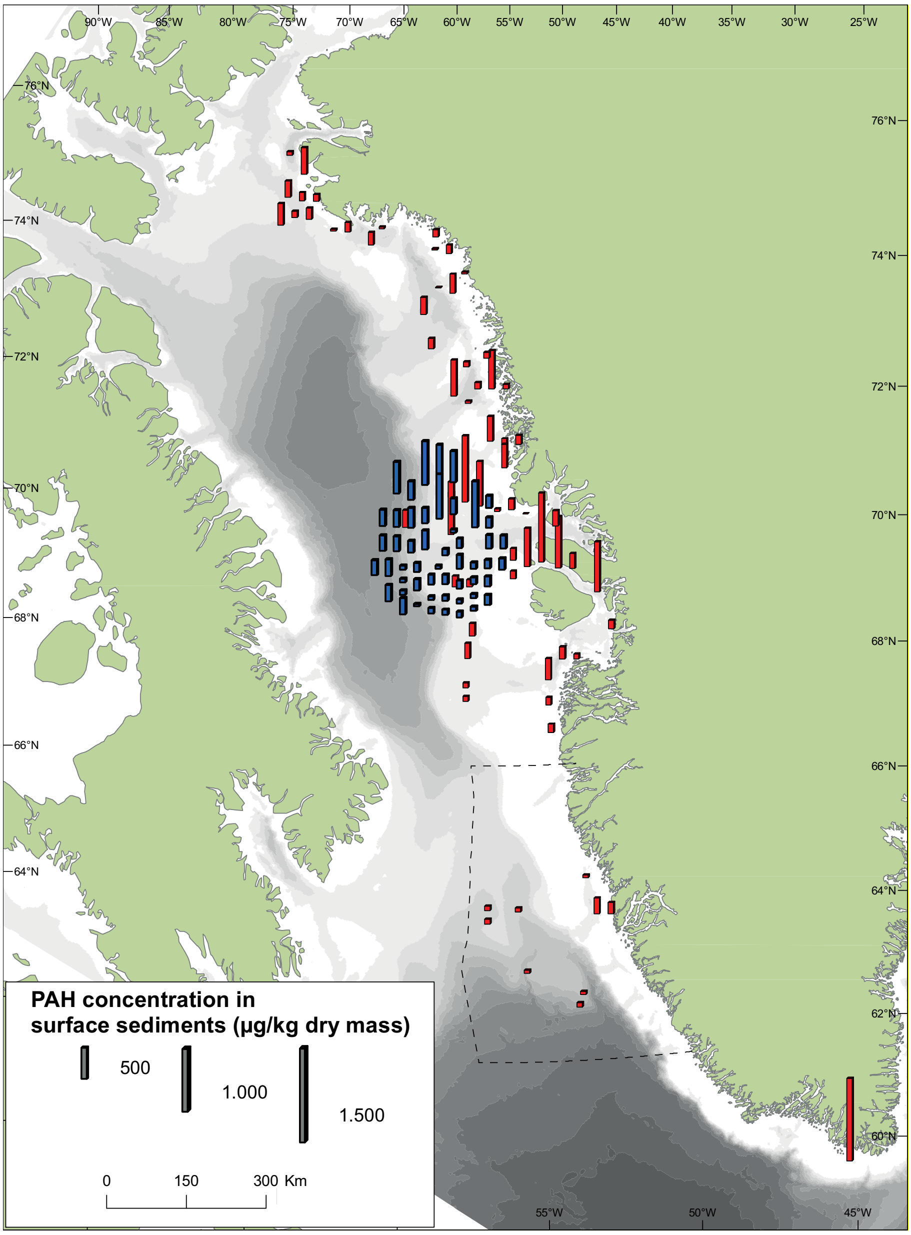



**Figure 7.1.1.** Polycyclic aromatic hydrocarbon (PAH) concentrations (µg kg-1 dry mass) in surface sediments (usually in the 0-1 cm) in western Greenland. Coloured bars indicate PAH concentrations and sampling carried out by different companies/-institutions. Red bars indicate sampling by NERI (Aarhus University, Denmark) and blue bars by Capricorn (Cairn, Edinburgh). Note: Data is based on 23 PAH values which are included in the United States Environmental Protection Agency (EPA) compounds as priority pollutants.

## 7.2 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 in relation to bio-magnification of PCBs and DDT. AMAP activities have also shown a decrease in the levels of some POPs (e.g. PCBs and DDT), resulting from 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, such as brominated flame retardants, are on the increase (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 documents that our present knowledge on contaminant levels in marine organisms from West Greenland and the assessment area is still limited. Further studies are needed to understand better whether and to what degree the biota in the assessment area are already impacted by contaminants, but also to serve as a baseline for future monitoring and assessments. In this respect it is important to learn more about the relationship between contaminant loads and potential biological impact, including sublethal health effects or impairments.

## 7.3 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 in contaminant level have been found as well as differences between species, with highest concentrations apparent in top predators (e.g. polar bear, seals). However, contaminant levels are often still lower than in biota from more temperate regions, e.g. the North Sea or Baltic Sea. The question arises of whether the levels found in the Arctic are sufficiently high to cause biological effects and what the threshold level of impact might be.

Threshold levels have been estimated for various contaminants 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 endpoint of the pollutant impact. Differences in response have been demontrated 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 very few tests have been published on polar species.

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 can differ when compared to more temperate species (AMAP 2004). The lower temperatures in Greenlandic waters are also likely to have an impact on the toxicity of contaminants.

Limited data are available to determine whether species adapted to cold are more (or less) sensitive to contaminants than temperate species and thereby whether the relationships between contaminant concentrations and impacts derived from temperate species can be applied to the sub and high Arctic environment. As part of the AMAP assessment in 2009, the most recent studies have been reviewed and summarised in regard to biological effects and how they relate to organohalogen contaminant (OHC) exposure (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 that OHCs are having a widespread effect 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 (Letcher et al. 2010). Among these 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 have also been investigated on polar bears (*Ursus maritimus*) in more detail, since this species exhibits 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 are summarised and assessed by Sonne (2010). The review shows 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.

### 7.3.1 Polyaromatic Hydrocarbons (PAH) and possible effects on biota

At present, PAH levels are relatively low in Greenland biota; although, as described in the previous section, point sources in harbour areas are found. With intensification of human activities, e.g. in relation to oil exploration, however, this may change and reliable environmental monitoring tools are required to identify any potential impact on the biota.

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 of oil droplets containing PAHs from the surrounding water.

The effects of PAHs on organisms are extensive and occur on various levels, including biochemical and physiological and/or genotoxic (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 (APs), and polycyclic aromatic hydrocarbons (PAHs). Composition varies between wells, among other reasons due to the different chemicals added during the oil production process. Possible effects on biota caused by PAHs are discussed in more details in chapters 10 and 11. In general, it can be stated that exposure to PAHs causes effects at different biological levels and that the thresholds can differ according to species.

To be able to assess better the potential risk for Arctic and sub-Arctic biota and their environment due to petroleum related contamination, e.g. oil spills, more integrated studies are necessary. Knowledge concerning the sensitivity of key species in the assessment area and their responses to oil or PAH exposure is also in need of improvement.

Studies performed in Norway on polar cod and other typical Artic-sub-Artic species have documented that application of a range of biomarkers should be considered when assessing biological effects. Moreover, assessment criteria have to be established allowing any unacceptable impact to be assessed. Such criteria are based on ecotoxicological tests covering the sensitivity range of relevant species at different trophic levels, e.g. OSPAR Environmental Assessment Criteria (EAC). Toxicological tests with relevant species from the Davis Strait are not available for establishing such criteria. Knowledge concerning species' sensitivity and assessment criteria as well as an adequate monitoring strategy need to be available before any increase in drilling activity, e.g. during oil exploration or production, commences in West Greenland.

# 8 Impacts of climate change

*Doris Schiedek, Morten Frederiksen, Michael Dünweber, (AU) & Martin Blicher (GINR)*

## 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 (SWIPA) 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, though with considerable variation from year to year. A nearly ice-free summer is now considered likely for the Arctic Ocean by the middle of the century (AMAP 2011).

Also in Greenland, 2010, for example, was marked by record high air temperatures, ice loss through 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 that in 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 it was before 2000 (Box et al. 2010).

Ongoing and future warming has an impact on 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 severe consequences for the composition of biological communities and their productivity and influencing in turn ecosystems on local and regional scales.

Changes in oceanographic conditions will affect primary production and thereby the timing, location and species composition of phytoplankton blooms. This will in turn affect zooplankton communities and the productivity of fish; e.g. a 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 atmospheric. There is also some evidence that increased $CO_2$ concentrations will reduce ocean pH and carbonate ion concentrations, and thereby 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 difficulty 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), also in the assessment area.

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, ranging from planktonic communities to large mammals.

Wassmann et al.'s (2011) evaluation is 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 8.1.1).

**Table 8.1.1.** 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 with the ice, and species now being 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 autumn 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 |

Some of the ongoing and expected changes and their relevance for the assessment area are described below.

## 8.2 Primary production and zooplankton

Currently, marine Arctic ecosystems are dominated by the diatom-feeding *Calanus glacialis* and *C. hyperboreus*; both of which are favoured food for specialised important seabirds, such as the little auk (*Alle alle*). 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 a food resource for planktivorous birds and mammals (bowhead whale and little auk). As a result, 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 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 three throughout the year, depending on food availability (Pedersen et al. 2005, and references therein). With increasing temperature the predominance of *C. finmarchicus* will further increase, as also shown experimentally by Kjellerup (2011). 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 share in biomass accounted for by *C. finmarchicus* will further increase (Hirche & Kosobokova 2007) due to its higher growth rate and short life cycle (Scott et al. 2000). A regime shift towards *C. finmarchicus* will without doubt influence important seabirds such as the little auk negatively (Karnovsky et al. 2003) and favour certain intermediate species like herring (Falk-Petersen et al. 2007).

*C. finmarchicus* also plays an important role as prey for larval stages of the Atlantic cod *Gadus morhua*. 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 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. Based on satellite data collected from 1997-2009 (Kahru et al. 2011) there is already some evidence that *Chl* maxima occur earlier in the year off Greenland, indicating changes in the development of phytoplankton blooms and thereby 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 at 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 this 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 within 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 in 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 for 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 efforts are highest. Nevertheless, they can be regarded as examples of changes occurring in many other marine Arctic ecosystems, including the assessment area.

A future Arctic warming is also likely to result in increased freshwater runoff from rivers and glaciers. Besides a freshening of surface waters in near-shore areas, this will also lead to increased turbidity and inorganic sedimentation, with potential effects on the species composition of benthic communities (e.g. Wlodarska-Kowalczuk & Pearson 2004, Wlodarska-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 represent an important prey for many seabirds and marine mammals. Changes in temperature and oceanographic conditions will influence fish populations directly causing them to shift to areas with preferred temperature, and indirectly through the food supply and the occurrence of predators. Survival of organisms and populations depends upon the degree to which they can coincide in time with 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 ocean 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 (*Gadus morhua*), and this may favour piscivorous birds and mammals. Greenland halibut (*Reinhardtius hippoglossoides*) 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 in relation to the abundance of Atlantic cod (*Gadus morhua*) and Greenland halibut, *Reinhardtius hippoglossoides* (Horsted 2000, Drinkwater 2006, Stein

2007). Ecosystem changes associated with the warm period during the 1920s and 1930s included the expansion northwards ofboreal species, such as cod, haddock and herring, while colder 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 reduced 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 (*Pandalus borealis*) and Greenland halibut (*R. hippoglossoides*). Meanwhile, the shrimp fishery replaced cod as a dominant industry in West Greenland (Hamilton et al. 2003).

A similar response by cod as that observed during the previous warm period could be expected in 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 reduced compared with those observed during the early 20th century warming (Drinkwater 2009). It is not yet possible to indicate how far north Atlantic cod would be distributed if temperatures increase further.

For shrimp (*Pandalus borealis*), duration of egg development and hatching are determined by local bottom temperature and are correlated to the spring phytoplankton bloom (Koeller et al. 2009). Shrimp appears 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 northern shrimp.

Current knowledge on the distribution and abundance of capelin (*Mallotus villosus*) 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 in the southernmost part of Greenland could disappear from this area (Huse & Ellingsen 2008).

Changes in physical conditions in high latitude ecosystems will probably also affect fisheries. Positive effects of warming have already been documented for the distributions 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 years, 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% for the most important cod and herring stocks in Iceland, and approximately 200% 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 native species and how this affects food web interactions, including those 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, and not so straightforward 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 various 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 dependent on sea ice (e.g. hooded seal, polar bear and 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. Due 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, the 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.). 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 reorganisation of the food web by altering the nutrient or light cycle, or top-down reorganisation by altering critical habitat for higher trophic level (Macdonald et al. 2005). Alterations in the density, distribution and/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 (UNEP) 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 – to include climate, chemicals and biodiversity – is needed to fully understand marine ecosystems in Greenland, including the assessment area as well as how human activities affect them.

# 9 Impact assessment

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## 9.1 Methodology and scope

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. 1996a, 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 12, supplementary studies may be carried out subsequent to this preliminary SEIA. Results from these studies will form part of the impact assessment in an updated version of this preliminary SEIA.

### 9.1.1 Boundaries

The assessment area covers the area described in the introduction (Fig. 1.1.1). It is the region which potentially can be impacted by oil exploration related activities and particularly by a large and long-lasting oil spill deriving from activities in the expected licence areas. However, it cannot be ruled out that the area affected might be even larger, including coasts both north and south of the assessment area and also areas on the Canadian side of Davis Strait.

The assessment includes, as far as possible, all activities associated with an oil field, from exploration to decommissioning. Exploration activities are expected to take place during summer and autumn due to the possibility of ice cover in winter and early spring, especially in the western part of the assessment area.

Production activities will, if decided upon and initiated, 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, *cf.* section 2.6.

### 9.1.2 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 area, both in time and space. Interactions are then evaluated for their potential to cause impacts.

Since it is often not possible to evaluate all ecological components in the area, the concept of Valued Ecosystem Components (VEC) can be applied. VECs can be species, populations, biological events or other environmental features that are important to the human population (not only economically), have a national or international profile, can act as indicators of environmental change, or can be the focus of management or other administrative efforts. VECs can also be important flora and fauna groups, habitats (also temporary and dynamic like the marginal ice zone and polynyas) and processes such as the spring bloom in primary production.

The potential impact on VECs of activities during the various phases of the life cycle of a hydrocarbon licence area are summarised in a series of tables in chapters 10 and 11. 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 therefore 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. Dashes (-) are used when it is not relevant to discuss the described effect (if no members of a VEC are vulnerable to a given activity).

The scale of potential impact is assessed as local, regional or global. Impacts may be on a higher scale than local 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.

It should be emphasised that quantification of the impacts on ecosystem components is difficult and in many cases impossible. The spatial overlap of the expected activities can only be assessed to a limited degree, as only the initial oil activities are known at this point. Furthermore, the physical properties of potentially spilled oil are similary not known. Moreover, there is still a lack of knowledge concerning important ecosystem components and how they interact. In addition, ecosystem function will potentially 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 sources – the Arctic Council Oil and Gas Assessment (Skjoldal et al. 2007), the extensive literature from the Exxon Valdez oil spill in Alaska in 1989, as well as the Norwegian EIA of hydrocarbon activities in the Lofoten-Barents Sea (Anon 2003b) have been drawn upon.

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’.

# 10 Impacts of the potential routine activities

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## 10.1 Exploration activities

In general all activities relating 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 more or 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.

### 10.1.1 Assessment of noise

**Noise from seismic surveys**

The main environmental impacts from the 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). But there are some potential detrimental consequences. Short-term behavioural changes (such as avoiding 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 that should be considered. It cannot be assumed that there is a simple relationship between sound pressure levels and distance to source due to ray bending 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 southern latitudes to the Arctic (Urick 1983). For example, 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 re µPa, pp) 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 the airguns (comprising a few metres) (Nakken 1922).

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 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). So it appears that the fish avoidance behaviour demonstrated in the open sea protects the fish from damage. In contrast to these results, marine fish and invertebrates monitored with a video camera in an inshore reef did not move away from airgun sounds with peak pressure levels as high as 218 dB (at 5.3 m relative 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 TV and tagged individuals did not reveal any sign of disorientation, and the 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 sand eels were buried in the sediment (Hassel et al. 2004).

The studies quoted 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 (Anon 2003a). 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 (Anon 2003a). 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. Recent studies suggest that eggs and larvae drift slowly though the assessment area at depths of 13-40 m (Simonsen et al. 2006). There is limited data on fish egg and larvae densities as well as zooplankton, but it can be assumed that the density in the upper 10 m will not be significantly higher than that which has been found to date in 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 (*Gadus morhua*) and haddock (*Melanogramma aeglefinus*) at 250–280 m in 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 catches would return to normal after the studies. The effect was, moreover, more pronounced for large fish compared with smaller fish.

The commercial fisheries which will overlap in space with seismic surveys in the assessment area are the offshore trawling for Greenland halibut and northern shrimp and snow crab catches.

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 results of Engås *et al.* (1996) described above cannot be applied to other fish species and to fisheries at other water depths. Greenland halibut is very different from Atlantic cod and haddock with respect to anatomy, taxonomy and ecology. For example Greenland halibut has no swim bladder, which means that its hearing ability is reduced compared with 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. The only study including Greenland halibut is a Norwegian study dealing with gillnet and longline fisheries (Løkkeborg et al. 2010). However, this study showed contradictory results, where gillnet catches increased during seismic shooting and remained higher in the period after shooting, while longline catches of Greenland halibut, on the other hand, decreased during seismic shooting.

Based on these contradictory 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. The offshore fishery of Greenland halibut in the assessment area is large in relation to the total catch in Greenland and the trawling grounds are restricted to specific depths at approximately 1,500 m. Alternative fishing grounds would therefore be limited if Greenland halibut are displaced by seismic activity. Another potential impact is the risk of scaring spawning fish away from the spawning grounds. These are assumed to be situated on the slope of the sill between Greenland and Baffin Island, but as spawning is assumed to take place in early winter the seismic activity would probably be absent or very low. In Norway, some spawning grounds for herring and cod are closed for seismic surveys in the spawning period.

It should be mentioned that there are other examples where fisheries have increased after seismic shooting, which is 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. 5.1.1 and 5.1.2) 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, seismic surveys carried out near the coast may disturb (due to the presence and activity of the ship) breeding and moulting congregations.

Next to nothing is known about underwater hearing in diving sea birds and no-one has attempted to assess the possible impact of exposure to airgun sounds during diving. Their hearing ability underwater is likely to be inferior to marine mammals and in any case 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 in the case of 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 therefore 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 effects 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 damage. Under experimental conditions temporary elevations in hearing threshold (TTS) have been observed (Richardson et al. 1995, Anon 2005). In the USA a sound pressure level of 180 dB re 1µPA) (rms) or higher is believed to provoke TTS or PTS 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 generally 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 of 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 been observed as close as 100 m to operating airgun arrays (AU unpublished), which is potentially close enough to sustain physical damage.

The ecological significance of displacement effects is generally unknown. If alternative areas are available the impact probably will be low and the temporary character of seismic surveys 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 covers the northern part of the assessment area. Displacement from major feeding areas can therefore 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. In this case marine mammals could be excluded from key habitats and unable to use alternative foraging grounds.

The US National Marine Fisheries Service defines the radii about a seismic ship with received sound levels of 160 dB (re 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 kilometres away. 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 (re 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 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 setup is 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. 4.8.6), so 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 as a result of 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 most affected by auditory masking from seismic surveys (Gordon et al. 2003). It has furthermore 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). Similarly, 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 foraging 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 belong to the baleen whales – minke, fin, blue and humpback whale – and the toothed whales – sperm whale and bottlenose whale (probably) – all of 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 whales, pilot whales, white beaked dolphins or harbour porpoises. White whales, narwhals and bowhead whales are also sensitive to seismic sounds, but are present in the area during wintertime only. Bowhead whales, for example, migrate through part of the assessment area in December-January (Heide-Jørgensen & Laidre 2010). The risk of overlap between these species and seismic operations is therefore confined to winter.

In general, seals display considerable tolerance to underwater noise (Richardson et al. 1995), confirmed by a study in Arctic Canada in which 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). However, walruses, especially when hauled out, may be disturbed and displaced by seismic activity but not so much by the seismic noise. There is an important winter feeding and mating ground for walrus where they haul out on ice directly north of the assessment area.

#### Mitigation of impacts from seismic noise

Mitigation measures 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 allows marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals.

Secondly, it is recommended that skilled marine mammal observers are present onboard the seismic ships in order to detect whales and instruct the crew to delay shooting when whales are within a certain distance (usually 500 m) of the array. In sensitive areas detection of whales in the vicinity can be made more efficient, depending on species, with the additional use of hydrophones for recording whale vocalisations (Passive Acoustic Monitoring – PAM); although the whales present would not necessarily emit 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.

NERI (now DCE) has issued a set of guidelines for conducting seismic surveys in Greenland waters, and protection areas (where seismic surveys are regulated) for narwhal and walrus are designated in areas outside the present assessment area (Boertmann et al. 2010). A similar protection area for the bowhead whale should be considered in the Disko Bay waters in spring.

Finally, it is recommended that local authorities and hunters' organisations be informed before seismic activities take place in their local area. This may help hunters to 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 (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 NERI guidelines for seismic surveys (Boertmann et al. 2010) some important issues to consider in assessing the impacts of seismic surveys 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 greater 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, such as hydrographic and bathygraphic conditions, may result in highly unusual sound transmission properties. Potential consequences of these effects should be included in the assessment.

When planning surveys efforts should be made to minimise the overall exposure to the degree possible by using the smallest airgun array that enables collection of the data needed. Total exposure is a complex function of the number of animals exposed, the time each animal is exposed and the sound level each animal experiences. Nevertheless, reducing any of these three parameters would reduce the total exposure, so the possibility of reducing one or more factors should be considered in the planning phase.

#### Conclusions on disturbance from seismic noise (Table 10.1.1)

The VECs 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 in risk of being displaced from critical summer habitats. A displacement will also impact the availability (for hunters) of whales if the habitats include traditionally hunting grounds. Narwhals, beluga whales, bowhead whales and walruses are also sensitive to seismic noise, but their occurrence will only overlap with seismic surveys during winter.

As seismic surveys are temporary, the risk of long-term impacts is low. But 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). There is a small risk of long-term effects for toothed whales suffering permanent auditory damage caused by critical exposure to seismic noise.

**Table 10.1.1.** Overview of potential impacts from a single seismic 2D survey on VECs in the Davis Strait assessment area. See section 4.9 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. 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 | copepods, fish larvae | - | insignificant (L) | insignificant (L) |
| Tidal/subtidal zone | none | - | - | - |
| Demersal fish & offshore benthos | Gl. halibut | short term (L) | insignificant | none |
| Seabirds (breeding) | none | - | - | - |
| Seabirds (non-breeding) | none | - | - | - |
| Marine mammals (summer) | baleen & toothed whales | short term (L) | insignificant (R) | none** |
| Marine mammals (winter) | bowhead, beluga, narwhal | short term (L) | insignificant (R) | none** |

* L = local, R = regional and G = global; ** For toothed whales permanent auditory damages can theoretically be lethal, but death would occur long after the event of sound exposure. Here, this risk is defined as a sublethal effect.

The fishery at risk of impacts from seismic surveys in the assessment area is the Greenland halibut fishery. There is a risk of a temporary displacement of fish and consequently reduced catches from the trawling grounds. Although the precise location of the Greenland halibut spawning grounds is not known, the planning of seismic surveys in the suspected area should consider avoiding overlap in the spawning period. The fishery of northern shrimp and snow crab will probably not be affected.

### Noise from drilling rigs

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

Generally a drill 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 risk from drift ice and icebergs.

Whales are believed to be the organisms most sensitive to this kind of underwater noise (Table 10.1.2), 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. But also seals (especially bearded seal) and walrus communicate when underwater. However, systematic studies on whales and noise from drill 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 beluga 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 drill 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).

**Table 10.1.2.** Overview of potential impacts of noise[1] and discharge[2] from a single exploration drilling on VECs in the Davis Strait assessment area. See section 4.9 for a summary of the VECs. This assessment assumes the application of current (2011) mitigation guidelines, see text for details (no use of oil based mud).

| VEC | Typical vulnerable organisms | Population impact* - worst case | | |
|---|---|---|---|---|
| | | Displacement | Sublethal effect | Direct mortality |
| Pelagic hotspots[2] | plankton, zooplankton | - | insignificant (L) | insignificant (L) |
| Tidal/subtidal zone | none | - | - | - |
| Demersal fish & | Gl. halibut, sandeel | short term(L) | minor (L) | none |
| offshore benthos[2] | filter feeders (e.g. corals) | short term(L) | minor (L) | minor (L) |
| Seabirds (breeding) | none | - | - | - |
| Seabirds (non-breeding) [2] | king eider | short term (L) | insignificant (R) | none |
| Marine mammals (summer)[1] | baleen & toothed whales | short term (L) | minor (L) | none |
| Marine mammals (winter) [1] | bowheads, bearded seal, walrus, narwhal | short term (L) | minor (L) | none |

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

As described in section 4.8 bowhead whales occur in the assessment area in winter and during spring migration. Their migration corridor seems to be wide enough to provide alternative routes (Fig. 4.8.7), and displacement of single animals similar to that described from the Beaufort Sea probably has no significant effect here, provided that drilling operations are not simultaneous in multiple sites.

Also narwhals, beluga whales and walruses will only overlap with the season for exploration drilling for a brief period in winter, and no large effects are expected.

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 to date on critical habitats for these species.

#### Conclusion on noise from exploration drilling rigs

Exploration activities are temporary and displacement of marine mammals caused by noise from drilling rigs will also be temporary. The most vulnerable VECs in the assessment area are the baleen whales such as fin, minke and humpback whales and toothed whales such as sperm whale and harbour porpoise. The walruses occurring at the northern edge of the assessment area are also highly vulnerable. If alternative habitats are available to the whales no long-term effects are expected (Table 10.1.2), but if several rigs operate in the same region there is a risk for cumulative effects and displacement from key habitats.

### 10.1.2 Drilling mud and cuttings

Drilling creates substantial quantities of drilling waste composed of rock cuttings and the remnants of drilling mud (see section 2.3). Cuttings and mud are usually deposited on the sea floor beneath the drill 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 (SM – synthetic mud; ethers, esters, olefins, etc). Previously oil was used (OBM – oil based mud), but this has almost been eliminated on the grounds of 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 therefore have short-lived and moderate effects on the fauna.

Most of the impact studies on mud and drill cuttings 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 discharge ceased (Breuer et al. 2008) and sublethal effects in some species of fish living near drill sites were also detected (Davies et al. 1984). A further risk from discarding cuttings polluted with oil residues is tainting of commercial fish (see Section 11.2.6).

Synthetic mud also leads to impacts on benthic fauna, though less pronounced than around platforms where OBMs were used (Jensen et al. 1999).

Field studies on 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 (Table 10.1.2). The use of WBM potentially moves effects on the seafloor to the water column, where dilution is a major factor in reducing impacts. In Norway a change to WBM has resulted in a marked decrease of 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 (Table 10.1.2) (Freiwald et al. 2004, SFT 2008). Corals have been found in the western part of the Davis Strait (Edinger et al. 2007) and in Greenland waters they are frequently encountered along the continental slope of Southwest Greenland, including the assessment area (ICES 2010a). Recently, a ban against trawling in two areas south of Maniitsoq (64°N) was suggested due to 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 this sensitive biota in Greenlandic waters.

Multiple drillings carried out when a field is developed may cause more widespread effects on the benthos and it is important to note in this regard 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 on the hydrodynamics to evaluate the spreading, dilution and sedimentation of the substances. Biological effects from the particles in the 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 these to land or re-inject the material into wellbores. This, however, creates other environmental impacts such as increased emission of greenhouse gasses from the transport and pumping and problems with treatment or re-use on land (SFT 2008). These have then to be balanced against the impacts on the water column and on the seafloor. A recent report (SFT 2008) has recommended that general zero-discharge requirements relating to water-based drill cuttings and mud are not introduced in Norway.

It is generally assessed that impacts from water-based muds are limited, which is why they are usually released to the marine environment when the drilling is over. However, as part of the post-drill environmental monitoring that licence holders off the coast of Greenland are required 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 yet been evaluated under Arctic conditions with regard to degradation and toxicity, and all chemicals to be discharged should 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% in the period 1997-2007, through application of the international standards, BAT and BEP (SFT 2008). In Greenland the use of 'black' chemicals is not allowed and specific permission is required for the use of 'red' chemicals.

Impacts from oil-contaminated drill cuttings should be mitigated by keeping them on board for deposition or cleaning on land.

#### Conclusion on discharges from exploration drilling

Within the assessment area only very local effects on the benthos are to be expected from discharging the water-based muds (WBM) during exploration drilling (Table 10.1.2). For this reason, the potential impact on benthic feeders, such as king eider, walrus and bearded seal, will probably not be significant. 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.

## 10.2 Appraisal activities

Activities during the appraisal phase are similar to 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.

## 10.3 Development and production activities

In contrast to the temporary activities of the exploration phase, 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.

### 10.3.1 Produced water

During production several by-products and waste products are produced that have to be disposed of in one way or another. Produced water is by far the largest contributor in his respect from an oil field (see section 2.4).

Generally it is assessed that the environmental impacts from produced water discharged to the sea are small due to dilution. For example, discharges during the 5% 'off normal time' in Lofoten-Barents Sea 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). Particular concern surrounds polycyclic aromatic hydrocarbons (PAHs), the hormone-disrupting phenols, radioactive components and nutrients in relation to toxic concentrations, bioaccumulation, fertilisation, etc (Rye et al. 2003).

Impacts on the marine environment from produced water can be reduced by injecting it into wellbores. This is not always possible (STF 2008) and when it is international standards (OSPAR) must be applied as a minimum. This means that the oil content may 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 2011a).

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 a fertiliser, which could impact especially the composition of primary producers (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 together with other low concentration oil discharges, such impacts may be significant (Fraser et al. 2006).

To test potential effects of produced water on organisms, cages with Atlantic cod and blue mussels, respectively, were positioned at various distances (0-5000 m) in different directions from oil platforms in Norway. In addition, two reference locations were used, both 8000 m away from the respective platforms. PAH tissue residues in blue mussels ranged between 0-40ng/g ww depending on the distance to the oil rigs. 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 belong to those substances that cause endocrine disruptive effects in fish (Lie et al. 2009). In another study the genotoxic potential of water-soluble oil components on Atlantic cod has 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).

### 10.3.2 Other discharged substances

Besides produced water, discharges of oil components and various chemicals occur in connection with deck drainage, cooling water, ballast water, bilge water, cement slurry and testing of blowout preventers. Such releases are regulated by the OSPAR convention, and these standards should be applied as a minimum in order to minimise impacts. Sanitary wastewater 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 periods of time may be of concern. BAT (Best Available Technology), BEP (Best Environmental Practice), applying international standards (OSPAR and MARPOL) and introduction of less environmentally damaging chemicals or reduction in volume of the releases all represent ways in which the effects can be reduced. It should be mentioned that release of environmentally hazardous substances from the oil industry to the marine environment in Norwegian areas has been reduced by 99% over 20 years by applying these measures (SFT 2008).

Ballast water from ships poses a special biological problem, i.e. the risk that non-native and invasive species (also termed as Aquatic Nuisance Species – ANS) are introduced to the local ecosystem (Anon 2003a). This is generally considered 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* 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 future.

There are methods to minimise the risk from releasing ballast water, e.g. in 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.

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

### 10.3.3 Placement of structures

Construction of subsea wells and pipelines has the potential to destroy parts of important habitats on the seafloor. In other regions especially sponge gardens and reefs of cold water corals are considered as sensitive. Other important habitats are feeding grounds for bearded seal, walrus and king eider, which live on benthic mussels and other invertebrates. 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 at night (Wiese et al. 2001). In Greenland this problem especially relates to eider ducks. Under certain weather conditions (e.g. fog and snowy weather) on winter nights, eiders are attracted to the 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 antennae 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 song birds cross on their nocturnal autumn and spring migrations. Large numbers of song birds under certain weather conditions are attracted to light from illumination and flaring (Bourne 1979, Jones 1980). No such migrations take place in the assessment area. However, concern for nocturnalmigrating little auks has recently been expressed (Fraser et al. 2006), and this species occurs in very large densities within the assessment area. A method to mitigate the attraction of birds is changing the colour of the lighting to colours that do not attract birds, e.g. green (Poot et al. 2008).

Placement of structures affects the fisheries due to exclusion (safety) zones. These areas, however, would be small compared with the total fishable area. A drilling platform with 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 to be low, except in areas where very localised and intensive fishery activity takes 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 that allows trawling across them; although a temporary exclusion zone must be expected during the construction phase of pipelines. 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 2003b).

Another effect of 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 the fish may be exposed to the contaminants from release of produced water.

Placement of structures onshore in coastal habitats may impact rivers with spawning and wintering Arctic char by creating obstructions they cannot cross, resulting in the loss of a local population.

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. Greenlandic tourism's main asset – its unspoilt nature – is readily made much less attractive by buildings, infrastructure and other facilities.

### 10.3.4 Noise/Disturbance

Noise from drilling and the positioning of machinery is described under the exploration heading (section 2.2). These activities continue during the development and production phase, supplemented by noise from many other activities. If several production fields are active in the waters west of, for example, Nuuk town, the 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 has been shown to result 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 transshipment facilities on a regular basis, even in winter. The loudest noise levels from shipping activity come from large icebreakers, particularly when they operate in ramming mode. 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 fin whales, minke whales, white whales, narwhals and walruses which are hunted from motor boats will be expected to be particularly sensitive (whaling for bowhead whales and humpback whales has recently re-started). Also seabird concentrations may 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. Particularly walruses hauled out on ice are sensitive to this activity, and there is risk of displacement of the walruses from critical feeding grounds. Walruses have a narrow foraging niche restricted to the shallow parts of the shelf. Activities in these areas may displace the walruses to suboptimal feeding grounds or to coastal areas where they are more exposed to hunting. The main habitats for walruses overlap with the northern part of the assessment area.

Seabird concentrations are also sensitive to helicopter flyovers. The most sensitive species is thick-billed murre at breeding sites. They will often abandon their nests for long periods of time, and when scared away from their breeding ledges they often push eggs or small chicks 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. 4.7.1), and only one is situated on the outer coasts over which helicopters may pass en route to offshore installations. Concentrations of feeding birds may also be sensitive, as they may lose feeding time due to the disturbance.

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

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

The effects of disturbance of moulting seaducks 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).

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 in Gordon et al. 2003), in Gordon et al. (2003), 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 noise. Such impacts are, however, local and will mainly be a threat on an individual level.

### 10.3.5 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 Statfjord in Norway (Section 2.8), for example, is twice the total current Greenland $CO_2$ emission, which in 2008 was 685,500 tonnes (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 it successor. Another very active greenhouse gas is methane ($CH_4$), which is released in small amounts together with other VOCs from produced oil during trans-shipment or from vented gas.

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

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

Emission of black carbon (BC) from combustion is another matter especially of concern in the Arctic, because the black particles reduce albedo from snow and ice surfaces increasing the melt. Emission of BC is particularly problematic when using heavy fuel oil. Use of this, however, is not permitted in Greenland waters in relation to oil activities, and only low-sulphur (< 1.5% by weight) gas oils may be used.

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

### 10.3.6 Cumulative impacts

Cumulative impacts are changes to the environment that are caused by an action in combination with other past, present and future human actions. 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 over time can develop to be significant. Cumulative impacts also include interactions with other human activities impacting the environment, such as hunting and fishing; moreover, climate change is also often considered in this context (Anon 2003a).

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 their fitness due to decreased storage of the lipids needed for the winter migration and breeding activities.

The concentration of oil discharged within produced water is low. But the amounts of produced water from a single production 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 population and subsequently be transferred to the higher levels of the food web, i.e. seabird 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. 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. Tighter hunting regulations were introduced in 2001, which has resulted in fewer birds being reported shot. 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 sublethal 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 are particularly vulnerable during the swimming migration, which is performed by flightless adults (due to moult) and chicks still not able to fly. This migration was studied in the Disko Bay in 2005 and 2006, and similar studies have been initiated in Qaanaaq in 2007.

### 10.3.7 Mitigating impacts from development and production

Based on 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 are classified by OSPAR 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 reinjections (CRI). 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, releases to the marine environment asca minimum should follow the standards described by OSPAR, applying sound environmental management based on the Precautionary Principle, Best Available Techniques (BAT) and Best Environmental Practice (BEP).

Based on knowledge concerning site-specific biological, oceanographic and sea-ice conditions, discharges should occur at or near the seafloor or at a suitable depth in the water column, to prevent large sediment plumes. 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 of 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 2003b): This, however, gives rise 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.

### 10.3.8 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 in order 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 with regard to the long-term effects of radionuclides and hormone-disruptive chemicals. These effects should be mitigated by regulation, monitoring of the sites and new technologies 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 Ballast Water convention, will secure that the 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, bowhead whales, narwhals and white whales. There is a risk of permanent displacement of populations from critical habitats and therefore for negative population effects.

Placement of structures both has biological and aesthetic impacts. Biological impacts mainly include permanent displacement from critical habitats – walrus is highly sensitive and occurs at the northern part of the assessment area. Destruction of unique seabed communities, such as sponge gardens and cold water coral reefs, is also a risk. Aesthetic impacts primarily include impacts on the pristine landscape, which may impact on the local tourism industry.

The commercial fishery may be affected by closure zones if rigs, pipelines and other installations are placed in the Greenland halibut fishing grounds. 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 the 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 impacts. Furthermore, monitoring of effects on the sites is essential.

## 10.4 Decommissioning

Impacts from decommissioning activities are mainly from noise at the sites and from traffic, assuming that all materials 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, decommissioning 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.

# 11 Impacts from accidental oils spills

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## 11.1 Oil spills

A serious issue of environmental concern from hydrocarbon activities in the marine Arctic environment is a large oil spill (Skjoldal et al. 2007). The probability of such an event is low and in general the global trend in amounts of spilled oil is decreasing (Schmidt-Etkin 2011). But 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 Arctic and sub-Arctic conditions reduce the degradation of oil, prolonging potential effects. The occurrence of ice, at least in winter, may influence the distribution and fate of oil (see below), and will also make oil spill response difficult in periods with extensive ice coverage or otherwise harsh weather conditions.

According to the AMAP oil and gas assessment 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 tanker spills are continuous and may last for many days; for example, the Deepwater Horizon blowout lasted 106 days before it was stopped by relief drilling.

### 11.1.1 Probability of oil spills

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

Drilling in deep waters (between 1000 and 5000 feet ~ 305-1524 m) and ultra-deep waters (> 5000 feet ~ 1524 m) increases the risk for a long-lasting oil spill, due to the high pressures encountered in the well and due to difficulties in operating at these depths. It took three months to cap the Macondo well (Deepwater Horizon spill), partly because of the deep water (1500 m) (Graham et al. 2011).

### 11.1.2 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 are highly variable. Fate and behaviour depend on the physical and chemical properties of the oil (light oil or heavy oil), how it is released (surface or subsea, instantaneous or continuous) and on the conditions of the sea into which it is spilled (temperature, ice, wind and current).

General knowledge on the potential fate and degradation of spilled oil relevant for the Greenland marine environments has been reviewed by Pritchard & Karlson (in Mosbech 2002). Ross (1992) evaluated the behaviour of potential offshore oil spills in West Greenland with special regard to the potential for cleanup. 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 the Statoil drilling in the Fylla area in 2000. More recently DMI simulated oil spill drift and fate in the Disko West area (Nielsen et al. 2006), in eastern Baffin Bay (Nielsen et al. 2008), in South Greenland (Ribergaard et al. 2010) and presently they are working on simulation of subsurface spills in the deep waters off South Greenland. Updated oil spill drift scenarios for the eastern Davis Strait have not yet been developed.

### Surface spills

Oil released to open water surfaces spreads rapidly resulting in a thin slick (often about 0.1 mm in the first day) that covers 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 have generally addressed surface spills and the subsequent drift. However oil may also sink to the seabed, depending on the density of the oil spilled. Even light oil may sink if it adsorbs onto sediment particles in the water (Hjermann et al. 2007). Sediment particles are frequently seen in coastal Greenland surface waters where meltwater from the 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 collapse. 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 why DMI have modelled subsurface spills in West Greenland which quickly float to the surface (Nielsen et al. 2006), while SINTEF modelled subsurface spills which would not reach the surface at all but rather form a subsea plume at a depth of 300-500 m (Johansen 1999). High total hydrocarbon concentrations (> 100 ppb by weight) were estimated in an area close to the outflow.

The Deepwater Horizon oil spill in the Mexican Gulf in 2010 was unusual in size, location and duration (though similar to the Ixtoc blowout in 1979, also in the Mexican Gulf), and revealed new and undescribed ways spilled oil could be distributed in the environment (which probably was also the case during the Ixtoc spill) (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site being on the seabed in waters more than 1500 m deep. Dispersants were applied at the wellhead and huge subsea plumes of dispersed oil were formed in different depths and they moved long distances with the water currents (Diercks et al. 2010, Thibodeaux et al. 2011). Oil also settled on the ocean floor far from the spill site (Schrope 2011). The Deepwater Horizon oil spill has been estimated at 840,000 oil tonnes, making it the largest recorded peacetime spill. The oil dispersed at the wellhead and had a very slow buoyant migration towards the surface, which allowed volatile hydrocarbon to be dissolved in the water column. Adding of dispersants at the wellhead contributed to the formation of huge plumes of dispersed oil at different depths ranging between 800 and 1,200 m (Hazen 2010, Valentine 2010). It is estimated that 50% of the oil 'remains' dispersed, has sunk to the seabed or has degraded in the water column (Kerr 2010).

Studies of deepwater blowout events have predicted that a substantial fraction of the released oil and gas would become suspended in pelagic plumes, and that 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 the deep sea (Joye & MacDonald 2010). In the Gulf of Mexico, natural oil seeps contribute to the marine environment with an estimated 140,000 tonnes of oil annually (Kvenvolden & Cooper 2003), which means there should be intrinsic potential for microbial degradation (i.e. presence of the responsible organisms) (Hazen 2010). This was confirmed by 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 the deep water may persist for long periods of time, because deep water oxygen is not replenished *in situ* by photosynthesis as it is in surface waters (Joye & MacDonald 2010).

There are indications of unexpected and severe deep-sea impacts (Schrope 2011). However, at the time of writing the environmental impacts are not really understood or described (Graham et al. 2011), (Schrope 2011) and therefore it has not been possible to include clear conclusions in this SEIA. But a natural resource damage assessment is under preparation (Graham et al. 2011) and the consequences of the Deepwater Horizon subsea blowout will be discussed in more detail in a later version of this assessment.

### 11.1.3 Dissolution of oil and toxicity

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 toxic components can increase the potential for acute toxicity to marine organisms. The rate and extent to which oil components dissolve in seawater depends mainly on the amount of water-soluble fractions (WSF) in the oil. The degree of natural dispersion is also important for the rate of dissolution; although surface spreading and water temperature may also have some influence.

PAHs are among the toxic components of crude oil. The highest PAH concentration found in the water column in Prince William Sound within a sixweek period after the Exxon Valdez spill was 1.59 ppb, at a depth of 5 m. 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 (0.9 ppm or 900 ppb) and applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 ppb oil for 96-hour exposure. This is based on fresh oil which leaks a dissolvable fraction, most toxic for eggs and larvae. Weathered oil will be less toxic.

The concentrations of oil in the waters at the Deepwater Horizon blowout in the Mexican Gulf in 2010 published to date were > 50 µg/l (50 ppb) BTEX (benzene, toluene, ethylbenzene and xylene, constituting only a fraction of the oil) measured in a subsea plume of oil 16 km from the well site (Camilli et al. 2010) and total PAH concentrations up to 189 µg/l near the well site (Diercks et al. 2010). The latter study found PAH concentrations associated with acute toxicity in discrete depth layers between 1000 and 1400 m extending at least as far as 13 km from the wellhead.

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, Norway (Faksness & Brandvik 2005). The results show that the concentration of water-soluble components in the ice decreases with ice depth, but that the components could be quantified even in the bottom ice core. A concentration gradient as a function of time was also observed, indicating migration of water-soluble components through the porous ice and out into the water through the brine channels. The concentration of water-soluble components in the bottom 20 cm ice core was reduced from 30 ppb to 6 ppb in the experimental period. Although the concentrations were low, exposure time was long (nearly four months). This might indicate that the ice fauna are exposed to a substantial dose of toxic water-soluble components and at least in laboratory experiments with sea-ice amphipods sublethal effects have been demonstrated (Camus & S. 2007, Olsen et al. 2008). Leakage of water-soluble components to the ice is of special interest due to the high bioavailability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

## 11.2 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 11.2.1 gives an overview of potential impacts from a large oil spill.

**Table 11.2.1.** Overview of potential impacts of a large oil spill on VECs in the Davis Strait assessment area. See section 4.9 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 | halibut larvae | - | moderate (L) | moderate (R) |
| Tidal/subtidal zone | capelin, bivalves | long term (L) | major (L) | major (L) |
| Demersal fish & offshore benthos | sandeel, Gl. halibut, shrimp, shelf bank benthos | short term (L) | moderate (L) | moderate (L) |
| Seabirds (breeding) | auks, c. eiders | short term (L) | major (R) | major (R) |
| Seabirds (non-breeding) | auks, eiders, harlequins | short term (L) | major (R) | major (R) |
| Marine mammals (summer) | baleen- & toothed whales | short term (L) | moderate (R) | minor (R) |
| Marine mammals (winter) | bowheads, hooded seals, walruses, narwhals | short term (L) | moderate (R) | moderate (R) |

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

### 11.2.1 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). Shrimp habitats can therefore 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/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 layer 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 have 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 just be 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 in the region of 5%, and in some cases up to 15%, for a blowout lasting less than two 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 it would take approx. eight years for the population to recover fully.

Hjermann et al. (2007) reviewed the impact assessment of the Barents Sea stock of Atlantic cod, herring and capelin by Johansen et al. (2003) and suggested improvements by emphasising the need for more focus on oceanographic and ecological variation in the modelling. It was also emphasised that it is not possible to draw conclusions about on long-term effects due to the variability in the ecosystem. At best, we can attempt, by modelling, to attain a quantitative indication of the possible outcomes of oil spills in the 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 with the Lofoten Barents Sea area, there is much less knowledge available on concentrations of eggs and larvae in West Greenland, including the assessment area. However, the highly localised spawning areas of cod with high concentrations of eggs and larvae for a whole stock near the surface seen in the Lofoten-Barents Sea do not currently occur in West Greenland. However, there have been spawning grounds of cod in West Greenland during the past century and recolonisation 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 quantities of offspring 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 would 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 would therefore most likely be insignificant. However, a subsea blowout with the properties and quantities of the Deepwater Horizon spill in 2010, when huge plumes of dispersed oil occurred in the water column, may expose eggs and larvae over much larger areas and depth ranges, and potentially impact the recruitment and stock size of these bottom-living species.

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 in new background study programmes prior to an updated version of this report. With respect to Greenland halibut, snow crab and shrimp, 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. For Greenland halibut the assessment area is known as the main spawning ground in the Northwest Atlantic, and fish from important fishing grounds in the Davis Strait, Baffin Bay, eastern Canada and inshore waters in Northwest Greenland are recruited from this area. Recent studies suggest that eggs and larvae drift slowly though the assessment area at 13-40 m depths (Simonsen et al. 2006).

#### 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 2003a). Recent studies showed negative effects of pyrene (PAH) on reproduction and food uptake among *Calanus* species (Jensen et al. 2008b), and on survival of females, feeding status and nucleic acid content in *Microsetella* spp. from western Greenland (Hjorth & Dahllöf 2008). Also negative effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *C. finmarchicus* and *C. glacialis* were demonstrated (Hjorth & Nielsen 2011).

Again, the experience learned from the Macondo oil spill, where huge 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.

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, zooplankton, including shrimp and fish larvae, can be expected. Except for the shelf banks, however, very little information is available on such events 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 plankton bloom, when high biological activity of the pelagic food web from phytoplankton to fish larvae is concentrated in the surface layers.

A study of the density and distribution of chlorophyll (as a measure of primary productivity) in the Disko Bay area in spring 2006 (Mosbech et al. 2007) indicated wide spatial and temporal variability in chlorophyll levels and that high chlorophyll levels (spring bloom) are distributed over large areas. Moreover, areas of high importance for primary production vary both between seasons and between years, depending for example on ice conditions. An oil spill therefore has at least the potential to impact small and localised primary production sites, while primary production as a whole will only be slightly impacted even during a large spill in open waters. Additional information about primary productivity is available for the area around Nuuk, including Fyllas Banke (Greenland Climate Center), and this information should be included in an updated version of this assessment.

### 11.2.2 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 macroalgae cover in the littoral zone (mainly *Fucus gardneri*) was lost. It has taken many years to fully re-establish these areas with years with fluctuations in *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 off the coast of Cornwall, UK (Hawkins et al. 2002). For Prince William Sound the fluctuations were considered to be a result of the homogeneity of the evolving *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), and resulted in a longer time span for *Fucus* population heterogeneity to recover (Driskell et al. 2001).

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

The scenarios of the Exxon Valdez accident and the Baffin Island Oil Spill (BIOS) study differ in that 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 add to the impacts of 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 total 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 on *Fucus* dynamics at oiled and unwashed versus oiled and washed sites (Driskell et al. 2001). Use of dispersants in cleaning up oil spills, as has been practised in earlier years, may increase recovery time of the treated shores. Recovery lasted from 2-3 years to at least 10 years after the Torrey Canyon spill off southern 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.

### 11.2.3 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 sublethal 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, frequently seen in Greenland waters where meltwater runoff from glaciers may disperse widely into the open sea.

Effects on benthos have been documented from the Macondo subsea blowout in the Gulf of Mexico in 2010 where deepwater plumes moved tens of kilometres away from the blowout site (Diercks et al. 2010, 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 sublethal effects (e.g. reduced reproduction). Such bivalves may act as vectors of toxic hydrocarbons to higher trophic levels, particularly bearded seals, walruses and eider ducks. 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 yet been assessed in detail.

However, in broad terms, the shallow water (down to 50 m) communities have high species richness (bivalves, macro algae etc.) and the fauna is available to higher trophic levels such as eiders and walruses. 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 that often constitute the majority 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 can potentially cause a significant reduction in the total species richness for a long period of time.

### 11.2.4 Oil spill impacts on ice habitats

There is very little knowledge available on oil spill impact on the sea-ice ecosystem (Camus & S. 2007, Skjoldal et al. 2007). Oil may accumulate under the ice and stay until break-up and melt; weathering processes are inhibited which means that the toxicity may persist much longer than in open waters. See also section 11.1.3 above.

At least in laboratory experiments with sea-ice amphipods sublethal effects of exposure to WSF have been demonstrated on sea-ice fauna (Camus & Olsen 2008, Olsen et al. 2008). Polar cod have also been exposed to PAHs and crude oil, both in the field and laboratory, and several sublethal effects were demonstrated. Moreover polar cod seems to be a suitable indicator species in relation to monitoring pollution effects caused by oil (Nahrgang et al. 2009, Christiansen et al. 2010, Jonsson et al. 2010, Nahrgang et al. 2010a, Nahrgang et al. 2010b, Nahrgang et al. 2010c, Nahrgang et al. 2010d).

The sympagic ecosystem is however very resilient as it necessarily has to re-establish each season when new ice is formed, at least in areas dominated by first-year ice.

It is apparent that polar cod could be particularly sensitive, due to the fact that their eggs stay for a long period just below the ice, where also oil would accumulate (Skjoldal et al. 2007).

### 11.2.5 Oil spill impacts in coastal habitats

One of the lessons learned from the Exxon Valdez oil spill was that the near-shore 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 in recovery (several bird species, clams, mussels) and a few were recently assessed as ‘not recovered’ (pigeon guillemot – a close relative to the black guillemot in Greenland, and also Pacific herring) (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 may be forced to stay in oil contaminated shallow waters when they assemble before they move 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, selected randomly and 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 this may represent a source of 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 the Shetland Islands oil-containing spray carried by wind even impacted fields and grasslands close to the coast.

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

The coastal areas have been mapped and classified according to their sensitivity to oil spills (Mosbech et al. 2000).

### 11.2.6 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 (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 and Greenland halibut fisheries within the assessment area, as well as to the local fisheries targeting Atlantic cod, lumpsucker, capelin, wolfish and Atlantic halibut. 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 suspension usually lasts some weeks and in coastal waters longer. The coastal fishery was banned for four months after the Braer incident off the Shetland Islands 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 in September 2010, 230,000 km$^2$ were closed for both commercial and recreational fishing and in September 2010 approx. 83,000 km$^2$ were still closed (Graham et al. 2011). Some fisheries remained closed one year after the spill (Law & Moffat 2011, NOAA 2011a).

The offshore fisheries for Greenland halibut within the assessment area constitute a significant proportion of the overall Greenland/Canada fishery in Davis Strait. In 2010, half the Davis Strait landings were caught in the assessment area (14,000 tons, Jørgensen 2010). The main offshore fishing grounds are located west of Nuuk (Fig. 5.1.3). Closing the fishery in this area could therefore have socio-economic impacts. There is a risk that closure zones could extend further west and also cover Canadian fishing grounds. This is because Greenland halibut moves considerable distances over a very short time, and contaminated (tainted) fish may move out of the assessment area and be caught far from a spill site.

### 11.2.7 Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Schreiber & Burger 2002). Birds which rest and/or dive from the sea surface, such as auks, seaducks, cormorants and divers (loons), are more exposed to floating oil than birds which spend more time flying and on land. But 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 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 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 on 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 media attention when oil spills occur and demonstrate the high individual sensitivity to oil spills. However, of greater concern must be the case where whole populations suffer from oiling. To assess this issue, extensive studies of the natural dynamics of affected populations and the surrounding ecosystem are necessary.

The seabird species most vulnerable to oil spills are those with low reproductive capacity and a corresponding high average lifespan (low population turnover). Such a life strategy is found among auks, fulmars and many seaducks. Thick-billed murres (an auk), for example, do not breed before they reach 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 of 15–20 years or more. These seabirds 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 recolonised from neighbouring colonies. Recolonisation is dependent 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

A large number of seabird species breed in the assessment area (see section 4.7.5) and the majority are associated with habitats along the outer coastline (sea-facing cliffs or on low islets), which are highly exposed to drifting oil. Such exposed areas are almost inaccessible to oil spill response due to remoteness and often harsh weather conditions. A further risk situation is when adults swim away from the colony accompanying their chicks, e.g. auks and seaducks. Some will move further inshore to find sheltered areas; others (e.g. murres, being flightless) will move offshore and disperse over extensive areas. Two of the species breeding in the assessment area, Atlantic puffin and common murre, are rare breeders to Greenland and listed as near threatened or endangered, respectively, on the Greenland Red List, while two other species, Iceland gull and white-tailed eagle (subspcies), are endemic to Greenland (Boertmann 2007). The two auk species are also colonial breeders, which mean that a large proportion of the Greenland population risk 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 international 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., murres). Just in the coastal area of Southwest Greenland, the number of wintering birds is estimated to be more than 3.5 million and a very large proportion of these are found within the assessment area. In addition, king eiders utilise the shallow water offshore on banks and 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). A large number 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 northern Baffin Bay or eastern Canada (Mosbech et al. 2006a, Mosbech et al. 2006b, Mosbech et al. 2007, Boertmann et al. 2009). The number of birds potentially affected by a large oil spill in the assessment area could therefore be extensive. On their northwards spring migration through the Davis Strait, murres and little auks are assumed to follow the ice edge of the western pack ice, where also oil will tend to accumulate in case of a spill.

### 11.2.8 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 hooded seal is particularly sensitive in this respect because whelping patches are located within the assessment area, on the eastern edge of the Davis Strait pack ice. For the polar bear, contact with oil also means loss of the insulation 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 number of polar bears is low and their occurrence is dependent on the presence of sea ice.

Marine mammals are forced 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-coverage where oil can fill the spaces between the ice floes, the risk of inhalation of toxic vapour may be even more serious because marine mammals are forced 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 especially 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 filtration may be seriously affected (Werth 2001).

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, Anon 2003a, Matkin et al. 2008).

As top predators, marine mammals have a risk of being affected through toxic substances accumulating 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. Bearded seals are also vulnerable, as their diet includes benthic organisms such as polychaetes, bivalves and sea cucumbers.

Marine mammals species affected by an oil spill during winter in the assessment area could include bearded seal, hooded seal, ringed seal, harbour seal, bowhead whale, narwhal, white whale, polar bear, harbour porpoise and occasionally also walrus, bottlenose whale and sperm whale. Harbour seals are especially vulnerable because they are endangered in Greenland and conservation of the remnant populations still existing in the assessment area is crucial for the recovery of the population. As previously mentioned, the hooded seal is also highly vulnerable due to whelping patches on the eastern edge of the Davis Strait pack ice. Marine mammals common in the area 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 whale occurs only rarely in the assessment area, but is vulnerable due to a very small population and the survival of single individuals is important for the recovery of the population.

Assessing oil-related mortality of marine mammals is difficult as carcasses are rarely found in conditions suitable for necropsies. Nevertheless, increased mortality of killer whales, sea otters and harbour seals exposed to the Exxon Valdes 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 standings per year to 101 in 2010. Both numbers are expected to represent only a small fraction (approx. 2%) of the true death toll (Williams et al. 2011).

The banks on the shelf of the assessment area are important feeding grounds for seals and baleen whales. If the prey species are contaminated with toxic substances after an oil spill this may affect the top-predators relying on this feeding area.

### 11.2.9 Long-term effects

A synthesis of 14 years of oil spill studies in Prince William Sound since the Exxon Valdez spill has been published in the journal 'Science' (Peterson et al. 2003), and here it is 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 they were 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 unoiled coasts. On oiled coasts they displayed the detoxification enzyme CYP1A nine years after the spill. Harlequin ducks on oiled coasts displayed lower survival, their mortality rate being 22% instead of 16%; body mass was smaller; and they showed a decline in population density as compared with stable numbers on unoiled 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-known group of local killer whales experienced a 41% loss; there has been no reproduction 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 strands 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, Perez et al. 2008).

### 11.2.10 Mitigation of oil spills

Risk of oil spills and their potential impact can be minimised with high HSE standards, BAT, BEP 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 prevents effective oil recovery methods.

An important tool in oil spill response planning and implementation is oil spill sensitivity mapping, which has been carried out in the assessment area but should be updated (Mosbech et al. 2000). See also the following section, 11.3.

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 try 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.

Before activities are initiated, provision of 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, for example, by the displacement of important quarry species. Such information may help hunters and fishermen to plan their activities accordingly.

## 11.3 Oil spill sensitivity mapping

The coast of the assessment area has been mapped according to its sensitivity to oil spills (Mosbech et al. 2000). This atlas integrates all available knowledge on coastal morphology, biology, resource use and archaeology. It also classifies coastal segments of approx. 50 km in length according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coastal type, logistics and proposed oil spill countermeasure methods. Extensive descriptions of ice conditions, climate and oceanography are also included.

An overview of the sensitivity classification of the coastlines in the assessment area is shown in Figure 11.3.1. A large proportion of the coastline is classified as highly or extremely sensitive to oil spills, especially in the central and northern part of the assessment area. It should be noted that this sensitivity atlas (Mosbech et al. 2000) was published 10 years ago and production of an updated version which incorporate the new information is recommended.

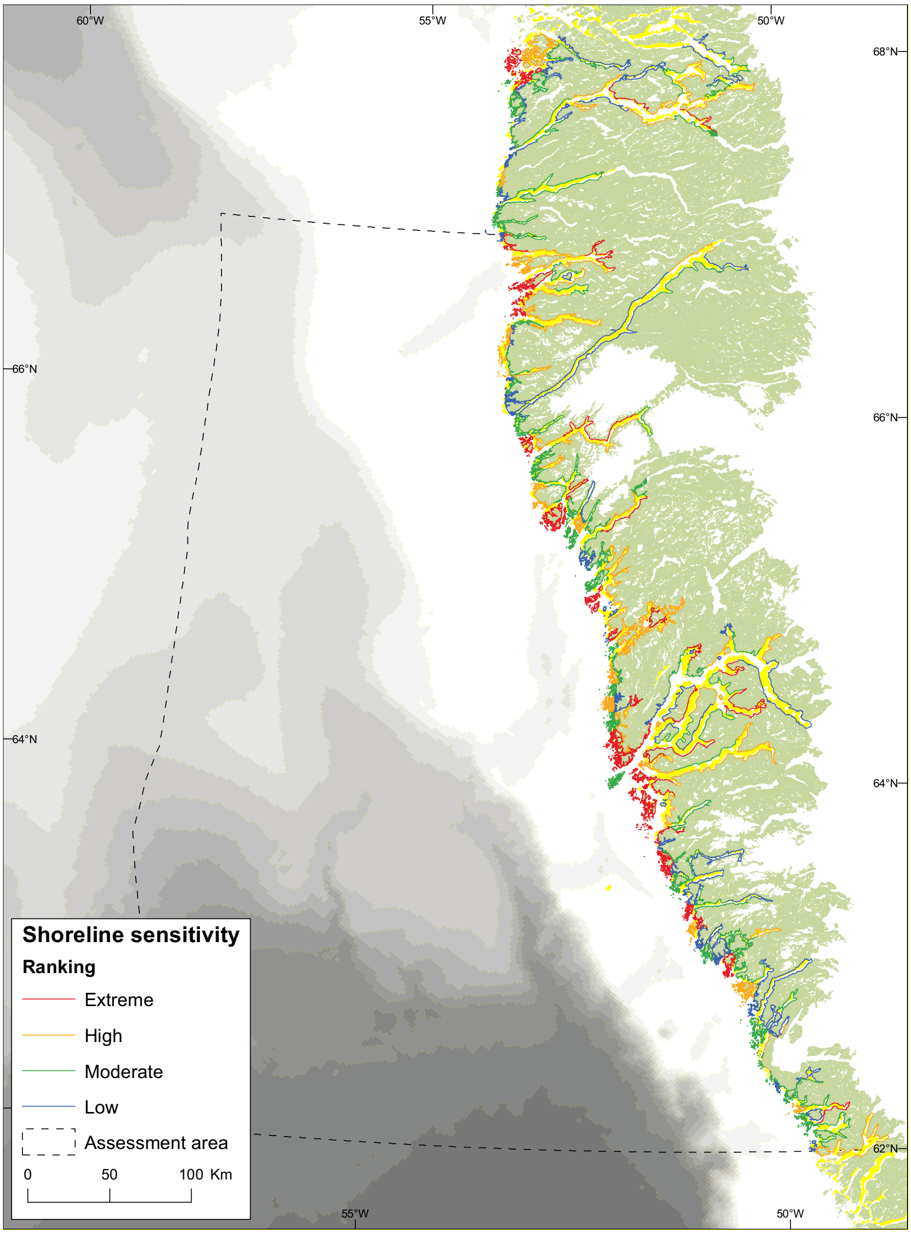


**Figure 11.3.1.** Oil spill sensitivity of coastlines in the assessment area according to the oil spill sensitivity atlas (Mosbech et al. 2000).

### 11.3.1 Seasonal summary of offshore oil spill sensitivity

In relation to this assessment classification of offshore areas is particularly relevant and this has been updated with the newest available data (Figures 11.3.2). The offshore areas were defined on the basis of a cluster analysis in order to obtain ecologically meaningful areas, and the four seasons were calculated separately. The cluster analysis included twelve variables: air temperature, air pressure, sea surface temperature (two different measurements), temperature at a depth of 30 m, salinity at the surface and at 30 m in depth, wind speed, ice coverage, sea depth, slope of seabed and distance to coast (for details see Mosbech et al. 2004b).

For each season and offshore area various symbols are shown in Figure 11.3.2 for important species or species groups according to their relative abundance. For each season the relative sensitivity to oil spill is calculated for each offshore area, ranging from low to extreme sensitivity. This classification is based on the relative abundance of resources, but also species specific sensitivity values, an oil residency index, a human use factor and a few other parameters. It should be notede that the sensitivity ranking shown in figure 11.3.2 is relative for each season and therefore cannot be directly compared between seasons.

A direct comparison of seasons for the assessment area, based on absolute sensitivity values and averaged across all offshore areas, shows that winter is most sensitive to oil spill (index value 48), closely followed by spring and autumn (both value 46), while summer is least sensitive to oil spill (value 36). One general reason that winter, spring and autumn are relatively more sensitive than summer, is the large number of wintering/migrating seabirds, which all are very sensitive to oil (especially auks and seaducks). For more details see the seasonal description below.

### Spring (April/May-June)

Depending on the winter conditions the ice edge of the western pack ice may still be present in the northern and western part of the assessment area, but in early May there is normally open water throughout the area. As the sea ice also disintegrates and retreats elsewhere, large numbers of wintering auks and seaducks start migrating out of the assessment area towards breeding areas north, west or east of Southwest Greenland. Large numbers of surface feeders (kittiwakes and fulmars) which winter further south also pass through the assessment area on their way to breeding colonies further north. While many bird species leave or pass through the assessment area during spring, baleen whales move in from the south to use the assessment area as part of their summer foraging area. They take advantage of the productive upwelling areas of the banks and prey on items such as krill, capelin and sandeels, which are especially important for the whales. Also in spring, large schools of capelin and lumpsucker move towards the coasts, where they spawn in the intertidal zone. This attracts both seabirds and marine mammals.

The sensitivity classification of the offshore areas (Fig. 11.3.2) shows that the near-coastal offshore areas are classified as highly sensitive or extremely sensitive to oil spills during spring. This is mainly due to the large numbers of wintering/migrating birds and extensive human use. Especially the fishery for northern shrimp and snow crab is important in the near-coastal offshore blocks, but also hunting and small-scale fisheries. The offshore block in the southwest corner of the assessment area is also classified as highly sensitive to oil spill due to the extensive Greenland halibut fishery (Fig. 5.1.3) and whelping areas for hooded seals in the western pack ice in March and April.

### Summer (July-August)

For many of the same reasons as mentioned above for the spring period, baleen whales, human use of northern shrimp and snow crab and seabirds, the near-coastal offshore areas are classified as highly sensitive or extremely sensitive to oil spills during summer (Fig. 11.3.2); although relatively less than during the other seasons (see above). Even though most wintering birds now have left the assessment area, there is still a variety of breeding birds (around 20 species), which largely forage in offshore areas. In addition, over-summering (non-breeding) seabirds utilise the shelf areas and other non-breeding seabirds utilise near-coastal areas during moulting.

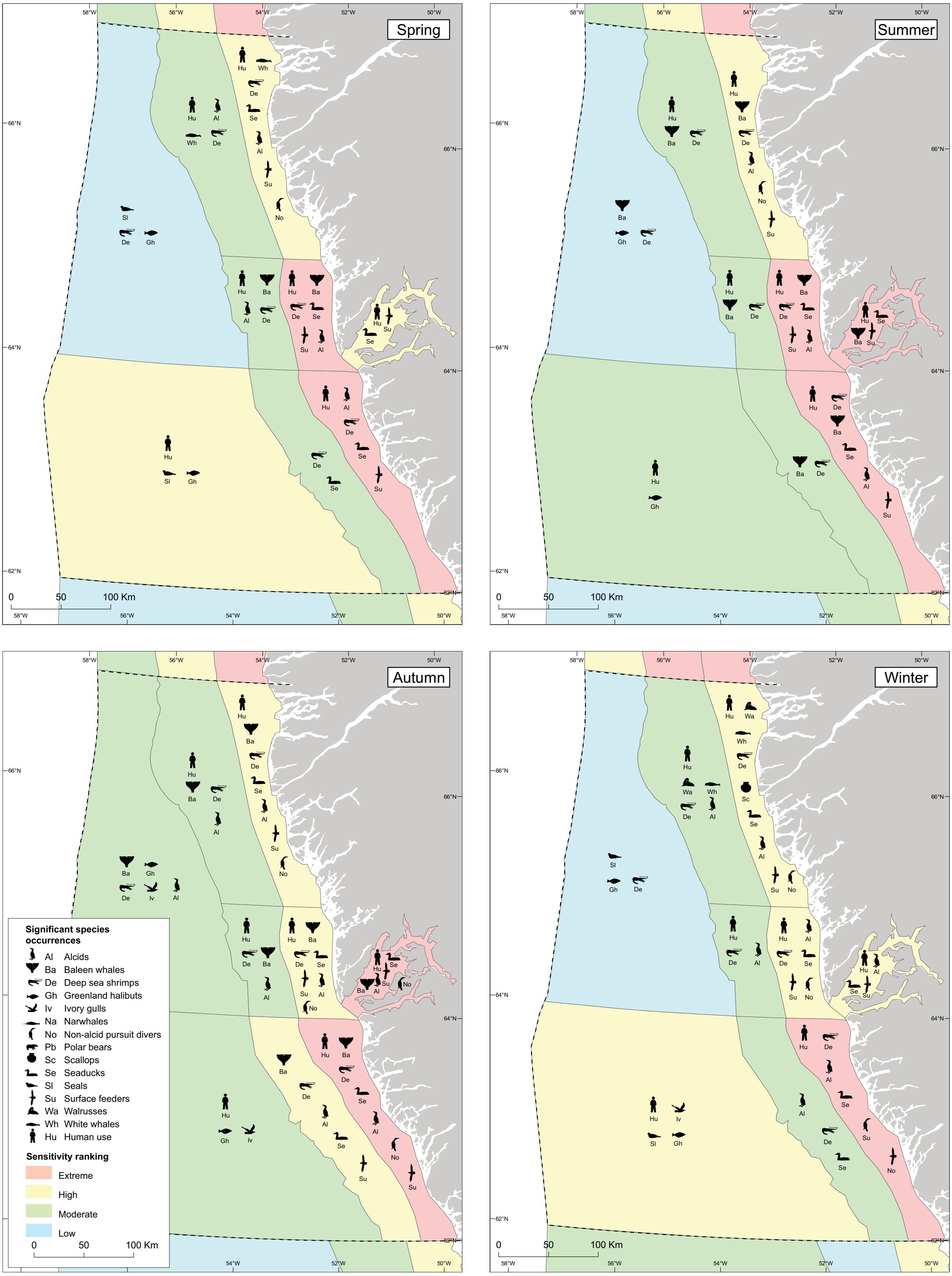


**Figure 11.3.2.** Oil spill sensitivity of offshore areas in the assessment area partly based on and further developed from the oil spill sensitivity atlas (Mosbech et al. 2000). Symbols for species or species groups relate to their relative abundance, while the sensitivity ranking also includes other parameters, such as species-specific oil sensitivity, oil residency and human use.

### Autumn (September-November)

During autumn the near-coastal offshore areas are still classified as the most sensitive areas (high or extreme) with respect to oil spills (Fig. 11.3.2). Auks and seaducks from a variety of breeding locations now return to the assessment area, boost bird densities and add to the human use factor. The baleen whales gradually start their migration southwards, but densities remain high throughout most of the period. The northern shrimp and snow crab fishery is still important.

During autumn also the middle offshore block in the south is classified as highly sensitive to oil spills. This is mainly due to a large influx of auks (murres, little auks and puffins) and surface feeders (shearwaters, kittiwakes and fulmars).

### Winter (December-April)

In general, winter is the most sensitive period among seasons when considering absolute sensitivity values and averaged across all offshore areas in the assessment area. As mentioned above, this is highly influenced by the large number of oil-sensitive seabirds overwintering in the assessment area.

Once again, the near-coastal offshore areas classify as some of the more sensitive blocks within the season (Fig. 11.3.2). In addition to use by seabirds, human use is extensive throughout the period (seabird hunting, northern shrimp and snow crab fishery) and the wintering area for beluga whales extends into the northeastern offshore block. During cold winters the southern areas become increasingly important as the western pack ice may force animals to the south.

As in spring, the offshore block in the southwest corner of the assessment area is classified as highly sensitive to oil spill. Again the extensive Greenland halibut fishery (Fig. 5.1.3) and the whelping area for hooded seals in the western pack ice during March and April are the main contributors to the sensitivity index.

# 12 Preliminary identification of information needs and knowledge gaps for environmental management and regulation of oil activities in Davis Strait

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## 12.1 Knowledge gaps

In the Davis Strait several knowledge gaps need to be filled in order to: a) assess, plan and regulate activities so the risk of impacts 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. Moreover, climate change in the Arctic is rapid, altering the ecological conditions and demanding long-term studies and monitoring to understand the ecosystem dynamics and the effects of human activities. Long time series are invaluable and a coordinated long-term monitoring programme should be considered. A programme of this kind could take advantage of existing monitoring of utilised 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 Davis Strait assessment area. This list is not exhaustive; new gaps may appear, for example when the implications of climate change become more apparent.

Some knowledge gaps are specific to 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, and participation by Greenland can secure that specific Greenland perspectives are included. The most important of these are also listed below.

### 12.1.1 Specific knowledge gaps for the assessment area

#### Location of recurrent offshore hot spots for biological productivity and biodiversity

*Relevance*: These hot spots include recurrent (predictable) areas with localised (in time and space) primary production, high concentrations of fish and shrimp larvae, zooplankton, seabirds and marine mammals. The sites are sensitive to oil spills and possibly release of produced water (formation water with oil residues discharged during oil production).

*Methods*: Surveys, remote sensing and modelling of oceanographic data.

#### Shrimp larvae and snow crab larvae distribution, drift and settling in the Davis Strait

*Relevance*: The northern shrimp fishery is the single most important industry in Greenland and snow crab is also an important fishery. The larvae move passively in the upper part of the water column, where they can be exposed to oil spills and produced water. It is important to identify recruitment areas and recurrent concentrations including the larvae depth distribution.

*Methods*: Studies of the early life history of northern shrimp and snow crab, including larval drift, variation in settling and occurrence of benthic stages and interaction with climate change. Dedicated field studies and modelling.

**Benthic flora and fauna – identification of sensitive areas and baseline (diversity, spatial variation, biomass, primary production)**
*Relevance*: Benthic flora and fauna is sensitive to oil spills, to placement of structures and to release of drilling mud. Sponge gardens and cold-water coral reefs are especially sensitive to sedimentation of drilling mud and cuttings. Sensitive benthic areas are important to consider when subsea activities are to take place and when drilling locations are identified. For shore habitats (sub tidal and intertidal zone) knowledge on benthic flora and fauna is especially important for identification of the most oil spill sensitive areas, where shoreline protection measurements can potentially be established during an oil spill.

*Methods*: Dedicated regional (strategic) field surveys in combination with the studies carried out by the licence holders during site surveys.

**Fish – biology, spawning areas, stock relationships of important species (esp. Greenland halibut, capelin, sandeel, lumpsucker, Atlantic cod)**
*Relevance*: Fish, especially egg and larvae, can be sensitive to oil spills and produced water and fish can be tainted if there are oil components in the sediment. Adult fish can be displaced by acoustic activities, such as seismic surveys, and this displacement can influence stock recruitment if spawning fish are scared away from optimal spawning areas.

*Methods*: Dedicated surveys, tagging, modelling and other methods for identification of important spawning sites, including the depth at which spawning occurs, larval drift and retention areas with high concentrations of larvae. This is especially pertinent for Greenland halibut, for which the main spawning grounds are in the central Davis Strait, and for species that spawn in coastal areas where oil concentrations are more likely to be high during an oil spill. Behavioural and physiological experiments on the reaction of selected local fish to sound from seismic surveys.

**Seabirds – distribution and abundance of breeding and wintering birds, migratory movements and concentrations, population delineation and population dynamics, especially for declining or less known species**
*Relevance*: Seabirds are very sensitive to oil spills and knowledge of seabird concentration areas is important to mitigate impacts. The assessment area is an internationally important key wintering area for seabirds from all over the North Atlantic.

*Methods*: Surveys and ecological studies in breeding colonies. Tracking of migrating birds by satellite telemetry, and geo-locators, bio-loggers, and molecular techniques combined with dedicated surveys by ship and aircraft (in combination with the hot-spot studies listed above).

**Marine mammals – distribution and abundance, relationship to sea ice, stock identity and movement, general biological knowledge of less known species and of endangered species**

*Relevance*: Marine mammals are sensitive to oil spills and to anthropogenic noise. To mitigate impacts and understand the consequences of these impacts it is important to know where marine mammals are, why they are there and what their status is.

*Methods*: Tracking by means of satellite transmitters and bio-loggers, dedicated surveys, passive acoustic monitoring, molecular studies and mark-recapture (tags, biopsies or photo-ID, depending of species).

**Marine mammals – reactions to noise from drilling and seismic studies**

*Relevance*: Marine mammals are sensitive to noise and there is a risk of displacement from critical habitats especially for whales if there is a cumulative impact from concurrent activities in several licence blocks. Knowledge on reaction distance and the potential for habituation to noise is important.

*Methods*: Field studies, passive acoustic monitoring, satellite tracking.

## 12.2 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 some important issues that should be addressed before production activities are initiated in Greenland are listed. 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 issues to address include:

- Biological effects and sensitivity to PAHs and other oil components of key species (e.g. sandeel, capelin) under Arctic conditions
- Rate of degradation of oil and chemicals in Arctic water and sediment
- Oil vapours and their effects on marine mammals.

Similar issues relating to produced water are:

- 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.

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 living in the assessment area. Integrated studies on these issues are needed.

### 12.2.1 Ecotoxicological Monitoring

Assessment criteria have to be established when using biological indicators to assess whether there is an unacceptable impact from discharges. These will be based on ecotoxicological tests that cover the sensitivity range of relevant species at different trophic levels. To establish such environmental assessment criteria (EAC) toxicological tests have to be developed or adapted using relevant species from the Davis Strait. Knowledge concerning species' sensitivity, assessment criteria as well as an adequate monitoring strategy should be developed.

## 12.3 Proposal for a new environmental study programme

Based on this preliminary SEIA for the Davis Strait 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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# THE DAVIS STRAIT

A preliminary strategic environmental impact assessment of hydrocarbon activities in the eastern Davis Strait

The Bureau of Minerals and Petroleum (BMP) is planning for further exclusive licences for exploration and exploitation of hydrocarbons in the Greenland offshore areas of Davis Strait. To support the decision process BMP has asked DCE - Danish Centre for Environment and Energy and the Greenland Institute of Natural Resources (GINR) to prepare this preliminary Strategic Environmental Impact Assessment (SEIA) for the eastern Davis Strait between 62° and 67° N.

Based on existing published and unpublished sources, including three previous assessment reports that were prepared in connection with the existing licence blocks, the SEIA describes the physical and biological environment including protected areas and threatened species, contaminent levels, and natural resource use. This description of the existing situation then forms the basis for assessment of the potential impacts of oil activities.

If more licences are granted in the assessment area implementation of an environmental background study programme is planned to fill the data gaps that have been identified and provide information required to support the environmental planning and regulation of the oil activities. The new information will be included in an updated SEIA, which will become the new reference document for the environmental work and substitute this preliminaryversion.

ISBN: 978-87-92825-28-5
ISSN: 2245-0203