EASTERN BAFFIN BAY

A strategic environmental impact assessment of hydrocarbon activities

Scientific Report from Danish Centre for Environment and Energy No. 9 2011

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Data sheet

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Abstract: This report is a strategic environmental impact assessment of activities related to exploration, development and exploitation of oil in the Baffin Bay off Northwest Greenland.

Keywords: Strategic environmental impact assessment, Baffin Bay, Greenland, hydrocarbon exploration, marine mammals, seabirds

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Preface

In 2006 the Bureau of Minerals and Petroleum decided to initiate a decision process for the so-called KANUMAS areas in connection with preparation of a hydrocarbon licensing round to be completed by the end of 2008. The KANUMAS areas comprise the waters off Northeast and Northwest Greenland. A preliminary strategic environmental impact assessment was then prepared to be included in the decisions process (Boertmann *et al.* 2009). At the same time several studies were initiated to augment the biological background knowledge (see Section 12) and the results of these studies should be used in an updated version of the SEIA. The present report is the updated document covering the KANUMAS West area (Figure 1). However, as licence blocks have been granted in December 2010, the term KANUMAS West area will in this report be substituted with 'Baffin Bay assessment area'.

Acknowledgement

The sections on weather, oceanography and ice conditions are modified from a DMI contribution to the oil spill sensitivity map covering the West Greenland region between 68° and 72° N (Mosbech *et al.* 2004b).

Summary and conclusions

This document is a Strategic Environmental Impact Assessment (SEIA) of activities related to exploration, development and exploitation of hydrocarbons in the Baffin Bay off Northwest Greenland between 71° and 78° N. The area was opened for licence applications in 2010 and seven licenses were granted in December 2010.

A preliminary version of this document (Boertmann *et al.* 2009) was issued in 2009, and contributed in combination with descriptions on the environmental conditions in the specific licence blocks to the political decision process. This is now updated with new information primarily derived from the background study programme initiated by Bureau of Minerals and Petroleum.

The SEIA was prepared by the Danish Centre for Environment and Energy (formerly known as National Environmental Research Institute) and the Greenland Institute of Natural Resources.

The assessment area is shown in Figure 1. This is the region which potentially could be impacted by a large oil spill deriving from activities within the expected licence areas, although drift modelling indicates that oil may drift beyond the borders of this area.

The expected activities in the 'full life cycle' of a petroleum field are briefly described. Exploration activities are likely to take place during summer and autumn, because harsh weather and particularly sea ice hamper activities in winter and spring. However, if oil production is initiated activities will take place throughout the year.

The environment

The physical conditions of the study area are briefly described with focus on oceanography and ice conditions. Sea ice and icebergs are present throughout the year, with the lightest conditions in the period June-November. One of the most important physical features of the biological environment is the polynyas (ice-free or almost ice-free areas surrounded by sea ice), of which the most important is the North Water between the Qaanaaq area and Ellesmere Island in Canada. Polynyas become free of ice very early in spring (April) and also have ice-free parts throughout the winter, and particularly the North Water is an important winter habitat for marine mammals and spring and summer habitat for seabirds. Another important feature is the shear zone between the dynamic drift ice and the coastal fast ice. Here open water often occurs in winter.

The study area is situated within the Arctic region, with all the typical biological properties of this climatic region: low biodiversity but often numerous and dense animal populations; a relatively simple food web from primary producers to top predators and with a few species playing a key role in the ecology of the region (Figure 10). The most significant ecological event in the marine environment is the spring bloom of planktonic algae, the primary producers in the food web. These are grazed upon by zooplankton, including the important copepods *Calanus*, which is one of the key species groups in the marine ecosystem (Figure 10).

Benthos is the fauna living on and in the seabed. Benthic macrofauna species are an important component of coastal ecosystems. They consume a significant fraction of the available production and are in turn an important food source for fish, seabirds and mammals. Little is known on the benthos communities in the assessment area.

Northern shrimp is found in the southern part of the assessment area and commercial fishery takes place on this stock.

In and on the underside of the sea ice a specialised ecosystem exists: the sympagic flora and fauna. Algae live in and on the ice and are grazed upon by crustaceans, which sustain populations of polar cod and Arctic cod which again are important food to ringed seals.

Fish, seabirds, marine mammals and humans represent the higher trophic levels in the marine environment, where polar bear and man are the top predators.

The fish fauna is low in diversity, but some species are very important in the food web. The polar cod is very numerous and usually associated with the ice, and it constitutes a major food resource for seals, whales and seabirds, why it is another key species in the marine ecosystem. The bottom dwelling Greenland halibut is also important. It is very abundant and widely distributed in the deeper parts of the assessment area. Greenland halibut is a major food resource for narwhals. The Arctic char is an important species in the coastal waters.

Seabirds are locally abundant with several species present in the study area in summer and spring. Many species breed in dense colonies, mainly close to the polynyas, where dense aggregations of birds can be found as early as May. In spring and autumn millions of seabirds migrate through the area on their passage between breeding sites in Northwest Greenland and Arctic Canada and winter grounds off Southwest Greenland and Newfoundland. Some of the most important species are northern fulmar, common eider, thick-billed murre, little auk, black-legged kittiwake and ivory gull (Table 3). Almost all the marine birds leave the area for the winter to return in April and May. Thick-billed murre, common eider, black-legged kittiwake and ivory gull are all red-listed in Greenland due to declining, or in case of the common eider previously declining, populations. Other red-listed bird species which occur in the marine part of the assessment area include Sabines gull, Arctic tern and Atlantic puffin.

Furthermore, some species are designated as species of national responsibility (which means that the population in Greenland is so large that the local management of the species is vital to the global population). The most important of these species is the little auk, as an estimated 80 % of the global population breed on the coasts of the former Qaanaaq municipality. Other national responsibility species are black guillemot and light-bellied brent goose.

Marine mammals are significant components of the marine ecosystem. Four species of seals as well as walrus, many species of whales and polar bear occur in the assessment area. The most important species are narwhal, white whale, bowhead whale, walrus, ringed seal, bearded seal and polar bear (Table 3). They are often associated with ice edges, polynyas or shear zones.

Polar bear, walrus, bowhead whale, white whale and narwhal are all red-listed because their populations have been reduced by present or past hunting or are expected to decline because of climate change (especially polar bear).

Human use of natural resources occurs throughout the assessment area, except for the most offshore parts. Subsistence hunting (marine mammals and seabirds) and subsistence fishery takes place mainly in the inshore waters near the towns and settlements, while some species are hunted during long trips by means of boat or dog sledge for example in the Melville Bay.

Commercial fishery takes place in the southern part of the assessment area and is aimed at Greenland halibut and northern shrimp. The catches of these species in offshore waters in the assessment area constitute a small proportion of the total Greenlandic catch, while the inshore fishery of Greenland halibut in the former Uummannaq and Upernavik municipalities is significant.

Tourism is a relatively new and growing industry in Greenland and this is also the case in the assessment area, where activities take place from early spring (April) and throughout the summer.

Knowledge on background levels of contaminants such as hydrocarbons and heavy metals is important for future monitoring of and in assessing environmental impacts from petroleum activities. The available knowledge on background levels of hydrocarbons in the assessment area is limited, but the general picture is that levels are low.

Climate change will have profound impacts on the ecosystems and their components in the Arctic, and it will act on populations in combination with the human induced stressors such as oil spill, contaminants and hunting. Most true Arctic species populations such as polar bears, ivory gulls and little auks, will most likely suffer from the climate changes and by that become much more sensitive to the other human induced stressors. This fact makes it important to consider all the stressors in combination when assessing potential impacts of especially major oil spills in the future.

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. However, as pointed out previously, the Arctic is changing due to climate change, and this process seems to accelerate, why conclusions and assessments may not apply to future conditions. Furthermore, the current assessment area is remote and still poorly studied and an increase in knowledge also may contribute to adjustment of assessments and conclusions.

Presently, we do not know much about the adaptation capacity of some important species in the assessment area and how their sensitivity to human impacts might change under changing environmental conditions. Changes in habitat availability, e.g. due to reduced ice coverage, are to be expected, with consequences for the local fauna. This, as well as increased temperatures will affect the distribution patterns of relevant species, with consequences for the food web. Northward range expansion of fish targeted by commercial fisheries could for example result in increased fishing activities in the assessment area.

Normal operations – exploration

Exploration activities are temporary. They last for some years and will be spread throughout the license areas. They moreover take place during the ice free seasons – the summer and autumn. Seismic and site surveys have in recent years been conducted as late as November. Exploration drilling shall be terminated in the Eastern Baffin Bay area by September to provide an ice free window for relief drilling before sea ice arrives.

If no commercial discoveries are made, activities will terminate and all equipment be removed. If oil or gas is found, and appraisal shows it to economically feasible to exploit, activities will proceed for many years.

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

Noise from a seismic survey has the potential to scare adult fish away from fishing grounds, but this effect is temporary and normal conditions will re-establish after some days or weeks after the seismic survey, time mainly depending on fish species. It is assessed that potential impacts of seismic activity on the commercially utilised Greenland halibut populations will be low and temporary and that shrimp distribution (and fisheries) will not be affected by seismic activities.

It is also assessed that effects from a seismic survey on fish larvae and eggs will be very low due to the low concentrations in the assessment area, and consequently no effects will be expected on recruitment to adult fish stocks.

It is well known that seismic noise can scare away marine mammals, but it is expected that the effect of a single seismic survey is temporary and that seals and whales will return when a seismic survey have terminated. If displacement from traditional hunting grounds occurs, a temporary reduction in hunting yield must be expected.

Drilling operations also have the potential to displace marine mammals. Migrating bowhead whales avoided an area of 10 km from drill ships in Alaska (Richardson *et al.* 1990). Therefore and depending on the location in the assessment area, displacement of migrating and staging whales must be expected. The main species concerned are narwhal, white whale and bowhead whale during autumn, winter and spring, but also narwhal (in the Melville Bay) and rorquals during summer can be impacted. Walrus and bearded seals may also be displaced from areas where drilling activity takes place. There is therefore a risk of displacing populations from critical feeding grounds and also a risk for reduced availability of quarry species for local hunters.

Stronger impacts are expected if several seismic surveys or drillings take place in adjacent areas or in the same area in consecutive years (cumulative impacts).

Drilling mud and cuttings will be released on the seabed, with local impacts on the benthic fauna as a consequence. During exploration, when wells are few and dispersed, this impact can be minimal if proper mitigation is applied. This may include release of environmental safe chemicals only, such as defined by the OSPAR standards. However, the knowledge on degradation and toxicity of even the environmentally safe chemicals under Arctic conditions is very limited, why use and discharge should be thoroughly evaluated, including further testing of degradation and toxicity.

Exploration drilling is an energy demanding process emitting large amounts of greenhouse gasses. The drilling of three wells in 2010 increased the Greenland contribution by 15 %.

Finally will there be a risk for oil spills during exploration drilling. Effects are assessed below in Section 11.

Environmental impacts from exploration activities are best mitigated by careful planning based on thorough environmental background studies, Best Environmental Practice (BEP) and Best Available Technique (BAT) and application of the Precautionary Principle and international standards (OSPAR). For example, activities should be avoided in the most sensitive areas and in the most sensitive periods.

Normal operations – development and production

Development and production activities are difficult to evaluate when their location and the level of activity are unknown. Overall, impacts will depend on the number of activities, how far they are scattered in the areas in question, and also on their durability. In this context cumulative impacts will be important to consider.

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

Emissions and discharges

The largest contribution to pollution from an oil field is expected to be the discharge of produced water (if not re-injected or brought to land). This contains, besides oil residues, small amounts of substances which are acutely toxic or radioactive, contain heavy metals, have hormone-disruptive effects or a nutrient effect. Some of the substances may bio-accumulate, although long-term effects of release of produced water are limited. There is, however, an increasing concern about the environmental impacts of produced water. Particularly if it is released under ice, with limited turbulence in the surface layer, increased impacts could occur for example on polar cod eggs which accumulate here. The most obvious way to mitigate effects of produced water is better cleaning before discharge or even better to re-inject it into the wells.

Also discharge of ballast water is of concern because of risk of introducing non-native and invasive species. This is currently not a severe problem in the Arctic, but the risk will increase with climate change and the intensive tanker traffic associated with a producing oil field. However, this problem may be mitigated when the IMO convention on ballast water is ratified.

Use of drilling mud and cuttings will continue as drillings will take place throughout most of the production time. Large amounts of the waste products will therefore have to be disposed of. If released to the seabed stronger impacts on fauna must be expected than during exploration because of the larger quantities released

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

Noise

Drilling will continue throughout the development and production phase. Just as with exploration drilling there will be a risk of displacement of marine mammals from critical habitats. However, during operation the effects are permanent (or at least long term). Walrus and whales, particularly narwhal, white whale and bowhead whale are sensitive in this respect and may be permanently scared away from specific habitats. This could also impact hunters if quarry species are scared away from traditional hunting grounds.

Intensive helicopter flying also has the potential to displace seabirds and marine mammals from habitats (e.g. feeding grounds important for winter survival) as well as traditional hunting grounds, impacting on local people. Applying fixed flying lanes and altitudes will reduce impacts.

Placement of structures

Placement of offshore structures and infrastructure may locally impact seabed communities and there is a risk of spoiling important feeding grounds particularly for walrus and king eider. Structures may in certain areas limit access to critical habitats and walrus is probably the most sensitive species in this respect, because the population is dependent on relatively few and localised benthic feeding areas.

Inland structures primarily have aesthetical impacts on landscapes, but there is also a risk for obstruction of rivers with implications for anadromous Arctic char and of damage to coastal flora and fauna.

A specific impact on fisheries is the exclusion/safety zones (typically 500 m) which will be established around both temporary and permanent offshore installations. These will constitute a problem in areas where fishery for Greenland halibut and northern shrimp takes place.

Illuminated structures and the flame from flaring may attract seabirds in the dark hours, and there is a risk of mass mortality on especially eiders and perhaps little auks.

There is also a risk for impacting the tourism industry in the assessment area, as large and obvious industrial installations and activities will compromise the impression of unspoilt Arctic wilderness, which is the main asset to tourist operators.

Cumulative impacts

There will be a risk of cumulative impacts when several activities takes 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, taking place in the assessment area.

Mitigation

Careful planning of structure placement and transport corridors based on detailed background studies localizing sensitive ecosystem components can reduce inevitable impacts, and strict Health, Safety and Environment (HSE) procedures, application of the Precautionary Principle in combination with Best Environmental Practice (BEP), Best Available Technique (BAT) and international standards (OSPAR) can do much to reduce environmental impacts. Particularly, the discharge policy, as applied in the Barents Sea (Norway), can contribute significantly to reduce impacts.

Accidents

The environmentally most severe accident from the activities described above is a large oil spill. Such 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 cannot be eliminated and in a frontier area like Baffin Bay with the presence of sea ice and icebergs, the probability of an accident will be elevated.

Oil spill trajectory modelling was carried out by DMI as a part of this SEIA. In most of the modelled oil spill drift scenarios oil did not reach the coasts, but stayed offshore. However, three of the 24 scenarios indicate that under certain conditions, oil may reach shores up to several hundred kilometres from the spill site.

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 even species level (Skjoldal *et al.* 2007) and the impacts may last for decades as documented in Prince William Sound in Alaska. The lack of adequate response methods in ice-covered waters and the remoteness and lack of infrastructure in large parts of the assessment area will add to the severity of an oil spill.

Oil in ice
In general, oil slicks occurring in the coastal zone are more harmful and cause longer-lasting effects than oil spills staying in the open sea. This naturally applies to the assessment area, but another especially vulnerable feature is the ice covered waters. In the beginning spilled oil will be contained between the ice floes and on the rough underside of the ice. However, such oil may be transported in an almost un-weathered state over long ranges and may impact the environment, e.g. seabirds and marine mammals, far from the spill site when the ice melts. Oil may also be caught along ice edges, in polynyas and in the shear zone where sensitive 'Valued Ecosystem Components' (VECs) aggregate, such as primary production, seabirds and marine mammals. Particular concern have been expressed about polar cod stocks, because this fish spawns in late winter, and the eggs accumulate just below the ice where spilled oil will also accumulate.

Furthermore, knowledge on the behaviour of spilled oil in ice environments is very limited and the technology for the clean-up of oil spills in ice-covered waters is inadequate and needs to be further developed (Brandvik *et al.* 2010).

Oil spills on sea surface
That the impact of a surface oil spill in the assessment area on primary production, plankton and fish/shrimp larvae in open waters will be low due to the large temporal and spatial variation of these events. There is, however, a risk of impacts (reduced production) on localised primary production areas; although overall production probably will not be significantly impacted. The same may be true for potential localised concentrations of plankton and fish/shrimp larvae if they occur in the uppermost part of the water column, but on a broad scale no or only slight effects on these ecosystem components are expected. An exception to this conclusion could be polar cod, as egg concentrations may occur under the ice and these will be at risk if oil accumulates below the winter ice.

Sub sea oil spills
It is too early to assess effects of a subsea spill like the spill from the *Macondo*-well in the Mexican Gulf in 2010, as there is still very little information available on effects from this incident. But if subsea plumes of dispersed oil are generated in the Baffin Bay area, impacts in the water column must be expected for example on primary production, zooplankton and fish/shrimp larvae.

Impacts in the coastal zone
The coastal zone of the assessment area is particularly sensitive because of the high biodiversity present, including concentrations of breeding and moulting seabirds, spawning capelin and Arctic char. The high sensitivity is also related to the fact that oil may be trapped in bays and fjords where high and toxic concentrations can build up in the water. Furthermore, local fishermen and hunters use the coastal zone of the assessment area intensively. There will be a risk of negative impacts on spawning concentrations of capelin in spring, Arctic char assembling outside their spawning rivers and on many seabird populations both in summer and migration periods. Long-term impacts may occur in the coastal zone if oil is buried in sediments, among boulders, in mussel beds or is imbedded in crevices in rocks. From such sites oil seeps and causes a chronic pollution which may persist for decades. In Prince William Sound in Alaska such preserved oil has caused long-term effects e.g. on birds utilising the polluted coasts and several populations have still not recovered.

Impacts on the seabed
Bottom-living organisms such as bivalves and crustaceans are vulnerable to oil spills; however, no effects are expected in the open water unless oil sinks to the

seabed. In shallow waters (< 10-15 m), highly toxic concentrations of hydrocarbons can reach the seafloor with possible severe consequences for local benthos and thus also for species utilising the benthos – especially walrus, eider and king eider. Again a subsea spill with the size and properties of the spill from the *Macondo*-well in the Mexican Gulf which produced large subsurface plumes of dispersed oil have the potential to impact the seabed communities in deep waters too.

Impacts on fish

Impacts from a surface spill on adult fish stocks in the open sea are not expected. But if an oil spill occurs in ice-covered waters there is a risk to polar cod populations. This is an ecological key species and significant impacts on polar cod stocks may be transferred up in the food web (to other fish, seabirds and marine mammals).

Another exception is a subsea spill. This could impact both the fish directly or through the food. Greenland halibut will also be exposed in both ways because they move up in the pelagic waters to feed.

Impacts on seabirds

In open waters, seabirds are usually more dispersed than in coastal habitats. However, in the assessment area there are some very concentrated and recurrent seabird occurrences in polynyas and in the shear zone. Post breeding concentrations of staging birds (as thick-billed murres, Box 4) may also be vulnerable. Such concentrations of seabirds are extremely sensitive to oil spills and population effects may occur in case of oil in one of these open-water habitats in spring. The most vulnerable species are thick-billed murre, little auk and king eider. Several nationally red-listed species occur in the marine environment and will be exposed to potential oil spills. The little auk is moreover a national responsibility species, because a vast majority of the world population is found within the assessment area, where a major oil spill could seriously affect the viability of the species.

Impacts on marine mammals

Among the marine mammals the polar bear is sensitive to oiling, and several individuals may become fouled with oil in case of a large oil spill in the marginal ice zone. The impact of an oil spill may add to the general decrease expected for the polar bear stocks (therefore red-listed both nationally and internationally) as a consequence of reduced ice cover (global warming) and heavy hunting pressure.

Whales, seals and walruses are also vulnerable to oil spills, particularly if they have to surface in oil slicks. Baleen whales may get their baleens smothered with oil and ingest oil. The extent to which marine mammals actively will avoid an oil slick and also how harmful the oil will be to fouled individuals is poorly known. White whales, bowhead whales and walruses are especially sensitive because they all have small or declining populations. Oil spills (and disturbance) may therefore have disproportionably high impacts on these populations. These species are also listed on the Greenland Red List.

The assessment area is particularly important to many whales (e.g. narwhal, white whale, humpback whale, bowhead whale) because their main food intake takes place (on an annual basis) here, even though they only spend a limited time of their annual cycle here. Effects from oil spills (and disturbance) may therefore have disproportionably high impacts on the populations.

Recent studies indicate that whales and seals are very sensitive to inhaling oil vapours, and particularly narwhals, white whales and bowhead whales could be vulnerable during an oil spill in winter when the availability of open waters is limited by the sea ice. Walruses and other seals living in the ice may also be vulnerable in this respect.

There is also a risk of indirect impacts on walrus and bearded seal populations through contamination of benthic fauna, especially at shallow (< 10-15 m) feeding grounds where oil may reach the seafloor.

For some animal populations oil spill mortality can to some extent be compensatory, while for others it will be largely additive to natural mortality. Some populations may recover quickly while others will recover very slowly to pre-spill conditions, depending on their life strategies. A general decline in a population may be enhanced by oil spill induced mortality. 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.

Hunting in oil spill impacted areas can both be affected by closure zones and by changed distribution patterns of quarry species.

Impacts on fisheries

An oil spill in the open sea will affect fisheries mainly by means of temporary closure in order to avoid contamination of catches. Closure time will depend on the duration of the oil spill, weather, etc. Even though the offshore fisheries for Greenland halibut within the assessment area is small (compared to other Greenland fisheries for this species), a closure zone probably will extend further south and cover a much larger area, including both Greenland and Canadian fishing grounds. In this combined fishing ground approx 13,000 ton are taken annually. The reason is that Greenland halibut moves considerable distances over very short time, and contaminated fish may move out of the assessment area and be caught far from a spill site.

The northern shrimp fishery in the assessment area is small and economic consequences will be limited in case of closure. However these shrimp ground may increase in importance caused by climate change.

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 inshore fishery for Greenland halibut within the assessment area is important on a national scale, and a closure of these fishing areas will have significant economic consequences.

Impacts on tourism

The tourist industry in the assessment area will probably also be impacted negatively by a large oil spill.

Long term impacts

In case an oil spill hits the coasts, long term effect of residual oil caught in the beach sediments must be expected, as described from the Prince Williams Sound. Here oil from the *Exxon Valdez* spill on 1989 still is present in such habitats and still impacts the environment.

New and further studies

There is a general lack of knowledge on many of the ecological components and processes in the Baffin Bay area. To fill some of these information needs, BMP, GINR and DCE carried out a number of background studies in 2009 and 2010.

The results from these studies have been incorporated in this revised and updated SEIA. See section 12.1 for a review of the projects.

However there are still information needs, and further regional strategic studies as well as project specific studies have to be carried out in order to provide adequate data for future monitoring and site-specific EIAs. A list of the most important studies identified so far is given in section 12.2. Some of these research needs are generic to the Arctic and have also been identified in the Arctic Council Oil and Gas Assessment (Skjoldal *et al.* 2007), and relevant studies will hopefully be initiated by cooperative international research.

A new environmental study programme will be initiated in 2011. The programme includes eleven projects which are described briefly in Section 12.3.

Dansk resumé

Strategisk miljøvurdering af olieaktiviteter i den grønlandske del af Baffin Bugt

Denne rapport er en strategisk miljøvurdering af aktiviteter forbundet med olieefterforskning og -udvinding i den grønlandske del af Baffin Bugt ud for Nordvestgrønland. Nærmere bestemt den grønlandske del af farvandet mellem 71° og 78° N (Figur 1). Dette område betegnes Baffin Bugt-vurderingsområdet (Baffin Bay 'assessment area'). En del af Baffin Bugt blev i 2010 åbnet for ansøgninger om olieefterforskning og syv tilladelser blev tildelt i december 2010.

I 2009 udgav Danmarks Miljøundersøgelser (DMU) en foreløbig strategisk miljøvurdering af olieaktiviteter i dette område (Boertmann *et al.* 2009). Den foreliggende rapport er en opdatering af den foreløbige, og opdateringen er baseret på resultater fra de baggrundsundersøgelser, der blev sat i gang af Råstofdirektoratet i 2008.

Rapporten her er udført af DCE – Nationalt Center for Miljø og Energi ved Aarhus Universitet og Grønlands Naturinstitut (GN) i samarbejde med Råstofdirektoratet.

Rapporten behandler et område som er større end selve udbudsområdet fra 2010 (se Figur 1). Det skyldes, at der skal tages højde for, at oliespild kan drive meget langt og også ud af udbudsområdet.

Området er beliggende i den højarktiske zone og har de for denne zone karakteristiske biologiske træk: Forholdsvis lav biodiversitet, korte fødekæder, og områder med meget høje koncentrationer af organismer. Den lave biodiversitet modsvares af at visse arter er uhyre talrige, og nogle af disse er nøglearter i fødekæderne. Det medfører at dyr fra de højere trofiske niveauer er afhængige af nøgleartemes forekomst i tid og rum.

Det vurderede område er meget rigt i biologisk/økologisk forstand. Primærproduktionen om foråret er visse steder meget høj, der er rige dyresamfund på havbunden ligesom der er store og meget vigtige forekomster af både fugle og havpattedyr. Blandt fuglene er der vigtige (både nationalt og internationalt) og rødlistede arter som polarlomvie, ederfugl, ride, havterne og lunde. Blandt havpattedyrene er der vigtige (både nationalt og internationalt) arter som isbjørn, hvalros, narhval, hvidhval og grønlandshval.

Et meget væsentligt biologisk område er det store polynie, Nordvandet, beliggende mellem Qaanaaq-området og Ellesmere Island. Her er mere eller mindre isfrit om vinteren og om foråret starter primær-produktionen meget tidligere end i de omkringliggende isdækkede områder. Dette medfører koncentrationer af havpattedyr og fugle, som bl.a. har gjort det muligt for mennesker at etablere sig permanent i området. Langs de grønlandske kyster af dette polynie yngler for eksempel mere end 80 % af den globale bestand af den meget talrige søkonge; vurderet til mere end 30 millioner par. De vigtige arter af fugle og havpattedyr som er nævnt ovenfor forekommer særligt talrigt i polyniet.

Hellefisk og rejer udnyttes kommercielt i den sydlige del af vurderingsområdet og fangst og fiskeri til lokalt brug er vigtige aktiviteter langs de beboede kyster.

Aktiviteterne fra en komplet livscyklus for et oliefelt er 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 Sound i Alaska i 1989, den norske miljøvurdering af olieaktiviteter i Barentshavet (2003) og på Arktisk Råds (Skjoldal *et al.* 2007) "Arctic Oil and Gas Assessment", som endnu kun er delvist tilgængeligt på internettet (Link). Miljøpåvirkningerne fra den store udblæsning i den Mexicanske Golf i april 2010 er endnu ikke vurderet eller rapporteret, hvorfor der kun er få referencer til dette spild i rapporten her.

Vidensgrundlag

Vurderingerne bygger på de eksisterende klimatiske forhold. Klimaændringer forventes at påvirke miljøet væsentligt i vurderingsområdet i de kommende årtier. Især isens forekomst forventes at ændre sig. Det betyder ændrede leveforhold, som vil medføre at nogle arter reduceres i forekomst og udbredelse mens andre begunstiges og nye arter vil indvandre og etablere sig. Vurderingerne bygger på den tilgængelige biologiske viden, som i mange forhold stadig er mangelfuld. Der blev igangsat en række studier i 2008 for at forbedre den tilgængelige baggrundsviden, og der foreslås i denne rapport yderligere studier for at forbedre vidensgrundlaget.

Efterforskning

Efterforskningsaktiviteter er midlertidige, de varer typisk nogle år og vil for det meste være spredt ud over de tildelte licensområder. De udføres desuden kun i den isfrie periode, dvs. om sommeren og efteråret. Seismiske undersøgelser og "site surveys" er i de senere år gennemført så sent som i november. Prøveboringer skal stoppe med udgangen af september, for at give tid, inden isen indfinder sig, til at foretage en aflastningsboring, hvis en løbsk brønd ikke kan stoppes på anden vis.

Hvis efterforskningen ikke påviser olie eller evt. gas det kan betale sig at udvinde vil aktiviteterne ophøre og alt udstyr fjernes. Findes der derimod olie, som efter en "appraisal"-periode viser sig muligt at udnytte, vil aktiviteterne overgå til en udvikling af oliefeltet med afgrænsningsboringer og udbygning af faciliteter og derpå en egentlig udvinding af den fundne olie (se nedenfor).

De væsentligste påvirkninger fra efterforskningsaktiviteter vil blive forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, fra boreplatforme og helikopterflyvning). Der forventes kun relativt svage, midlertidige og/eller lokalt forekommende påvirkninger, idet mere alvorlige påvirkninger kan undgås med forebyggende tiltag, som f.eks. ved at undgå aktiviteter i særligt følsomme områder eller perioder. Dog kan de særlige 3D-seismiske undersøgelser der foregår i begrænsede områder, give anledning til mere markante midlertidige påvirkninger.

Vinterperioden er særligt følsom overfor støjende aktiviteter bl.a. på grund af forekomster af hvidhval, narhval, grønlandshval, hvalros og remmesæl, men efterforskningsaktiviteter forventes ikke i den periode, hvor de fleste af disse arter er til stede. Narhvaler har dog et vigtigt sommerområde i Melville Bugt, og der er tillige vigtige trækruter for både nar- og hvidhvaler gennem Melville Bugt og langs kysten af Upernavik og Uummannaq distrikter, som benyttes endnu inden vinteren sætter en stopper for olieaktiviteter.

Intensive seismiske undersøgelser kan formentlig få hellefisk til at søge væk fra området i en periode, og sker det i vigtige fiskeområder vil undersøgelserne kunne påvirke fiskeriet negativt. Men undersøgelser af andre fiskearter tyder på at denne påvirkning er midlertidig. Fiskenes gydeområder betragtes generelt som særligt følsomme overfor seismiske undersøgelser, men hellefisk gyder ikke i vurderingsområdet, og dette problem er derfor ikke aktuelt.

Seismiske undersøgelser forventes ikke at påvirke rejebestandene eller deres fordeling i området.

Der er en risiko for at havpattedyr vil søge bort fra vigtige fødesøgningsområder og trækruter pga. forstyrrelserne fra seismiske undersøgelser. Det forventes dog at påvirkningen vil være midlertidig (varighed uger til måneder), fordi aktiviteten ophører.

Det er påvist at trykbølgen fra de luftkanoner, der benyttes ved seismiske undersøgelser, kan slå fiskeæg og -larver ihjel ud i en afstand af maks. 5 m. I Norge er der bekymring for at meget intensive seismiske undersøgelser i områder med høje koncentrationer kan dræbe så meget fiskeyngel, at det kan påvirke rekrutteringen til bestanden af voksne fisk. Tilsvarende høje koncentrationer af fiskeyngel kendes ikke i grønlandske farvande, og de højeste koncentrationer forekommer desuden om foråret før seismiske undersøgelser normalt udføres. Det konkluderes derfor at seismiske undersøgelsers indvirkning på larver og æg ikke giver anledning til risiko for væsentlige påvirkninger af fiskebestandene.

Efterforskningsboring giver også anledning til støjende aktiviteter. Maskineri og skruer, der holder en flydende platform på plads (vandet er næsten overalt for dybt til at man kan bruge borerigge, der står på bunden) frembringer kraftig støj. Denne kan skræmme havpattedyr, og hvaler angives at være særligt følsomme. Der er derfor risiko for at særligt narhvaler, hvidhvaler, grønlandshvaler og hvalros kan blive bortskræmt fra vigtige opholdsområder. For hvidhval, grønlandshval og hvalros er risikoen dog lille, da deres tidsmæssige overlap med en prøveboring bliver begrænset til en kort periode i det sene efterår. Der er også risiko for midlertidig bortskræmning af fin-, våge og pukkehval i sommermånederne. Dette kan tænkes at påvirke fangstmulighederne i den periode aktiviteterne står på, hvis aktiviteterne foregår i traditionelle fangstområder.

Den væsentligste risiko for miljøpåvirkninger under en efterforskningsboring opstår i forbindelse med uheld ("blow-out"), som medfører et stort oliespild. De mulige følger af oliespild er omtalt nedenfor.

Ved en prøveboring benyttes boremudder til at smøre boret, kontrollere trykket i borehullet og til at transportere det udborede materiale (borespåner) op til platformen. Er dette vandbaseret udledes det ofte til havet efter endt boring, mens de oliebaserede typer, som er mere miljøskadelige, i dag normalt bringes til land for at blive behandlet eller deponeret under kontrollerede forhold.

I Grønland må der kun bruges vandbaseret boremudder. Ved de tre boringer ud for Disko i 2010 blev der i alt udledt 6000 tons boremudder og 2261 m^3 borespåner. Nogle af tilsætningskemikalierne som ofte bruges i de vandbaserede typer er dog klassificerede som "røde" i OSPARs system. I norske havområder har man helt udfaset brugen af disse, sådan at man kun benytter de mere miljøvenlige "grønne" og "gule" kemikalier. Det skal dog nævnes at man tillige benytter oliebaseret boremudder i Norge, men under betingelse af at det deponeres/behandles i land og dermed ikke udledes til havmiljøet.

I Grønland er målet at afskaffe de "røde" tilsætningskemikalier. Vanskelige boreforhold har dog betydet at man indtil videre (i 2010 og 2011) har accepteret brugen af et enkelt "rødt" tilsætningskemikalie , som er klassificeret sådan på grund af langsom nedbrydelighed. Men udledningen af de "grønne" og "gule" tilsætningsstoffer bør fremover også vurderes konkret med henblik på giftighed og nedbrydning under arktiske forhold.

Ved udledning af vandbaseret boremudder og borespåner er der en risiko for at påvirke bundfaunaen i nærheden af udledningsstedet ved sedimentation af materiale og forplumring af vandet.

Det er vanskeligt at vurdere virkninger af udledning af boremudder og -spåner i vurderingsområdet, fordi den foreliggende viden om bunddyrsamfundene er meget begrænset. Men det forventes at udledningerne fra en enkelt efterforskningsboring kun vil give minimale påvirkninger, hvis de mest miljøvenlige typer af boremudder benyttes. Påvirkninger kan undgås ved at undlade at udlede boremudder og -spåner, men i stedet bringe det i land eller pumpe det tilbage i borehullet ved endt boring. Men dette giver også miljøpåvirkninger, som skal afvejes mod dem fra udledningen.

Endelig er prøveboringer meget energikrævende, hvilket resulterer i store udslip af drivhusgasser. De tre boringer i 2010 ud for Disko forøgede det samlede grønlandske bidrag med 15%.

Udvikling og produktion

I modsætning til efterforskningsfasen er aktiviteterne under udvikling af et oliefelt og produktion af olie af lang varighed (årtier), og flere af aktiviteterne har potentiale til at forårsage alvorlige miljøpåvirkninger. Disse påvirkninger kan i høj grad forebygges gennem nøje planlægning, anvendelse af anerkendte "Health, Safety and Environment" (HSE) procedurer, brug af "Best Available Technique" (BAT) og "Best Environmental Practice" (BEP). Der er dog mangel på viden om kumulative virkninger og langtidsvirkninger af de udledninger (f.eks. fra produktionsvand), der forekommer selv ved anvendelse af førnævnte tiltag.

Produktionsvand (der pumpes op sammen med olien) udgør langt den største udledning til havmiljøet. Et oliefelt kan udlede op til 30.000 m^3 om dagen, og på årsbasis udledes der på den norske sokkel 174 millioner m^3. Der er i de senere år udtrykt en vis bekymring for udledning af produktionsvand, på trods af at det er behandlet og overholder internationale miljøstandarder. Der knytter sig desuden specielle problemer til udledning af produktionsvand i et isdækket hav, der har reduceret opblanding i overfladelaget. Miljøproblemerne ved produktionsvand kan for eksempel undgås ved skærpede krav til indholdsstoffer eller endnu bedre ved at pumpe vandet tilbage i oliebrønden, sådan som den norske politik foreskriver for olieproduktion i Barentshavet.

Den anden store potentielle udledning omfatter boremudder og -spåner, da der skal bores intensivt under udvikling og produktion. Miljøpåvirkningerne for en enkelt efterforskningsboring er beskrevet ovenfor. Under udvikling og produktion vil de udledte mængder blive væsentlig større, med risiko for at større områder af havbunden påvirkes. Miljøpåvirkningerne fra boremudder og -spåner forebygges bedst ved at bringe begge dele i land til deponering eller ved at pumpe det tilbage i gamle borehuller. Ved brug af vandbaseret boremudder med miljøvenlige tilsætningsstoffer kan udledning være miljømæssigt acceptabelt.

Energiforbruget ved udvikling og produktion er meget stort, og etablering af et stort oliefelt i Baffin Bugt-vurderingsområdet vil bidrage meget væsentligt til Grønlands samlede udledning af drivhusgasser. F.eks. udleder et af de store norske oliefelter mere end dobbelt så meget CO_2 som Grønlands samlede bidrag.

Selve placeringen af installationer og de forstyrrelser, der kommer fra disse, kan påvirke havpattedyr, sådan at de bortskræmmes permanent fra vigtige fourageringsområder eller således at de ændrer trækruter. I Baffin Bugt-området er det især narhval, hvidhval, grønlandhval og hvalros, der er på tale i denne sammenhæng. Dette kan desuden vanskeliggøre fangst på de jagtbare af disse arter.

Det skal i den sammenhæng nævnes at seismiske undersøgelser foretages gennem hele levetiden af et oliefelt, hvorfor de effekter der omtaltes ovenfor under efterforskning også forekommer i udvindingsfasen og nu med risiko for kumulative påvirkninger.

Ved placering af installationer i land, skal deres landskabelige påvirkninger vurderes og minimeres, idet de medvirker til at reducere et områdes værdi som turistmål.

Intensiv helikopterflyvning har også potentialet til at bortskræmme både havfugle og havpattedyr fra vigtige områder. Dette imødegås bedst ved at flyve ad fastsatte ruter og i fastsatte højder.

Fiskeriet i de områder, hvor der vil forekomme udvikling og produktion vil blive begrænset omkring installationer på havbunden (brønde og rørledninger) og ved de forskellige typer af platforme. Normalt anlægges en sikkerheds/afspærringszone i en afstand ud til 500 m fra sådanne installationer.

Problemet har hidtil ikke været særligt stort i Arktis, men formodes at blive større som følge af klimaændringerne.

Produceret olie skal transporteres bort med skib, som tømmer deres tanke for ballastvand inden de laster olie. Dette vil medføre en risiko for at indføre invasive (dvs. at de breder sig på bekostning af lokale arter), fremmede arter til det grønlandske havmiljø. Risikoen kan formindskes ved behandling og udledning af ballastvandet som det foreskrives af den internationale maritime organisation IMO.

Det skal påpeges, at det er meget vanskeligt at vurdere de påvirkninger eventuel udvikling og produktion kan medføre, fordi lokaliseringen, omfanget, varigheden og typen af aktiviteter ligesom de tekniske løsninger ikke er kendt.

Oliespild

De mest alvorlige miljøpåvirkninger, der kan forekomme i forbindelse med olieaktiviteter, er store oliespild. De forekommer enten fra udblæsninger ("blow-outs"), hvor kontrollen med borehullet mistes, eller fra uheld i forbindelse med opbevaring og transport af olie, f.eks. ved forlis af tankskibe.

Store oliespild er meget sjældne nu om dage, fordi teknikken og sikkerhedsforanstaltningerne hele tiden forbedres. Men risikoen er til stede, og særligt i "frontier"-områder, som de grønlandske farvande med tilstedeværelsen af en særlig risikofaktor i form af isbjerge, er muligheden for uheld og ulykker forhøjet. AMAP (Skjoldal *et al.* 2007) vurderer at risikoen for oliespild i Arktis er størst i forbindelse med transport af olie.

DMI har modelleret drivbanerne for oliespild i Baffin Bugt-vurderingsområdet med udgangspunkt i fire spildsteder. De viser at oliespild med oprindelse langt til havs som regel ikke vil nå kysterne, men under visse forhold kan kyster op til flere 100 km fra spildstederne blive påvirket.

Oliespild i kystnære farvande regnes generelt som meget mere ødelæggende end oliespild på åbent hav. Men i et område som Baffin Bugt må denne generalisering modificeres. Det hænger sammen med forekomsten af is, som kan holde på olien og transportere den over lange afstande uden at den nedbrydes væsentligt. Men is kan også begrænse et spilds udbredelse sammenlignet med et spild i isfrie farvande. Den foreliggende viden om oliespilds adfærd og skæbne i isdækkede farvande er begrænset.

Grunden til at kystnære fravande er mest sårbare over for oliespild er, at olien her kan påvirke områder med høj biodiversitet og med tætte dyrebestande, som f.eks. gydende lodde (ammassat), banker med bunddyr som hvalrosser lever af og områder med store fugleforekomster. Olien kan fanges i bugter og fjorde, hvor høje og giftige koncentrationer af oliekomponenter kan bygges op i vandsøjlen og nå bunden. Der er også risiko for at olie kan fanges i bundsedimenter, i strande med rullesten og i muslingebanker, hvorfra olie langsomt kan frigives til det omgivende miljø med risiko for langtidsvirkninger f.eks. på fuglebestande som udnytter kysterne. Endelig udnyttes de kystnære farvande af lokale indbyggere til fangst og fiskeri.

På åbent hav er fortyndingseffekten med til at mindske miljøeffekterne af et oliespild. I og nær Baffin Bugt-vurderingsområdet kan det ikke udelukkes at der er områder langt fra kysten, som alligevel er særligt sårbare over for oliespild. Men den foreliggende viden er ikke tilstrækkelig til at udpege sådanne områder. Det kan f.eks. være frontzoner, "up-welling"-områder og de ydre dele af drivisen, hvor primærproduktionen er særligt høj om foråret, og hvor høje koncentrationer af planktoniske alger og dyrisk plankton forekommer i den øvre del af vandsøjlen.

Et oliespild på havoverfladen vil dog næppe påvirke bestandene af rejer og hellefisk, de vigtige arter for det grønlandske fiskeri.

Fugle er særligt sårbare overfor oliespild på havoverfladen, og i Baffin Bugt-vurderingsområdet er der talrige meget udsatte fugleforekomster. Ynglefuglene omfatter ofte store kolonier af polarlomvie, søkonge, ederfugl, havterne og lunde, ligesom der er vigtige forekomster af fældende kongeederfugle.

Havpattedyr kan også påvirkes af oliespild på havoverfladen. Indenfor Baffin Bugt-vurderingsområdet forekommer bestande som er særligt sårbare, fordi de i forvejen påvirkes af fangst. Det gælder særligt hvidhval, narhval og hvalros. Hvalros og remmesæl lever desuden af bunddyr, og kan blive udsat for at indtage olie med deres føde. Der er tillige helt nye undersøgelser der tyder på, at spækhuggere (og dermed formentlig også andre hvaler) er sårbare overfor indånding af oliedampe over et spild.

Isbjørne er specielt sårbare, fordi de har en tendens til at rense olie af pelsen ved at slikke den ren og derved blive forgiftet af den indtagne olie.

Et oliespild i havområder med is vil formentlig samles i åbne revner og under isflager. Her kan den påvirke de fugle og havpattedyr, der er afhængige af åbent vand og også yngel af polartorsk, der netop samles lige under isen. Havpattedyr kan blive tvunget til at dykke ud i oliespild i de meget begrænsede åbenvandsområder og derved blive udsat for at indånde oliedampe.

Fiskeri og fangst kan blive påvirket ved at oliepåvirkede områder lukkes for den slags aktiviteter. Dette gøres for at hindre at der fanges og markedsføres fisk, der har været i kontakt med olie (for eksempel med afsmag) eller som er mistænkt for at have været det. Der er eksempler på at oliespild har lukket for fiskeri i månedsvis. Der er også en risiko for at fangstdyr bliver sværere tilgængelige i en periode efter et oliespild, ligesom sælskind bliver umulige at afsætte hvis der er olie på dem.

Det meget store oliespild fra *Macondo*-brønden i den Mexicanske Golf havde udgangspunkt på havbunden på meget stor dybde (ca. 1500 m). Det resulterede i dannelsen af store skyer af dispergeret olie i vandsøjlen i forskellige dybder. Olien forblev i disse dybder og drev vidt omkring. Der er tilsvarende dybder i Baffin Bugt-vurderingsområdet. Hvis sådanne olieskyer dannes her, må der forventes påvirkninger af sårbare forekomster i vandsøjlen (primærproduktion, plankton, fiske- og rejelarver) og på havbunden (rejer, bunddyr), særligt hvis olieskyerne driver ind over bankerne.

Baggrundsviden

Da arbejdet med denne miljøvurdering blev indledt, var det klart at der manglede væsentlig viden til at foretage vurderinger af olieaktiviteter i Baffin Bugt-vurderingsområdet. Flere studier blev sat i gang, og en lang række resultater er indarbejdet her (Box 1-6).

Men ved siden af de mere projekt-specifikke undersøgelser, som selskaberne selv skal gennemføre i forbindelse med miljøvurdering og -overvågning af deres konkrete aktiviteter, er der stadig behov for regionale, strategiske studier. Der er allerede igangsat sådanne regionale strategiske studier i Disko West-området, syd for Baffin Bugt-vurderingsområdet, og i 2011 indledes flere studier som skal bidrage med yderligere baggrundsviden fra Baffin Bugt-vurderingsområdet.

Imaqarniliaq kalaalliisooq

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Nalunaarusiaq una Aarhus Universitetimi Nationalt Center for Miljø og Energi-mit (DCE) Pinngortitaleriffimmillu (GN) Aatsitassaanut Pisortaqarfik suleqatigalugu suliarineqarpoq.

Imartaq nalunaarusiami uani sammineqartoq 2010-mi neqerooruteqarfimmit anneruvoq (tak. Figur 1). Uuliaarluertoqarneratigut uuliakoorneq neqerooruteqarfiup avaterujussuanut siaruaassinnaanera tamatumunnga pissutaavoq.

Imartaq pineqartoq issittorsuarmiippoq taamaattumillu tamatuma uumasoqarnermut takussutissartaanik ilisarnaataasunik naapitsivissaalluni: Uumasui assigiinngisitaat amerlasoorsuunngillat, nerisareqatigiinnerit naatsuinnaapput, tamannalu annertoorujussuarmik uumasuaraaqqanit katersuusimaffiuvoq. Uumasulli assigiinngitsut amerlasoorsuunnginnerat illuatungilerneqarpoq uumasut tamaaniittut ilaasa amerlasoorujussuunerannik, uumasullu tmakkua ilaat tassaapput nerisareqatigiinnermi pingaaruteqarluinnartut. Tamatuma kinguneraa uumasunut nerisareqatigiinnermi qaffasinnerusumiittunut nerisareqatigiinnermi appasinnerusumiittut qaqugukkut sumilu takkusimaartarnerat apeqqutaalluinnartarmat.

Imartaq nalilersuiffigineqartoq uumassusillit/uumasoqatigiinnerullu tungaatigut pingaarutilerujussuuvoq. Upernaakkut sumiiffiit ilaanni tappiorarnartuliorneq annertoorujussuusarpoq, immap naqqani uumasoqatigippassuaqarpoq aammalu tamakkua timmissanut miluumasunullu imarmiunut pingaaruteqarluinnartuupput. Timmissanut tamakkununnga ilaapput (kalaallinut nunanullu allanut) pingaarutillit navianartorsiortut allattorsimaffianniittut, soorlu appat siggukitsut, mitit, taateraat, imeqqutaallat qilanngallu. Miluumasut imarmiut ilagaat (kalaallinut nunanullu allanut) pingaarutillit, soorlu nannut, aarrit, qilalukkat qernertat qaqortallu arfiviillu.

Uumasoqarfik pingaarutilerujussuaq tassaavoq Aakkarnersuaq, Qaanaap Ellesmere Islandillu akornanniittoq. Tamanna ukiuugaluartumiluunniit ammajuartuuvoq upernaakkullu eqqaminiittunut sikuusunut naleqqiullugu annertoorujussuarmik uumasuaqqanik pinngorarfiunerulluni. Taamaannera pissutaalluni miluumasorpassuarnik imarmiunik timmissanillu katersuuffissuuvoq, ilaatigullumi inuit tamatuma eqqaanut nunassivissinnaasimanerannut tamannarpiaq pissutaavoq. Assersuutigalugu aakkarnersuarmut tamaanga kalaallit sineriaanni nunarsuarmi appaliarsuit 80 %-ii sinnerlugit, aappariit 30 millionit sinnerlugit amerlassuseqarunartut, piaqqiortuupput. Timmissat miluumasullu imarmiut pingaarutillit tamakkua oqaatigineqartutut amerlaqalutik pingaartumik aakkarnersuarmiittarput.

Qalerallit kinguppaallu nalilersuiffigineqartup kujasinnerusortaani aningaasarsiutaapput aammalu tamaani sinerissami najugalinnut piniarneq aalisarnerlu inuuniutaapput pingaarutilerujussuit.

Uuliasiorfimmi ingerlataasartut tamarmiusut annertunerusumik avatangiisinut misilittakkat tunngavigalugit sunniuteqarnerusartut sapinngisamik salliutillugit nalilersorneqarput. Kalaallit Nunaannili uuliamik qalluinikkut misilittagaqanngimmat ingerlatamut taamaattumut tunngatillugu naliliinerit piviusunik tunngavilernagit allanili assingusunik atugaqarfiusuni misilittakkat sapinngisamik tunngaviginiarneqarput. Pingaartumik Alaskami Prince William Sound-imi 1989-imi uuliaarluerneq pillugu naqitarpassuit, aammalu norskit Barentshavet-mi (2003) uuliasiornermut tunngatillugu avatangiisinik nalilersuinerat, aamma Arktisk Rådip (Skjoldal *et al.* 2007) ”Arctic Oil and Gas Assessment”, internetimi (Link) ilaannakortumik pissarsiarineqarsinnaasoq, pissarsiorfigineqarput. Mexicanske Golf-imi 2010-mi aprilimi uuliamik aninasoorujussuarnerup avatangiisinut sunniutai suli nalilersorneqarnatillu nalunaarusiorneqanngillat taamaattumillu ikittuinnarnik uuliaarluerneq taanna uani nalunaarusiami taaneqarsimavoq.

Ilisimasatigut toqqammaviusut

Nalilersuinerni klimami pissutsit atuuttut toqqammavigineqarput. Kisiannili ukiuni qulikkuutaani aggersuni klimap allanngornerisa avatangiisinut sunniuteqalerumaarnerat ilimagineqarpoq. Pingaartumillu sikuusarnerata allannguuteqarnissaa ilimagineqarpoq. Tamanna inuuniarnikkut allanngornernik sunniuteqarumaarpoq aammalu artit ilaasa ikilinerannik najortagaasalu allanngornerannik artinullu allanut iluarusunnarnerusunik kinguneqarumaarpoq artillu nutaat takkusorlutillu tamaaniilerumaarput. Naliliinerni biologitut ilisimasat pigineqartut toqqammagivineqarput, naak arlalissuarnut tunngatillugu amigaateqartaraluartut. Misissuinerit arlalissuit 2008-mi ilisimasat toqqammaviusinnaasut pitsanngorsarniarlugit aallartinneqarput , nalunaarummilu uani inassutigineqarpoq suli amerlanerusunik misissuineqartariaqartoq ilisimasat toqqammaviusinnaasut suli pitsaaneruleqqullugit.

Ujarlerluni misissuineq

Ujarlernikkut ingerlatat utaqqiisaannaagallarput, amerlanertigut tamakkua ukiualuit ingerlasarput akuersissuteqarfimmilu tunniunneqartumi siamasissumik ingerlanneqartarlutik. Aammalu sikuersimanerata nalaani taamaallaat tamakkua ingerlanneqartarput, imaappoq aasaanerani ukiakkullu. Sajuppillatitsisarluni misissuinerit aamma ”site surveys” ukiuni kingullerni ilaanni novemberiulereeraluartoq ingerlanneqartarput. Misiliilluni qillerinerit septemberip naanerani sikunialinnginnerani unitsinneqarsimasussaapput, uuliaqarfik aniasuulissagaluarpat allamik periarfissaqassanngippat atugassamik sillimmataasumik qillerinissaq periarfissinniarlugu.

Ujarlerneq uuliaqarneranik, imaluunniit gassimik malussarfiunngippat ingerlatat unitsillugit atortut tamaasa peernissaat imminut akilersinnaavoq. Uuliamilli piffissap ”appraisal”-periode-p kingornagut iluaqutigineqarsinnaasumik nassaartoqarpat taava ingerlatat uuliasiorfiliorninngussapput nassaap sumut killeqarnera paasiniarlugu qillerinernik uuliamillu nassaamik piiaanissamut artulersorninngussaaq (ataaniittoq takuuk).

Ujarlernikkut ingerlatat sunniutiginerusartagaat tassa nipiliorluni ingerlatat (assersuutigalugu sajuppillatitsisarnerit, qilleriveqarfimmiit pisorpaluk aammalu helikoptererpalunneq) akornusersuinerat. Ilimagineqarpoq akornutit tamakkua annertoorsuussanngitsut aammalu/imaluunniit qanittuinnarmut sunniiumaartut, tassami sunniutit annertunerusut iliuuseqarnertigut pinngitsoorneqarsinnaammata, assersuutigalugu imartani piffissaniluunniit sunniuteqarfigiuminarnerni ingerlatsinnginnikkut. Kisiannili sajuppillatitsisarluni immikkut ittumik 3D-seismiske-mik misissuinerit sumiiffinni aalajangersuni ingerlanneqartartut annertuunik, qaangiukkumaartunilli, sunniuteqarsinnaapput.

Ukiuunera nipiliortunut misikkarinnerujussuuvoq, taamaalinerani ilaatigut qilalukkat qaqortat qernertallu, arfiviit, aarrit ussuillut takkusimaartarmata, ujarlernerilli ukiuunerani tamakkua takkusimaarnerisa nalaanni ingerlanneqartarnissaat ilimagineqanngilaq. Qilalukkalli qernertat aasaanerani pingaarutilimmik tamaani najortagaqarput, Qimussersiarsuarmi, aammalumi qilalukkat qaqortat qernertallu Qimusseriarsuaq, Upernaviup Uummannallu kommunii ukiakkut suli uuliasiornikkut ingerlatat uninngitsut ingerlaartarfigaat.

Sajuppillatitsisarluni annertuumik misissuinerit qalerallit qimagukkallartissinnaagunarpaat, misissuinerillu tamakkua aalisarfinni pingaartuni ingerlanneqarsimappata tamanna aalisarnermut akornutaasinnaavoq. Aalisakkanilli allanik misissuinerit takutippaat sunniut taamaattoq qaangiuteqqittartoq. Aalisakkat suffisarfii sajuppillatitsisarluni misissuinikkut akornuersuinermit sunneruminarnerpaatut isigineqartarput, qalerallilli nalilersuiffigineqartumi suffineq ajorput, taamaattumik tamanna taakkua suffisarnerannut ajornartorsitaanavianngilaq.

Sajuppillatitsisarluni misissuinerit kinguppaqarfinnut kinguppaallu tamaani immikkuutaartuunerannut sunniuteqassangatinneqanngilaq.

Miluumasut imarmiut neriniarfimminnit ingerlaartarfimminniillu pingaarutilinnit sajuppillatitsisarluni misissuinernit qimagutitinneqarnissaat aarleqqutigineqarsinnaavoq. Naatsorsuutigineqarporli akornusiineq taamaattoq qaangiuteqqikkumaartoq (sapaatip akunnialui qaammataaluilluunniit ingerlaneranni) ingerlataq uneriarpat.

Paasineqarporli qamutiliusat silaannarmik ingerlasut sajuppillatitsisarluni misissuinermi atorneqartartut naqitsineq pilersitaat aalisakkat suaannik tukerlaanillu toqutsisinnaasut ungasinnerpaamik 5 m ungasitsigisoq angullugu. Norgemi aarleqqutigineqarpoq annertoorsuarmik sajuppillatitsisarluni misissuinerit aalisagaqarfissuarni ingerlanneqartut aalisagaaqqanik ima amerlatigisunik toqutsisinnaasut aalisakkanut inersimasunut akuliussorneq sunnernerlussinnaallugu. Taamatorsuaq aalisagaaqqanik eqimmaffissuarnik kalaallit imartaanni peqanngilaq, amerlanerpaamillu eqiterunnerit upernaakkut pisarput suli sajuppillatitsisarluni misissuinerit aallartinngitsut. Taamaattumik naliliineqarpoq sajuppillatitsisarluni misissuinerit aalisagaaqqanut tukerlaanut suannullu sunniutaat aalisagaqatigiinnut malunnaatilimmik sunniuteqarnissaat aarleqqutigisariaqanngitsoq.

Misissuilluni qillerinerit aamma ingerlatanut nipiliortunut ilaapput. Maskinat sarpiillu, qilleriveqarfimmik puttasumik nikinnaveersaartitsisut (sumiiffinnimi tamani imaq itivallaartoq qillerivinnik immap naqqanut tunngasunik atuisinnaatitsinngimmat) tamakkua tamarmik sakkortuumik nipiliortuupput. Nipip tamatuma miluumassut imarmiut tatamisissinnaavai, arferillu tamatumunnga misikkarissorujussuusut oqaatigineqartarpoq. Qilalukkat qernertat, qaqortat, arfiviit aarrillu najugannaaminnit pingaarutilinniit nujutsinneqarnissaat aarleqqutigineqarsinnaavoq. Qilalukkanulli qaqortanut, arfivinnut aavernullu tunngatillugu aarlerinartoq annikitsuinnaavoq, tassami misissuilluni qillerinerup nalaa sivikitsumik ukiarluarneranilu aatsaat pisarmat. Aammalu arleqqutigineqarsinnaavoq aasaanerani tikaagulliusaanik, tikaagullinnik qipoqqarnillu nujutitsigallarsinnaaneq. Tamatumuuna piniarnissamut periarfissat sunnerneqarsinnaassapput ingerlatat piniarfiusartuni ingerlanneqarsimappata.

Ujarlerluni qillerinerup nalaani avatangiisinik sunniinissamut aarlerinarnerpaaq tassaavoq pikialasoorluni ajutoorneq ("blow-out")-imik taaneqartartoq annertoorujussuarmik uuliamik aniasoornermik kinguneqartartoq. Uuliaarluernerup kingunerisinnaasai ataani eqqartorneqarput.

Misiliilluni qillerinermi maralluk atorneqartarpoq qillerummut perrassaataallunilu qillikkami naqitsinermut aqutsissutaasarlunilu qillernerlukunik qilleriveqarfimmut qalluutaasartoq boremudder. Taanna imermik akoqarpoq ilaannilu immamut avatangiisimut aniatiinnarneqartarluni, taamaattulli uuliamik akullit, avatangiisinut ajoqutaasut ullumikkut nunamukaassorneqartarput tassani peqqissaartumik suliarineqassallutik imaluunniit toqqortorneqassallutik.

Kalaallit Nunaanni maralluk taamaattoq imermik akulik taamaallaat atorneqartussaavoq. Qeqertarsuup avataani 2010-mi pingasunik qillerinermi maralluk qillerinermi atortoq 6000 tonnes qillernerlukullu 2261 m^3 immamut aniatinneqarput. Kemikaliat akuliunneqartarajuttut ilaat imermik akoqarput, taamaakkaluartorli OSPAR'ip systemiani "aappaluttumik" nalunaaqutsigaapput, pingaartumik pissutigalugu arriitsuinnarmik tamakkua arrotikkiartorneqartarmata. Norskit imartaanni tamakkua atorunnaarluinnarsimapput, taamaalillunilu kemikaliat avatangiisinut ajoqutaannginnerusut "qorsuit" "sungaartullu" atorneqarlutik. Ilanngulluguli oqaatigisariaqarpoq Norgemi maralluk qillerinermi atorneqartoq uuliamik akulik aamma atorneqarmat, kisiannili piumasaqaataalluni taanna nunaliaallugu toqqorneqassasoq/suliarineqassasoq taammalu immami avatangiisinut aniatinneqassanngitsoq.

Kalaallit Nunaanni kemikaliat akuliunneqartartut "aappaluttut" atorunnaarnissaat anguniarneqarpoq. Qillerinikkulli pissutsit ajornartorsiutitallit pissutaallutik maannamut (2010-mi 2011-milu) akuerineqarsimavoq kemikalia akuliunneqartartoq "Aappaluttoq" ataaseq atorneqarsinnaasoq. Kisiannili kemikaliat akuliunneqartartut "qorsuit" "sungaartullu" siunissami atorneqaannassanersut nalilersorneqartariaqaraluarpoq issittumi atorlugit toqunartoqarsinnaanerat arrortikkuminassusiallu paasiniarlugu.

Maralluup qillerinermi atorneqartup qillernerlukullu aniatinneqarneratigut tamatuma qanittuani uumasut immap naqqani uumasuusut sunnerneqarsinnaanerat aarlerinarsinnaavoq aniatitsivimmiit qillernerlukunik aniatitsineq immamik isortunngortitsisarmat.

Nalilersuiffimmi maralluup qillerinermi atorneqartup qillernerlukullu aniatinneqarnerisa sunniutaat nalilersoruminaappoq, tassami uumasunut natermiunut tunngatillugu ilisimasat pigineqartut pissarsiarineqarsinnaasullu annertunngeqimmata. Ilimagineqarporli maralluk avatangiisinut ajoqutaanngimnerusoq atorneqarpat taava misissuilluni qillerivimmit ataasiinnarmit aniatitat sunniutaat annikitsuararsuujumaartut. Sunniutaasinnaasut pinngitsoorneqarsinnaapput maralluk qillernermi atorneqartoq qillernerlukullu maangaannaq aniatinnagit nunamukaassorneqartuuppata imaluunniit qillerinerup inernerani qillikkamut ikiorarneqaqqittartuuppata. Tamannali aamma avatangiisinut sunniuteqartussaammat taava aniatitsiinnarnissamit qanoq pitsaanerutiginersoq sanilliussuuttariaqassaaq.

Aammalumi misiliutaasumik qillerinerit nukissamik atuiffiusorujussuusarput, tamatumalu naatitsiviit gassiinik annertoorujussuarmik aniatitsineq kingunerisarpaa. Qeqertarsuup avataani 2010-mi qillerinerit pingasut kalaallit aniatitsinerata tamarmiusup 15 % -ianik annertusisitsipput.

Ineriartortitsineq tunisassiornerlu

Ujarlerluni ingerlatanut sanilliullugu uuliasiorfimmik ineriartortitsineq uuliamillu qalluineq sivisoorujussuarmik ingerlasarpoq (ukiuni qulikkuutaani arlalissuarni), tassanilu ingerlatat arlallit annertuumik ajortumillu avatangiisinik sunniisinnaasuupput. Sunniinerit tamakkua peqqissaartumik eqqarsaatigilluakkamillu pilersaarusiornikkut pinngitsoorniarneqarsinnaapput, soorlu periaatsinik "Health, Safety and Environment" (HSE) akuerineqartunik, "Best Available Technique" (BAT) aamma "Best Environmental Practice" (BEP) atuinikkut. Aniatitalli katersuunnerisa sivisuumillu sunniisimanerisa (assersuutigalugu erngup tunisassiornermi atorneqartup) siornani taaneqartut atorneqaraluartullunniit kingunerisartagaannut tunngatillugu ilisimasat amigaatigineqarput.

Imeq tunisassiornermi atorneqartoq (uuliamut ilanngullugu milluarlugu qallorneqartoq) immami avatangiisinut aniatitsinikkut aarlerinartorsiortitsisut pingaarnersaraat. Uuliasiorfik ullormut 30.000 m^3 angullugit aniatitsisinnaasarpoq, norskillu immap naqqani tunngavianni ukiumut aniatinneqartarpoq 174 millioner m^3. Ukiuni kingullerni erngup tunisassiornermi atorneqartup aniatinneqarnera isumakuluutaajartulersimavoq, naak imeq taanna salinneqarsimagaluartoq aammalu nunarpassuit avatangiisinut piumasaqaataat malillugit ingerlanneqaraluartoq. Aammalumi immami sikulimmi tunisassiornermi erngup atukkap aniatinnera immikkut ajornartorsiutitaqarpoq immap qaffasissumiittup kaajalukaarluni akuliussuunnera annikinnerusarmat. Tunisassiornermi imermut atorneqartumut tunngatillugu ajornartorsiut pinngitsoorneqarsinnaavoq imeq qallugaq utertillugu uuliaqarfimmut immiussuuteqqikkaanni, soorlu taamaaliornissaq norskit Barentshavemi uuliasiornermut atatillugu piumasarigaat.

Aniatitsinerujussuusinnaasoq alla tassa qillerinermi maralluup qillernerlukullu aniatinnerat, tassami annertuumik qillerisarneq uuliasiorfimmik tunisassiornermilu ineriartortitsinermi ingerlanneqartarmat. Ujarlerluni ataasiinnarmik qillerinikkut avatangiisinut sunniutaasartut qulaani eqqartorneqarput. Uuliasiorfimmik ineriatortitsinermi tunisassiornermilu aniatitat annertunerungaatsiaqaat taamaattumillu immap naqqanik annertunerusumik sunniisinnaanerat aarlerinarnerulluni. Aammalumi aarleqqutigineqarsinnaavoq aalisakkat sunnerneqarsimasumiittut mamaat uuliasunnimik sunnerneqarsinnaavoq ("tainting") uuliaminernit qillernerlukuniittunit. Maralluup qillerinermi atorneqartup qillernerlukullu avatangiisinik sunniineri pitsaanerpaamik pinngitsoorniarneqarsinnaapput taakkua marluk nunaliaallugit katersorneqarpata imaluunniit utertillugit qillersimasamut immiuteqqinneqarpata. Kisiannili maralluk qillerinermi atorneqartartoq imermik akulik avatangiisinut ulorianannginnerusunik akulik avatangiisit eqqarsaatigalugit akuersorneqarsinnaavoq.

Ineriartortitsinermi qalluinermilu nukik atorneqartartoq annertoorujussuuvoq, aamma uuliaqarfiusinnaassup annertoorujussuup Baffin Bugtimi nalilersuiffigineqartumi pilersinneqarnera annikigisassaanngitsumik Kalaallit Nunaata naatitsiviup gassiinik aniatitsineranik tamarmiusumik annertusisitsisussaavoq. Assersuutigalugu norskit uuliasiorfii Kalaallit Nunaata aniatitaata CO_2 –p tamarmiusup marloriaata sinnerlugu aniatitsipput.

Atortut sumut inissinneqarnerat taakunanngalu akornusersuinerit miluumasut imarmiut sunnersinnaavaat, neriniarfiinit pingaaruteqarluinnartuniit uteqqittussaajunnaarlugit nujutsillugit imaluunnit ingerlaartarfii allanngortillugit. Baffin Bugt-imi tunngatillugu pingaartumik qilalukkat qernertat, qaqortat arfiviit aarrillu eqqarsaatigineqarput. Tamatumalu aamma uumasut takkua piniarneqartartut piniarniarnerat ajornarnerulersissinnaavaa.

Tassunga atatillugu oqaatigisariaqarpoq sajuppillatitsisarluni misissuinerit uuliasiorfiup atuunnera tamaat ingerlanneqartarmata, tamatumalu sunniutai qulaani eqqartorneqartut uuliamik qalluinermi aamma atuuttarput taammalu taamaattuarnermikkut sunniuteqarnerlussinnaallutik.

Atortut nunamut inissinneqarneratigut nunami sunniutissaat nalilersorneqarlutillu sapinngisamik annikitsuutinniartariaqarput, taasami tamakkua nunap taamaattup takornarianit orniginneqarneranik annikillisitsisarmat.

Annertuumik helikopterimik angallannertaaq timmissanik miluumasunillu imarmiunik najortagaanniit pingaarutilinniit nujutitsisinnaavoq. Tamanna pinngitsoorniarneqarsinnaavoq aalajangersunik timmisartut timmiffilernerisigut aalajangersumillu portussusilimmik timmeqqusaanerisigut.

Ineriartortitsiviusuni qalluiffiusunilu atortut immap naqqaniittut (puilasut ruujorillu) aammalu qilleriveqarfiit aalajangersumik ilusillit aalisarnermut periarfissanik killiliijumaarput. Nalinginnaasumik sillimaniarnikkut killeqarfik/palleqqusaanngiffik atortunit taamaattunit 500 m ungasissusilimmiittarpoq.

Uulia qallugaq umiarsuit atorlugit aallarussorneqartussaavoq, taakkualu imaq ballasterisartik uuliamik usilersortinnatik maqillugu peeqqaartartussaavaat. Taamaallornikkut uumasunik tamaanimiuunngikkaluartunik kalaallit imartaanni takornartaasunik tikiussuisinnaaneq (imaappoq uumasut tamaaneereersut qerlerlugit amerliartortut) aarleqqutigineqarsinnaavoq. Aarlerinartoq tamanna minnerulersinneqarsinnaavoq erngup ballastiusimasup nunarpassuit imarsiornermut tunngatillugu kattuffianni IMO-mi piumasarineqartut malillugit suliarineqarneratigut.

Ajornartorsiut tamanna Issittumi imatorsuaq ajornartorsiutaasimanngilaq, kisiannili klimap kissakkiartornerata kinguneranik annertunerulernissaa ilimagineqarpoq.

Erseqqissartariaqarpoq ineriartortitsillunilu uuliasiulernissap kingunerisinnaasaanik siumut naliliiniarneq assut ajornakusoortuummat, tassami sumi inissisimanissaat, qanoq annertutiginissaat, qanoq sivisutigisumik ingerlanissaat ingerlatallu suunissaat aammalumi teknikikkut aaqqiissutit suut atorneqarnissaat ilisimaneqanngimmat.

Uuliaarluerneq

Uuliasiornermut atatillugu avatangiisinut ajornerpaamik sunniutaasinnaasut tassa annertoorsuarmik uuliaarluernerit. Tamakkua pisarput supisuusamik aniasoorujussuarnertigut ("blow-outs") qilleriviup ammarngata nakkutigineqarsinnaajunnaarneratigut imaluunniit uuliap toqqortorneqartup ingerlanneqartulluunniit ajutoorutaaneratigut, assersuutigalugu umiarsuup uuliamik assaartuutip ajunaarneratigut.

Uuliamik aniasoorujussuarnerit ullumikkut qaqutigoortorujussuanngorput, tassa teknikki isumannaallisaanerillu pitsanngorsarneqartuarmata. Aarleriunnaartariaqanngilarli, pingaartumik "frontier"-områdinik taaneqartartuni, kalaallit imartaattut ittuni iluliarsualinni, taamaattunimi ajutoornissaq ajunaarnissarlu aarlerinarnerusarmat. AMAP (Skjoldal *et al.* 2007) naliliivoq Issittumi uuliaarluernissaq uuliap assartorneqarneranut atatillugu aarlerinarnerpaasartoq.

DMI Baffin Bugtimi uuliaarluernerup tissukarfissaa assersuusiorlugu modeliliorsimavoq uuliaarluerfinnut sisamanut tunngatillugu. Tamatuma takutippaa avasissorsuarmi uuliaarluerneq sinerissamut anngutikulanngitsoq anngutinngivissinnaasorluunniit, ilaanneeriarlunili sineriak kilometerinik 100-ikkuutaanik arlalinnik uuliakoorfiusumiit ungasissusilik sunnerneqarsinnaasartoq.

Sinerissap qanittuani uuliaarluerneq imaannarmi uuliaarluernermi aseruinerpaasartutut isigineqartarpoq. Immamili Baffin Bugtenimisut ittumi taamatut ataatsimut isiginninneq allaasariaqarpoq. Tamatumunnga pissutaavoq sikoqarnera uuliamik tigooraasinnaallunilu sumorsuaq ingerlatsisinnaammat imatut annertunerusumik uuliaarluernermik arrortitsinani. Sikuli aamma immamut sikoqanngitsumut naleqqiullugu uuliaarluernerup siaruarnissaanik killilersimaarinnissinnaavoq . Immani sikulinni uuliaarluernerup qanoq pisarneranut tunngatillugu ilisimasat killilerujussuupput.

Imartat sinerissap qanittuaniittut uuliaarluernermit ajoquseruminarnerunerannut pissutaavoq uuliap assigiinngisitaartorujussuarnik uumasoqarfiit uumasorpassuallit, assersuutigalugu ammassat suffisut, ikkannersuit immap naqqani aarrit nerisartagaannik uumasullit timmiarpassuillu najugaat aqqusaartarmagit. Uulia iterlanni kangerlunnilu unissinnaavoq uuliap akui toqunartullit immami immallu naqqani uninngalersinnaallutik. Aarleqqutissaavortaaq uuliap immap naqqata sananeqaataanut, sissami tuapannut uiloqarfinnullu nippussinnaanera taammalu arriitsuinnarmik uulia avatangiisinut tamaaniittunut siaruarterusaarsinnaalluni sivisoorsuarmik sunniusimalluni, assersuutigalugu timmissanut sissamik qanittuanillu atuisunut. Aammalumi imartat nunap qanittuaniittut tamaani najugalinnit piniarfiullutillu aalisarfiupput.

Immami sikoqanngitsumi uuliap immap qaavani siaruartarnerata uulia arroriartupallannerulersittarpaa taamalu avatangiisinut sunniutai minnerulersittarlugit. Taamaakkaluartoq Baffin Bugtimi nalilersuiffimmi tamatumalu qanitaani imartani sinerissamiit ungasissumiikkaluartut uuliaarluernernit ajortumik eqqornerlunneqarsinnaanerat ilimagisariaqarpoq. Ilisimasalli pigineqartut naammanngillat taamaattut sumerpiamiinnersut tikkuarnissaannut. Taakkua, assersuutigalugu tassaasinnaapput frontzonit, pikialaarfiit, "up-welling"-ngeqarfiit sikullu tissukartut sinaavisa ilaat ("marginal ice zone"), tamaani immap qaavatungaani tappiorarnartunik naasuusunik uumasuusunillu upernaakkut annertoorujussuarmik pinngorarfiusut.

Immalli qaavani uuliaarluernerup kinguppaat qalerallillu, kalaallit aalisarnerannut pingaaruteqarluinnartut, sunnernavianngilai.

Timmissat immap qaavani uuliaarluernermit ajoquseruminartorujussuupput, Baffin Bugtimilu nalilersuiffiusumi timmiaqatigiippassuaqarpoq uuliaarluertoqassagaluarpat navianartorsiortinneqartussanik. Amerlasoorsuullutik piaqqiortartunut ilaapput appat, appaliarsuit, mitit, imeqqutaallat qilanngallu, aammalu mitit siorakitsut pingaartunik tamaani isasarfeqarput.

Miluumasut imarmiut aamma immap qaavani uuliaarluernermit sunnerneqarsinnaapput. Baffin Bugtimi nalilersuiffimmi misikkarilluinnartunik uumasoqatigeeqarpoq, taakkualumi misikkarequtaasa ilagaat inuit ingerlataannit allanit - pingaartumik piniarnermit, sunnerneqarsinnaareeramik. Tamakkua tassaapput qilalukkat qaqortat, qernertat aarrillu. Aarrit ussuillu pingaartumik immap natermiunik nerisaqartuupput taamalu nerisaminnut ilanngullugu uuliamik iijoraasinnaallutik. Missiissuinerittaaq nutaalluinnartut malillugit aarluit (taamatullu aamma arferit aamma allat) anersaarnerminni uuliaarluernermeersup uuliap aalaanik najuussusinnaanertik ulorianartorsiutigaat.

Nannut ulorianartorsiortikkuminarluinnartuupput, taakkuami meqqutik uuliaarlueraangata aluttorlugit salinniartarpaat taamaalillutillu uuliamik iijorakkaminnit toqunartoqalersinneqartarlutik.

Immami sikulimmi uuliaarluerneq qularnanngitsumik sukumi quppani sikutallu ataanni katersuuttassagunarpoq. Tamatuma timmissat miluumasullu imarmiut, immamik ammasumik pisariaqartitsilluinnartuusut aammalu eqalugaasat piaraat sikup ataani katersuusimasartut sunnersinnaavai. Miluumasut imarmiut sikumi imarnersani uuliaarluernikkut pikiarsaarsinnaapput taammalu uuliap aalaanik najuussuillutik.

Aalisarneq piniarnerlu sunnerneqarsinnaapput imartat uuliaaluerneqarsimasut ingerlatanut taamaattunut tamanut matuneqartarmata. Taamaaliortoqartarpoq aalisakkat uuliamut attuussimasut pisarineqarlutilluunniit tuniniarneqassanngimmata (uuliasunnilersimasinnaammata) imaluunniit tamanna pasitsaasimaneqaannaraangat. Uuliaarluertoqarneratigut aalisarnerup qaammaterpassuarni matoqqatinneqartarneranut assersuutissaqarpoq. Aarleqqutissaavortaaq piniagassat uuliaarluerneqartillugu piniaruminaannerusinnaanerat, aammalumi puisit amii uuliaarluernillit tuniniarneq ajornarluinnassapput.

Mexicop kangerliumanersuani *Macondo*-brønden-imiit uuliamik aniasoorujussuarneq immap itisoorsuup naqqani (1500 m missiliorlugu ititigisoq) pivoq. Tamatuma kinguneraa uuliap itissutsini assigiinngitsuni siaruartiternera. Uulia itissutsini tamakkunaniiginnarluni sumorsuaq tissukaalluni siaruarpoq. Baffin Bugtimi nalilersuiffigineqartoq taamatuttaaq ititigisunik ilaqarpoq. Uulia taamatut immap ikerinnaani pujuusanngorluni tamaaniilissagaluarpat itissutsini assigiinngitsuni misikkarissut (pinngorartitsineq, tappiorarnartut, aalisakkat kinguppaallu piaraat), pingaartumik uuliap immami ikerinanrmi taama pujuusanngorluni ikkannersuarnut anngutissagaluarpat ajoquserneqarnissaat ilimagisariaqarpoq.

Ilisimasat tunuliaqutaasut

Avatangiisinik nalilersuilluni suliaq aallartinneqarmat Baffin Bugtimi nalilersuiffiusumut tunngatillugu ilisimasat nalilersuinermi atorneqarsinnaasut amigaataanerat erseqqilluinnarpoq. Misissuinerit assigiinngitsut aallartinneqarput paasisallu assigiinngtsorpassuit suliamut uunga ilanngussuunneqarlutik (Boxe 1-6).

Misissuinerit suliamut tunnganerusut ingerlatseqatigiiffiit pinngitsooratik avatangiisinik nalilersuinermi nakkutilliinermilu ingerlatassaasa saniatigut najukkanut assigiinngitsunut tunngatillugu siumut sammisillugu misissuinissaq suli pisariaqartitsineqarpoq. Taamatut najukkanut aalajangersunut tunngatillugu misissuinerit aallartinneqareerput Disko West-imi, Baffin Bugtimi nalilesuiffiup kujataani aammalu 2011-mi misissuinerit amerlanerusut aalartinneqartussaapput Baffin Bugtimi nalilersuiffimmut tunngatillugu ilisimasat tunngaviusut suli amerlisarniarlugit.

1 Introduction

This document is a strategic environmental impact assessment (SEIA) of expected activities in the Greenland part of Baffin Bay. It was initiated and funded by the Bureau of Minerals and Petroleum (BMP), and prepared by DCE – Danish Centre for Environment and Energy (formerly known as National Environmental Research Institute – NERI) and the Greenland Institute of Natural Resources (GINR).

Many sources of information have been used, including impact assessments of oil activities from more or less similar areas. Especially the recent assessment from the Lofoten-Barents Sea area in Norway (Anonymous 2003a) has been drawn upon for comparison of potential impacts, because the environment there in a number of respects is comparable to West Greenland waters. Another important source of information is the Arctic Council's working group's (AMAP) Oil and Gas Assessment from 2007/8, which is under publication and is available in part on the AMAP homepage (Link). Also the extensive literature form the *Exxon Valdez* oil spill in 1989 has been a valuable source of information.

Several studies were initiated to supplement the background knowledge and fill data gaps relevant to this assessment. The results from these studies are included to the extend possible, as they have not yet been published in a scientific context. And for two marine mammals, polar bear and walrus, more detailed accounts are provided a.o. to present still unpublished information.

It is important to stress that a SEIA does not replace the need for site-specific Environmental Impact Assessments (EIAs). The SEIA provides an overview of the environment in the licence area and adjacent areas which may potentially be impacted by the activities. It identifies major potential environmental impacts associated with expected offshore oil and gas activities. The SEIA will also identify knowledge and data gaps, highlight issues of concern, and make recommendations for mitigation and planning. It is also part of the basis for relevant authorities' decisions (in this case a preliminary edition issued in 2008), and may identify general restrictive or mitigative measures and monitoring requirements that must be dealt with by the companies applying for oil licences.

Finally, an important issue in this Arctic context is climate change. This affects both the physical and the biological environment; as for example, the ice cover 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 conditions may then be very different from the present conditions described in this report.

1.1 Coverage of the SEIA

The offshore waters and coastal areas between 71° N to 78° N (from Uummannaq Fjord northwards to Smith Sound) are the area in focus, as this is the region which potentially can be most affected by hydrocarbon activities, particularly from accidental oil spills originating from oil activities in the licence blocks granted in 2010 (Figure 1). This area will be referred to as 'the assessment area'. However, the oil spill trajectory models developed by DMI indicate that oil may drift further, outside the boundaries of this area and into the Canadian EEZ (Nielsen *et al.* 2008).

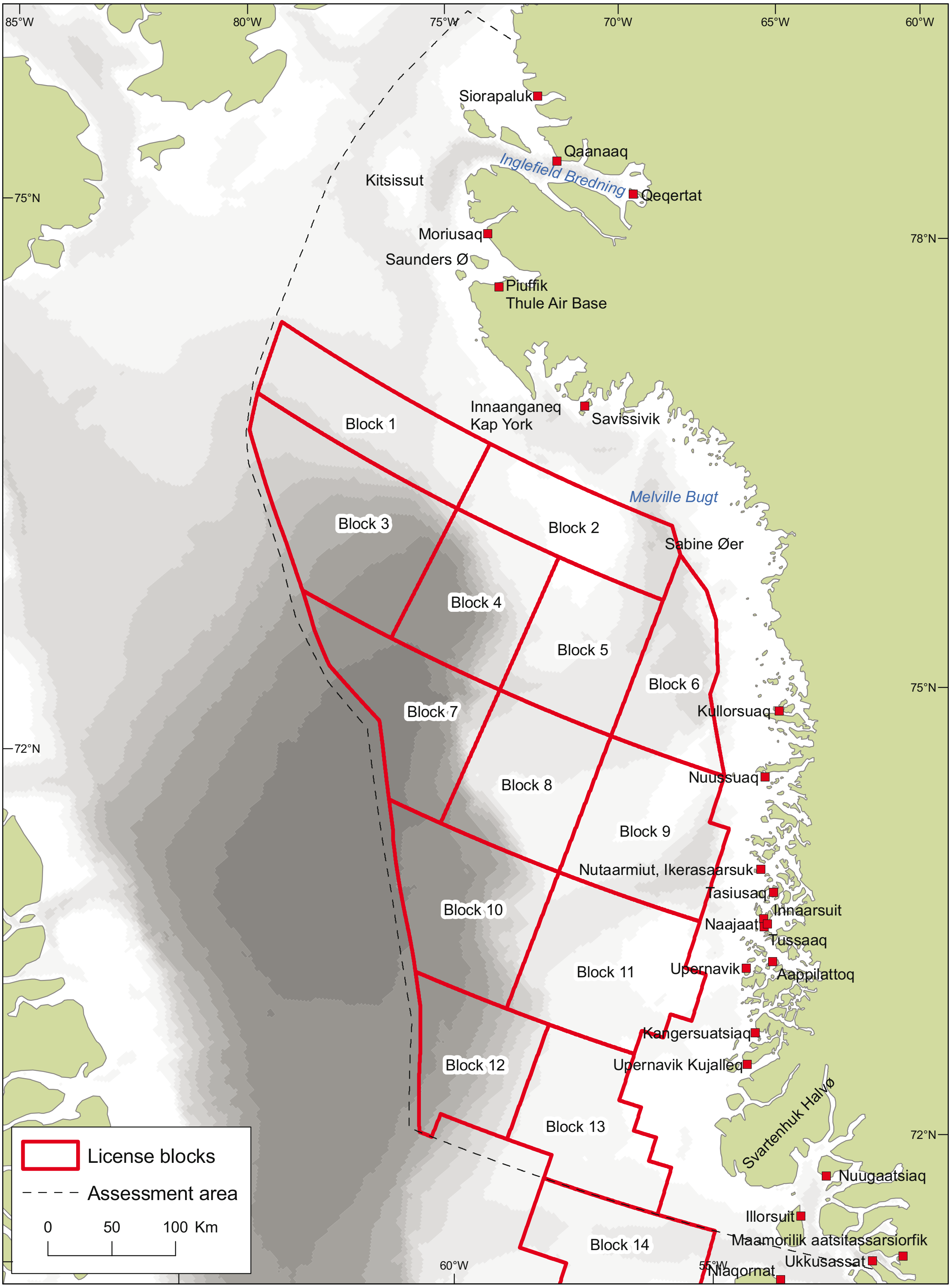


Figure 1. The Baffin Bay assessment area, the licence blocks and the adjacent areas. The most important places names are shown. Red dots indicate inhabited sites: Mainly towns and settlement. See also text. The southernmost block (14) is included by the SEIA covering the Disko West area (Mosbech *et al.* 2007a).

The assessment area extends over waters of the former municipalities of Uummannaq, Upernavik and Qaanaaq. The major towns in the area are Uummannaq, Upernavik and Qaanaaq and these are supplemented with three settlements in Uummannaq, 11 settlements in Upernavik and four in Qaanaaq. In total the region house 6200 inhabitants (Statistics of Greenland 2009).

To the south, the assessment area borders the former municipalities Qeqertarsuaq and Ilulissat. All the former municipalities in northwest Greenland (between Kangaatsiaq and Qaanaaq) are now merged to a single municipality covering entire northwest Greenland: Qaasuitsup Kommunia.

1.2 Abbreviations and acronyms

AMAP	Arctic Monitoring and Assessment Programme, working group under Arctic Council
ANS	Aquatic Nuisance Species
APNN	Ministry of Fisheries, Hunting and Agriculture, Greenland Government
BAT	Best Available Technique
bbl	barrel of oil
BC	black carbon
BEP	Best Environmental Practice
BFR	Brominated flame retardants
BMP	Bureau of Mineral and Petroleum, Greenland Government
BTX	Benzene, Toluene and Xylene components in oil, constitute a part of the VOCs
BTEX	Benzene, Toluene, Ethylbenzene and Xylene, constitute a part of the VOCs
CI	confidence interval
CRI	Cuttings Re-Injecting
CV	Coefficient of Variance
DCE	Danish Centre for Environment and Energy
DDT	Dichloro-Diphenyl-Trichloro-ethane
df	degrees of freedom
DMI	Danish Meteorological Institute
DPC	Danish Polar Centre
dw	dry weight
EAC	Environmental Assessment Criteria
EDCS	Endocrine-disrupting chemicals
EEZ	Exclusive Economical Zone
EIA	Environmental Impact Assessment
EPA	U.S. Environmental Protection Agency
FPSO	Floating Production, Storage and Offloading unit
GBS	Gravity Based Structure
GCM	General Circulation Models
GEUS	Geological Survey of Denmark and Greenland
GINR	Greenland Institute of Natural Resources
gww	grammes, wet weight
HCB	Hexachlorobenzene
HCH	Hexachlorocyclohexane
HOCNF	Harmonized Offshore Chemical Notification Format (OSPAR)
HSE	Health, Safety and Environment
ICES	International Council for the Exploration of the Sea
IMO	International Maritime Organization
IWC	International Whaling Commission
JCNB	Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga

LRTAP	Convention on Long-Range Transboundary Air Pollution
JNCC	Joint Nature Conservation Committee (UK)
MARPOL	International Convention for the Prevention of Pollution from Ships
MIZ	Marginal Ice Zone
NAO	North Atlantic Oscillation
NED	Nunavut Department of Environment
NERI	National Environmental Research Institute, Denmark.
NEW	Northeast Water Polynya
NGO	Non-Governmental Organisation
NMDA	N-methyl-D-aspartate
NOW	North Water Polynya
OBM	Oil based drilling mud
OC	organochlorines
OCH	Organohalogen contaminants
OSPAR	Oslo-Paris Convention for the protection of the marine environment of the Northeast Atlantic
PAH	Polycyclic Aromatic Hydrocarbons
PAM	Passive Acoustic Monitoring
PBDE	Polybrominated diphenyl ethers
PCB	Polychlorinated biphenyls
PFC	Perfluorinated compounds
PFOS	Perfluorooctane sulfonate
PLONOR	OSPARs list over substances which Pose Little Or No Risk to the Environment
PNEC	Predicted No Effect Concentration
POP	Persistent Organic Pollutants
pp	peak to peak (in units for sound pressure levels)
ppm	parts per million
ppb	parts per billion
PTS	permanent elevation in hearing threshold shift
rms	root mean squared (in units for sound pressure levels)
SBM	Synthetic based drilling mud
SEIA	Strategic Environmental Impact Assessment
SM	Synthetic drilling mud
TAB	Thule Airbase
TAC	Total Allowable Catch
TBT	Tributyltin
TPH	Total Petroleum Hydrocarbons
TTS	Temporary elevation in hearing threshold
USCG	United States Coast Guard
VEC	Valued Ecosystem Components
VOC	Volatile Organic Compounds
VSP	Vertical Seismic Profile
WAF	Water-accommodated fraction
WBM	Water based drilling mud
WSF	Water Soluble Fraction
ww	wet weight

2 Summary of petroleum activities

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 (see the guidelines to EIA of seismic surveys in Greenland waters issued by National Environmental Research Institute (NERI) in 2010 (Boertmann *et al.* 2010)). 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 (e.g. 500 m) lines.

Rig site investigations and shallow geophysical investigations use comparatively much smaller sound sources than used during 2D seismic surveys. For example, a company carrying out site surveys, used a single airgun (150 inch^3). Vertical seismic profiles (VSPs) are essentially small-scale seismic surveys carried out during exploration drilling. They are highly localised and of short duration (a few days), and their effects will be covered by the discussion of seismic surveys in general.

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 Baffin Bay is limited to summer and autumn by 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 approx. 450 m^3 cuttings are produced and approx. 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 in total 2262 m^3 cuttings and 6000 tonnes 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 mud is 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). However, OBMs are still used under conditions when they can be brought to land for treatment. The mud contains several chemicals to optimise the performance, and these chemicals may be toxic and slowly degradable.

Cuttings (the material drilled out from the well) and low toxic mud have usually been deposited on the sea floor surrounding drill sites, resulting in 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 related 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 low concentrations of 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 (south 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 (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, bio-accumulation, etc. (Meier *et al.* 2002, Rye *et al.* 2003, Armsworthy *et al.* 2005).

Due to environmental concerns in the Arctic environment, discharges should be further reduced, e.g. as done in the Lofoten-Barents Sea area (Anonymous 2003a), where produced water will be re-injected except during a 5 % 'off-normal' operation time (Anonymous 2003a).

2.8 Air emissions

Emissions to the air occur during all phases of petroleum development, including seismic survey and exploration drilling, although the major releases occur during development and production. Emissions to air are mainly combustion gases from 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 (SFT 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 trans-shipment.

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 Baffin Bay assessment area.

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

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 main issue of environmental concern for the marine Arctic environment is a large oil spill, which particularly in ice-covered waters represents a threat to animal populations and even to species.

3 Physical environment

This section only gives a short account of some of the most important physical components of the assessment area. Other components will be dealt with by the Danish Meteorological Institute (DMI *in prep.*), which previously reviewed weather, sea and ice conditions (Valeur *et al.* 1996).

The assessment area lies within the Arctic climate zone, which means that the average July temperature does not exceed 10° C. The Arctic zone is divided into the low Arctic (average July temperature higher than 5° C) and the High Arctic (average July temperature below 5° C). The major part of the assessment area is within the High Arctic zone. It is also far north of the Polar Circle, why continuous daylight is present during summer and there is a period of continuous darkness in the winter.

The most significant feature in the physical marine environment is the presence of icebergs and sea ice throughout a large part of the year (Section 3.4), and permafrost is widespread in the inland areas.

The offshore part of the assessment area is the Baffin Bay. The shelf (depths less than 200 m) is generally rather narrow, usually less than 50 km, compared to further south in West Greenland. Outside the shelf depths reach more than 2,000 m in central parts of the bay.

3.1 Weather

The weather conditions in the area are influenced by the North American continent and the North Atlantic Ocean, but also the Greenland Inland Ice and the steep coasts of Greenland have a significant impact on the local weather. Many Atlantic depressions develop and pass near the southern tip of Greenland and frequently cause very strong winds off West Greenland. 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 can be found in the sensitivity atlas for West Greenland which now cover the coast as far north as 75° N and which will be extended to 77° N during 2011 (Mosbech *et al.* 2004a, 2004b, Stjernholm *et al.* 2011, Link to sensitivity map).

3.2 Oceanography

3.2.1 Currents

Along West Greenland the West Greenland Current (WGC) flows with two principal components. Closest to the shore, cold polar water from East Greenland moves northward. On its way, this is diluted by run-off waters from the various fjord systems. The other component, from the North Atlantic, derives from the Irminger Sea. This relatively warm and high saline water can be traced all the way along West Greenland from Cape Farewell to Qaanaaq (Figure 2). The East Greenland Current component loses its momentum on the way north, and does not enter the waters of the assessment area.

The currents in the northern part of the assessment area, where the North Water Polynya is situated, is dominated by a strong southward flow of cold water and ice from the Arctic Ocean (Figure 3). Although most of the warm West Greenland

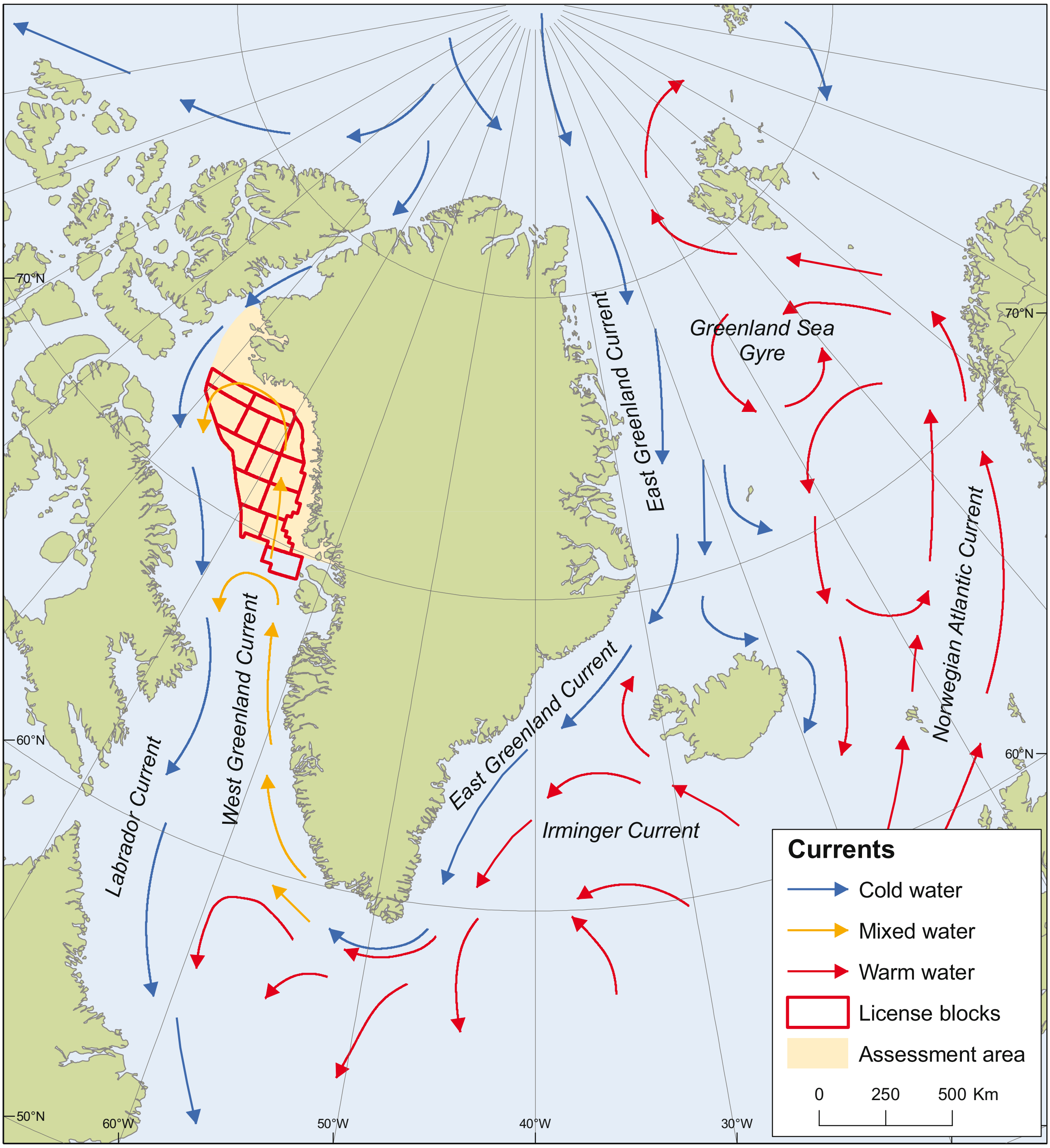


Figure 2. Major sea surface currents in the northern Atlantic.

Current crosses Baffin Bay to the south of the polynya, a branch provides a modest northward flow of warm water up the eastern side. When the inflow of ice from the north is blocked in Smith Sound, the continued drift out of northern Baffin Bay is sufficient to create the North Water, without oceanic heating. Cold Arctic waters of lower salinity flow over the remnant of the warm flow that continues northward. However, upwelling near the Greenland coast forced by Ekman transport brings the warm water to the base of the turbulent surface layer where it is mixed in (Melling *et al.* 2001).

The polar water inflow to the assessment area through the narrow Nares Strait north of the assessment area is strongest during spring and early summer (May-July). The inflow of Atlantic water masses from the south is strongest during autumn and winter.

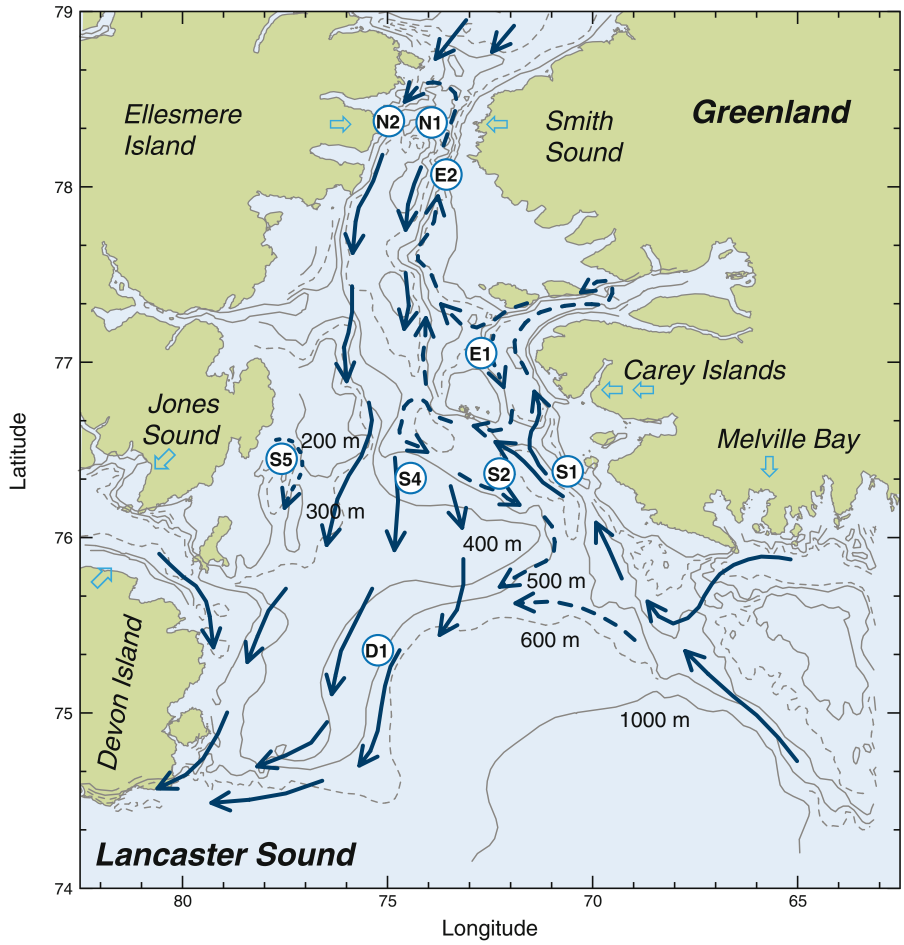


Figure 3. Schematic view of ocean circulation in northern Baffin Bay. Solid arrows represent the direction of motion throughout the water column, except in areas where dashed arrows indicate counter-flow at depth (from Melling *et al.* 2001).

A fifty-year long time series of temperature and salinity measurements from West Greenland oceanographic observation points reveals strong inter-annual variability in the oceanographic conditions off West Greenland. However, in recent years there has been a tendency towards increased water temperatures and reduced ice cover in winter (Hansen *et al.* 2006, Stirling & Parkinson 2006).

3.2.2 Bathymetry

The bathymetry of Baffin Bay with shallow sills both to the north and south creates a relatively isolated body of cold, deep, polar water, unique among the Arctic Seas.

3.2.3 Hydrodynamic discontinuities

Hydrodynamic discontinuities are areas where different water masses meet with sharp boundaries and steep gradients between them (Figure 4). They can be upwelling events where nutrient-rich water is forced upwards to the upper layers, fronts between different water masses or ice edges (inclusive marginal ice zones). Upwelling occurs often along the steep sides of the banks driven by the tidal currents, with upwelling usually alternating with downwelling. Hydrodynamic simulations performed as part of the Disko West assessment programme (just to the south of the assessment area) revealed some significant upwelling areas some of which are located within the present assessment area (Figure 5).

The upwelling described in Section 3.2.1 differs in the fact that it is relatively warm water which is forced to the surface, but it still carries the nutrients essential for the primary productivity (Melling *et al.* 2001).

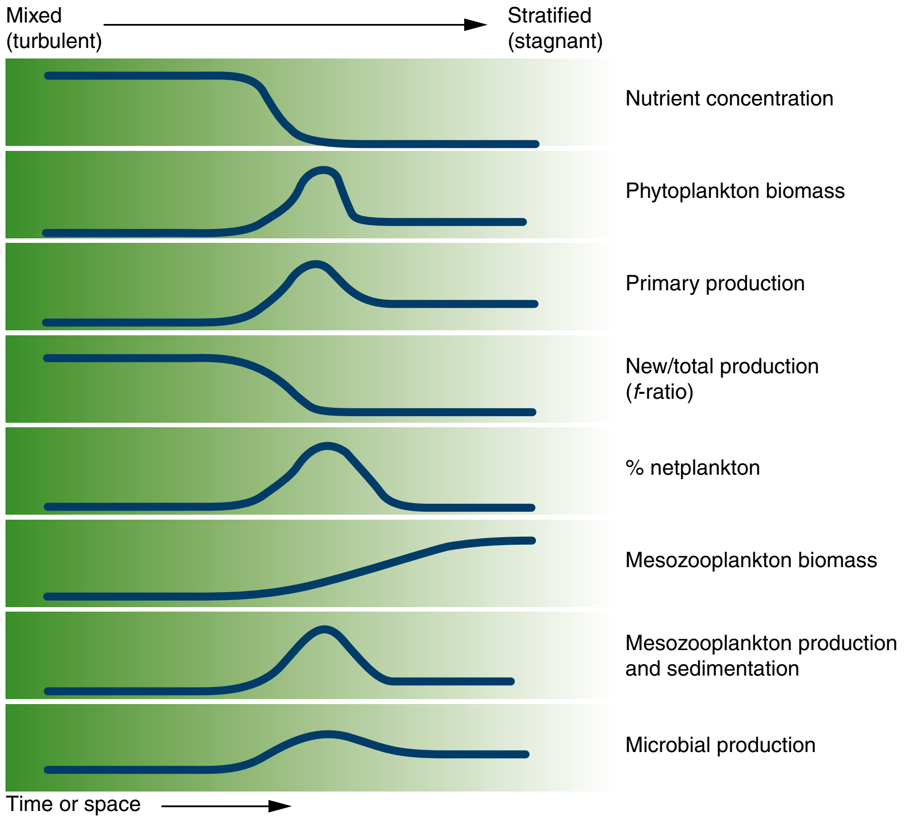


Figure 4. Enhanced biological activity is often found at sites with hydrographic discontinuities. Such can be defined in time, e.g. the shift from mixed water in the winter to stratified water in the spring or in space when two water masses meet or at the marginal ice zone where the frontal zone will provide better growth conditions for plankton and the succeeding links in the food web (Legendre & Demers 1984).

3.3 The coasts

The coasts of the assessment area are dominated by bedrock shorelines with many skerries and archipelagos. But there are also extensive areas dominated by basalts and sedimentary rocks as well as low shores with loose sediments. In the Melville Bay glaciers reach the coast over very long stretches (~ 400 km).

3.4 Ice conditions

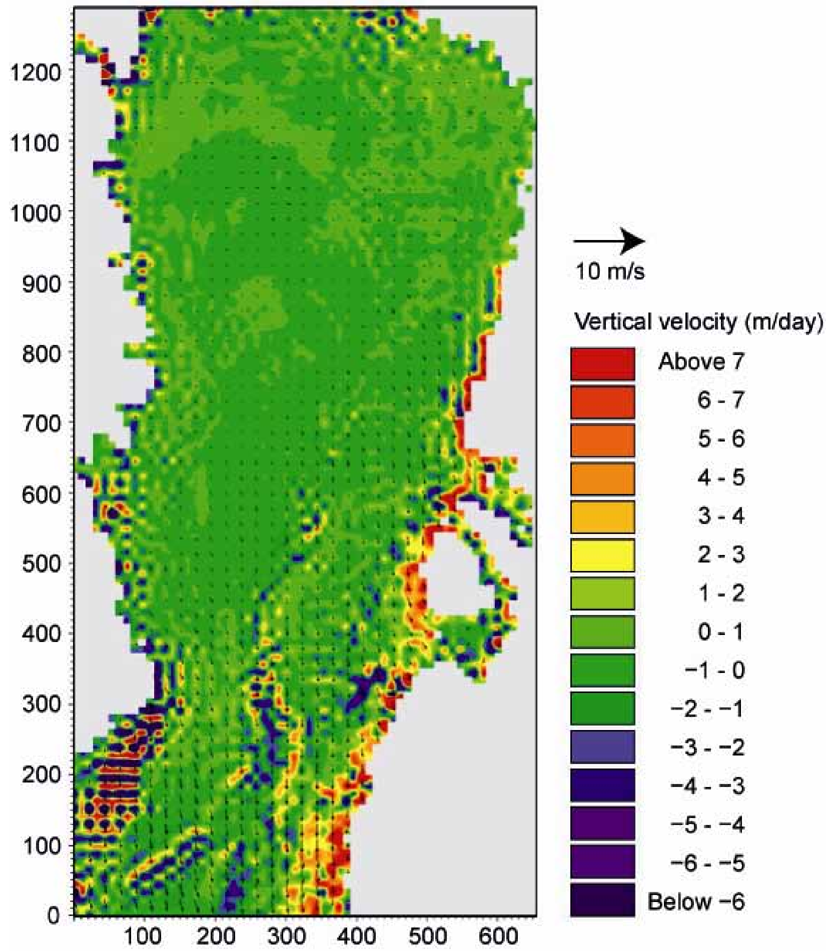
Two types of sea ice occur in the assessment area: fast ice, which is stable and anchored to the coast, and drift ice, which is very dynamic and consists of floes of varying size and density. The drift ice is often referred to as 'The West Ice' because it is formed to the west of Greenland. In addition to sea ice, icebergs originating from calving glaciers are very frequent. The description of ice conditions given here is based on a DMI contribution to the Oil Spill Sensitivity Atlas covering the coasts south of 72° N (Mosbech *et al.* 2004a).

3.4.1 The drift ice

Drift (or pack) ice is a significant feature of the Baffin Bay environment. During November and December ice gradually build up from the west and enclose the Greenland coast from January. The maximum extend of the ice is usually seen in late March, when the break-up slowly commences from southeast along the West Greenland coast (along the shear zone) towards north. In late July the area usually is completely ice free, although fields of drift ice may remain in the area throughout summer (Taylor *et al.* 2001).

The predominant sea-ice type in Baffin Bay is first-year (annual) ice. Small amounts of multi-year ice of Arctic Ocean origin drift to the western parts of the bay 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

Figure 5. Model results, when using a Hybrid Coordinate Ocean Model (HYCOM), showing the daily mean value of vertical velocity at 20 m depth, and wind speed in Baffin Bay. The present figure show daily mean value on the 24th of April, 2005, but it shows a frequent model feature during spring. The colour scale shows the daily mean value of upwelling velocity (m day^{-1}), and the arrows show wind speed. Large vertical velocity suggests up/down-welling or large mixing at 20 m. depth. For this specific date there is strong upwelling along the Greenland west coast, especially near the Store Hellefiskebanke, which has an approximate coordinate on the map at (300,300). Large vertical velocities as presented here is a very common model feature during late winter and spring 2005. Within the assessment area the vertical currents are found only along the coats. The present model set up is described in detail in Ribergaard *et al.* (2006).



about 100 km from the Greenland coast). Western and central parts of Baffin Bay are dominated by medium and thick first-year ice categories, mixed locally with small amounts (1-3 tenths) of multi-year ice (Figures 6, 7). The thickness of the drift ice at end of freeze-up increases towards the north, from approx. 75 cm off Disko Island to 120-150 cm in the northern Baffin Bay (in a severe winter), and the land fast ice in Melville Bay is probably even thicker, 130-180 cm (Valeur *et al.* 1996).

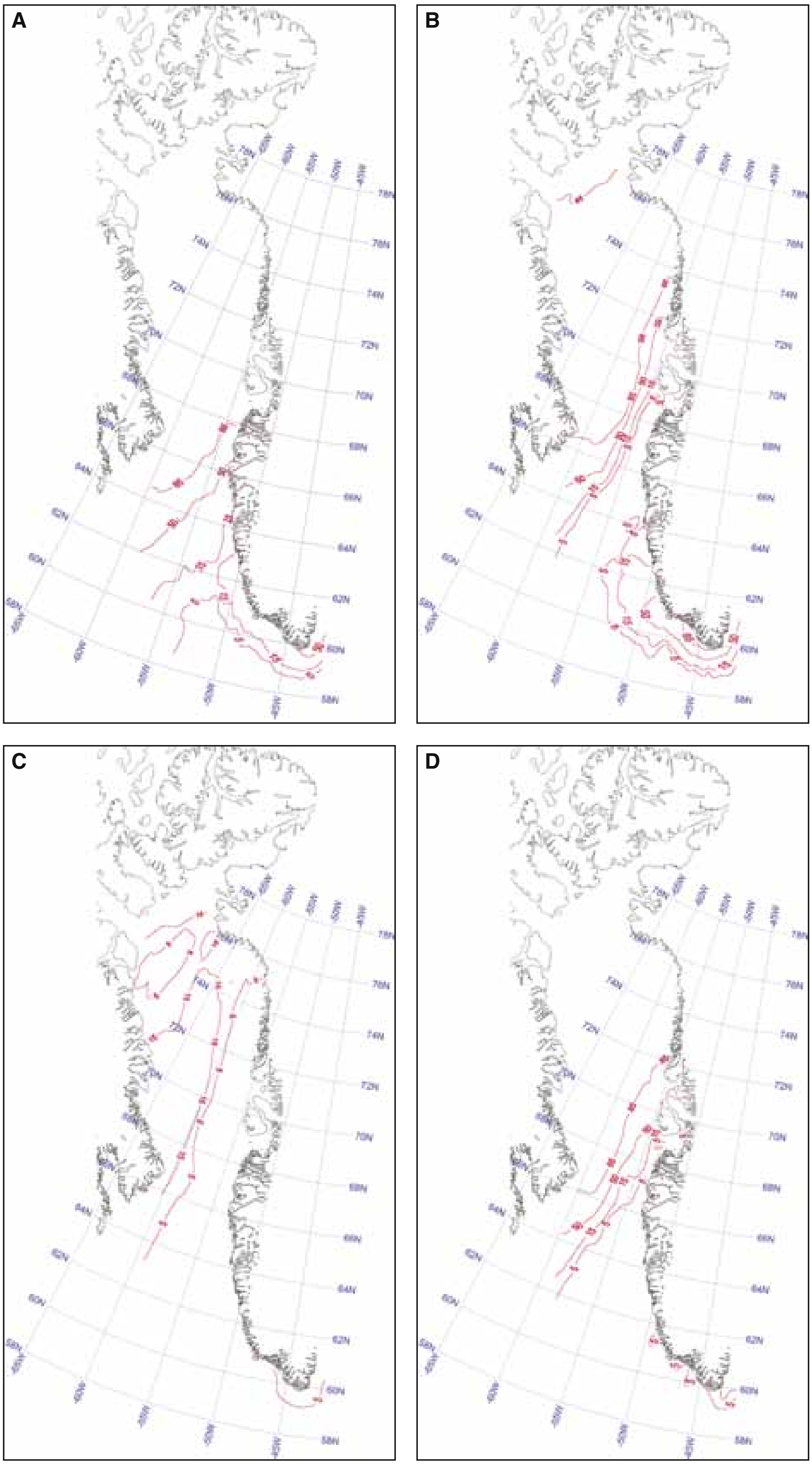
The dominant size of ice floes ranges from less than 100 m wide to vast floes larger than 50 km. These floes are often made up of consolidated lesser floes and they continuously break apart and freeze together. In recent years both the extension of the winter ice and the ice cover period has been reduced (Stirling & Parkinson 2006, Parkinson & Cavalieri 2008).

3.4.2 Sea-ice drift

The drift pattern of the sea ice off West Greenland is not very well known. 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. The drift pattern was studied in the southernmost part of the assessment area in April 2006 (Figure 8) and an earlier study is presented in the DMI review (Valeur *et al.* 1996).

Isolated from the offshore ice conditions, sea ice forms locally throughout the winter in most of the fjords and coastal waters of the region. Generally freeze-up begins at the inner parts of the fjords in October or November.

Figure 6. Probability of sea ice in West Greenland offshore waters based on data from the period 1960-96. (**A**) March the 1st, (**B**) June the 4th, (**C**) September the 3rd, (**D**) December the 3rd.



3.4.3 Polynyas and shear zone

Polynyas are open waters surrounded by sea ice. They are predictable in time and space, and are of a high ecological significance. The most important polynya of the assessment area is the North Water (NOW) in the entrance to Smith Sound. This was during the International North Water Polynya Study in 1997-1999 shown to be the most productive area in the Arctic (Deming *et al.* 2002).

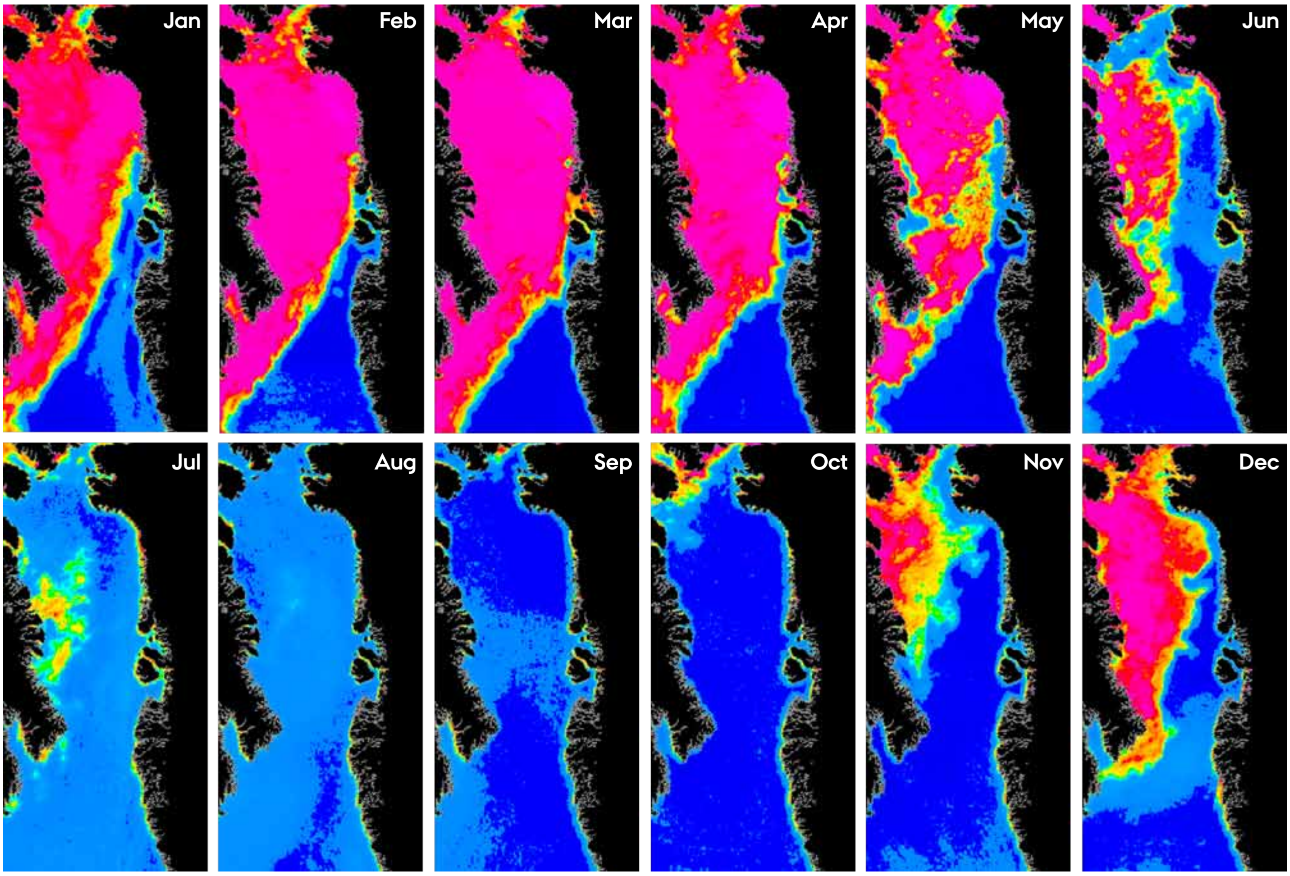


Figure 7. Distribution of ice in the Baffin Bay area in 2010. Images based on Multichannel Microwave Radiometer (AMSR and SMMR. Red and magenta indicate the very dense ice (8-10/10); while yellow indicate somewhat looser ice. The loosest ice (1-3/10) is not recorded. (Data sources: DMI).

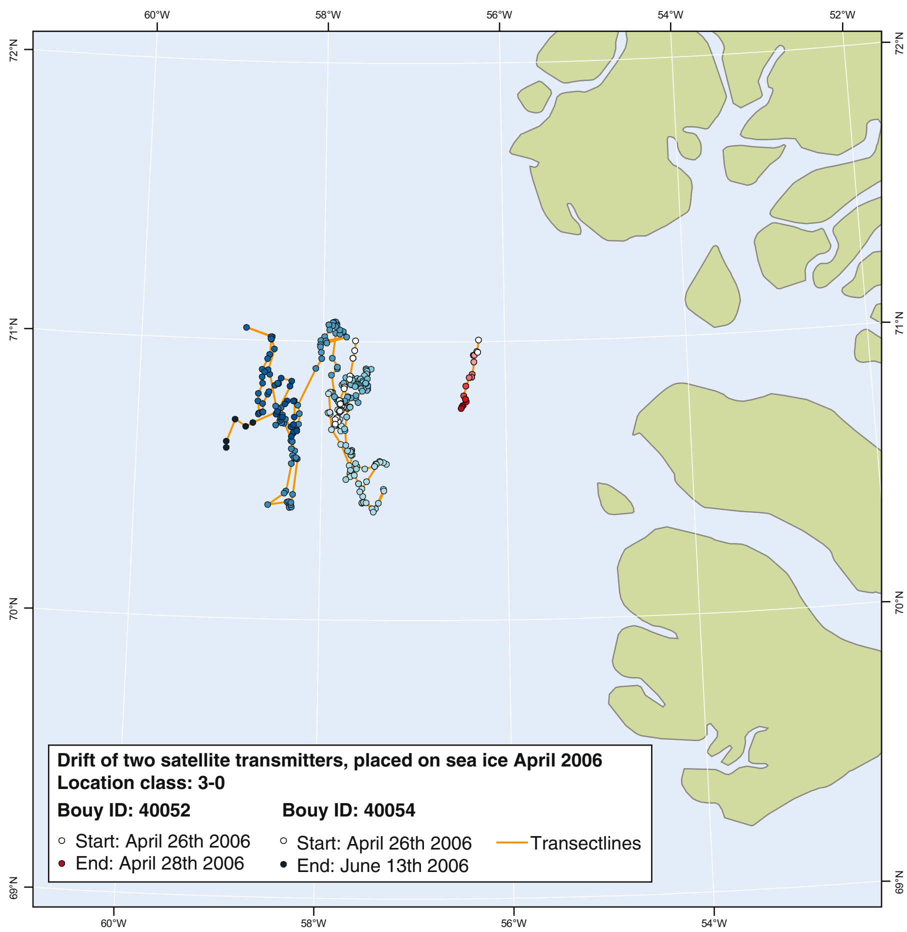


Figure 8. Drift of two buoys equipped with satellite transmitters deployed in the drift ice just south of the assessment area on 27th April 2006. One stopped transmitting after only two days, when it had moved 21 km to the south. The other was tracked until June 13th. The track of this buoy is approx. 500 km long, but overall it only moved 66 km towards south-west. Source DMI (study carried out at the request of BMP and GEUS).

The North Water evolves seasonally from a relatively small area in winter, where ice is thinner than elsewhere, to a large area of ice-free water in June and ultimately in summer ceases to exist as a distinct ice-bounded region within Baffin Bay. Although the area often has 95% ice cover in January, this ice is mobile and criss-crossed by open leads (Melling *et al.* 2001).

Smaller polynyas are found at several sites along the Greenland coast. Moreover, a shear zone occurs (with open cracks and leads) between the land fast ice and the drift ice, and this is also very important to marine mammals and seabirds, particularly in spring when populations are migrating northwards. In this shear zone, open water gradually extends northwards during the spring.

3.4.4 Icebergs

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

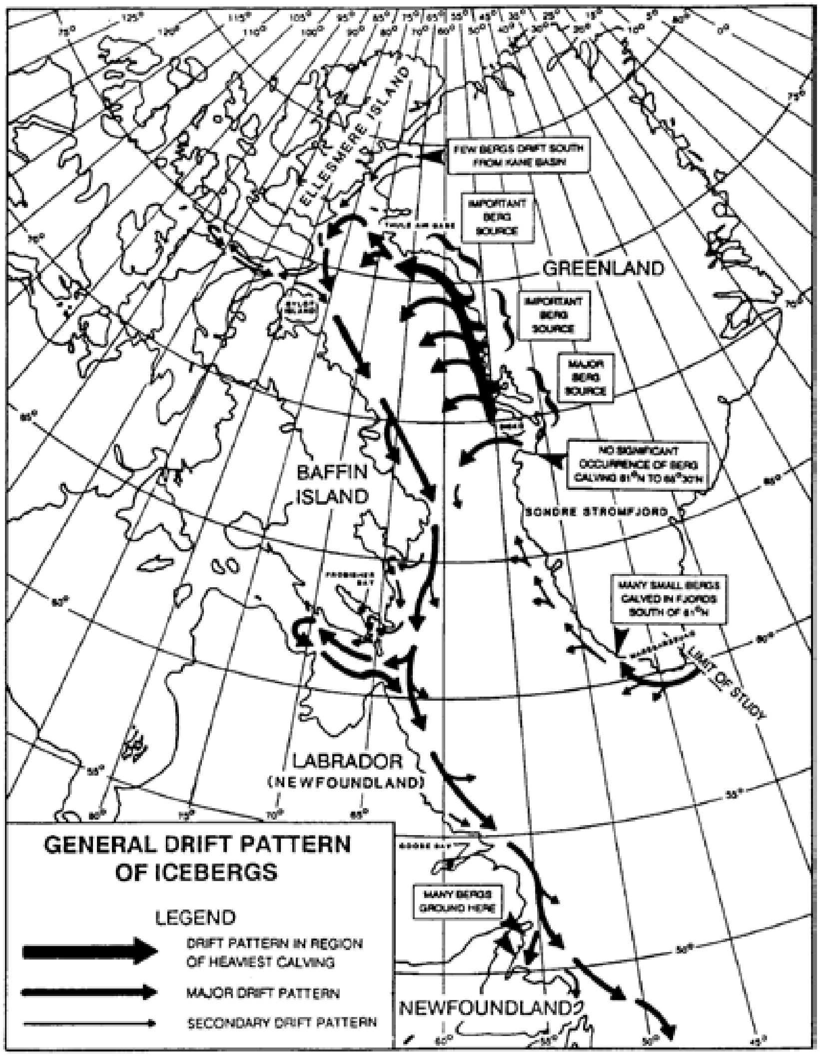
The production of icebergs on a volumetric basis varies only slightly from year to year. Once calving is accomplished, meteorological and oceanographic factors begin to affect the icebergs. Icebergs are carried by sea currents directed by the integrated average of the water motion over the whole draft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

Iceberg sources
Glaciers are numerous in the coastal parts of the assessment area, and the most productive glaciers in West Greenland are in fact concentrated between Nares Strait and Disko Bay, including the assessment area.

Melville Bay north of the former Upernavik municipality is a major source of icebergs. Thousands of icebergs are calved from 19 major glaciers each year (Figure 9). The volume produced in this region was estimated at 60 km^3 annually. Some of these glaciers are capable of producing icebergs of about 1 km in diameter. Several active glaciers in Uummannaq Fjord and Disko Bay produce 10-15,000 icebergs per year (95 km^3) creating a significant input of icebergs to Baffin Bay. The total annual production of icebergs calved in the Baffin Bay and the northern Davis Strait was estimated to be about 25-30,000; estimates however vary, up to as high as 40,000 (Valeur *et al.* 1996). Climate change may have changed these estimates considerably.

Iceberg drift and distribution
On a large scale the basic water currents and drift of icebergs in Baffin Bay and the northern Davis Strait are fairly simple (Figure 9). There is a north-flowing current along the Greenland coast and a south-flowing current along Baffin Island and the Labrador coast, giving an anti-clockwise drift pattern. However, branching of the general currents causes variations, and these can have a significant impact on the iceberg population and their residence time. Although the majority of icebergs from Disko Bay are carried northward to northeastern Baffin Bay and Melville Bay before heading southward, icebergs have also been observed to be diverted into one of the west-branching eddies without passing north of 70° N. 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 area west of Disko Island instead. Icebergs produced in Disko Bay or Baffin Bay gener-

Figure 9. Major iceberg sources and general drift pattern of icebergs in the West Greenland Waters (US National Ice Centre, Washington DC).



ally will never reach the Greenland shores south of 68° N. During the 2010-drilling by Capricorn in the Disko West-area, icebergs were tracked and local movements deviated considerably from the general pattern described above.

Iceberg dimensions

The characteristics of iceberg masses and dimensions off the west coast of Greenland are poorly investigated, and the following is mainly based on a Danish study in the late 1970s (Valeur *et al.* 1996).

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. In Disko Bay, the average mass of icebergs was in the range 5-11 million tonnes with a maximum recorded mass of 32 million tonnes. Average draft was 80-125 m and maximum draft was 187 m. It is worth noting that many icebergs are deeply drafted and, due to the bathymetry, large icebergs will not drift into shallow water regions.

The measurements of iceberg drafts north of 62° N indicate that an upper limit of 230 m will only be exceeded very rarely; however, no systematic 'maximum draft measurements' exist and the extremes remain unknown. The largest icebergs originating in Baffin Bay are expected to have a maximum draft of about 250-300 m, and the largest iceberg recorded in a study there in 1997 were characterised by a draft of more than 260 m, a mass of up to 90 million tonnes and a diameter of more than 1,400 m. Icebergs from the highly productive Ilulissat glacier pass a sill which allows for a maximum draft of 250 m.

4 Biological environment

4.1 Primary productivity

M. Frederiksen and K. Johansen

4.1.1 General context

From an Arctic perspective, the shelves around Northwest Greenland are 'outflow shelves' (*sensu* Carmack & Wassmann 2006), i.e. regions where the dominant flow is of cold, nutrient-poor water from the Arctic Ocean into the northern Atlantic. Such regions are generally less productive than 'inflow shelves' such as the Barents Sea. Furthermore, Arctic waters are primarily 'beta oceans' (*sensu* Carmack & Wassmann 2006), where the most important permanent stratification mechanism is a salinity gradient. Beta oceans generally have a brief and intense phytoplankton bloom immediately after ice break-up, characterised by high (transient) biomass and a grazing food web dominated by large copepods, but relatively low total primary production integrated over depth and season. However, this general picture is modified by the presence of large polynyas, where early ice break-up and availability of nutrients from upwelling lead to locally very high production.

The ice-free period in high-Arctic areas around Northwest Greenland is generally 3-4 months, but in polynyas may be >6 months. Occasionally some areas are dominated by heavy drift ice throughout the summer. Three sources contribute to total primary production: phytoplankton, ice algae embedded in fast or drift ice, and benthic algae. The relative importance of the three sources is likely to vary geographically with depth and extent of ice cover. In Lancaster Sound in high- Arctic Canada, Welch *et al.* (1992) estimated that phytoplankton contributed 90%, ice algae 10% and benthic algae 1% of the total primary production. Similarly, Søreide *et al.* (2006) found that the primary carbon source for pelagic grazers in marginal ice zones of the Barents and Greenland seas was phytoplankton, but that the contribution from ice algae was locally important. Ice algae are also expected to be relatively unimportant producers in polynyas (Michel *et al.* 2002).

In addition to the magnitude of total primary production, it is important to know the strength of the benthic-pelagic coupling, or in other words how much of the produced organic carbon is recycled through the microbial loop, how much remains available to pelagic consumers, and how much is 'lost' through sinking to the bottom, thus becoming food for benthic fauna. Several studies have attempted to quantify the various pathways of organic carbon through planktonic ecosystems in the Arctic, but general conclusions have been difficult to achieve. This is partly because primary production varies considerably among the different Arctic regions, due to differences in hydrography and thus physical forcing.

The assessment area is highly heterogeneous in terms of ice cover and thus primary productivity. The northern part of the area is dominated by the large North Water Polynya, which is one of the most biologically productive marine areas in the Arctic. This area is also relatively well studied. Further south, the ice-free period in Melville Bay and Baffin Bay is much shorter, although the whole region becomes ice-free during most summers. A number of small polynyas are present along the Greenland coast. The whole region south of the North Water Polynya is very poorly studied. In the following, we review published studies of primary productivity in the assessment area, and supplement this with a series of maps of satellite-derived estimates of surface chlorophyll concentration.

4.1.2 The North Water Polynya (NOW)

The North Water is one of the largest (~80,000 km^2) and biologically most productive polynyas in the Arctic and is exceptionally important for consumers at higher trophic levels, including humans. Nevertheless, until fairly recently very little was known about the ecology of the area due to logistical constraints. Preliminary data were collected during a brief cruise in 1991 (Lewis *et al.* 1996). The physical, biological and bio-geochemical processes were studied intensively during the international North Water Polynya Study in 1997-99 (Deming *et al.* 2002), leading to a better ecological understanding of this productive region than of any other part of the assessment area. However, few more recent in situ data are available. Exceptionally for Arctic areas, phytoplankton biomass and primary productivity were high throughout the ice-free period (April-October), although a clear peak was present in early June (Tremblay *et al.* 2006b). Annual primary production was among the highest recorded in the Arctic (average for the whole polynya: 251 g C m^{-2} yr^{-1}), dominated by large producers such as diatoms (Klein *et al.* 2002), particularly *Thalassiosira* spp. and *Chaetoceros socialis* (Booth *et al.* 2002). Despite the importance of diatoms, total primary production was most likely limited by nitrate rather than silicate (Tremblay *et al.* 2002). Most of this production was channelled through the grazing food chain, and a relatively small proportion (~20 %) was lost through sinking to the benthic system (Tremblay *et al.* 2006a). This implies that most of the local secondary production was available to plankton consumers, including larger zooplankters, fish, marine mammals and planktivorous seabirds. The bloom started in the eastern part of the polynya, where ice break-up and attendant stratification were earliest due to the relatively warm West Greenland Current, and progressed westwards over the season (Odate *et al.* 2002, Tremblay *et al.* 2002). The extremely early start of the bloom (April, similar to temperate oceans) was likely due to stratification (shallow mixing) in the eastern part of the polynya (Tremblay *et al.* 2006b). The prolonged phytoplankton bloom was likely maintained by storm-driven admixture of nutrients (primarily nitrate) from deeper waters (Lovejoy *et al.* 2002, Tremblay *et al.* 2002, Tremblay *et al.* 2006b), and it is possible that the bloom would be more short-lived in years with fewer storms during spring and summer. During cruises in late summer and early autumn 2005 and 2006, Martin *et al.* (2010) found a distinct subsurface chlorophyll maximum at ~20 m depth in the North Water, and suggested that this might account for a substantial proportion of total primary production.

There are many interactions between the mesoplankton (i.e. diatoms-zooplankton) and microbial food web. The microbial food web is complex and its internal and external pathways web change with seasonal development (Berreville *et al.* 2008). In this regard NOW differs from the North East Water polynya in Northeast Greenland (NEW) where the interactions are less complex. This is probably caused by differences in their longevity, i.e. the longer-lived NOW polynya having more time to develop complex trophic interactions.

4.1.3 Baffin Bay and Melville Bay

This region, constituting most of the assessment area, is poorly studied in terms of primary production, at least partly because of logistical issues due to high ice concentrations and a short open-water season. During summer, a distinct subsurface chlorophyll maximum was found in northern Baffin Bay (Harrison *et al.* 1982, Herman 1983), and primary production was similar to other Arctic and Antarctic waters (Harrison *et al.* 1982). Jensen *et al.* (1999a) measured primary production in the southernmost part of the assessment area during summer and found that it was similar to areas further south along the West Greenland coast (*cf.* Söderkvist *et al.* 2006).

4.1.4 Satellite-derived maps of estimated surface chlorophyll concentration

In Figure 11, a series of maps are presented showing estimated monthly (April-September 2003 and 2007) mean surface chlorophyll concentration, based on data from the MODIS Aqua satellite.

Several important caveats apply to these maps. Firstly, the satellite sensor can only detect chlorophyll at the surface, and the resulting images thus only produce reliable indices of total chlorophyll concentration if there is a consistent relationship between surface and total chlorophyll. This is not likely to be the case, and the maps should be interpreted with this in mind. Secondly, there is some uncertainty regarding the scale of conversion of satellite readings to chlorophyll concentrations, so absolute estimated concentrations should not be given much weight. Relative spatial and temporal patterns are likely to be more reliable. Thirdly, although the maps represent monthly means, data are still missing for some areas (shown as white on the maps). White areas may represent e.g. sea ice, areas with too little incident light to get proper readings (mainly in northern areas in September), or areas with very high cloud concentration. In many cases, the ice edge can be reliably detected from these maps, but, for example, irregular white areas in central Baffin Bay in August-September are more likely to represent extremely high and persistent cloud concentration.

Despite the high annual and seasonal variation in ice cover, some spatiotemporal patterns were recurrent between years. For example, the pronounced early bloom in NOW in May-June was apparent in all years, although the intensity and spatial extent varied. Widespread surface blooms were also observed in the south-eastern part of the assessment area in 2006 and 2007. In addition, a small but highly regular coastal bloom occurred every year in the Upernavik area.

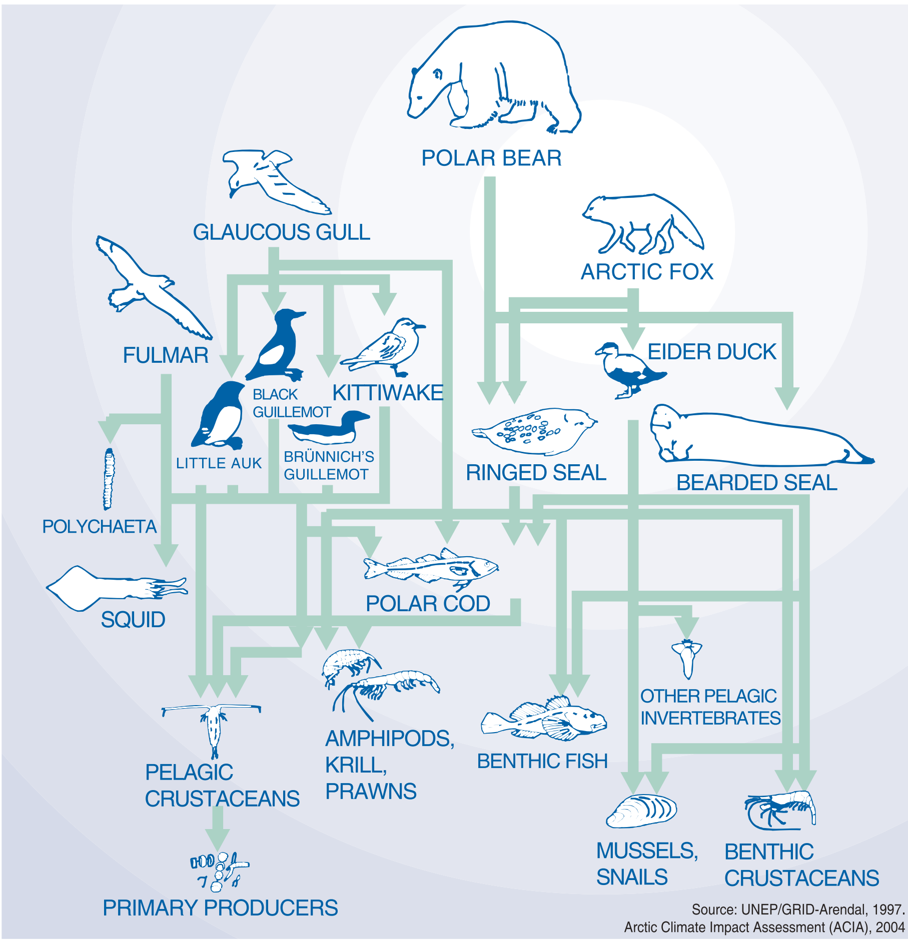


Figure 10. A schematic description of the interactions in the marine Arctic environment.

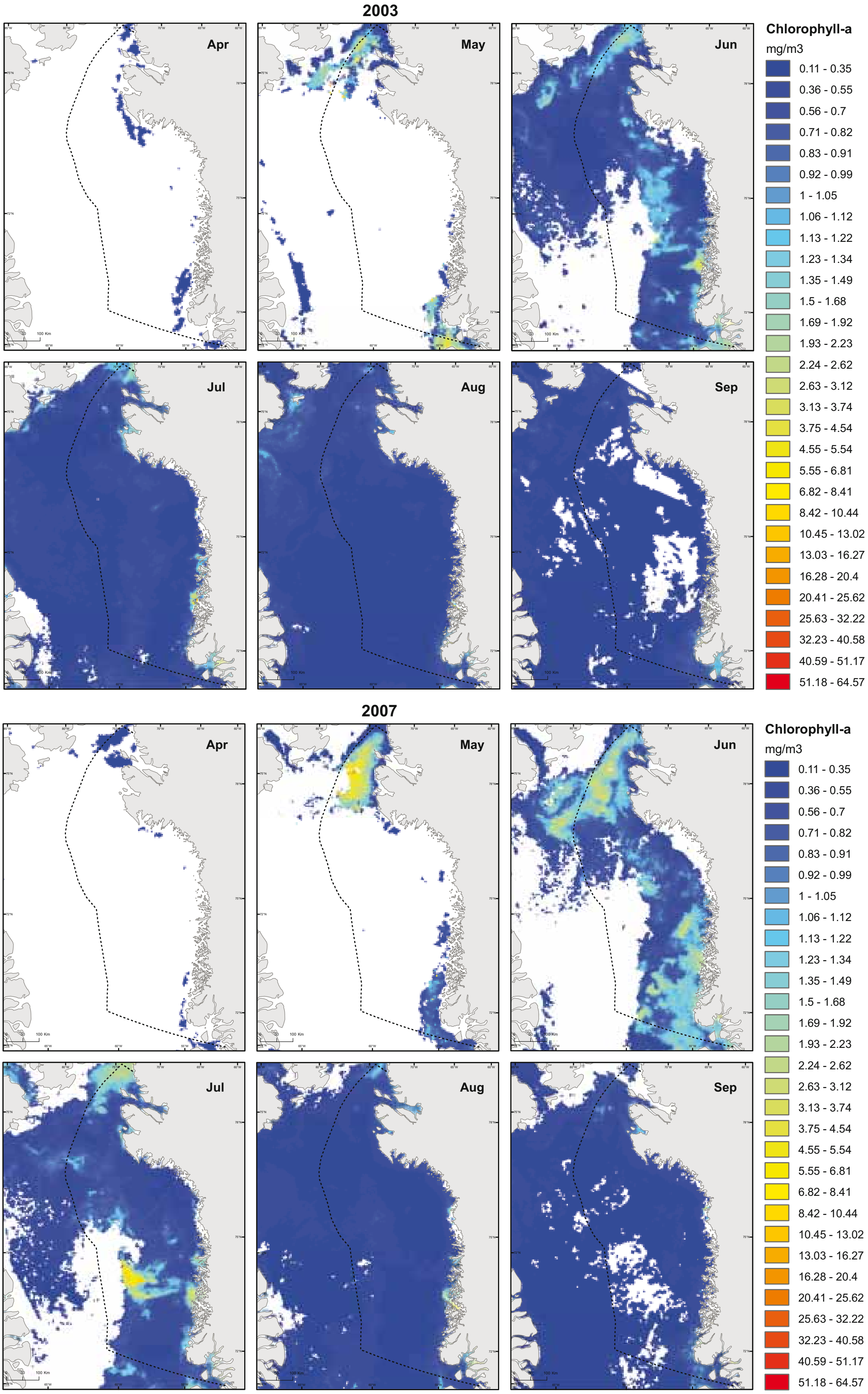


Figure 11. Estimated monthly mean surface chlorophyll concentration in the period April-September 2003 and 2007 in the Baffin Bay area. The map is based on level 3 data from the MODIS Aqua satellite sensor and downloaded from OceanColorWeb (http://oceancolor.gsfc.nasa.gov). The spatial resolution used was 4 km, and 16-bit satellite readings were converted to chlorophyll concentrations using the equation: Chl (mg/m^3) = exp10((0.00005813776*scaledreading)$^{-2}$). White areas represent lacking data, due to e.g. sea ice, lack of light or high cloud concentration. The dashed line shows the limit of the assessment area.

4.1.5 Important and critical habitats

The International North Water Polynya Study (1997-1999) showed that the eastern part of the NOW along the Greenland coast was much more productive than the other parts, and therefore will be particularly sensitive to oil spills. However, localised areas were not identified. Outside the NOW, information on primary productivity generally is too sparse and the location of potential hot-spots too irregular to identify localised important and/or critical areas.

4.2 Zooplankton

M. Dünweber and D. Schiedek

4.2.1 General considerations

Zooplankton has an important role within marine food webs (Figure 10), 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, marine mammals and seabirds. The little auk (*Alle alle*) and the bowhead whale (*Balaena mysticetus*), for instance, are specialised zooplankton feeders primarily utilizing the large copepods of the genus *Calanus* (Karnovsky *et al.* 2003, Heide-Jørgensen *et al.* submitted). Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipids that are accumulated in *Calanus* (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 through excretion by zooplankton is crucial for bacterial and phytoplankton production. Zooplankton products (faecal pellets) also sustain diverse benthic communities such as bivalves, sponges, echinoderms, anemones, crabs and fish, when sinking down to the seabed (Turner 2002, and references therein). Especially *Calanus* plays an ecological key role in supplying the benthic communities with high quality food by their large and fast sinking faecal pellets (Juul-Pedersen *et al.* 2006).

In the Arctic, marine zooplankton is not only governed by low temperatures, but also by extremes in solar radiation and associated cycles in pelagic primary production. The absence of light during winter, and its nearly continual presence for four summer months per year has a strong influence on food availability and on the life cycle of the organisms living there. Specific adaptations are required, such as the capacity to store lipid when food is plentiful and to overwinter on these stores. The ability to synthesise and/or store lipids is a critical aspect in the life cycles, since these depot lipids not only provide energy during starvation in winter but also the materials for egg production and larval development (Lee *et al.* 2006, and references therein, Falk-Petersen *et al.* 2009).

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 the large copepods of the genus *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 over-wintering at depth and to fuel reproduction in the following spring. Their life cycles have been estimated to be 1-4 years (Madsen *et al.* 2001, Ashjian *et al.* 2003).

Meanwhile, general aspects of the life histories of *Calanus* are known. Two species, *Calanus hyperboreus* and *C. glacialis*, have been characterised as Arctic species (Falk-Petersen *et al.* 2007). *C. hyperboreus* undergoes a 2-4 years life cycle, reproducing at depth early in the year (November-March). The females release their eggs throughout the winter and some eggs ascend early enough to hatch and moult into different larval stages before the initiation of the spring phytoplankton bloom. The life cycle of *Calanus* includes several larval and one adult stage. The first larval stage, exploits the spring phytoplankton bloom. Larger larvea and females also ascend to feed during spring after overwintering in the deeper parts (Madsen *et al.* 2001, Ashjian *et al.* 2003). This specific reproduction and overwintering strategy is seen as ecological advantage compared to other copepod species (Hirche & Niehoff 1996).

The other Arctic species, *C. glacialis* probably follows a 2-year life cycle, reproducing during spring and summer in the upper water column and using both stored reserves and available food. During overwintering both species utilise lipid reserves stored during the productive summer (Ashjian *et al.* 2003, Lee *et al.* 2006, and references therein, Falk-Petersen *et al.* 2009). The third main copepod species, *Calanus finmarchicus*, was first characterised as a boreal species but is now generally regarded as a North Atlantic species (Falk-Petersen *et al.* 2007). The life cycle duration for this species is still debated, but *C. finmarchicus* is known to overwinter in diapause in deep water. This species is imported into the assessment area by the inflow of Atlantic water. The last major copepod species, *Metridia longa*, has been classified by several authors as an Arctic deep-water species that overwinters large larvae and adults (Ashjian *et al.* 2003).

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 when animals move into surface depths.

The smaller species, such as *Oithona similis*, *Pseudocalanus* spp. and *Microcalanus pygmaeus*, are often found in large numbers. They exhibit a shorter generation time and more sustained reproduction, suggesting that their importance in ecosystem productivity could be greater than implied by their biomass alone (Hopcroft *et al.* 2005, Madsen *et al.* 2008).

Although copepods are typically predominant in Arctic marine systems, there is a broad assemblage of other holoplanktonic groups and their role has yet not fully been understood. Larvaceans (Appendicularians), for example, have been shown to be abundant in Arctic seas. These soft-bodied filter feeders are capable of much higher ingestion rates, faster growth and reproduction than crustaceans, allowing them to respond more rapidly to shifts in primary production. During times when larvaceans are abundant, the efficiency with which primary production is exported to the benthos may be greatly increased (Hopcroft *et al.* 2005). Other important and common predatory groups are chaetognaths, amphipods, ctenophores and cnidarians. Arctic chaetognaths may represent considerable biomass, have long life cycles (e.g. 2 years) and are thought to be important in controlling *Calanus* populations (Falkenhaug 1991). Hyperiid amphipods (e.g. the genus *Parathemisto* – also known as *Themisto*) can also be abundant in Arctic waters (Mumm 1993, Auel & Werner 2003), with 2- to 3-year life cycles and a similar potential to graze a notable proportion of the *Calanus* population (Auel & Werner 2003). In turn, polar cod (*Boreogadus saida*), seabirds and marine mammals are often feeding on these amphipods. Thus, hyperiid amphipods play a key role in the Arctic pelagic food web (Figure 10) as a link between large zooplankton and seabirds and marine mammals (Auel *et al.* 2002). A special amphipod, *Apherusa glacialis*, lives in and on sea ice, grazing on ice-associated algae. Also euphausiids (krill) and mysids (*Mysidacea*) can be very numerous and constitute important food for seals, whales and seabirds.

In general, life cycles of Arctic zooplankton are prolonged compared with populations of closely related species at lower latitudes, and often exceed one year. Zooplankton concentrations are often highest in the upper 500 m. However, as described above, especially the predominating *Calanus* species perform extended seasonal migrations from the surface to deeper layers for overwintering (Madsen *et al.* 2001, Falk-Petersen *et al.* 2009).

Most of the higher trophic levels rely on the lipids accumulated in *Calanus* mainly as wax esters. Those can be transferred through the food web and incorporated directly into the lipids of consumers through several trophic levels. For instance, lipids originating from *Calanus* can be found in the blubber of white and sperm whales, which feed on fish and squid (Smith & Schnack-Schiel 1990, Dahl *et al.* 2000). Consequently, many biological activities – e.g. spawning and growth of fish – are synchronised with the life cycle of *Calanus*. For larvae of the Greenland halibut (*Reinhardtius hippoglossoides*) and sand eel (*Ammodytes* sp.) from the West Greenland shelf, copepods were the main prey item during the main productive season (May, June and July). They constituted between 88 % and 99 % of the ingested prey biomass (Simonsen *et al.* 2006).

The possible linkages between hydrographical processes and plankton variability were studied in the Disko Bay area (just south of the Baffin Bay assessment area) and on the important fishing banks off southwest Greenland (Munk *et al.* 2003). The relationship between hydrographical characteristics and plankton distribution differed among species and apparently specific plankton communities were established in different areas of the shelf. Ichthyo- (fish larvae and eggs) and zooplankton communities also differed in the dominance of species with polar versus temperate origin. It was suggested that the flow of major currents and the establishment of hydrographical fronts are of primary importance to the plankton communities in the West Greenland shelf area, influencing the early life of fish. The importance of hydrographical fronts on the plankton community is also expected for the Northern Baffin Bay area.

Results provided by Söderkvist *et al.* (2006) from Disko Bay showed that the highest abundance of shrimp and fish larvae was observed in early summer in association with the peak abundance of their plankton prey. Moreover, plankton dynamics were closely linked with the prevailing hydrography in the area. The interactions between hydrography, plankton and shrimp and fish larvae indicate that the productive cycle in Disko Bay is highly pulse-like in nature, which is characteristic for Arctic marine ecosystems.

High biological activity in the surface waters can be expected in connection with hydrodynamic discontinuities, i.e. spring blooms, fronts, upwelling areas or at the marginal ice zone.

Anthropogenic impacts, e.g. oil pollution, might also have an impact. In past years, exposure experiments performed on phytoplankton (Hjorth *et al.* 2007, Hjorth *et al.* 2008) and copepods (Hjorth & Dahllöf 2008, Hjorth & Nielsen 2011) with pyrene have shown reduced primary production, copepod grazing and secondary production. These experiments suggest that the plankton community could be vulnerable to this kind of exposure. In Arctic marine habitats, the most severe ecological consequences of massive anthropogenic impacts (such as oils spills) are to be expected in seasons with high activities of the pelagic food web (i.e. spring and summer). On a horizontal scale the most important areas are the fronts in association with the transition zone between different water masses. Later in the season, when the biological activity is more scattered or concentrated at the pycnocline, ecological damage from an oil spill would be assumed to be less severe (Söderkvist *et al.* 2006).

4.2.2 Zooplankton in the Baffin Bay assessment area

For larger parts of the assessment area, no information is available regarding the distribution and population dynamic of important zooplankton taxa and their role in the food web. Based on studies performed in the vicinity of Melville Bay, north-eastern Baffin Bay (75° to 76° N, 68° to 72° W) in summer 1980, the most dominant copepod species are *Calanus hyperboreus*, *C. glacialis* and *C. finmarchicus*. Their vertical distribution was linked to food availability as well as to salinity and temperature (Herman 1983, Sameoto 1984, Head *et al.* 1985). The three *Calanus* species were most abundant in water masses with temperatures below 0° C whereas at temperatures above 0° C other planktonic species (i.e. pteropod molluscs) showed highest abundance. In addition to *Calanus*, a range of other species and taxonomic groups were present in the plankton (Sameoto 1984).

Zooplankton diversity and its functional role have also been studied in the North Water Polynya (NOW) as part of the International North Water Polynya Study. NOW is one of the largest and northernmost Arctic polynyas and represents a productive region (*cf.* Section 4.1 on primary productivity) with abundant seabird and marine mammal populations. Several comparisons indicate that NOW is among the most productive ecosystems north of the Polar Circle (Tremblay *et al.* 2006). The extensive ice-free periods in polynyas are associated with increased primary production, resulting in a diverse zooplankton community (Prokopowicz & Fortier 2002, Ringuette *et al.* 2002). By number, copepods represented > 80 % of the zooplankton assemblage in the North Water. The copepod assemblage was quite diverse, including taxa typically found in Arctic Ocean waters, such as *C. hyperboreus*, *C. glacialis*, *C. finmarchicus*, *Metridia longa*, *Pseudocalanus* spp., *Microcalanus pygmaeus*, *Oithona similis* and *Oncaea borealis* (Ringuette *et al.* 2002). Their distribution patterns varied and were often directly linked to hydrographical features, i.e. temperature and salinity, but also to duration of ice coverage. Other studies have shown that the copepod biomass in NOW was comparable to that observed in other Arctic polynyas. Nevertheless, dominant diatoms accumulated indicating that copepod abundance was not sufficient to control phytoplankton biomass. It was speculated that planktivory, especially by little auks, limit the abundance of large *Calanus* spp. (Saunders *et al.* 2003). The little auk is present in many millions in the NOW region and known to consume large amounts of *Calanus* spp. Calculations of carbon requirements show a reasonable agreement between auk populations and production rates of *C. hyperboreus* (Saunders *et al.* 2003). Other studies have revealed that the carbon demand of the little auk amounted to about 2 % of the biomass synthesised by *C. hyperboreus* and that most of the secondary carbon production was therefore available for pelagic carnivores, e.g. polar cod (*Boreogadus saida*) and marine mammals (Tremblay *et al.* 2006). The trophic studies based on stable isotope measurements also documented that a large fraction of the primary production in NOW was already ingested by consumers in the upper 50 m. It was estimated that only about 15 % of the particulate primary production was left to sink directly to the bottom (pelago-benthic coupling) to be used by benthic organisms (Tremblay *et al.* 2006).

During the last decades the physical forcing of the plankton succession in the Arctic has changed. The reduction of the sea ice cover (Bates *et al.* 2008) potentially has an impact on stratification and light conditions (phytoplankton) and consequently on the timing and succession of the lower trophic levels of the food web.

Moreover, the influx of Atlantic water masses to the Arctic Ocean has increased during the last decades, but it remains unclear how this flux variability affects the pelagic ecosystem. Plankton species are in general good indicators for ocean climate variability (Daase & Eiane 2007, and references therein). Indications from the North Atlantic show changes in the distribution of species, in the seasonal timing of peak abundances, and poleward movement of temperate species. Unfortunately, plankton data from the Arctic are scattered in space and time. Thus, our current level of knowledge about ecological variability in the Arctic seas may limit the ability to detect ecological changes related to climate variability (Daase & Eiane 2007, and references therein).

4.2.3 Important and critical areas

The knowledge on zooplankton is not yet sufficient to designate any important or critical areas within the assessment area, except for the North Water Polynya (NOW) as such.

4.3 Benthic flora

S. Wegeberg

Shorelines with a rich primary production are of high ecological importance. 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 (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 (Peterson *et al.* 2003). However, some shorelines are highly impacted by natural parameters such as wave action and ice scouring, and shorelines will therefore naturally sustain a relatively lower production or may appear as barren grounds. Thus to identify important or critical areas a robust baseline knowledge on littoral- and sublittoral ecology is essential.

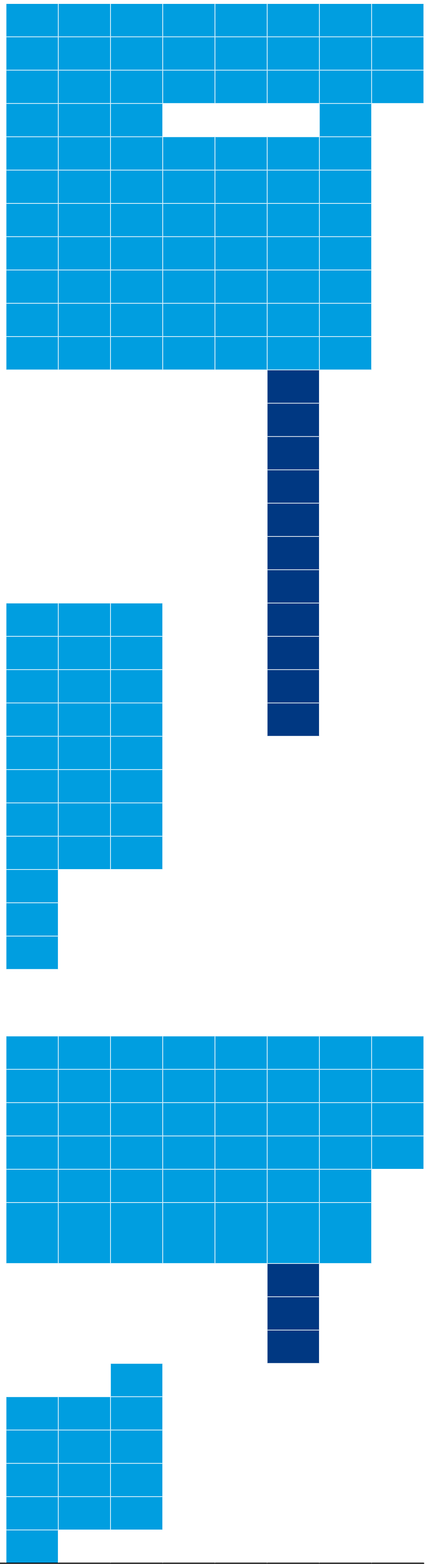
Studies of the marine benthic flora in the assessment area are scarce and have mainly been conducted as floristic studies. Marine macroalgae were collected at different expeditions to West Greenland during the 19th century, and were identified and described by Rosenvinge (e.g., 1893, 1898). In addition, two studies of the macroalgal flora have been conducted in the assessment area: Wilce (1964) collected and described the macroalgae at Qaanaaq; and in 2004 macroalgal samples were collected and analysed in connection with an assessment of the environmental impact of Thule Airbase at North Star Bay (Andersen *et al.* 2005). A check-list with indication of distribution of the marine algae of Greenland was compiled separately for the east and west coast by Pedersen (1976) and here supplemented by the data of Andersen *et al.* (2005) (Table 1).

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 mostly 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 characterized by fucoid species. The majority of the macroalgal species grows, however, below low-water mark. The submerged vegetation is restricted to depths with sufficient light conditions. In Greenland, a relatively rich flora can be found until 20-30 m's depth, but macroalgae may occur as deep as 50 m.

Table 1. Distribution of the macroalgae species in the assessment area in relation to latitude. Based on Pedersen (1976) ■ and Andersen *et al.* (2005) ▨. Binomial names follow Pedersen (2011).

Latitude (°N)	71	72	73	74	75	76	77	78
Cyanophyta								
Calothrix scopulorum	■	■	■					
Aphanothece sp.	■							
Rhodophyta								
Bangia fuscopupurea	■	■	■	■	■	■	■	■
Ptilota serrata	■	■	■	■	■	■	■	■
Scagelothamnion pusilla	■	■	■	■	■	■	■	■
Neodilsea integra						▨	■	
Clathromorphum compactum	■	■	■	■	■	■	■	
Coccotylus truncatus incl. *Coccotylus brodiaei*	■	■	■	■	■	■	■	
Devaleraea ramentacea	■	■	■	■	■	■	■	
Fimbrifolium dichotomum	■	■	■	■	■	■	■	
Hildenbrandia rubra	■	■	■	■	■	■	■	
Meiodiscus spetsbergensis	■	■	■	■	■	■	■	
Palmaria palmata	■	■	■	■	■	■	■	
Pantoneura fabriciana	■	■	■	■	■	■	■	
Phycodrys rubens	■	■	■	■	■	■	■	
Polysiphonia arctica	■	■	■	■	■	■	■	
Rhodocorton purpureum	■	■	■	■	■	■	■	
Rhodomela lycopodioides	■	■	■	■	■	■	■	
Turnerella pennyi	■	■	■	■	■	■	■	
Wildemania miniata	■	■	■	■	■	■	■	
Acrochaetium secundatum						▨		
Grania efflorescens						▨		
Phymatolithon foecundum			■	■		▨		
Acrochaetium microscopicum			■			▨		
Phymatolithon tenue	■	■	■			▨		
Callymenia schmitzii???			■			▨		
Harveyella mirabilis			■					
Euthora cristata	■	■	■					
Lithothmanion glaciale	■	■	■					
Lithothamnion tophiforme	■	■	■					
Peyssonellia rosenvingii	■	■	■					
Polysiphonia stricta	■	■	■					
Phaeophyceae								
Platysiphon verticillatus								■
Agarum clathratum	■	■	■	■	■	■	■	■
Chaetopteris plumosa	■	■	■	■	■	■	■	■
Desmarestia aculeata	■	■	■	■	■	■	■	■
Desmarestia viridis	■	■	■	■	■	■	■	■
Dictyosiphon foeniculaceus	■	■	■	■	■	■	■	■
Fucus evanescens	■	■	■	■	■	■	■	■
Laminaria nigripes	■	■	■	■	■	■	■	■
Laminaria solidungula	■	■	■	■	■	■	■	■



Pylaiella littoralis
Saccharina longicruris
Stictyosiphon tortilis
Symphyocarpus strangulans
Alaria pylaiei
Battersia arctica
Chordaria flagelliformis
Delamarea attenuata
Elachista fusicola
Petroderma maculiforme
Pleurocladia lacustris
Chordaria chordaeformis
Dictyosiphon chordaria
Ectocarpus fasciculatus
Halosiphon tomentosus
Hincksia ovata
Punctaria sp.
Pylaiella varia
Chorda filum
Ectocarpus siliculosus
Fucus vesiculosus
Leptonematella fasciculata
Coelocladia arctica
Eudesme virescens
Punctaria plantaginea
Scytosiphon lomentaria
Ascophyllum nodosum
Dermatocelis laminariae
Sorapion kjellmanii

Chlorophyta

Acrosiphonia arcta
Acrosiphonia sonderi
Enteromorpha prolifera
Urospora penicilliformis
Chaetomorpha melagonium
Spongomorpha aeruginosa as *Chlorochytrium inclusum*
Blidingia minima
Ulothrix flacca
Ulvaria splendens
Chlorochytrium schmitzii
Chaetomorpha capillaris
Gomontia polyrhiza
Ostreobium quekettii
Rhizoclonium riparium
Ochlochaete hystrix

In Greenland, shorelines with rich inter- and subtidal macroalgal floras are widespread and have been studied in the Disko Bay area (Hansen 1999, Hansen & Schlütter 1992, Hansen 2010a). With regard to the Baffin Bay assessment area, predominant species of the tidal zone (mainly *Fucus* spp.) and the upper subtidal zone (species like *Agarum clathratum*, *Alaria esculenta*, *Laminaria* spp. and *Saccharina longicruris*) are recorded along the west coast of Greenland as far north as 78° N (Pedersen 1976, Wegeberg *et al.* 2005).

In general, though, there is a lack of data on macroalgal biomass, production, species specific coverage and associated fauna, and in the Baffin Bay area only sparse information on the macroalgal vegetation is available.

Tidal and subtidal investigations, conducted in southern Greenland and the Nuuk area, of macroalgal biomasses show relatively large biomasses of *Ascophyllum nodosum* and *Fucus vesiculosus*, e.g. 7-8 kg m^{-2} of the dominant species at sheltered localities near Qaqortoq (Wegeberg *et al.* 2005). In the upper subtidal, biomasses of kelp averaged 3-8 (-13.5) kg m^{-2}, with the largest biomasses at sites with relatively high degree of exposure (Wegeberg 2007).

The annual productivity of kelp species in NE Greenland and the Beaufort Sea, Alaska, has been estimated, and showed an annual length increase of *Saccharina latissima* of app. 55-88 cm depending on depth (Borum *et al.* 2002, Dunton 1985).

The most important environmental conditions for the macroalgal flora in the assessment area are the low temperatures, strong seasonal changing light regime and ice cover throughout a large part of the year. Adaptions to these conditions are for example keeping the older generation lamina (together with the new) for up to three summer seasons, whereas in temperate regions the lamina are lost when new are developed in spring. This is seen for example in *Laminaria solidungula* and *Saccharina latissima* in Northeast Greenland (Lund 1959, Borum *et al.* 2002). As discussed by Borum *et al.* (2002), maintenance of old lamina, and thereby accumulation of surface area of an individual, enhances light and inorganic carbon harvesting, implied that the old tissue is still photosynthetically active and thus contributing to a positive carbon balance of the individual. Borum *et al.* (2002) found that the photosynthetic capacity of the lamina from the proceeding year was similar to that of the current year of *Saccharina latissima* in Young Sound.

The ability to support a photosynthetic performance comparable to that of macroalgae in temperate regions may be explained by low light compensation points and relative 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 ensure optimal harvest of light when available (Becker *et al.* 2009, Krause-Jensen *et al.* 2007). No studies elucidating the macroalgal production or photosynthetic strategies have been conducted in the assessment area, though.

The sea ice possesses a high physical impact factor on the macroalgal vegetation because of ice scouring. The mechanical scouring of floating ice floes prevent especially perennial fucoid species to establish in the littoral, which is the zone mostly influenced by the ice dynamics. At such, often quite wind exposed, ice scoured localities, communities of opportunistic macroalgae, like green algal species of the filamentous genera *Ulothrix* and *Urospora* and the smaller leafy species

Blidingia minima, develop quickly during the summer months due to the available substratum and life history microstages not detached by ice. This scenario was observed in the assessment area at North Star Bay by Andersen *et al.* (2005).

Perennial species from the littoral zone do tolerate freezing and survive frozen into an ice foot if the ice melts gradually without being disrupted. The macroalgal vegetation then remains intact, which may be the case in more sheltered areas as demonstrated in the fjord Qaamarujuk, close to Uummannaq, just to the south of the assessment area (Johansen *et al.* 2001a, figs p. 21 and 35). It was shown for *Fucus evanescens* from Spitsbergen that the species was able to halt the photosynthetic activities at subzero temperatures and resume almost completely when unfrozen (Becker *et al.* 2009).

Fresh water and water of low salinity may influence the macroalgal vegetation negatively especially in the intertidal when exposed to rain and snow during low tide and when sea water mix with fresh and melt water during seasons with high water run off from land. Low tolerance to hyposaline conditions may result in increased mortality or bleaching (strong loss of pigments), which suggests that hyposalinity also impacts on the photosynthetic apparatus, as shown for kelp species at Spitsbergen (Karsten 2007).

Substratum characteristics are additionally important for the distribution and abundance of macroalgal vegetation, and only hard and stable substratum can serve as base for a rich community of marine, benthic macroalgae. However, commonly some macroalgal species are attached to shells, small stones or are loose-lying in localities with a soft, muddy bottom. In North Star Bay, video records show *Saccharina longicruris* on a muddy bottom intermixed with small stones and shells as well as relatively high quantities of *Desmarestia aculeata* (video recordings provided by DHI). However, natural occurring loose-lying macroalgae tend to be depauperate, probably due to poor light and nutrient conditions. When not attached to stable substratum the algae material drifts and clusters resulting in self shading and nutrient deficiency within the algal cluster. Furthermore, soft bottom localities, often located in the inner part of fjords, are created and influenced by resuspended particles in melt water. In such sites, light conditions are impacted due to significantly reduced water transparency as well as the sedimentation of resuspended particles on the macroalgal tissue results in shading. This was also the case in North Star Bay where the vegetation generally was covered by a thin layer of fine particles.

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' (also known as the phenomenon of 'iso-yake' – Japanese: sea dessert) of stones, boulders and rocks, which as a result of the grazing 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). In North Star Bay in the assessment area, underwater video transects showed a relatively high number of sea urchins at patchy stony sea floors. The only presence of macroalgae there were, however, loose-lying green filaments, probably *Chaetomorpha melagonium* (video recordings), which might indicate overgrazing of the macroalgal vegetation. In connection with a study on the macroalgal species zonation in the intertidal of the west coast of Disko (right south of the assessment area), barren grounds with a relatively high number of sea urchins and grazed kelp forest have been reported (Hansen & Schlütter 1992).

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, crabs, 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 were important prey for the 21 fish species caught in the kelp forest (Norderhaug *et al.* 2005). A reduction in kelp forest 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 by especially longer season with open water, and thereby a longer season for growth. This coupled with oceanic warming therefore may change many species distribution towards north (Müller *et al.* 2009). On the other hand, melting of glaciers leads to increased runoff of freshwater with suspended material, which results in lowered salinity and increasing water turbidity (Borum *et al.* 2002, Rysgaard *et al.* 2007), and which again may have a negative impact on the local macroalgae vegetation.

There are different reports on the impact of oil contamination on macroalgal vegetations and communities. The littoral macroalgal cover (*Fucus gardneri*) lost in connection with the *Exxon Valdez* oil spill in 1989 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 it is still considered as recovering (NOAA 2010). In contrast, no major effects on shallow sublittoral macroalgae were observed in a study on macroalgae and impact of oil spill conducted by Cross *et al.* (1987). It was discussed that it 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 with indication of distribution of the marine macroalgal species in the assessment area is presented in Table 1.

Pedersen (1976) lists 183 macroalgal species (excl. the bluegreen algae, Cyanophyta) are listed for Greenland. 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 32 red algae, 38 brown, 17 green have been recorded and only a few species are registered for the highest latitudes (at 78° N), 3, 12 and 4, respectively.

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), and are all present in the assessment area, except for *Punctaria glacialis* and *Haemescharia polygyna*.

Wilce (1964) compared the macroalgal floras of Thule District, Qaanaaq and Disko Bay, and described the marine vegetation at Qaanaaq as relatively rich where suitable substratum and some protection from ice were available. He found an increased number of species as well as development of vegetation in the sublittoral below 2 m's depth. In addition, Wilce (1964) described a characteristic *Battersia arctica-Stictyosiphon tortilis* community as "... extremely dense and well-developed horizontal band of these two species in the low littoral and upper littoral and continued that he had 'never encountered a community of such luxuriance as that seen behind the natural rock bar which protects the Qaanaaq shore from the ice."

Andersen *et al.* (2005) did not observe this characteristic pattern of *Battersia arctica* and *Stictyosiphon tortilis* in the North Star Bay just south of Qaanaaq in the northern part of the assessment area, however, both species were recorded. In this area the littoral zone was described as having a poor vegetation of small green algal species such as *Ulothrix* spp. and *Blidingia minima*, and even though *Fucus* species were present (*F. evanescens*, *F. vesiculosus*), they were non-dominant, which is in accordance with the observations of Wilce (1964). Also, a rather poor sublittoral vegetation was observed, probably due to a sea floor of mud and relatively small stones and shells. Furthermore, the sea water in the bay was influenced by silt, also observable on the video recordings, from outflow of freshwater from two rivers in the area resulting in reduced light conditions. The total number of species in the focused area registered by Andersen *et al.* (2005) was 44; 11 red algal species, 23 brown and 10 green, respectively, compared to 24 red, 29 brown and 11 green algal species registered for that latitude according to Table 1. The lack of species is probably explained by the mentioned suboptimal conditions for macroalgae in North Star Bay with respect to substratum and light conditions. Wilce (1964) did not observe *Fucus vesiculosus* at Qaanaaq. It is registered in North Star Bay, though, indicating a northern limit of this species at c. 77° N on the west coast of Greenland.

Just to the south of the assessment area at Uummannaq, Johansen *et al.* (2001) have monitored contaminants from the zink-lead mine in Maarmorilik for a number of years and have collected samples of fucoid species for their analyses. Therefore, reports and pictures of a rich littoral vegetation of *Fucus* species are available from that area (*F. evanescens*, *F. vesiculosus*, P. Johansen, pers. comm., Johansen *et al.* (2001: Figures 21 and 35).

In general, however, the existing knowledge of macroalgal diversity is very limited, and macroalgal species composition, biomass, production and spatial variation are completely unknown in the assessment area. However, the present knowledge on macroalgae diversity and community shows a highly heterogeneous distribution and abundance linked with a highly variable physical environment in the assessment area. Therefore, important or critical habitats for macroalgae cannot be identified based on the present available information. But shoreline sensitivity to oil spills have at least been assessed including elements as exposure and substrate (Mosbech *et al.* 2004b). No research has been conducted on macroalgal community interactions; neither biodiversity/abundance of macroalgal associated fauna or mapping of macroalgal /-faunal interactions including grazing.

4.4 Benthic fauna

M.K. Sejr, P. Batty, A. Josefson, M.E. Blicher, J. Hansen and S. Rysgaard

Benthic macrofauna species are important components of coastal ecosystems in the Arctic. They consume a significant fraction of the available production and are in turn an important food source for fish, seabirds and marine mammals.

Approximately 20% of the world's shelf areas are located in the Arctic (Menard & Smith 1966). In these areas a high standing stock of benthic macrofauna is found even though input of food is low and highly seasonal. This is probably due to that large parts of the Arctic consist of relatively shallow shelf areas with a tight pelago-benthic coupling. In addition, the low temperatures prevalent in the Arctic Oceans reduce the energy requirements of benthic organisms. In combination with a high abundance of species that can live for more than 25 years (Blicher *et al.* 2007, Sejr & Christensen 2007), a high biomass is slowly build up despite a limited annual primary production. Particularly larger species such as bivalves and gastropods are important prey items for eiders, walruses and some seals. Also a number of commercially important species such as scallops, crabs, shrimp and halibut live on or near the sea floor. In addition to being important in the marine food web, the sea floor also constitutes a habitat with high biodiversity. It was estimated that approximately 90% of the 5000 invertebrates species present in the Arctic Sea are living on the sea floor (Bluhm 2010). Given that the majority of the more than 2000 marine invertebrates (not including meiofauna) expected in Greenland waters (Jensen & Christensen 2003) are benthic species, it can be assumed that the marine benthos could account for at least 75% of all animal species in Greenland or about 25% of all species in Greenland including plants and lichens.

A fundamental conclusion from findings of various benthic surveys conducted in the past years has been that there is not just one typical Arctic benthos community, but a wide variety found in different regions and distinct depth zones. Benthic zonation is often accompanied by an exponential decline in benthic diversity along a shelf-slope-basin gradient (Piepenburg 2005). In addition to depth, other factors such as sediment heterogeneity, disturbance, food availability, geographical setting, sea-ice cover, particle load from land and hydrographical regimes also influence benthic diversity and species composition. Compared to pelagic organisms, which often display significant seasonal variation in biomass, benthic biomass is much more stable and thus a predictable food source for the higher trophic levels (Hobson *et al.* 2002, Born *et al.* 2003, Richman & Lovvorn 2003).

The majority of benthic species have a life span of 5 to 10 years. In Arctic areas, however, the life span of large species such as sea urchins and bivalves may exceed 50 years. Due to the long life span, changes in the benthic community often occur over a number of years and, if the community is disturbed, it may take decades for the system to recover.

4.4.1 Benthic fauna in the assessment area

The SEIA prepared in 2009 (Boertmann *et al.* 2009) showed that the knowledge of benthic diversity in the Eastern Baffin Bay was very limited, and especially that species composition, diversity and spatial variability was largely unknown.

Among the very few benthos surveys previously carried out in the assessment area was that by Vibe (1939), who studied a few locations in the Upernavik area in 1936. Here at approx. 72° N, the total average wet weight of the *Macoma* community, which mainly constituted of the bivalves *Macoma*, *Mya* and *Hiatella*, was 160-388 g ww m^{-2}. Average benthic biomasses of about 1,482 g ww m^{-2} were found locally in this area, although such levels were considered exceptionally high (Vibe 1939, 1950).

In order to improve our knowledge and understanding of the benthic fauna in the Baffin Bay assessment area, a larger field study was initiated in 2008. It aimed at obtaining information on the species composition and diversity of benthic macro invertebrates in the eastern part of the Baffin Bay (71° to 78° N). Results presented in Box 1 are important baseline information concerning the benthic habitat in this area.

A wide range of physical and biological factors determine the composition and biomass of the benthic community. One of the most important is the composition of the sediment which can range form soft bottom sediments dominated by silt particles (grain diameter < 63 μm) across various types of sand and gravel to hard substrates made of large boulders or solid rock. Distinct benthic assemblages are often found at different substrates. Although soft bottom habitats generally dominate at depths below 100 m, the substrate composition is often highly variable at meter scale, i.e. between replicate samples at the same station. The variability of the substrate can be related to factors such as depth, distance from glaciers or rivers or input of ice rafted material such as drop stones. In shallow coastal areas scouring ice bergs occasionally crush the benthos thereby creating additional patchiness of the benthos (Gutt & Starmans 2003). Another challenge is that large boulders and rocky substrates are abundant especially at shallow depths. Such habitats cannot be sampled quantitatively using conventional grab sampling.

Compared to other Arctic regions, the composition of benthic fauna off West Greenland generally shows the highest resemblance to the western part of the Baffin Bay and Davis Strait and the northern Labrador although the pattern differs between different taxonomical groups (Piepenburg *et al.* 2011). However, in that study the West Greenland fauna is only quantified based on 45 stations from the sub-Arctic part of the region. The current data set and additional data from the Disko Bay area and southern Greenland is expected to greatly increase the information about which species can be considered as typical for the region and to what extend there is a latitudinal change along the Greenland west coast.

Northern shrimp *Pandalus borealis*

The northern shrimp is the only species from the benthic fauna, which is utilised on a commercial basis in the assessment area. Although not a true benthos species, it lives on and near the sea bed (epibenthic). It occurs on the West Greenland continental shelf more or less continuously distributed from Cape Farewell (60° N) to about 74° N, with the highest densities occurring at depths between 150 and 600 m. Within this area, there is little evidence of stock sub-structure, and the population has been assessed as a single stock. During the day, shrimp stay at the bottom, but may perform vertical movements up in the water (< 150 m) column during the night. The eggs are laid in summer and carried by the female until the following spring (April-May), when the females seek shallow water and release the larvae. These are planktonic for three or four months, at which time they drift passively with the currents and subsequently settle on the seafloor far from their release site (Pedersen *et al.* 2002). Three to six years later they become sexually mature first as males and later, when six to eight years old, as females. Females are larger than males and are therefore the main target for commercial fishery, which in the assessment area only takes place in the southernmost part (Section 5.1).

4.4.2 Important and critical areas

The existing knowledge on distribution, diversity and abundance of the benthos in the assessment area is still too incomplete to identify especially important and or critical habitats except for the shrimp fishing ground (Figure 43).

A special type of benthic communities is the cold water coral reefs and sponge gardens. These are particularly sensitive to activities that physically impacts the seabed and to sedimentation of particles (Freiwald *et al.* 2004). Such communities have not yet been described from the Greenland waters. But recently some were located on the Canadian side of Davis Strait (Gass & Willison 2005) and there are reports from fishermen, which indicate that they could occur off central SW Greenland.

In broad terms, the abundance of bivalves is highest in the shallow depth segment (0-50) where also the highest species richness is found. In terms of ecological significance the shallow areas is thus expected to be most important to seabirds and marine mammals. Other studies using underwater video surveys in the area have

Box 1

Benthic fauna studies in Baffin Bay assessment area

M.K. Sejr, P. Batty, A. Josefson, M.E. Blicher, J. Hansen and S. Rysgaard

During the study, a total of 41 stations were visited (see Figure 1) and at all of them photos of the sediment surface and the any epibenthic structures were taken. In addition, 29 stations were sampled (5 replicates) with a Van Veen grab (0.1 m^2), and benthic composition was analysed following standard protocols. At 15 stations samples were taken for different biogeochemical analyses (e.g. PAH content) using a HAPS corer. In addition, samples for sediment grain size distribution, carbon content and chlorophyll were collected.

Sampling locations were distributed from north to south in four 50 m depth ranges: 0-50, 50-100, 100-150 and 150-200 m. The shallow part, 0-50 m was given highest priority because at these depth range importance of the benthos as food source for higher trophic levels such as seabirds and marine mammals is likely to be highest. Moreover, it is to be expected that the shallow areas are mainly affected in case of oil pollution. Whenever weather and bottom conditions allowed it sampling was conducted near sites known to have high density of seabirds and walruses.

In areas where boulders and rocky substrates were abundant photos (approximately 0.2 m^2 each) were taken with a benthic drop camera to estimate abundance of large species on soft and hard substrates and the composition of the benthic fauna. The photos are an efficient way for obtaining basic information regarding type of substrate and the abundance of larger, especially epifaunal species. However, photos do not allow detailed taxonomic identification and provide no information on biomass. Examples of typical pictures from soft sediment, gravel and hard sediment are given in Figure 2. Most of the photos taken and analysed in this study are from sampling locations with a water depth less than 100 m at sites where soft sediments were dominating.

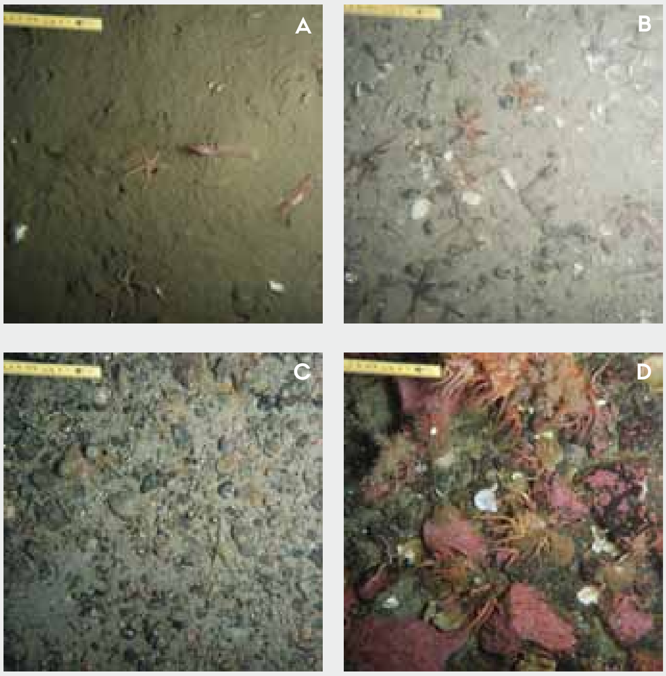


Figure 2. Photos of the seafloor at different stations in the sampling area describing variations in the physical and biological structure. (**A**) St. 15.3, (**B**) St. 8.1, (**C**) St. 9.3, (**D**) 9.1 and (**E**) St. 5.2 (Blicher *et al.* 2008).

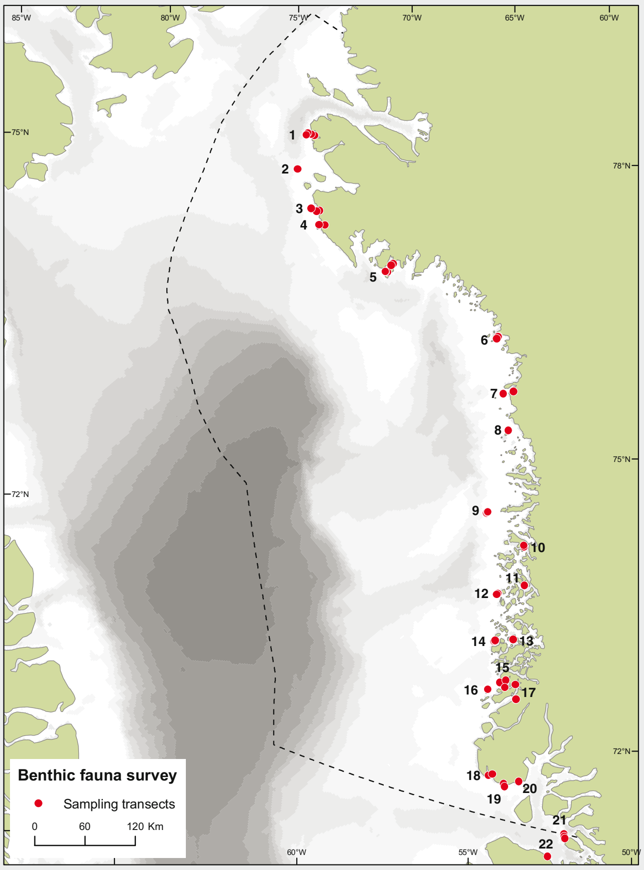


Figure 1. Sampling stations (transects along which several samples were taken) during the NERI/GINR 2008 survey.

Abundance and species composition based on photos

A total of 202 photos were analyzed covering approximately 35 m^2. Most photos were from depths less than 100 m at sites with soft sediments. Examples of typical pictures from soft sediment, gravel and hard sediment are shown in Figure 2.

A total of 38 different organisms were observed on the photos (Table 1); the most abundant being brittle stars (*Ophiura robusta*, *Ophiopolis aculeata* and *Ophiocten sericeum*), infaunal bivalves (*Mya* sp, *Hiatella arctica* and others), scallops (*Chlamys islandica*) and sea urchins (*Strongylocentrosus droebachiensis*) (Figure 3). As observed in other Greenland fjords (Sejr *et al.* 2000) the abundance of large infaunal bivalves was highly variable but it generally peaked at depths between 10 and 50 m where the sediments consisted of a mixture of soft sediment and gravel and stones. Scallops were mostly abundant in the same depth segment but attained highest abundance where the sediment was dominated by gravel. Brittle stars were by far the most abundant group in the photos. High abundances of several 100 individuals m^{-2} were encountered at both soft sediments and sediments dominated by gravel and larger stones. This is in line with observation from the Arctic in general where brittle stars are often the dominant epifaunal species (Piepenburg, 2000, Sejr *et al.* 2000).

Table1. Species list from benthic photos.

Phylum	species
Mollusca	Indet. infaunal bivalves
	Hiatella arctica
	Mya spp.
	Chlamys islandica
	Polyplacophora spp.
	Tectura sp.
	Gastropoda indet. 1
Echinodermata	*Strongylocentrotus droebachiensis*
	Ophiura robusta
	Ophiocten sericuem
	Ophioplolis aculeata
	Opiopleura borealis
	Ophioroidea indet.
	Holothuriodea
	Crossaster sp.
	Asteroidea sp.
	Crinoidea spp.
Cnidaria	Indet. Anemone
	Indet. Alcyonarian 1
	Indet. Alcyonarian 2
	Hydrozoa indet. sp. 1
Crustacea	Indet. Barnacle
	Mysicacea spp.
	Decapoda
	Indet. Isopoda
Pycnogonida	Indet Pycnogonid
Bryozoa	Indet. Bryozoa 1
	Indet. Bryozoa 2
	Indet. Bryozoa 3
	Indet. Bryozoa 4
	Indet. Bryozoa 5
Braciopoda	Brachiopoda indet.
Annelida	Polychata indet. 1
	Polychata indet. 2
Porifera	Porifera indet.
Hemichordata	Ascidia indet. 1
	Ascidia indet. 2
Chordata	Pisces spp.

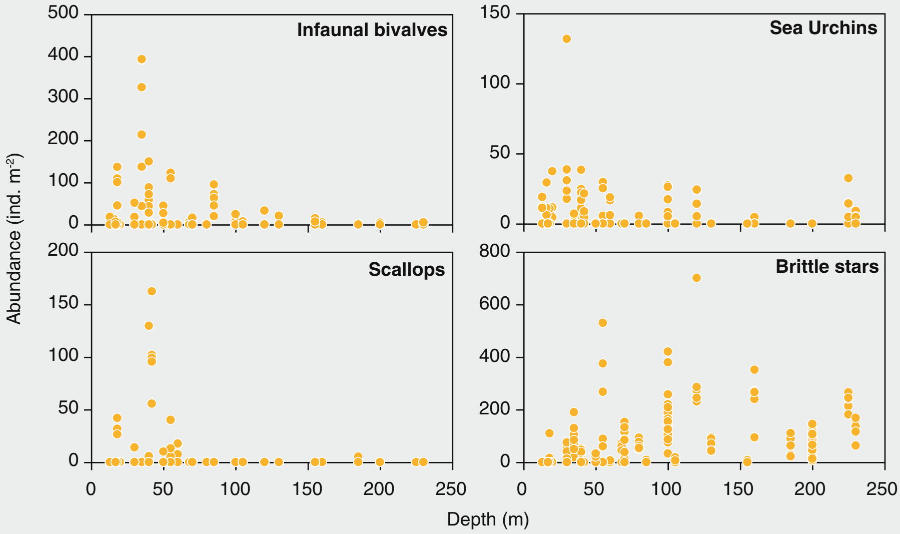


Figure 3. Abundance estimated from sea floor photos of the four dominant epifaunal taxa.

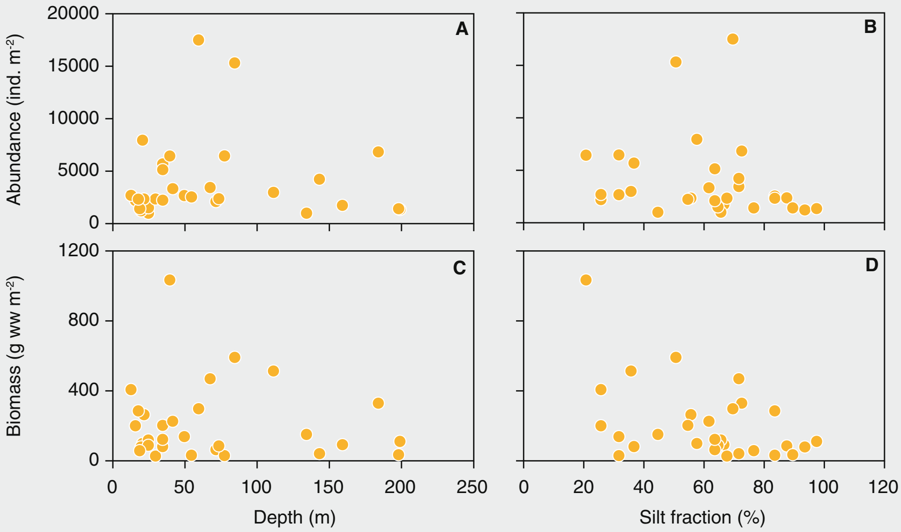


Figure 4. Average abundance (**A** and **B**) and biomass (**C** and **D**) at each station (mean of three grab samples) shown as function of station depth (**A** and **C**) and proportion of silt (particles < 63 µm) in the sediment (**B** and **D**).

Abundance and biomass based on grab samples

The average benthic biomass showed great variability between sampling stations ranging from 23 to 1030 g wet weight (ww) m^{-2} (including shells and skeletons). The biomass did not show any clear correlation with either depth or sediment type (% silt particles, Figure 4). An average biomass of around 200 g ww m^{-2} was found in the depth range 0-50 m, 50-100 m and 100-150 m and 175 g ww m^{-2} for the 150-200 m segment. This is within the range of previous observations in the area (Vibe 1939). The decreasing trend in biomass as a function of increasing depth is a general trend which has also been shown in other studies preformed in the Arctic. In a study on the Spitzbergen shelf (79° N) an significant decrease in biomass was found, from about 40 g ww m^{-2} at depths from 200-300 m to about 5 g ww m^{-2} at 2000 m depth (Wlodarska-Kowalczuk *et al.* 2004).

Molluscs and polychaetes were the dominant taxonomic groups (Figure 5) in terms of biomass, with a significant contribution from the remaining taxonomical groups in the 0-50 m depth range. Abundance was also highly variable between stations and showed no clear relationship with either depth or sediment type (Figure 4). Polychaetes were the most abundant group, followed by crustaceans which showed a high abundance at the shallow stations.

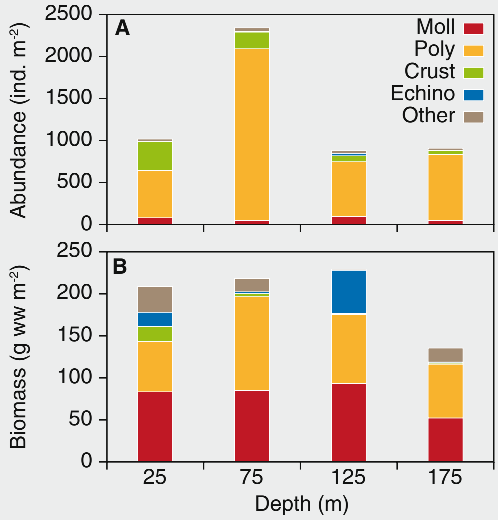


Figure 5. Contributions from different taxonomical groups to: (**A**) average abundance in each depth range (0-50 m, 50-100 m etc.); (**B**) average biomass. Abbreviations in legend: Moll = molluscs, Poly = polychaetes, Crust = crustaceans and Echino = echinoderms.

Table 2. The most abundant species in grab samples from the four depth segments. The five most abundant in each segment shown in bold for each depth segment and their relative contribution (%) to the total abundance.

	% contribution			
	0-50 m	**50-100 m**	**100-150 m**	**150-200 m**
Pholoe longa	9.3	0.7	0.2	0.0
Philomedes globosus	8.2	2.8	0.3	0.8
Chaetozone setosa	6.0	5.6	14.8	3.4
Prionospio steenstrupi	4.3	2.2	7.8	9.1
Owenia fusiformis	5.2	33.2	1.2	47.9
Polydora sp.	5.8	18.5	0.0	0.0
Spio sp.	1.3	7.6	0.1	0.1
Heteromastus filiformis	0.4	0.6	17.1	2.9
Polydora caulleryi	0.0	0.0	8.4	0.0
Cistenides hyperborea	0.8	2.1	7.6	2.1
Galathowenia oculata	0.9	2.0	2.6	8.9
Maldane sarsi	1.3	1.0	0.4	3.2
Total abundance	**11659**	**12444**	**1940**	**2715**
No. stations	16	7	3	4

Species compositions based on grab samples

The five most abundant species from each of the four depth ranges are shown in Table 2. In general, several species are abundant in more than one depth segment. Species such as the polychaetes *Owenia fusiformis*, *Chaetozone setosa* and *Prionospio steenstrupi* are generally abundant and were found at the majority of the sampling stations. Of the listed species in Table 1 most of them have been identified as being very abundant in other parts of Greenland and the Arctic. The most abundant species found in the Baffin Bay assessment area thus resemble that found in the sub arctic Disko Bay (Schmid & Piepenburg 1993) and the Godthaabsfjord (Sejr *et al.* 2010b) but also in the high arctic in NE Greenland (Sejr *et al.* 2000).

The ten species contributing most to the difference between deep and shallow stations and their average abundance are shown in Table 3. The table shows that much of the difference is due to differences in abundance of specific species rather than a shift in the species present in each depth segments.

Biodiversity

A total of 377 different species was found in the grab samples: 156 polychaetes, 123 crustaceans, 16 echinoderms, 54 molluscs and 28 species belonging to other taxonomic groups. Plots showing the statistical increase in total number of species for each new sample analyzed (species-area plots) show no tendency of saturation (Figure 6). Additional sample analysis is thus expected to add new species to the total species list. When comparing the different depth segments (Figure 6A) the deepest depth segment (150-200) shows the lowest species richness. Species area plots of replicates within stations also show a lack of saturation in species richness. Two other studies are available in West Greenland, which the total species richness can be compared with (Figure 6B). One study near Nuuk (64° N) was based on three replicates from each of nine different stations ranging in depth from 47 to 956 m in the

Table 3. List of the species contributing most to the difference in species composition between deep (150-200 m) and shallow (0-50 m) stations.

	Average abundance (0-50 m)	**Average abundance (150-200 m)**	**Accumulated contribution (%)**
Owenia fusiformis	38.00	325.25	2.21
Pholoe longa	67.56	0.25	4.20
Pontoporeia femorata	17.19	0.00	5.73
Galathowenia oculata	6.75	60.25	7.25
Maldane sarsi	9.81	22.00	8.74
Calanus hyperboreus	0.31	11.00	10.19
Spiochaetopterus typicus	0.56	13.25	11.63
Micronephtys sp.	12.63	0.75	12.90
Philomedes globosus	59.94	5.25	14.14
Cistenides hyperborea	5.88	14.50	15.30

Godthåbsfjord and shelf (Sejr *et al.* 2010b). The large difference in depth and substrate at the relatively few station sampled in the Godt-haabsfjord study is part of the reason for the steep increase in number of species identified compared to the present study. Another study was conducted at and around the Store Hellefiskebanke located at 63-68° N (Marin ID 1978). Samples were collected at 32 stations ranging in depths from 25 to 550 m. The species richness (excluding Bryozoans) was slightly higher than observed in the current study (Figure 6C). Whether the observed differences between surveys conducted in sub-Arctic and the present study can be attributed to a difference in the depth, substrate or latitudinal effects is presently unknown. From the data available, compiled in the ARCOD database, the benthic species richness in West Greenland is significantly higher than in North and East Greenland and West Greenland appears to be a region with high species richness compared to 14 other Arctic regions (Piepenburg *et al.* 2011). In a comprehensive study on the Norwegian shelf (56-71° N) the total species richness was 809 species based on 101 sites (5 replicates per site), ranging from 65 to 434 m depth, (Ellingsen & Gray 2002). No evidence of a latitudinal effect was found on the Norwegian shelf, whereas some aspect of diversity could be related to habitat (sediment) heterogeneity.

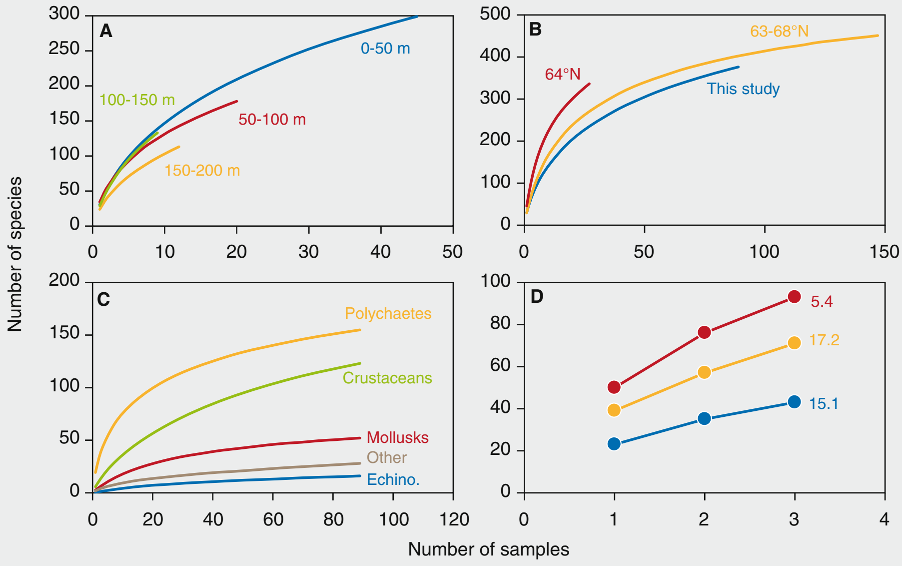


Figure 6. Species accumulation curves: (**A**) for the four different depth segments studied in the eastern Baffin Bay. (**B**) for major taxonomical groups; (**C**) from eastern Baffin Bay (this study) compared to two other studies in West Greenland; (**D**) for three replicates from three different stations sampled in this study.

The high variability of the diversity at sample level seems to be a general feature as found on other shelf areas, where no significant correlations to environmental parameters such as depth, grain size or carbon content were found (Ellingsen & Gray 2002). Other studies including deeper areas off the continental shelfs have shown a decreasing trend in species diversity and richness. In a study off Spitzbergen (Wlodarska-Kowalczuk *et al.* 2004) spanning depths from 200 to 3000 m the number of species per sample (comparable to Figure 6B) decreased significantly from 20-70 species per sample at stations below 500 m depth to 10 to 25 species per sample at stations from 2000-3000 m.

Other studies have found species richness to increase with depth from about 200 m to maximum values at 1500 to 2500 m (Etter & Grassle 1992, Gray 2002). The majority of the Eastern Baffin Bay assessment area is composed of depths below the depths sampled in this study (10 to 200 m), thus a higher diversity with a different species composition is expected in the deeper areas. It must be expected that only a modest part of the total benthic species pool is quantified and described in this study.

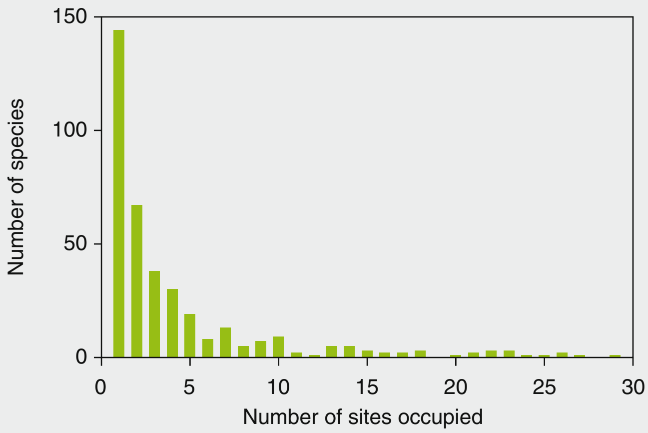


Figure 7. Distribution of species range given as the number of sites (stations) occupied of a species out of a total of 29 sites.

As mentioned above the dominant species found in this study are generally found at all depth ranges and the dominant species are largely similar to those found in other studies from Greenland and the North Atlantic. This emphasizes that rare species are important both to the total species richness but also in characterizing benthic species assemblages from different depth segments, habitat or Arctic regions. The distribution of the number of stations occupied by each species (Figure 7) shows a dominance of species found at only one or two sites. Only 6.5% of the species pool where found at 15 or more of the 29 sampled stations. Rarity of a species can in addition to a limited geographic distribution also be related to its abundance. Of the 377 species identified, 82 of them were only represented by a single individual. 44 species were represented by only two specimens.

also documented high abundance of large kelps, sea urchins and crustaceans at depths from 3-25 m (M.K. Sejr *pers. obs.*). Regarding the diversity it is important to note, that although the highest species richness has been observed in the shallow segment, species richness has been found to increase from 200 to 2500 m depth in other areas. Thus the region with the potential highest species richness is still not studied. Commercial fisheries of scallops and crabs take place within the study area and such areas can be considered vulnerable to impacts of oil explorations.

4.4.3 Vulnerability to disturbance

In general terms it can be noted that the occurrence of several species with an estimated maximum age of more than 25 years (the bivalves, *Mya* spp., *Hiatella arctica*, *Chlamys islandica* and the sea urchin *Strongylocentrotus droebachiensis*) indicates that the benthic community can be expected to 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 single specimens also suggest that mortality induced from disturbance from oil spills or exploration potentially can cause a significant reduction in the total species richness.

4.5 Ice fauna and flora

S. Wegeberg and D. Boertmann

During ice-breaking, especially in spring and summer, floes turned around often expose thick mats and curtains of algae on the underside and small fish – polar cod – are occasionally thrown up on the ice when the floes are tumbling around, indicating that there is a entire ecosystem associated with the ice. This is a specialised ecosystem based on bacteria, microalgae, micro- and meiofauna in and under the ice and macrofauna primarily found on the underside of the ice and in larger cavities. This ecosystem is found both in drift ice and in fast ice, and one of the most important structural parameters for the community is the age of the ice; multiyear ice having much more developed and richer communities than first-year (Quillfeldt *et al.* 2009).

These sea-ice environments are highly dynamic and have large variations in temperature, salinity and nutrient availability. Such variations lead to high degree of horizontal patchiness in microbial sea-ice communities. Furthermore, the microbial sea-ice community in the Arctic is highly diverse.

Strong patchiness of the sea-ice algae is commonly reported (Booth 1984, Gosselin *et al.* 1997, Gradinger *et al.* 1999, Rysgaard *et al.* 2001, Quillfeldt *et al.* 2009), caused by the heterogeneity of the ice as well as varying snow cover affecting light conditions. Rysgaard *et al.* (2001) found, in their study in Young Sound, Northeast Greenland, that the patchiness of algal activity was strongly linked to the corresponding patchiness in the light regimes below the ice.

In the North Water Polynya in the northern part of the assessment area, only < 1-3% of the in-ice community was found to consist of protists (ciliates and dinoflagellates). The microalgal fraction was strongly dominated by pennate diatoms (> 91%) of which the species *Nitzshia frigida* prevailed and contributed to, on average, 85% of total ice algal cell numbers. In the Greenland Sea, the algae was found to contribute to the biomass of the sea-ice communities with 43%, bacteria with 31%, heterotrophic flagellates with 20% and meiofauna with 4% (Gradinger *et al.* 1999). *Melosira arctica*, together with the pennate diatom, *Nitzshia frigida*, also dominant in the assessment area, tended to be the dominant diatom species off Northeast

Greenland/Barents Sea (Gutt 1995, Gosselin *et al.* 1997, Quillfeldt *et al.* 2009). Irwin (1990), however, only found *Nitzshia frigida* in the fraction of chain-forming diatoms, constituting 26% of the diatoms, while a large, centric *Cosinodiscus* species was dominant (65%) off Labrador, East Baffin Bay. In the fjord, Kobbefjord in West Greenland (south of the assessment area), 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 Davis Strait, Booth (1984) found a total dominance of pennate diatom genera.

The ice-algal production in the Arctic range from 5-15 g C m^{-2} $year^{-1}$ depending on sea-ice cover season (Mikkelsen *et al.* 2008). Irwin (1989) estimates an annual production of 4.4 g C m^{-2} off Labrador just east of the assessment area, and < 1 g C m^{-2} $year^{-1}$ has been reported from Kobbefjord (Mikkelsen *et al.* 2008) and in Young Sound, NE Greenland (Rysgaard *et al.* 2001).

The ice algal production in the northern part of the Barents Sea is reported to 5 g C m^{-2} $year^{-1}$, which corresponds to 16-22% of the total annual primary production (Quillfeldt *et al.* 2009), and the ice algae in the Arctic Ocean was found to contribute on average 57% of entire primary production (15 g C m^{-2} $year^{-1}$) (Gosselin *et al.* 1997). However, in the assessment area, Michel *et al.* (1992) found that ice algae only represented a small fraction of the total algal biomass, < 3%, in the North Water Polynya, and Mikkelsen *et al.* (2008) and Booth (1984) found that the ice algae only accounted for < 1%[1] of the pelagic primary production in Kobbefjord and Davis Strait, respectively. In Young Sound, Rysgaard *et al.* (2001) reached a similar result over their measuring period.

The annual productions of the ice algae communities in the Arctic seas are presented in Table 2.

Mikkelsen *et al.* (2008) tested if the ice algae acted as primers of the spring bloom of phytoplankton by algal seeding, but had, however, not 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 not present in the ice algal community in the North Water Polynya. Also Booth (1984) found that species composition in the sea-ice differed significantly from that of the phytoplankton.

The inside ice microfauna was found to be dominated by ciliates and heterotrophic dinoflagellates and the bottom-ice meiofauna by nematodes in the North Water Polynya within the assessment area (Michel *et al.* 2002). In other areas also flatworms and crustaceans are among the dominating species of meiofauna (Gradinger *et al.* 1999, Arndt *et al.* 2009). Gradinger *et al.* (1999) calculated a potential ingestion rate of the meiofauna, which levelled the estimated annual sea-ice primary production, and therefore they presumed that grazing could control biomass accumulation. However, Rysgaard *et al.* (2001) considered that the low ice algal production they found in Young Sound did not seem to be caused by high grazing pressure, since the biomass of grazers was not exceptionally high. In addition, Michel *et al.* (2002) concluded that very little ice algal production was channelled through the meio- and microfauna within the ice in the North Water Polynya, due to suboptimal prey size for predators.

[1] Calculated from an ice algal production of 0.8 g C m^{-2} and phytoplankton production of 94.4 g C m^{-2} from November to June in Kangerluarsunnguaq (Mikkelsen *et al.* 2008).

Table 2. Ice algal annual production (g C m^{-2} year^{-1}) in different areas of the Arctic. *Integrated over 7 months; November to June. It might therefore be an underestimate of the annual production. ** Calculated from an ice algal contribution averaging 57 % of the entire primary production (15 g C m^{-2} year^{-1}).

Source	Off Labrador	Arctic Ocean	Kobbefjord
Irwin (1990)	4.4		
Gosselin *et al.* (1997)		8,55**	
Quillfeldt *et al.* (2009)		6,5	
Mikkelsen *et al.* (2008)			0.8*

The importance of the sea-ice algal production compared to the phytoplankton may vary somewhat according to locality, but is close to negligible when considering the annual, pelagic primary production. However, during spring bloom, Horner & Schrader (1982) reported that the ice algae provided about two-thirds of the total, pelagic primary production in the nearshore regions of the Beaufort Sea. Booth (1984) found that the ice algae only contributed with < 1 % of the annual production of the phytoplankton in the Davis Strait, but also considered the contribution as important as it preceded the phytoplankton spring bloom and constituted the only algal biomass under heavy pack ice, in correspondence with Michel *et al.* (2002). They also found that ice algae only represented a small fraction of the total algal biomass, < 3 %, in the North Water Polynya, but as they considered limited grazing inside the ice, this biomass could play a significant role in ensuring availability of ice algae for under-ice pelagic and benthic grazers during spring.

The production of the ice community may be of great importance at times of the year when the pelagic and benthic productions are relatively low, especially just before spring bloom of phytoplankton, and thus also attracts crustaceans and fish species as polar cod (*Boreogadus saida*) and Arctic cod (*Arctogadus glacialis*).

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 as well as the oil may penetrate the ice through brine channels, all of which are the spaces occupied by sea-ice communities. Especially accumulations of polar cod eggs and larvae will be vulnerable (see below).

It is not possible to designate especially important or critical areas for sea ice fauna and flora; the information is too scanty and the ice associated ecosystem is too variable and dynamic. But is should be noted that the multi-year sea ice habitat is under very rapid decrease and may in few decades be restricted to very small patches along the north Canadian and north Greenland coast (Wang & Overland 2009). The major part (< 90 %) of the sea ice in Baffin Bay is however first-year ice.

Further studies are recommended to fully understand the role of sea-ice communities in the Baffin Bay marine ecosystem and to support identification of potential important or critical areas of sea-ice production in the assessment area.

4.6 Fish

H. Siegstad, K. Sünksen and O.A. Jørgensen

Our present knowledge concerning the fish fauna in Northwest Greenland (including the assessment area) is mainly based on information obtained during early Danish expeditions and follow-up analysis (Jensen 1926, 1935, 1939), on more recent studies on single fish species including the description of new species (Nielsen & Fosså 1993, Møller & Jørgensen 2000, Møller 2001) and fisheries related research activities and assessments (Jensen & Fristrup 1950, Pedersen 2005).

4.6.1 Fish assemblages

Based on 263 bottom trawl hauls conducted in the Davis Strait and Baffin Bay (to 74° N) at depths down to 1,500 m in 1999 and 2001, Jørgensen *et al.* (2005) were able to identify seven bottom fish assemblages that differed in respect to species composition, depth distribution and distribution in relation to bottom temperature. Four of these assemblages were unique to Baffin Bay:

1. An assemblage in relatively shallow and warm (mean 302 m, 2.6° C) with low abundance and diversity of fish and with the two small sculpins, *Triglops nybelini* and *Artediellus atlanticus* as 'primary indicator species'. It was also characterised by the daubed shanny (*Leptoclinus maculates*), the checker eelpout (*Lycodes vahlii*), the spotted wolffish (*Anarhichas minor*), the Atlantic sea poacher (*Leptagonus decagonus*) and the thorny skate (*Raja radiata*). Greenland halibut was rare in this assemblage.
2. On the upper slope of Baffin Bay (mean depth 534.6 m and 2.0° C) an assemblage was found dominated by Greenland halibut, but with some shallow water species such as the sculpins, *A. atlanticus* and *T. nybelini* and the American plaice (*Hippoglossoides platessoides*).
3. The slopes facing the central part of Baffin Bay inhabited two assemblages. The shallower one (mean depth 886.1 m and 1.0° C) was also dominated by Greenland halibut and characterised by the presence of the threadfin rockling (*Gaidropsaurus ensis*) and the double-line eelpout (*Lycodes eudipleurostictus*) and by the lack of shallow water species.
4. Greenland halibut was also the dominant species in the deepest assemblage (mean depth 1115.6 m and 0.7° C), which was further characterised by the presence of the Arctic skate, (*Raja hyperborea*), the threadfin sea snail (*Rhodichthys regina*) and the eelpout *Lycodes adolfi*.

The pelagic species were excluded from the analysis of the 1999 and 2001 surveys described above, but especially polar cod was caught in significant numbers in Baffin Bay.

The northern part of Baffin Bay (72° 02' N-76° 55' N) was surveyed by bottom trawl (105 hauls) at depths down between 150 and 1418 m in 2004 (Jørgensen 2005, Jørgensen *et al.* 2011). In total, 47 species (of these 42 benthic) were identified, but Greenland halibut was totally dominant and the only other species caught in notable numbers were pelagic polar cod (*Boreogadus saida*), Arctic cod (*Arctogadus glacialis*) and the Arctic skate (*Raja hyperborea*).

4.6.2 Selected species

Greenland halibut *Reinhardtius hippoglossoides*

The Greenland halibut is a sub-Arctic and Arctic species that is very abundant in the Baffin Bay (cf. above). Although a flatfish, spending most of its life on the bottom, it makes frequent migrations into the water column to feed. It is found typically in deep water along continental slopes and often in the vertical transitional layers between warmer and colder water masses at temperatures of 1-2° C (Alton *et al.* 1988, Godø & Haug 1989, Bowering & Brodie 1995). Greenland halibut spawns a large number of pelagic eggs in winter. The eggs have a long maturation period, and eggs and larvae when they hatch drift with the currents to nursery areas.

The biology of Greenland halibut in the Baffin Bay is poorly known. Neither spawning nor indications of spawning have been observed, either offshore or inshore, but the offshore area has only been surveyed in late autumn. At present it is believed that Greenland halibut recruits arrive as larvae from a spawning area in Davis

Strait. The larvae drift from Davis Strait along the coast in the West Greenland Current. In some years they are probably brought into the assessment area by the current or, when the current is weaker, they settle as young fish in the southern part of Baffin Bay and migrate into the assessment area. As they grow op they gradually migrate back towards the spawning areas in the Davis Strait. Preliminary tagging results support this assumption about the connection between the Greenland halibut population in the Davis Strait and Baffin Bay.

Greenland halibut is an important food source for narwhals (*Monodon monoceros*). During five winter months, 50,000 narwhals distributed at two wintering grounds in the central part of Baffin Bay were estimated to consume in the region of 790 tonnes of this fish per day assuming a diet consisting of 50% of Greenland halibut (Laidre *et al.* 2004). Based on studies of diving depths of narwhals, Laidre *et al.* (2003) concluded that polar and Arctic cod could be more important food sources in the northern wintering ground and during summer.

The Greenland halibut stock in the area is assessed annually by Northwest Atlantic Fisheries Organization (Jørgensen 2010). Bottom trawl surveys are conducted biannually in the Canadian part of the Baffin Bay by Canada (Treble 2009, 2011) and more irregularly by Greenland, latest in 2004 and 2010 (Jørgensen 2005, 2011).

Polar cod *Boreogadus saida*
Polar cod is a pelagic or semi-pelagic species with a circumpolar distribution in cold Arctic waters. It may form large aggregations and schools in some areas, often in the deeper part of the water column or close to the bottom in shelf waters. It occurs in coastal waters and is often associated with sea ice, where it may seek shelter in crevices and holes in the ice.

Polar cod spawn fairly large eggs in ice-covered waters in winter (November-February). The eggs float under the ice during a long incubation period. The larvae hatch in late spring when the ice starts to melt and the seasonal plankton production resumes (Bouchard & Fortier 2011). Most polar cod live to spawn only once (Cohen *et al.* 1990).

Polar cod is largely a zooplankton-feeder eating copepods and pelagic amphipods (Panasenko & Sobolova 1980, Ajiad & Gjøsæter 1990). As they grow larger they also take small fish. In coastal waters they feed on epibenthic mysids (Cohen *et al.* 1990) and in the ice they take ice-associated amphipods (Hop *et al.* 2000).

Polar cod play a very important role in the Arctic marine food webs (Figure 10) and constitute an important prey for many marine mammals and seabird species, notably ringed seal, harp seal, white whale, narwhal, thick-billed murre, northern fulmar, black-legged kittiwake, and ivory and Ross's gulls.

Arctic char *Salvelinus alpinus*
Arctic char is the most northern ranging freshwater fish and it is found throughout the circumpolar region. It is widespread in Greenland including in the most northern areas (Muus 1990). Arctic char occurs in different life history types. Resident populations live their whole lives in lakes and rivers, while anadromous populations migrate to the sea during summer to feed and move back to rivers and lakes in the autumn to spawn and winter. Migratory Arctic char constitute an important resource for local consumption and play a significant role in the nutrition of the people of Greenland (Riget & Böcher 1998).

To follow is a short description of the life history of anadromous populations. Life history characteristics such as growth rate, age of first seaward migration, age of maturity and time of year for seaward and upstream migration vary considerably between areas due to the extensive distribution of this population. In general, it must be expected that at higher latitudes with shorter growing season, lower temperature and variability in food resources, populations have a slower growth rate and later maturity than at lower latitudes (Malmquist 2004).

The eggs of the char winter in gravel in deep river pools or in lakes. The fry emerge in April-May and live off their yolk sac for about a month before feeding on small plankton organisms along the margins of rivers or lakes (Muus 1990). The young char called 'parr' remain in fresh water for several years before their first migration to the sea. At length 12-15 cm, corresponding to an age of 3 to 6 years depending on growth conditions, they begin their annual migration to the sea (Riget & Böcher 1998). The young char undergo morphological and physiological changes that make them able to live in saltwater. The seaward migration generally coincides with the spring freshet, which occurs in May-June, depending on the latitude. After their first seaward migration, the char return to rivers and lakes to winter and spawn. The anadromous char mature at a size of 35-40 cm (Muus 1990), corresponding to an age of 5-7 years.

At sea, Arctic char mainly stay in coastal areas not far (approx. up to 25 km) from the river they derived from (Muus 1990). Tagging experiments carried out in Southwest Greenland showed that only few char were recaptured more than 50 km from the tagging location (Nielsen 1961). However, there are examples of movements of tagged fish over considerably longer distances (up to 300 km) along the coasts of Alaska (Furness 1975). Both tagging experiments mentioned above showed that char populations from different rivers mix largely at sea.

At sea, the char feed intensively on small fish, fish larvae, zooplankton and crustaceans. In a study carried out in Young Sound, East Greenland the most important food items were amphipods and mysids (50%) followed by fish and fish larvae (20%) and copepods (11%) (Rysgaard *et al.* 1998). Most of the growth of Arctic char takes place during their stay in the sea, and the growth rate is also considerably faster than for lake resident populations. Investigations carried out in a river in Southwest Greenland showed that the annual growth rate for the resident river part of the population was only a couple of centimetres, while the anadromous part of the population showed a 5 cm annual growth (Grønlands Fiskeriundersøgelser 1982).

Both spawners and non-spawners migrate back to the rivers and lakes in June-September to winter in freshwater, after having spent 2-4 months at sea. Based on results from tagging experiments it appears that spawning char seek to their natal spawning rivers while non-spawning char may wander into non-natal river systems (Craig & McCart 1976). Mature and large char move back into streams before the smaller juvenile fish (Craig & McCart 1976). During their stay in freshwater they probably do not feed or only feed little.

Critical and sensitive habitats

In an oil spill context the river mouths and their adjacent coastal areas, where migrating char assemble before they move upstream, are the most sensitive habitats. The published knowledge of the occurrence of anadromous population along the coast of the assessment area is limited. Spawning rivers and fishing grounds were mapped based on local knowledge during an interview investigation in 2002 covering the former Uummannaq municipality and the southernmost parts of former Upernavik municipality north to 72° 30' N (Olsvig & Mosbech 2003). According to an earlier investigation there are very few char rivers in the northern parts of the former Upernavik municipality and in the former Qaanaaq municipality (Petersen 1993a, b). Figure 12 gives an overview of the known river outlets with spawning Arctic char.

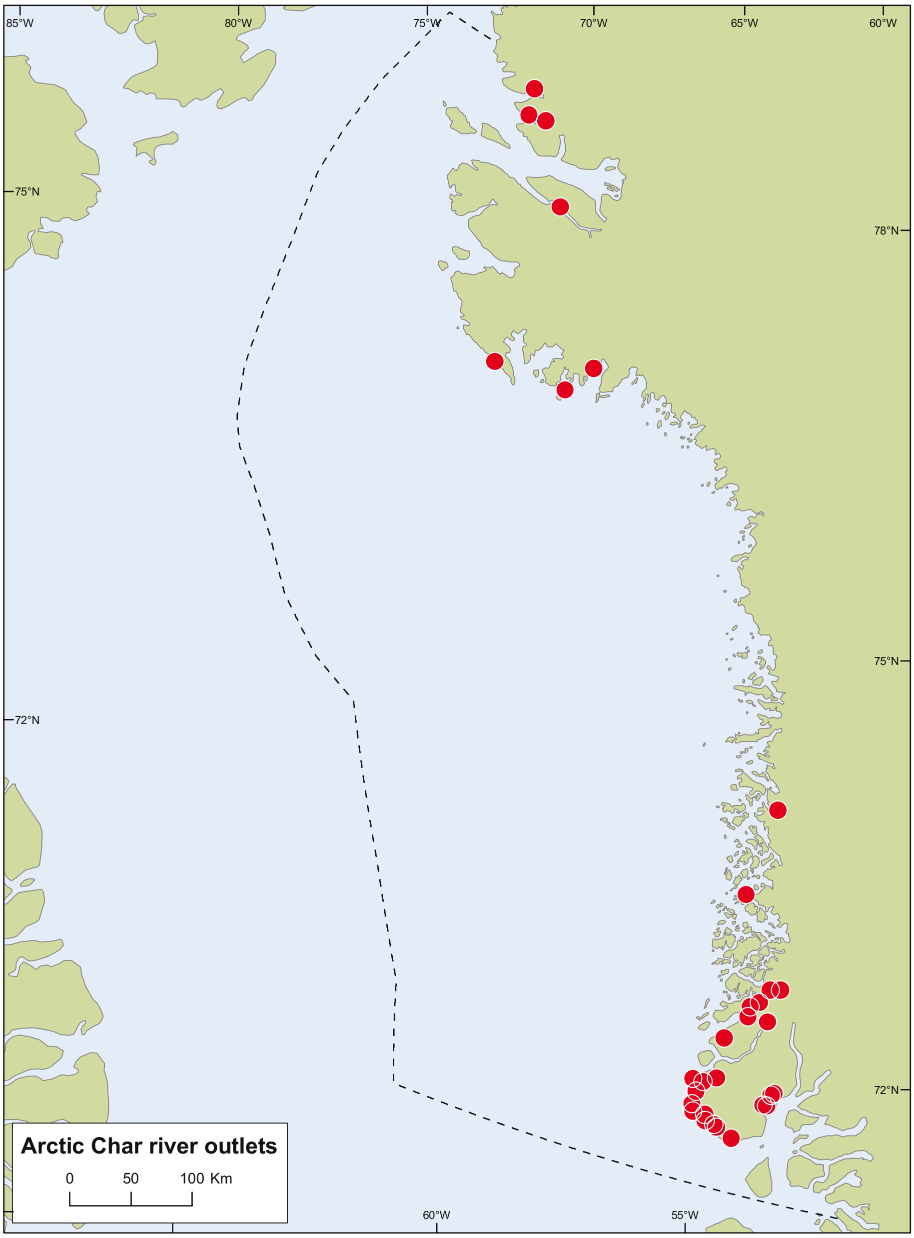


Figure 12. River outlets with Arctic char. Red circles indicate position of outlets of rivers with anadromous Arctic char. Based on local knowledge (Petersen 1993a, b, Olsvig & Mosbech 2003). The information from northern Upernavik and Qaanaaq municipalities is fragmentary and more rivers with Arctic char probably exist.

4.7 Seabirds

D. Boertmann and L.M. Rasmussen

During the ice-free periods seabirds are very numerous in the assessment area and constitute an important link between the productive marine ecosystem and the relatively low productive terrestrial ecosystem, as they transport nutrients from the sea to the breeding colonies on land. Many species are primarily fish consumers living from schooling species (capelin, sand eel and polar cod). Some species live on or supplement their fish diet with large zooplankton (copepods, krill), and others feed primarily on benthic invertebrates (e.g. bivalves) (Falk & Durinck 1993, Merkel *et al.* 2007). The species utilise the common resources by means of different feeding methods; for example, some species are deep-diving foragers while others take their food on the surface. Many seabird species tend to aggregate at breeding or foraging sites, where extremely high concentrations may occur (Box 3). For example, 80% of the global breeding population (N = 33 million pairs) of little auks (*Alle alle*) are estimated to breed on a 200 km-long shoreline of the former Qaanaaq Municipality of Northwest Greenland (Egevang *et al.* 2003). An overview of the seabird species occurring in the assessment area is given in Table 3.

Table 3. Overview of selected species of birds from the assessment area. b = breeding, s = summering, w = wintering, m = moulting, mi = migrant visitor, c = coastal, o = offshore. Importance of study area to population (conservation value) indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987).

Species		Occurrence	Distribution	Red List status in Greenland	Importance of study area to population	VEC
Fulmar	b	summer	c & o	Least Concern (LC)	high	+
Great cormorant	b	summer	c	Least Concern (LC)	high	+
White-fronted goose	b	May-September	c	Endangered (EN)	medium	
Snow goose	b	May-September	c	Least Concern (LC)	low	
Brent goose	b, mi	spring and autumn	c	Least Concern (LC)	high	
Common eider	b/s/m	summer	c	Vulnerable (VU)	high	+
King eider	s, m, mi,	July.-Sept.	c	Least Concern (LC)	high	+
Long-tailed duck	b/m	summer	c	Least Concern (LC)	medium	+
Red-breasted merganser	b/m	summer	c	Least Concern (LC)	low	
Red-necked phalarope	mi, (b)	spring and autumn	o	Least Concern (LC)	low	
Grey phalarope	mi, (b)	spring and autumn	o	Least Concern (LC)	low	
Arctic skua	b	summer	c	Least Concern (LC)	low	
Black-legged kittiwake	b, mi	summer	c & o	Vulnerable (VU)	high	+
Glaucous gull	b	summer	c & o	Least Concern (LC)	medium	
Iceland gull	b	summer	c & o	Least Concern (LC)	low	
Great black-backed gull	b	summer	c & o	Least Concern (LC)	low	
Sabines gull	b, mi	August and May/June	c & o	Near Threatened (NT)	low	
Ivory gull	mi	spring and autumn	c & o	Vulnerable (VU)	medium	+
Arctic tern	b, mi	May - September	c & o	Near Threatened (NT)	high	+
Thick-billed murre	b/s, mi	summer	c & o	Vulnerable (VU)	high	+
Razorbill	b	summer	c & o	Least Concern (LC)	high	
Atlantic puffin	b, mi	summer	c & o	Near Threatened (NT)	high	+
Black guillemot	b, mi	summer	c & o	Least Concern (LC)	high	
Little auk	b, mi	summer	c & o	Least Concern (LC)	high	+

Overall and general knowledge of seabirds in the assessment area is fairly good. However, knowledge about offshore distributions especially in migration seasons is needed, and several other specific questions remain to be studied.

Most seabirds are colonial breeders and numerous seabird breeding colonies are found dispersed along the coast of the assessment area (Figure 13). Colonies vary in size (from a few pairs to millions of pairs) and in species composition, from holding only a single species up to eight different species. In addition to the breeding birds, colonies are also used by many immature birds, which are potential breeders. The breeding seabirds utilise the waters near the breeding site; thick-billed murres (*Uria lomvia*) may fly more than 100 km to find their food, but most feed within a much smaller range (Falk *et al.* 2000, NERI unpublished). When the breeding season is over all the seabirds (adults + young birds) migrate out of the assessment area to winter in waters off Southwest Greenland and Newfoundland (Box 4).

Seaducks arrive from breeding sites in Canada and inland Greenland and assemble to moult in remote bays and fjords (Figure 14). The most numerous is the king eider (*Somateria spectabilis*), but also long-tailed ducks (*Clangula hyemalis*) and red-breasted mergansers (*Mergus serrator*) may occur in shallow fjords and bays (Mosbech & Boertmann 1999, Boertmann & Mosbech 2002). A few species occur mainly as migrant visitors during spring and autumn, e.g. two species of phalaropes and Sabines gull (*Larus sabini*). The rare and threatened ivory gull (*Pagophila eburnea*) does not breed within the assessment area (as far as known), but it occurs as migrant visitor and it is a frequent summer visitor in the North Water area, perhaps birds from breeding populations on southern Ellesmere Island (Boertmann 1994, Gilchrist *et al.* 2008).

There are 16 species of seabirds breeding in the assessment area (Boertmann *et al.* 1996). The most important are described in the following pages.

4.7.1 Important bird species occurring in the assessment area

This section gives an account of important birds in the assessment area (Table 3).

Northern Fulmar *Fulmarus glacialis*
Breeding distribution: Two breeding colonies are known from the assessment area (Figure 13), and the major part of the Greenland breeding population is found just to the south, in Uummannaq Fjord and Disko Bay (Boertmann *et al.* 1996). The breeding numbers in the two colonies are unknown, but at least several thousand pairs breed in each of them.

Offshore distribution: Fulmars occur almost everywhere in the offshore areas as long as open water is present, and they usually only avoid areas with high ice coverage. Concentrations are linked to foraging areas, and may occur at ice edges, upwelling areas and areas with commercial fisheries.

Biology: Fulmars feed usually at the surface, but can also perform shallow dives. They spend much time flying.

Catch: Fulmars are not very attractive as hunting quarry and relatively few are taken by the hunters of the assessment area. The fulmar is not among the species included in the catch statistics.

Conservation status: The fulmar population of the assessment area has a favourable conservation status, and it is not included on the Greenland Red List (listed as of 'Least Concern' (LC)).

Sensitivity and critical areas: The breeding colonies are sensitive because many fulmars often rest on the water surface below the breeding cliffs. Recurrent offshore concentration areas are not known, but may occur e.g. along the marginal ice zone in spring.

Great cormorant *Phalacrocorax carbo*
Distribution and population size: Cormorants breeds in several colonies on the coasts of the southern part of the assessment area (north to about 74° N) (Figure 13). In 1997, the population was estimated at about 150 pairs. It has increased considerably since then and may number more than 500 pairs today (Boertmann & Mosbech 1997), representing perhaps 10% of the total Greenland breeding population. Moreover, the population may have extended the breeding range further north. Colonies are generally small with fewer than 20 pairs.

Biology: The breeding birds arrive as soon as open water is present, and they leave again in late autumn for wintering grounds to the south of the assessment area.

Cormorants are diving birds that feed on fish. They are always found in coastal areas because they depend on terrestrial roosts to rest and dry their feathers.

Catch: Cormorants are hunted to a limited degree, and the species is not included by the hunting statistics.

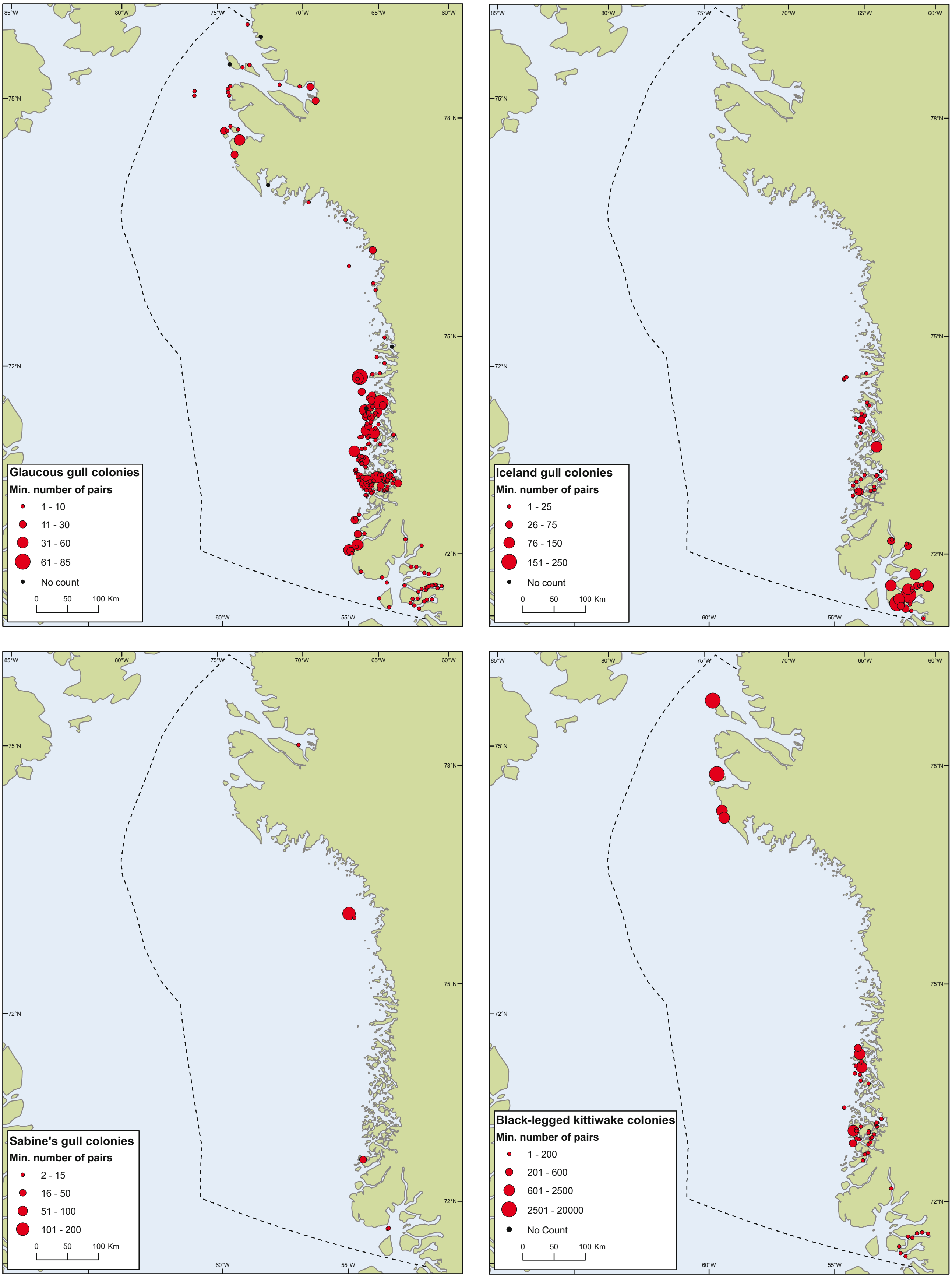


Figure 13A. Distribution and size of seabird breeding colonies in the assessment area. A1 glaucous gull, A2, Iceland Gull, A3 Sabines gull, A 4 black-legged kittiwake.

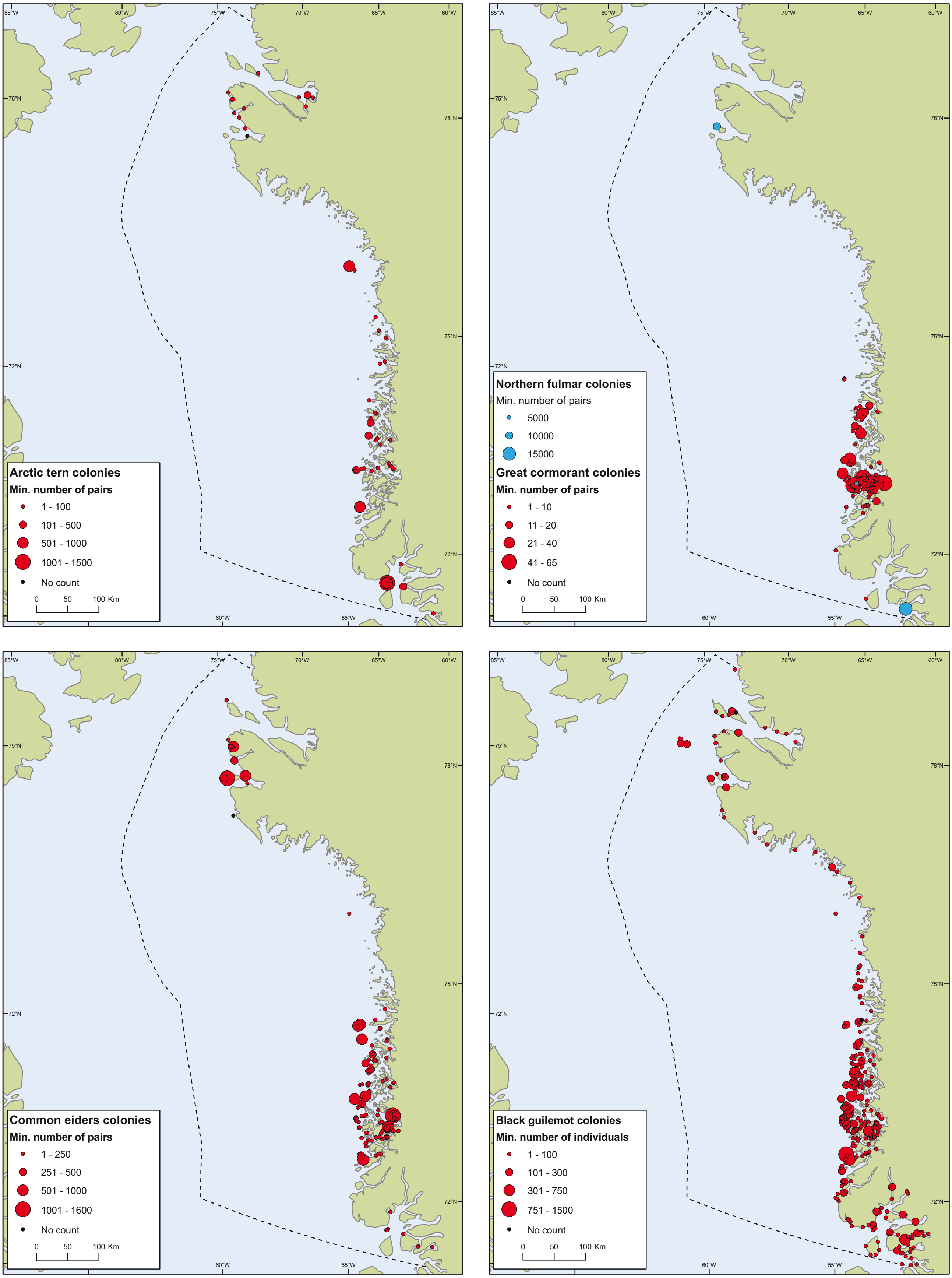


Figure 13B. Distribution and size of seabird breeding colonies in the assessment area. B1 Arctic tern, B2 northern fulmar and great cormorant, B3 common eider, B4 black guillemot.

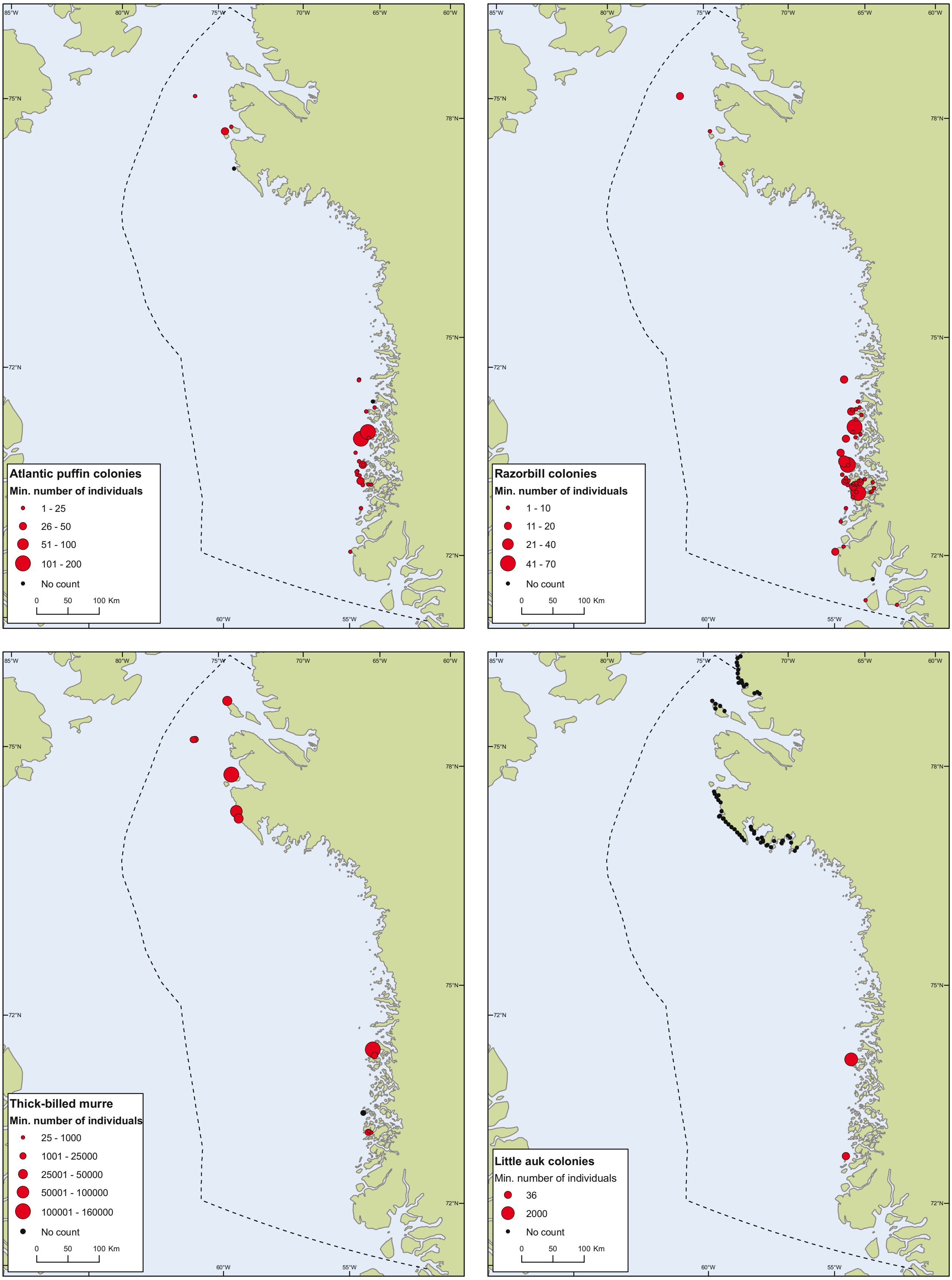


Figure 13C. Distribution and size of seabird breeding colonies in the assessment area. C1 Atlantic puffin, C2 razorbill, C3 thick-billed murre, C4 little auk. Note that the size of the huge colonies of little auk in Qaanaaq municipality is unknown. However, the total numbers breeding here has been estimated to more than 30 million pairs.

Conservation status: The cormorant population of the assessment area has a favourable conservation status, and it is listed as 'Least Concern' (LC) on the Greenland Red List.

Sensitivity and critical areas: The breeding colonies are sensitive because many cormorants often rest on the water surface below the breeding cliffs. Spring migration concentrations may occur, but have not been reported.

Common eider Somateria mollissima
Breeding distribution: 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 (Figure 13).

Non-breeding concentrations: Males assemble in moulting concentrations in remote fjords and archipelagos when the females have brooded 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.* 2006). 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 coastal waters of West Greenland, to the south of Disko Bay (Lyngs 2003, Mosbech *et al.* 2007c).

Population size: The number of breeding birds in the assessment area is unknown, but numbers probably amount to some thousands. The population declined considerably during the 1900s due to non-sustainable harvest. But recently, after hunting in the spring was prohibited, a population recovery has been demonstrated in Ilulissat and Upernavik, where active management and monitoring using local stakeholders has been carried out, and an annual population increase of 15% have recently been estimated (Merkel 2008).

Catch: The common eider is an important quarry for the hunters of the region. Approx. 5,000 were reported to the hunting statistics as caught in the assessment area in 1993 (Namminersornerullutik Oqartussat 1995).

Conservation status: The common eider population of the assessment area had an unfavourable conservation status due the decline in breeding numbers. It was therefore listed as 'Vulnerable' (VU) on the Greenland Red List. However, this status now seems out-dated, due to the population recovery.

Sensitivity and critical areas: Breeding colonies, moulting areas and staging areas during migration are sensitive, as birds may stay on the water in such areas. Particularly some of the archipelagos in Upernavik seem to be important moulting and staging areas during migration. Large flocks have been recorded for example at 'Fladøerne'.

Glaucous gull *Larus hyperboreus*
Breeding distribution: This is the most common and widespread gull in the assessment area. It breeds along the coasts, both dispersed and in small colonies rarely with more than 100 pairs (Figure 13).

Non-breeding distribution: Glaucous gulls are present in the region as long as open waters are present. Glaucous gulls are usually found in coastal areas, but some also venture far offshore. Concentrations occur at breeding sites and at good foraging areas, which are more or less unpredictable in their occurrence.

Population size: The total breeding population in the assessment area numbers probably more than 2,000 pairs.

Conservation status: The glaucous gull population of the assessment area has a favourable conservation status, and it is listed as of 'Least Concern' (LC) on the Greenland Red List.

Sensitivity and critical areas: Glaucous gulls are most sensitive 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 with other much more concentrated seabirds.

A similar species in most respects – Iceland gull, *Larus glaucoides* – occurs in the southern part of the assessment area (Figure 13).

Black-legged kittiwake *Rissa tridactyla*

Breeding distribution and population size: Kittiwakes are strictly colonial breeders placing their nests on vertical cliffs at the sea. There are at least 36 breeding colonies in the assessment area, with a total of about 40,000 breeding pairs (Labansen *et al.* 2010) (Figure 13).

Non-breeding distribution: Kittiwakes are migratory, leaving the breeding areas in September/October and returning again when open waters appear in April/May. Many non-breeders occur in offshore areas in summer.

Biology: Kittiwakes feed usually on the surface when swimming; they can also perform shallow dives. Results of recent studies in the assessment area are presented in Box 2.

Conservation status: The population in West Greenland has an unfavourable conservation status, as it has declined much since mid-1900s, probably due to excessive hunt. However, the large colonies in the former Qaanaaq Municipality that make up more than 80% of the population within the assessment area seem not to have declined (Merkel *et al.* 2007).

Catch: Kittiwakes are a preferred quarry for hunters of the assessment area. In 1993, approx. 3,000 birds were reported as shot in the region to the north of Disko Bay (Namminersornerullutik Oqartussat 1995).

Sensitivity and critical areas: Kittiwakes will be most vulnerable 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.

Arctic tern *Sterna paradisaea*

Breeding distribution and population size: Arctic terns are mainly colonial breeders, placing their nests on small and low islands. Colony size ranges from a few pairs to about 20,000 pairs. At least 40 colonies are known from the assessment area, and many in the southern part of the area hold more than 1,000 pairs (Egevang & Boertmann 2003) (Figure 13).

Biology: Arctic terns are highly migratory, wintering in the southern hemisphere. 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.

Conservation status: The West Greenland Arctic tern population has an unfavourable conservation status as it has been decreasing, perhaps due to excessive egg-collecting (which was banned in 2001). It is listed as 'Near Threatened' (NT) on the national Greenland Red list.

Sensitivity and critical areas: Breeding colonies are the most sensitive areas for Arctic terns. Offshore concentrations are not known from Greenland waters.

Thick-billed murre Uria lomvia

Breeding distribution and population size: This is one of the most numerous seabirds in the assessment area. By far the major part of the Greenland breeding population is found in colonies on the coasts of the assessment area. In the former Qaanaaq municipality there are five large colonies numbering in total 225,000 pairs and in Upernavik there are today three occupied colonies and a number of colonies either extinct or on the verge of extinction (Figure 13). There are approx. 100,000 pairs breeding in Upernavik.

Biology: Thick-billed murres of the assessment area are migratory, wintering in southwest Greenland and Newfoundland waters (Lyngs 2003, Boertmann *et al.* 2004, Box 4).

Murres are pursuit divers, chasing fish and large zooplankton down to more than a 100 m depth. They spend very long time on the sea surface, and only come on land in the breeding season. When the chicks are approx. three weeks old and far from fully grown or able to fly, they leave the colony in company with the male bird and swim/drift to offshore waters. The male then sheds all flight feathers and becomes flightless for some weeks. Murres are particularly sensitive to oil spills, and during this period of flightlessness their vulnerability increase.

Recent results of breeding biology studies in the assessment area are presented in Box 2 and 3, and results from satellite tracking studies of the migration pathways are presented in Box 4.

Catch: Murres are the most popular seabirds hunted in the assessment area. Approx. 13,000 were reported to the hunting bag register as shot in the assessment area in 2005 (Namminersornerullutik Oqartussat 2006).

Conservation status: The West Greenland population has an unfavourable conservation status because it is decreasing, except for the colonies in the former Qaanaaq municipality. The decrease has been particularly strong in Uummannaq and the southern part of Upernavik, where several colonies are abandoned today, some of which held up to 100,000 pairs before 1950. 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.* 2003).

Sensitivity and critical areas: 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 and probably also during the migration periods.

Black guillemot *Cepphus grylle*

Breeding distribution: This is probably the most widespread of the breeding colonial seabirds in the assessment area. There are colonies in most fjords, bays and coasts, and their numbers range from a few pairs to several hundreds (Figure 13). The total breeding population within the assessment area is unknown, but numbers at least 10,000 pairs. A few may stay in the assessment area throughout the winter in polynyas and leads (Renaud & Bradstreet 1980).

Biology: The nests are placed in caves, cracks in the cliff or among stones. Black guillemots are more or less migratory, leaving the assessment area when the ice covers the shallow coastal foraging areas. They winter in the offshore drift ice and in the open-water area to the south of the assessment area.

Box 2

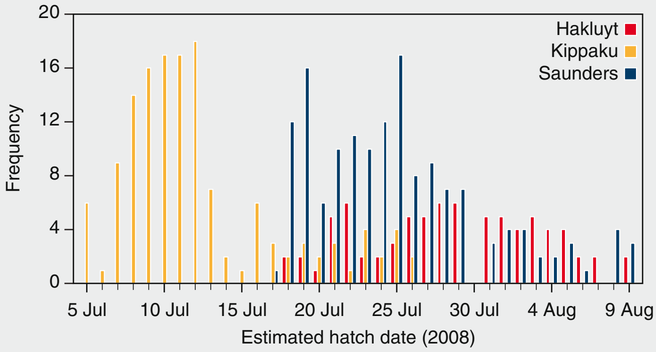


Figure 1. Breeding phenology of thick-billed murres. Samples of thick-billed murre chicks were aged (based on wing length) at all study colonies, and hatch dates back-calculated. In 2008, mean hatching was about two weeks earlier at Kippaku (mean = 12 July, n = 140) than at Saunders Island (mean = 24 July, n = 152) and Hakluyt Island (mean = 28 July, n = 78). Hatch dates were slightly later at the two northern colonies in 2007 (mean = 26 and 31 July, n = 86 and 65). At Kippaku, mean hatch date was earlier in 2010 (mean = 5 July, n = 69).

Breeding biology of thick-billed murres and black-legged kittiwakes in the Eastern Baffin Bay assessment area

M. Frederiksen, A. Mosbech and F. Merkel

The performance and success of chick-rearing seabirds is generally viewed as a good indicator of the prevailing environmental conditions during summer, specifically the availability of suitable food. Detailed studies of breeding biology were carried out at three colonies in the assessment area during 2007-2010. The results shown here illustrate the different conditions prevailing within this large area (Hakluyt Island and Saunders Island are in the former Qaanaaq Municipality and Kippaku is approx 500 km to the south in Upernavik). Food availability seemed to be higher in the S than in the N: thick-billed murre chicks achieved a better body condition despite being fed less frequently, and breeding success of black-legged kittiwakes was much higher. Unsurprisingly, breeding was also earlier in the S for both thick-billed murres and black-legged kittiwakes.

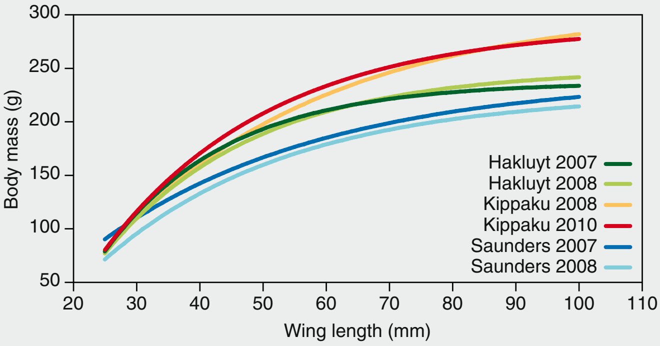


Figure 2. Body condition of thick-billed murre chicks. In order to assess feeding conditions, wing length and body mass were measured for samples (n = 65-152) of murre chicks at all study colonies. Asymptotic growth curves were then fitted to the data. Results show that chicks at the southern study colony (Kippaku) attained a higher body mass before fledging than at the other colonies. Chicks at Hakluyt Island initially grew faster than those at Saunders Island, but fledging masses were similar. Interestingly, at all study colonies growth patterns were very similar between years.

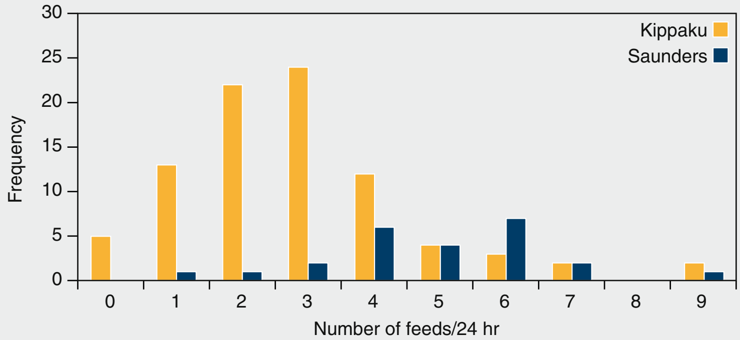


Figure 3. Feeding rates of thick-billed murre chicks. 24-hour feeding watches were performed at Kippaku (2) and Saunders Island (1) in 2008, with sample sizes of respectively 44 and 24 chicks. Mean feeding rate was substantially higher at Saunders Island (mean 4.92 feeds/chick/24 hr) than at Kippaku (mean 2.87 feeds/chick/24 hr). It is striking that despite the higher feeding rate at Saunders Island, chicks here were in poorer body condition than at Kippaku (Box 1, Fig. 2). This may reflect smaller and/or less nutritious food items being prevalent at the northern colony.

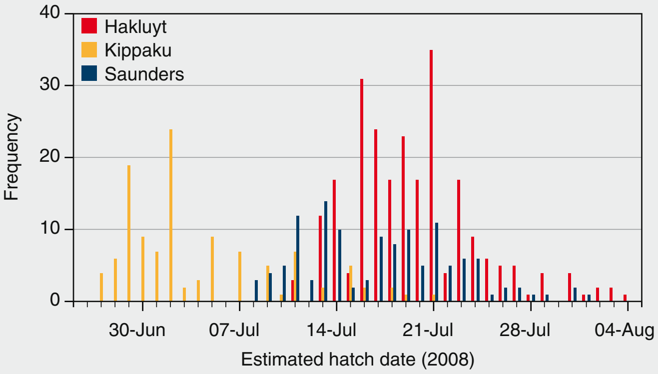


Figure 4. Breeding phenology of black-legged kittiwakes. Samples of black-legged kittiwake chicks were aged at all study colonies, and hatch dates back-calculated. In 2008, mean hatching was about two weeks earlier at Kippaku (mean = 4 July, n = 120) than at Saunders Island (mean = 17 July, n = 138) and Hakluyt Island (mean = 19 July, n = 251). Hatch dates were also very similar at the two northern colonies in 2007 (mean = 20 and 21 July, n = 54 and 86). At Kippaku, mean hatch date was also 4 July in 2009 (n = 222) and 2010 (n = 208).

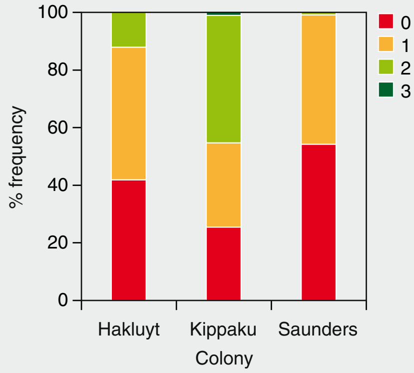


Figure 5. Breeding success of black-legged kittiwakes. Breeding success was estimated by counting chicks in active nests and attempting to identify failed nests. Most chicks were large, and mortality between survey and fledging is likely to have been low. In 2008, mean breeding success was much higher at Kippaku (mean = 1.21 chick/nest, n = 161) than at Saunders Island (mean = 0.47 chick/nest, n = 301) or Hakluyt Island (mean = 0.67 chick/nest, n = 432). Breeding success was lower at the two northern colonies in 2008 than in 2007 (mean = 1.24 and 1.11 chick/nest, n = 58 and 112), although it is uncertain whether data from Saunders Island in 2007 are strictly comparable. At Kippaku, breeding success was even higher in 2009 (mean = 1.73 chick/nest, n = 280) and 2010 (mean = 1.72 chick/nest, n = 276) than in 2008.

Box 3

Foraging areas and behaviour of thick-billed murres

M. Frederiksen, A. Mosbech, F. Merkel and K.L. Johansen

Foraging areas

While the locations of the large seabird breeding colonies in West Greenland are well known, little is known about the actual foraging areas during breeding in the colonies. This is very important information in relation to identification of critical habitats which can be affected by potential oil spills. We have combined the use of telemetry with ship-based surveys to identify foraging range and areas around two important colonies of thick-billed murre in the eastern Baffin Bay area: Saunders Island and Kippaku.

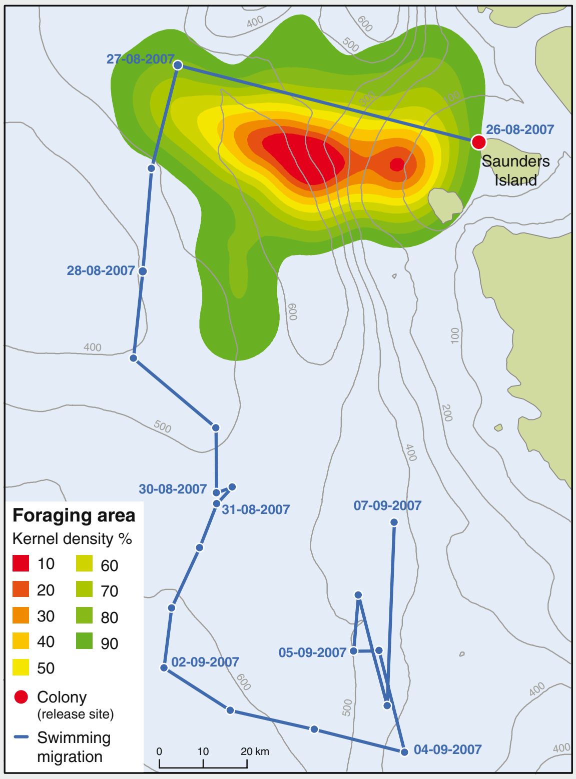


Figure 1. Foraging area for a thick-billed murre tracked with external satellite transmitter while commuting between the colony at Saunders Island and foraging areas. The foraging area was estimated by kernel analysis, including only locations away from the colony. The murre was tracked for 33 days, including 21 days at the colony during which time it made a minimum of 14 foraging trips with a mean duration about 24 h. The mean distance to the centre of the foraging area was about 60 km, and the foraging area was centred on the 500 m isobath SW of the colony. The figure also shows the route for the apparent swimming migration after the bird had stopped commuting to the colony.

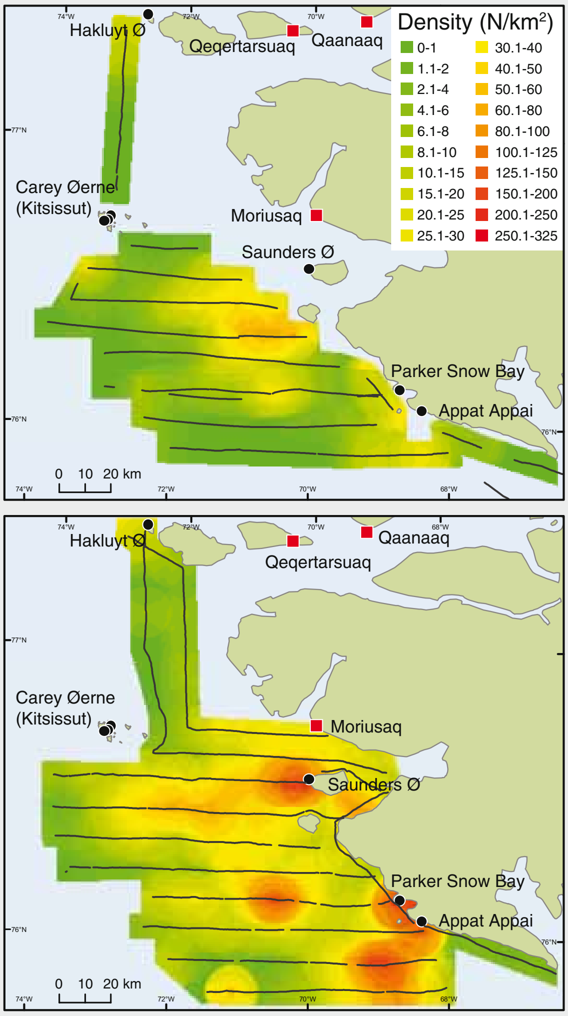


Figure 2. Densities of thick-billed murres recorded on ship-based line transect surveys in the breeding season in 2007 and 2008. The thick-billed murre colonies in the area are indicated with black dots. Significant concentrations were observed west and southwest of three southern colonies. Concentrations within few km of the colonies may not represent foraging birds while it is most likely that concentrations further away indicate foraging areas. In both years, foraging concentration areas extended about 40-60 km west and southwest of Saunders Island, and the foraging area of the tracked bird in Box 2, Fig. 1 is within this area. In both years, murre concentrations were low south of the colony at Hakluyt Island in accordance with earlier observations that birds from this colony mainly forage to the north. (Colony sizes (pairs) Saunders Island 116,250, Parker snow Bay 42,000, Appat Appai 33,750, Hakluyt 31,500, Carey Islands 7,500 (Merkel *et al.* (2007).

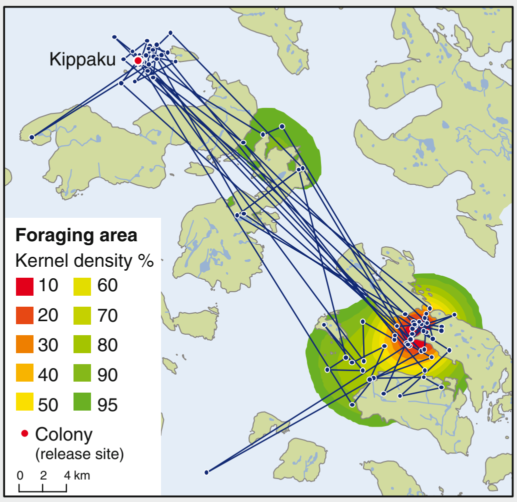


Figure 3. Foraging area for a thick-billed murre tracked with external satellite transmitter while commuting between the colony at Kippaku and foraging areas. The foraging area was estimated by kernel analysis, including only locations more than 4 km from the colony. The bird was tracked for 7 days and made at least 7 foraging trips with a mean duration of 6 hours and a mean distance to the foraging area of 31 km. The bird clearly returned repeatedly to the same foraging area over this period.

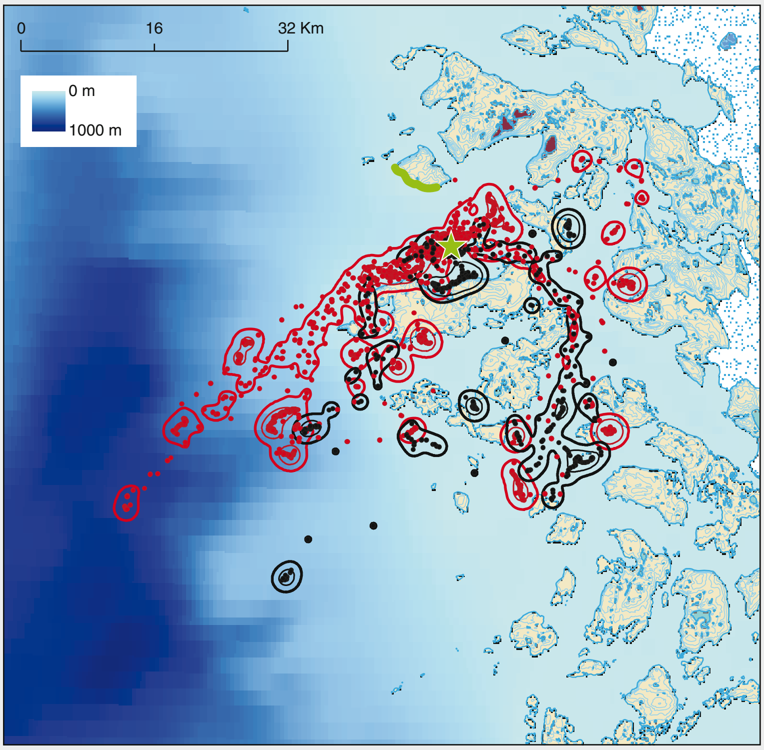


Figure 4. Foraging areas for GPS-tagged thick-billed murres at Kippaku in 2009 (shown in black) and 2010 (shown in red). Five birds were tracked in 2009 for an average of three days, and 11 birds in 2010 for an average of 24 hours. Foraging areas were estimated by kernel analysis (50% and 90% contours shown), including only locations more than 2 km from the colony. Birds foraged within 45 km of the colony, either within the archipelago or around the shelf break SW of the colony. All bird avoided the vicinity of the much larger colony Apparsuit (indicated by yellow highlighting). Most birds repeatedly returned to the same foraging area, although some also shifted to completely different areas.

Ship-based line transect surveys were carried out around Saunders Island in 2007 and 2008, and around Kippaku in 2008. Satellite tracking was used at Saunders Island in 2007 and at Kippaku in 2008. To achieve higher temporal and spatial resolution, we deployed GPS loggers at Kippaku in 2009 and 2010. The loggers weighed approx. 15 g including pressure-proofing, and were attached to feathers on the bird's back using Tesa© cloth tape. The loggers were programmed to sample positions with intervals of 10 minutes in 2009 and 2 minutes in 2010.

Around Saunders Island and the other colonies in the Qaanaaq area, most murres foraged around 50 km offshore, at a depth of several hundred meters. In contrast, murres at Kippaku foraged either inshore in the archipelago SE of the colony, or offshore to the SW, but at a more shallow depth (around 200 m), and most foraging took pace within 30 km of the colony. Line transect surveys indicated that birds from the very large colony at Apparsuit behaved similarly. Our results thus indicate that foraging behaviour differs substantially between the colonies in the Qaanaaq area, which are associated with the North Water Polynya, and the colonies in the Upernavik area, where the topography is more complex and prey diversity presumably higher.

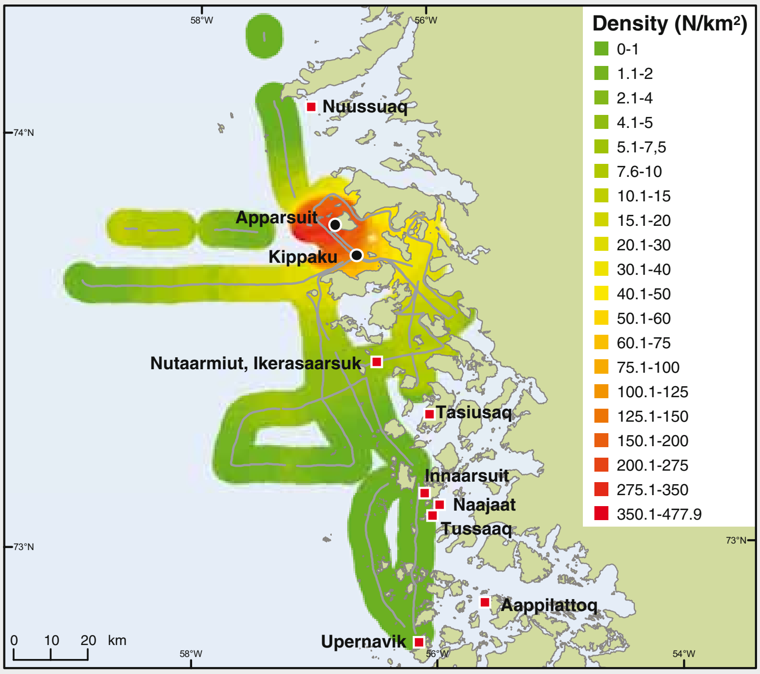


Figure 5. Densities of thick-billed murres recorded on ship-based line transect surveys in northern Upernavik in the breeding season 2008. The two thick-billed murre colonies in the area are indicated with black dots. High densities of murres occurred in the archipelago east of the colonies and also west of the colonies, but did not extend far offshore. The density distribution mainly reflects the larger colony Apparsuit and the data indicate that the main foraging area is within 25 km of the colonies. The murres tracked from Kippaku also to a large extent foraged within the archipelago (Box 2, Figs. 3 and 4) (Colony sizes as total numbers of birds present in colonies: Apparsuit 113.000 and Kippaku 17.000 (Nyeland 2004)).

Black guillemots feed on fish and large invertebrates by pursuit, diving from the surface and spend all of their time at sea except for the breeding season. In the breeding time they forage in the coastal environment, but during migration and winter they also occur far offshore and are often associated with ice.

Conservation status: The black guillemot population in the assessment area has a favourable conservation status and is listed as 'Least Concern' (LC) on the Greenland Red List. It is however a national responsibility species, because a very large fraction of the global population breed in Greenland and the majority of the Greenland population is found within the assessment area.

Sensitivity: Vulnerable concentrations occur mainly in the summer time at the breeding colonies, but also in the migrating period in spring when aggregations may occur in the marginal ice zone or at the edge of the fast ice of the coasts. However due to the wide dispersion of the colonies black guillemot sensitivity on a population level is relatively low.

Little auk *Alle alle*

Breeding distribution and population size: This small alcid is the most numerous seabird in the North Atlantic. The globally most important breeding area for this species is in Qaanaaq, where more than 80% of the total world population is estimated to breed (Nettleship & Evans 1985). This population is estimated at aprox. 33 million pairs, distributed along the shores between northern Melville Bay and Etah in Inglefield Land (Boertmann & Mosbech 1998, Kampp *et al.* 2000, Egevang *et al.* 2003). There are smaller colonies in Upernavik with max. 5,000 pairs (Boertmann *et al.* 1996) (Figure 13). Little auks often occur in huge flocks on the water below the colonies and in foraging areas.

Offshore distribution: Very large spring concentrations have been described from the Canadian side of Baffin Bay (Renaud *et al.* 1982), and it is likely that similar concentrations occur in autumn.

Biology: Little auks are planktivorous, feeding mainly on large crustaceans such as *Calanus* species and *Parathemisto* which they catch during pursuit diving. Breeding little auks in Qaanaaq were measured to dive to 35 m depths (Falk *et al.* 2000, Pedersen & Falk 2001). During the International North Water Polynya Study it was estimated that the little auks were responsible for 92-96% of the energy demand of the seabirds in the polynya, underlining their importance in the food web. Their main feeding areas are close to the Greenland coast underlining the high production in this part of the polynya (Karnovsky & Hunt 2002). The breeding colonies are situated in screes, where the birds place the nests under stones and boulders.

Like other alcids little auks spend all of their time at sea except when breeding.

Little auks are migratory, wintering in offshore waters especially off Newfoundland and Labrador on the edge of the banks (Brown 1986, Lyngs 2003, Mosbech *et al.* 2011). They arrive at the breeding colonies in May and leave again in mid- to late August and have probably left the Baffin Bay late September. After departure from the breeding sites the adult birds perform a simultaneous moult of the flight feathers and become flightless for some weeks.

Conservation status: The little auk population in the assessment area has a favourable conservation status and the species is listed as of 'Least Concern' (LC) on the Greenland Red List. It is however a national responsibility species (Table 7), because of the very large fraction of the global population breeding within the assessment area (see above).

Sensitivity: The large concentrations of little auks on the water will be very sensitive to oil spills and the high concentrations of flightless birds in September would be particularly vulnerable, but there is no knowledge available to elucidate this important issue. Tagging little auks with geo-locators in 2010 in the breeding colonies will hopefully give insights in the whereabouts of the little auks in the non-breeding season. The tacked birds will be caught in 2011 to retrieve the geo-locators.

Atlantic Puffin *Fratercula arctica* and Razorbill *Alca torda*
These two alcid species occur in the assessment area in much lower numbers than the other species of the alcid family. There are probably less than a 1,000 pairs of each species within the area. Their breeding colonies are usually small with less than 50 pairs and they are found on small islands; in the case of the puffin almost among the outermost islands. The colonies are mainly found in the archipelagoes of Upernavik supplemented by a few in Qaanaaq (Figure 13).

Both species place their nests concealed in cracks and caves or below boulders, and both feed on fish and large zooplankton. As the other alcids they spend all of their time at sea except when breeding.

Besides the breeding concentrations there is no knowledge on concentrations of these two species during their spring and autumn migration.

Their behaviour and sensitivity towards oil spills are similar to murres and guillemots, although puffins moult their flight feathers much later in the year (winter and even spring) than murres.

Other significant bird species more or less associated to the marine environment
Sabines gull (*Larus sabinii*) is a small gull with a limited breeding distribution within Greenland. Within the assessment area there are four breeding colonies on small islands in Melville Bay, in Inglefield Bredning and in southern Upernavik (Figure 13). Sabines gulls are migratory, wintering in the southern hemisphere and occurring in the assessment area from late May to August/September.

Ivory gull (*Pagophila eburnea*) does not breed within the assessment area, but close by, at Ellesmere Island in Canada. It is a common visitor, mainly at the ice edge in the northern part of the assessment area, and most of the birds are probably from the Canadian breeding population, although also birds from the East Greenland population may occur (Lyngs 2003).

Both Sabines gull and ivory gull are red-listed in Greenland, as 'Near Threatened' (NT) and 'Vulnerable' (VU) respectively. In Canada Ivory gull is listed as 'Endangered' (recently up-listed from 'Special concern') and globally it is red-listed as 'Near Threatened'. The main reason for this conservation concern is an expected population reduction due to climate change, a reduction already reported from Canada where the population has decreased more than 80 % (COSEWIC 2006).

Geese use salt marshes and other nearshore habitats for feeding. These salt marshes often become inundated at high water levels. Geese occur in the assessment area when breeding, moulting and staging on migration. Significant concentrations of moulting snow geese (*Anser caerulescens*) occur at the coasts of the former Qaanaaq municipality; and internationally important concentrations of brent geese (*Branta bernicla*) may occur throughout the assessment area during migration periods in May/June and again in August/September as the entire flyway population moves through both seasons. It is therefore a national responsibility species (Table 7). The endemic and red-listed Greenland white-fronted goose (*Anser albifrons flavirostris*) breeds in low numbers in inland areas of the southern part of the assessment area and Canada geese (*Branta canadensis*) occur probably rather commonly throughout the assessment area (Boertmann & Glahder 1999).

The brent geese belong to a small discrete population breeding in high Arctic Canada and on a few islands in the former Qaanaaq municipality. They winter in northwest Europe. The snow geese belong to a very large population, with the major part breeding in Arctic Canada and with winter quarters in northeast USA. The white-fronted geese belongs to a small decreasing population which breeds exclusively in West Greenland and winters in the British Isles. Canada geese on the other hand are increasing and belong to a population which has its main distribution in eastern Canada, with winter quarters in northeastern USA.

King eiders (*Somateria spectabilis*) do not breed in the assessment area. However, large numbers, primarily males, assemble from July in fjords, bays and straits to perform moult, and they become flightless for a period of three weeks (Salomonsen 1968, Mosbech & Boertmann 1999). Within the assessment area particularly the fjords in southern Upernavik are important for moulting king eiders (Figure 14).

Phalaropes (*Phalaropus* spp.) are small shorebirds (waders) associated with the marine environment during the non-breeding period. The grey phalarope (*Phalaropus fulicarius*) breeds on small islands together with Arctic terns, e.g. those in the Melville Bay (Egevang *et al.* 2004), while the red-necked phalarope (*Phalaropus lobatus*) breeds at ponds and small lakes on the tundra.

4.7.2 Seabird migration pathways in the Baffin Bay area

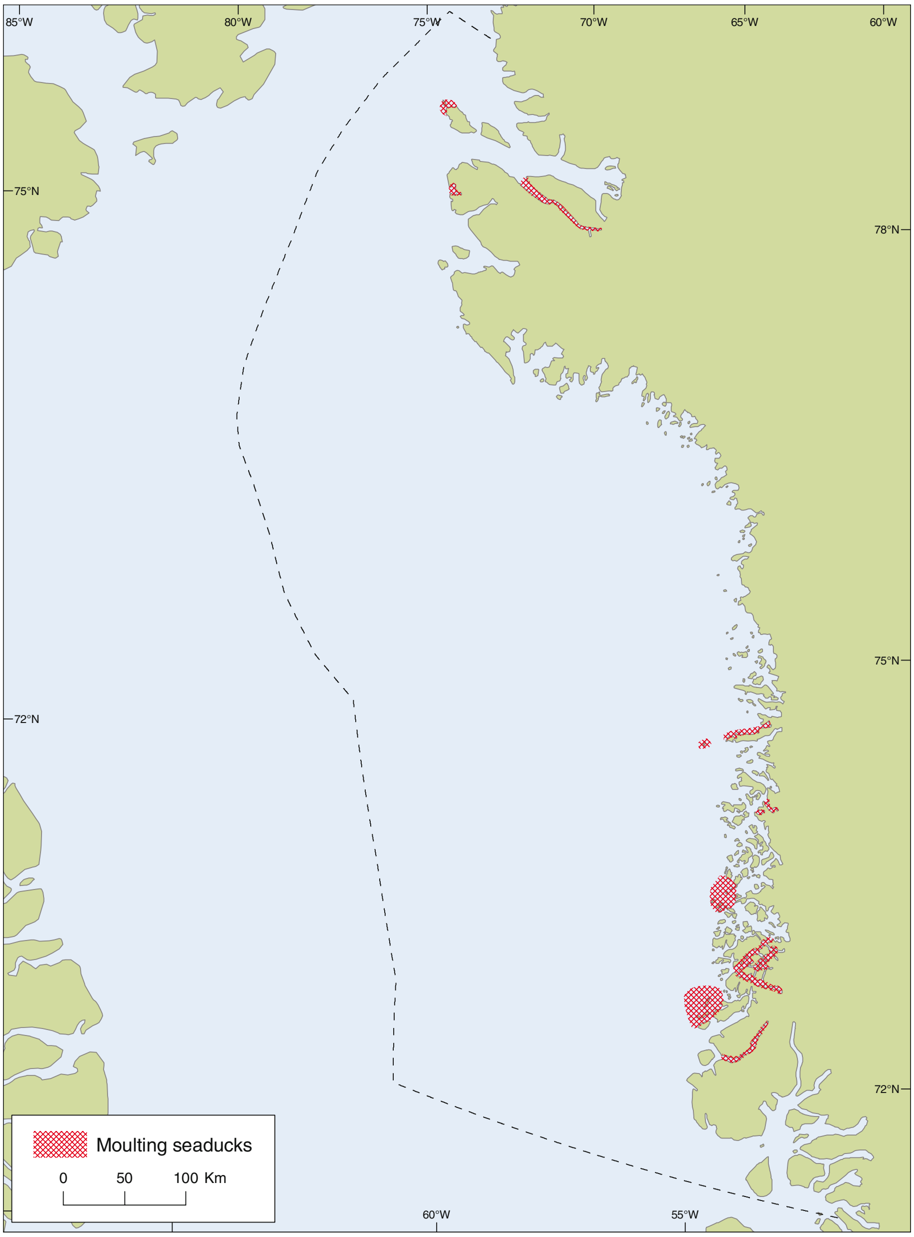
Besides the large breeding populations of alcids (thick-billed murres and little auks) on the Greenland side of the Baffin Bay at least 650,000 pairs of thick-billed murre breed on the Canadian side (Nettleship & Birkhead 1985). All breeding birds from Canada and Greenland, their offspring and populations of other seabird species move southwards through Baffin Bay towards winter quarters off southwest Greenland and Newfoundland/Labrador (Box 4). This is documented from recoveries of harvested birds banded in the breeding colonies (Lyngs 2003) and in recent years also from tracked birds (Box 4). Besides the very numerous species other species include for example black-legged kittiwake, ivory gull (especially important in conservation context) and black guillemot. A seabird-at-sea study in autumn 2009 in the waters just south of the assessment area showed that little auks were distributed mainly in the waters outside the shelfs with highest concentrations on the Canadian side, while thick-billed murres were found in more discrete patches on the Greenland side and closer to the shelfs (Box. 5, NERI unpublished).

In total, it is estimated that at least one hundred million seabirds (adults and juveniles combined) move through Baffin Bay during September and October. Migration routes, critical areas (e.g. staging areas or important feeding areas) for these migrating seabirds have until recently been largely unknown. NERI has, since 2007, focused on the migration of the thick-billed murres, by tracking birds by means of satellite telemetry and geo-dataloggers, and some results are presented in Box 4. In 2010 the studies also included little auks, but the results form this geo-locator tagging will be available in winter 2011/12.

4.7.3 Important seabird habitats

Besides the breeding colonies where large concentrations of seabirds can occur on the water, significant concentrations of seabirds may occur elsewhere in the assessment area. Polynyas (see Section 3.4.3) and ice edges act as very important staging and feeding areas when the birds arrive from the south and other areas of

Figure 14. Important areas for moulting seaducks (mainly king eiders) in the assessment area. Moulting takes place in July, August and early September.



the Baffin Bay are still ice-covered (Laidre *et al.* 2008b). There is a strong link between the polynyas and where the major seabird breeding colonies are situated, for example the North Water and the little auk colonies on the Qaanaaq shores.

Other areas with early ice break-up, such as the coastal shear zone, may also create open waters to the benefit of early arriving breeding seabirds. This seems to be the case especially in Upernavik, where the concentration of seabird breeding colonies is much higher than in other parts of West Greenland, despite the extensive ice cover until late-May.

No information is available on specific, important offshore feeding areas, but these may occur for example where upwelling events are recurrent.

Although not seabirds, geese should also be mentioned in this context, because they often utilise saltmarshes within the assessment area (see above). Particularly the Greenland white-fronted goose (*Anser albifrons flavirostris*) is vulnerable, because the population is seriously decreasing. Brent geese (*Branta bernicla*) on migration between breeding sites in Arctic Canada and wintering grounds in northwest Europe also utilise these salt marshes during stopovers (Boertmann *et al.* 1997, Egevang & Boertmann 2001b).

Box 4

Identification of migration routes of thick-billed murres using satellite telemetry and geolocation

A. Mosbech, F. Merkel and K.L. Johansen

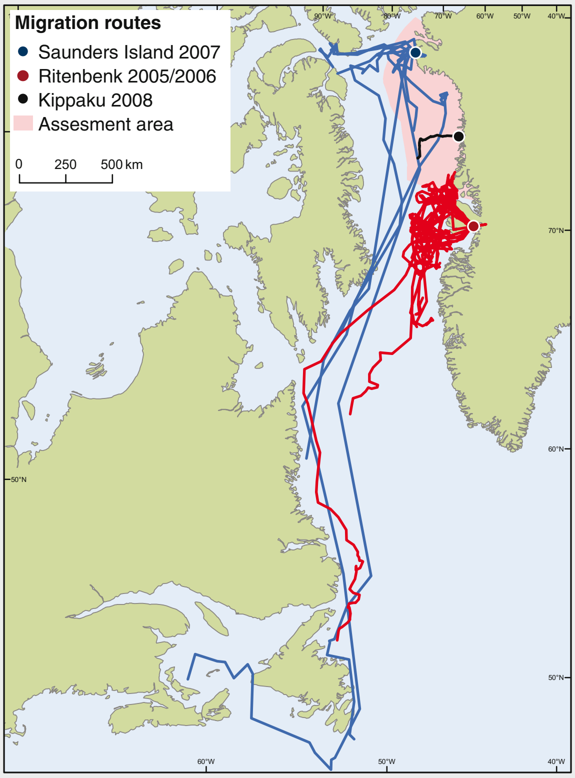


Figure 1. Thick-billed murres autumn migration tracked with satellite transmitters from three breeding colonies in West Greenland. The figure shows tracks for eight thick-billed murres tracked with internal satellite transmitters from Saunders Island, one tracked with external satellite transmitter from Kippaku and 26 tracked with internal satellite transmitters from Ritenbenk.

Migration routes

When the young thick-billed murres leap from the ledges at an age of 2-3 weeks, they are unable to fly but glide through the air to the water, usually closely followed by one or two adults. Once in the water, the chick starts a swimming migration accompanied by the male adult, which during the first weeks of the swimming migration moults its flying feathers and becomes flightless. The female will typically continue to attend the ledge for about two weeks before starting the migration and the moult. During the swimming migration, murres are very vulnerable to oil slicks on the sea surface. To identify the migration routes of thick-billed murres from the colonies at Saunders Island, Kippaku and Inaq/Ritenbenk we equipped murres with satellite transmitters and data loggers.

Satellite tracking

To track the autumn migration of the murres we used implanted satellite transmitters with an external antenna (26 g pressure proof implantable Microwave PTT). Murres with chicks were selected. The advantage of the implanted PTT is that it is not shed with the feathers and potentially it can give information on the movements during a full year. The disadvantage is that the surgery typically will cause the murre to give up breeding that year.

Murres with internal satellite transmitters from Saunders Island were tracked for up to 166 days (median 46 days). Of the ten murres tracked, eight were tracked for some or all of their autumn migration (Figure 5). The routes through northern Baffin Bay varied: four of the eight murres first headed towards Lancaster Sound and staged near the mouth, two staged in the local foraging area (approximately 60 km W-SW of Saunders Island), one staged in Melville Bay and one did not stage en route but flew directly south to western Davis Strait. However, regardless of staging area in northern Baffin Bay, all four murres which were tracked all the way through Baffin Bay followed an offshore route through central Baffin Bay. Four murres were tracked beyond Baffin Bay, and they all went to the western side of the Davis Strait towards the Labrador-Newfoundland wintering area. One murre tracked from Kippaku in northern Upernavik also went west to central Baffin Bay before heading south.

We have analysed the rate of movement of the eight murres tracked from Saunders Island for more than 33 days to see if the murres moved at a speed where they most likely were performing a swimming migration. Based on analysis of frequency distributions of rate of movement between locations, it appears that swimming migration is characterised by a maximum speed between locations of 3 km/h. Six of eight murres did not have rates of movements exceeding 3 km/h for the first 25 days or more, and potentially could have moulted the flying feathers during this period. Two of the eight birds moved with rates exceeding 3 km/h after one and two weeks respectively, and thus probably flew some of the way to the moulting area.

In conclusion, our results from satellite tracking show that the murres on autumn migration from Saunders Island tended to stage in northern Baffin Bay before heading south through the central part of Baffin Bay and into the Labrador Current in the western part of the Davis Strait and the Labrador Sea. The thick-billed murres from Ritenbenk tended to stage and moult in southeastern Baffin Bay, mainly to the south of the assessment area.

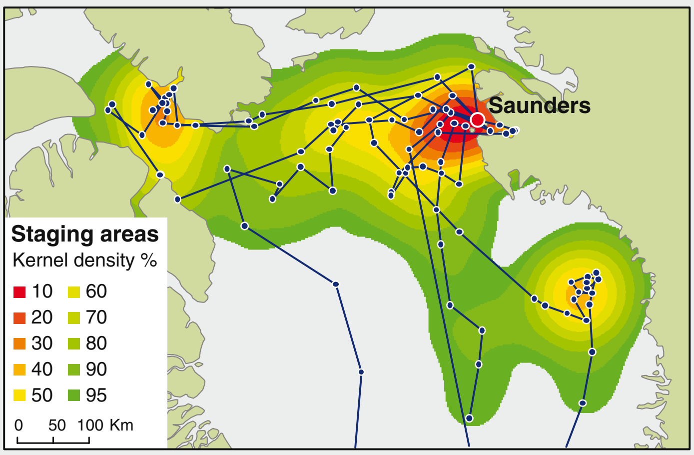


Figure 2. Post-breeding area usage for seven thick-billed murres tracked from the colony at Saunders Island. The figure shows track lines and kernel home range contours for the period from when the birds left the colony (stopped commuting to the colony) to when they headed south. The kernel home range presents an estimate of the probability of finding an animal in a defined area based on the Argos satellite location points that have been collected over a period of time. Thus, the bird is estimated to be within the 95 % probability contour for 95 % of the time etc.

Geolocation data loggers

To track the birds' migration we have also used geolocation data loggers, which are small archival tags recording time and light intensity. Some can also record additional information like temperature and pressure. The data loggers only store the information, and we therefore need to recapture the birds in the following field season to get the information. Based on the data retrieved from the logger on day-length and time of local noon, the latitude and longitude respectively can be calculated. The accuracy of the geolocators is quite coarse, typically within approximately ± 150 km for individual locations. However, even with this accuracy we can get very important information on the migration routes and wintering areas of the birds breeding in the colonies at Saunders Island and Kippaku.

In 2007 and 2008 we deployed geolocating data loggers on thick-billed murres at Saunders Island (n=21) and Kippaku (n=34) (5.5 g Lotek LTD2400 (n=21) and 3.6 g Lotek LAT2500 (n=14) and 1.8 g British Antarctic Survey (BAS) MK13 (n=20)). Murres with chicks were caught with a noose pole and had the tag attached to the tarsus with a metal ring. After attachment, the birds returned to their chicks within few minutes. In 2008, we retrieved 15 of the 21 deployed geolocating tags at Saunders Island.

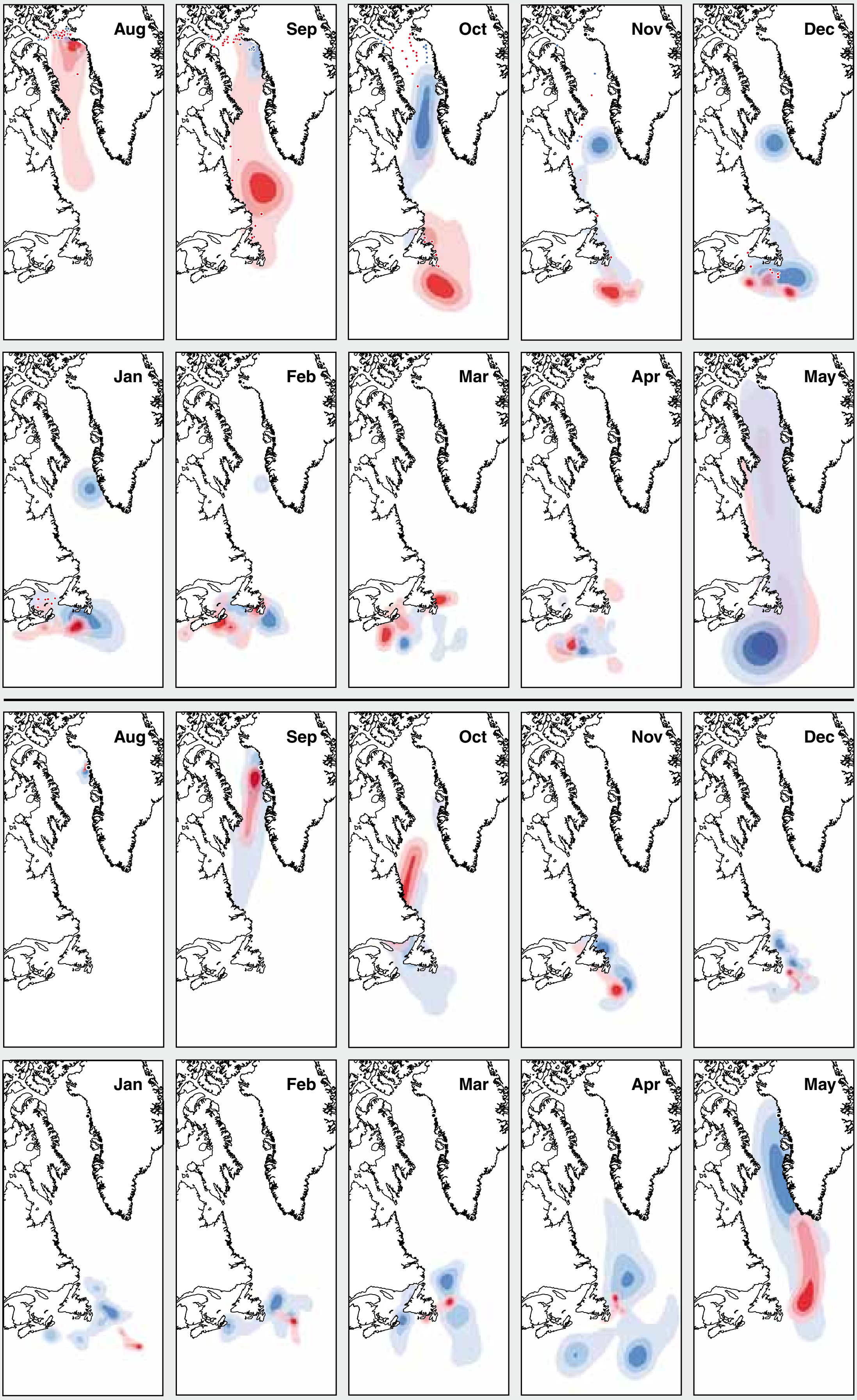


Figure 3. The migration of 15 thick-billed murres as tracked by means of geo-locators in 2007 and 2008. Upper two rows show birds tacked on Saunders Island in Thule and their whereabouts distributed on months in the off-breeding season. The two lower rows show the same for birds tacked on Kippaku in Upernavik red are females and blue are males..

Thick-billed murres from both colonies wintered mainly west of Newfoundland with the main southward autumn migration in September and October through the central Davis Strait. From the Saunders Island colony females tended to migrate first/faster while males as expected came later probably on swimming migration with the chicks. The autumn migration data from geolocation data loggers corresponded to the satellite tracking data (See Figure. 3). Based on the geolocation data the thick-billed murres staged in the Newfoundland and Grand Banks area during winter and spring until start of spring migration in May. Thick-billed murres from the northernmost colony at Saunders Island in Thule tended to migrate later than birds going to the Kippaku colony in Upernavik.

4.8 Marine mammals

The marine mammals constitute another important element of the ecosystem in the Baffin Bay assessment area. Four species of seals, at least eleven species of whales, walrus and polar bear occur (Table 4). Polar bear and walrus are relatively well studied species within the assessment area.

Table 4. Overview of marine mammals occurring in the assessment area. Importance of study area to population (Conservation value) indicates the significance of the population occurring within the assessment area in a national and international context as defined by Anker-Nilssen (1987)

Species	Period of occurrence	Main habitat	Distribution and abundance in assessment area	Protection/ exploitation	Greenland Red List status	Importance of assessment area to population	VEC
Polar bear	Whole year	Drift ice and ice edges	Relatively common and mainly when ice is present	Hunting regulated	Vulnerable (VU)	High	+
Walrus	Whole year	Polynyas, MIZ, shallow water	Mainly migrants in southern part, In NOW whole year	Hunting regulated	Endangered (EN)/Critical Endangered (CR)	High	+
Hooded seal	Jun-Oct	Mainly deep waters	Numerous	Hunting unregulated	Least Concern (LC)	Medium	
Bearded seal	Whole year	Waters with ice	Widespread and abundant	Hunting unregulated	Data Deficient (DD)	Medium	+
Harp seal	Jun-Oct	Whole area	Numerous	Hunting unregulated	Least Concern (LC)	Medium	
Ringed seal	Whole year	Waters with ice	Common and widespread	Hunting unregulated	Least Concern (LC)	High	+
Bowhead whale	Winter (Feb-Jun)	Pack ice/ marginal ice zone	Locally abundant migrant and winter visitor	Hunting regulated	Near Threatened (NT)	Medium	+
Minke whale	Summer (Apr-Nov)	Coastal waters and banks	Rather common mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Sei whale	Summe (Jun-Octr)	Off shore	Occasional in southern part	Protected	Data Deficient (DD)	Low	
Blue whale	Jul-Oct	Edge of banks	Few, and in southern part	Protected (1966)	Data Deficient (DD)	Low	
Fin whale	Summer (Jun-Oct)	Edge of banks, coastal waters	Abundant mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Humpback whale	Summer (Jun-Nov)	Edge of banks, coastal waters	Rather abundant mainly in southern part	Hunting regulated	Least Concern (LC)	Low	
Pilot whale	Summer (Jun-Oct)	Deep waters	Occasional in southern part	Hunting unregulated	Least Concern (LC)	Low	
White-beaked dolphin	Summer	Shelf waters	Occasional in southern part	Hunting unregulated	Not Applicable (NA)	Low	
Killer whale	Jun-Aug	Ubiquitous	Rare but regular	Hunting unregulated	Not Applicable (NA)	Low	
White whale	Winter (Nov-May)	Banks	Abundant migrant and winter visitor in NOW	Hunting regulated	Critical Endangered (CR)	High	+
Narwhal	Whole year	Winter: edge of banks, deep waters. Summer: Fjords coastal waters	Abundant summer, winter and migrant visitor	Hunting regulated	Critical Endangered (CR)	High	+
Sperm whale	May-Nov	Deep waters	Unknown	Protected (1985)	Not Applicable (NA)	Low	
Bottlenose whale	Summer	Deep waters	Unknown	Protected (1985)	Not Applicable (NA)	Low	
Harbour porpoise	Summer (Apr-Nov	Coastal waters	Only in southern part	Hunting unregulated	Data Deficient (DD)	Low	

4.8.1 Marine mammals, species treated in detail

Polar bear and walrus are the best studied marine mammal species in the Baffin Bay assessment area. This combined with the fact that much information is still unpublished makes it relevant to present a more detailed account on these two species compared to the other species occurring in the area.

Polar bear *Ursus maritimus*

E.W. Born, K.L. Laidre, R. Dietz and Ø. Wiig

The Baffin Bay assessment area is an important polar bear habitat during autumn, winter and spring, and the bears that occur here belong to the Baffin Bay subpopulation (Taylor *et al.* 2001).

The overall distribution of polar bears in Baffin Bay is governed by the presence of mountainous coasts on each side of the 'bay', seasonal changes in ice conditions and current ice patterns in the region (Born 1995, Taylor *et al.* 2001). The annual land-fast ice along the coast and fjords of Baffin Island and northwestern Greenland is usually formed during October and remains until July (Teilmann *et al.* 1999, Born *et al.* 2002, 2004). This ice is used extensively by polar bears (Taylor *et al.* 2001). The offshore pack ice in Baffin Bay consists mainly of annual ice that disintegrates and disappears in July (Ferguson *et al.* 1999, 2000, Stirling & Parkinson 2006, Amstrup *et al.* 2007).

When the central Baffin Bay field of consolidated pack ice disappears during spring and summer the polar bears are faced with the choice of either using eastern Baffin Island or the Melville Bay area as a summer retreat. Satellite telemetry during 1991-1997 indicated that the majority of polar bears followed the spring retreat of the pack ice towards the west to spend the open-water season on Bylot and Baffin Islands (Taylor *et al.* 2001, Figure 15, 16). This was confirmed by a new study in 2009-2010, see Box 6. However, in some years the ice remains during summer in the Melville Bay area and polar bears can be encountered on this ice (Figure 16). Observations by researchers from GINR and interviews with subsistence hunters living in Northwest Greenland indicated that polar bears can be m*et al*ong the coasts of Northwest Greenland during summer, when some bears choose to spend the open-water season on or by the glaciers in Melville Bay (Born *et al.* 2011).

During winter, spring and summer Baffin Bay polar bears select areas with more than 95 % ice cover of thick first-year ice found in large floes. During autumn, they selected 95 % ice cover of multi-year ice, as this previously was the predominant ice type in this season (Ferguson *et al.* 2000). This habitat preference was also seen during aerial surveys of the western and northwestern parts of Baffin Bay (Koski 1980). Moreover the bears showed a preference for ice edges (Ferguson *et al.* 2000).

In the shear zone between the land-fast ice in the Melville Bay and the Baffin Bay pack ice there is a lead running between Holm Ø to Kap York. This lead which has a more or less fixed position each winter attracts polar bears because it is used by ringed seals (Rosing-Asvid & Born 1990, Born *et al.* 2011) and is also a migration route for other marine mammals during spring. During winter and spring some polar bears occur at this shear zone as indicated by satellite telemetry (Taylor *et al.* 2001, Figure 16, Box 6) and information from the subsistence hunters living in Northwest Greenland (Born *et al.* 2011). The polar bear hunters often move along the edge of the land-fast ice at this lead during their sled hunting trips in spring (ibid.).

Forty-one adult female polar bears that were tracked by use of satellite telemetry in Baffin Bay during 1991-1997 only entered maternity dens in the Baffin Island-Bylot Island areas (M.K. Taylor & E.W. Born unpublished data). This was also the case for the two females which entered dens in the 2009-2010 study (Box 6). The central parts of the Melville Bay were established as a nature reserve in June 1980 (Anonymous 1980), allegedly because female polar bears have maternity dens in this area (Vibe 1971). However, interviews with experienced polar bears hunters living in the former municipalities of Upernavik and Qaanaaq in 1989-1990 (Rosing-Asvid & Born 1990) and 2006 (Born *et al.* 2011) confirmed that maternity dens are only rarely found in Northwest Greenland.

Since the beginning of the 1990s the polar bear hunters living in Northwest Greenland have observed an increased occurrence of polar bears in their regularly used hunting areas between approx. 72° N and approx. 80° N – i.e. the Assessment Area (Born *et al.* 2011). During an interview survey in 2005, a similar increased 'coastal' occurrence of bears was reported by Inuit living on the eastern coast of Baffin Island (Dowsley & Taylor 2006). In Northwest Greenland this increased occurrence was reflected in a significant increase in the catch of polar bears in the former Upernavik municipality during 1993-2005 (Born & Sonne 2006). The majority of the interviewees in Northwest Greenland and on Baffin Island were of the opinion that the increase reflected a real increase in the Baffin Bay subpopulation. However, in both areas the informants reported marked changes in the sea ice and several suggested that the apparent increase in bears within the hunting areas could rather reflect a change in distribution due to the reduction in sea ice (Dowsley & Taylor 2006, Born *et al.* 2011). Since 1979 the spring break-up of the sea ice in Baffin Bay has occurred significantly earlier in the season and the total amount of sea ice has decreased since c. 2000 (Stirling & Parkinson 2006). This decrease has been most pronounced in northeastern Baffin Bay (Born 2005) which is used intensively for polar bear hunting (Born *et al.* 2008).

With analogy to the situation in southwestern Hudson Bay, Stirling & Parkinson (2006) and Born *et al.* (2008) suggested that the apparent increase in nearshore observations of polar bears reflects a change in distribution due to reduced sea ice. Based on a population estimate of approx. 2,100 bears for the Baffin Bay subpopulation (Taylor *et al.* 2005) and the reported combined Canadian and Greenlandic catches it was concluded that the population was subject to over-exploitation and had declined rather than increased (Aars *et al.* 2007, Anonymous 2007).

Conservation status

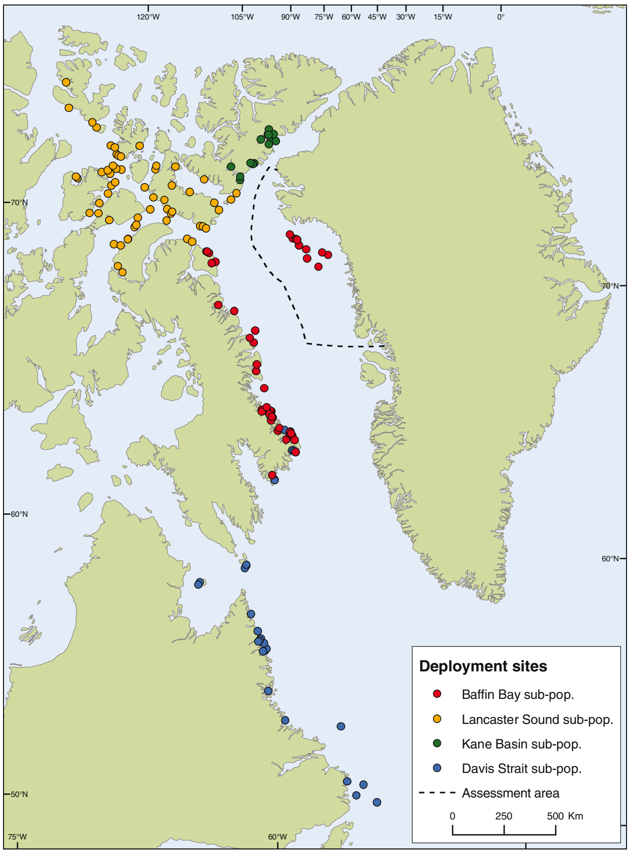
The population occurring in the assessment area has an unfavourable conservation status, mainly due to the expected reduction in the habitat (see further in Section 8 on climate change below).

The polar bear is listed as 'Vulnerable' (VU on both the global red-list (IUCN 2010) and on the Greenland red-list.

Delineation of populations

The Baffin Bay subpopulation is essentially closed to the east and west because of Greenland and Baffin Island, although movements across Baffin Island and into neighbouring subpopulations have been recorded (Taylor *et al.* 2001, Figure 15).

Recoveries from the subsistence hunt in Northwest Greenland of polar bears that have been tagged in Canada indicate that occasionally polar bears from other subpopulations enter the Baffin Bay assessment area (Born 1995, Born unpublished data, Figure 15). Between 1977 and 2004, a total of 55 tags (family groups counted as 1 recovery) have been delivered in Greenland from the Baffin Bay



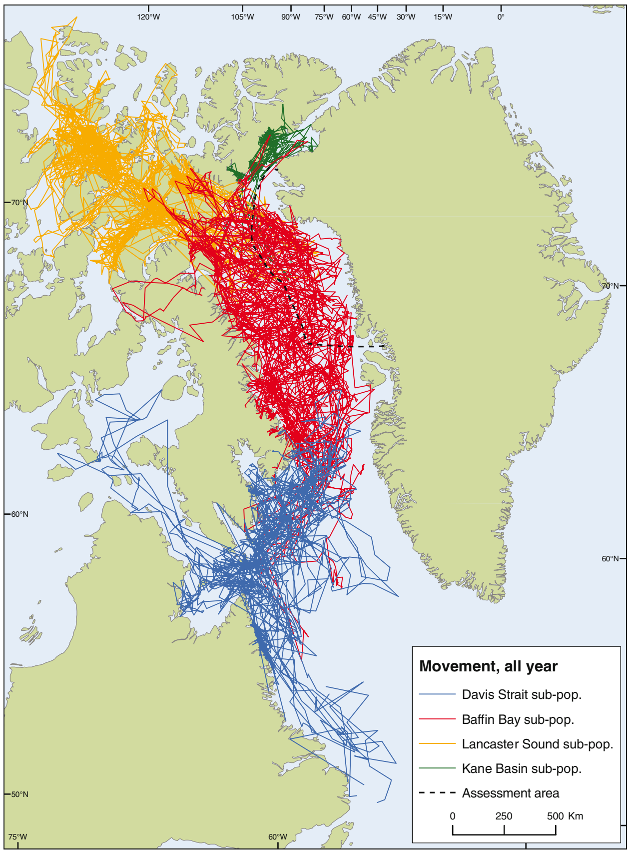


Figure 15. Left map: Locations where adult female polar bears were instrumented with satellite transmitters (1991-1995) given by sub-population. A total of 41 bears were instrumented in the Baffin Bay sub-population (9 in NW Greenland and 32 along eastern Baffin Island) and their movements were tracked during 1991-1997. The identification and delineation of the various sub-populations based on hierarchal cluster analyses is described in Taylor *et al.* (2001). Unpublished data: Greenland Institute of Natural Resources, Nunavut Wildlife Management Division, University of Saskatchewan.

Right map: Track lines showing the overall movement during 1991-1997 of 41 polar bears instrumented with satellite transmitters. A certain degree of overlap between the different sub-populations is apparent. The instrumented polar bears made little use of the fast ice and North Water Polynya area in the Baffin Bay assessment area in NW Greenland (i.e. the Melville Bay area). This was thought to be an avoidance response due to a relatively high hunting pressure in the area (Taylor *et al.* 2001). Unpublished data: Greenland Institute of Natural Resources, Nunavut Wildlife Management Division, University of Saskatchewan.

subpopulation. Of these 9 (approx. 16%) were from bears that had been tagged in other management zones than Baffin Bay (i.e. Davis Strait 1, Lancaster Sound 5, Viscount Melville Sound 1, and Kane Basin 2, Greenland Institute of Natural Resources unpublished data). Information obtained during the interview survey in 2006 indicates that only about half of the recovered tags are being delivered to the authorities (Born unpublished data).

The northern boundary of the Baffin Bay subpopulation is the North Water Polynya that extends south past Jones and Lancaster Sounds in most years. This boundary is relatively weak because pack ice continually drifts in and out, providing polar bears from Lancaster Sound with access to Baffin Bay and *vice versa* (Taylor *et al.* 2001).

The southern boundary runs from Cape Dyer, Baffin Island to Qeqertarsuaq/Disko Island, Greenland (Figure 15), where there is a submarine ridge influencing on ice and current conditions in Baffin Bay and Davis Strait (Taylor *et al.* 2001). Satellite telemetry during 1991-1997 indicated that this boundary was surprisingly strong given that Baffin Bay and Davis Strait are covered with pack ice from December until July. The ice platform presents no difficulties for polar bears that are capable of making unidirectional long-distance movements in active pack ice against both wind and current drift (e.g. Wiig *et al.* 2003).

Genetic analyses showed that polar bears in Baffin Bay differ significantly from those in Davis Strait and Lancaster Sound, whereas no difference was found between the Baffin Bay and Kane Basin subpopulations. It was suggested that this lack of difference was caused by a 'source-sink' relationship, meaning that the larger Baffin Bay subpopulation has supplied Kane Basin with polar bears as a result of long-term overexploitation of the Kane Basin subpopulation (Paetkau *et al.* 1999, Taylor *et al.* 2007).

Movements

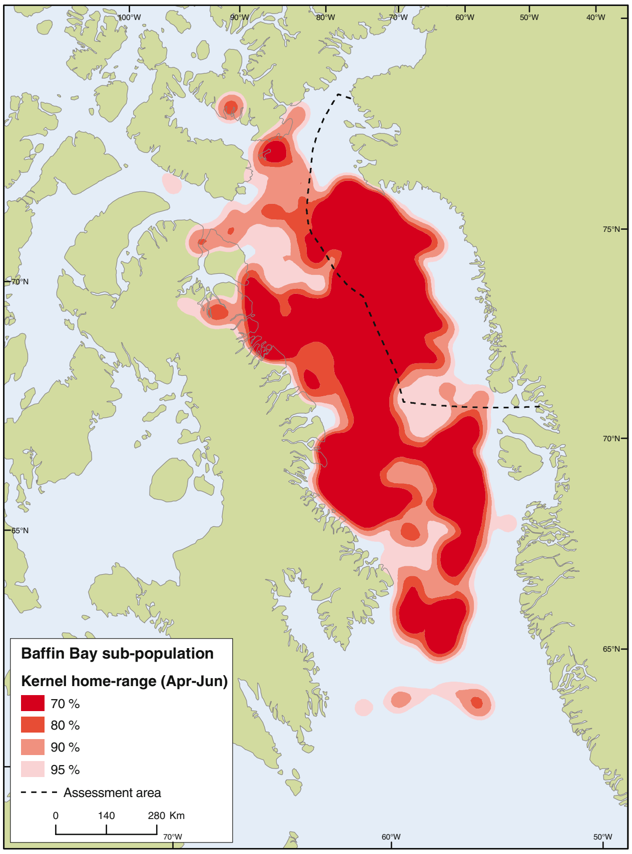
Female polar bears instrumented with satellite radios made remarkably few excursions onto the fast ice of Melville Bay (Taylor *et al.* 2001, Figure 15, Box 6) despite the fact that the land-fast ice in the Melville Bay is good ringed seal habitat (Born *et al.* 1999). It was suggested that this space-use pattern is an avoidance response (Taylor *et al.* 2001). The fast ice and the adjacent offshore pack ice are used intensively by the Greenlanders for hunting of polar bears during late winter and spring (Rosing-Asvid & Born 1990, Born *et al.* 2011).

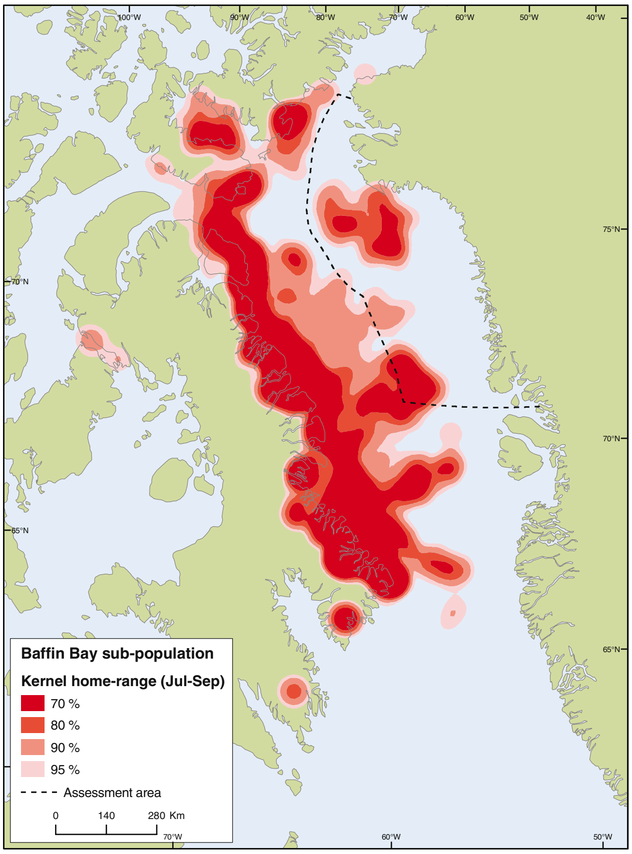
Non-denning bears return to the sea ice at Baffin and Bylot Islands in November (Ferguson *et al.* 1999), and many proceed across Baffin Bay to Greenland waters (Taylor *et al.* 2001). Of a total of 32 polar bears fitted with satellite transmitter on eastern Baffin Island during autumn, 17 (approx. 53%) occurred inside the Baffin Bay assessment area for periods of variable duration. Fifteen (approx. 47%) entered the assessment area during winter, 12 (approx. 38%) during spring and six (approx. 19%) occurred there during summer (for periods see Figs. 1-3). By comparison, of nine polar bears instrumented in the Melville Bay during spring, all used the assessment area at some point in the year. Six (approx. 66%) occurred there during winter, five (approx. 56%) in summer, and all during spring (Born unpublished data). This indicates the importance of these parts of the Baffin Bay to polar bears.

Most Baffin Bay individuals do not move south except along the Baffin Island coast because of the open-water barrier caused by the West Greenland Current. However, when the sea ice conditions permit, some Baffin Bay individuals may move as far south as the offshore hooded seal (*Cystophora cristata*) whelping areas that vary in position between years from Southeast Baffin Island to Nuuk, Greenland (Bowen *et al.* 1987, Stirling & Parkinson 2006).

The polar bears in Baffin Bay move considerable distances during the year. The home range size of polar bears exploiting Baffin Bay averaged 192,000 km^2, considerably larger than the home ranges of bears inhabiting areas with more consolidated ice (Ferguson *et al.* 1999). It was suggested that the explanation for the large home ranges of bears in Baffin Bay was that these bears explore a habitat with large seasonal flux of annual ice in which the distribution of various prey, in particular ringed seals, is variable and patchy. In addition 'offshore' polar bears have access to other food sources (narwhals, beluga whales, bearded seals, hooded seals and harp seals), the distribution of which changes seasonally and between years. Furthermore, the overall movement rates of polar bears exploiting the Baffin Bay pack ice are higher than those of polar bears inhabiting the land-fast ice (Ferguson *et al.* 2000).

Polar bears typically show fidelity to den and spring feeding areas (Ramsay & Stirling 1990, Wiig 1995). This was also the case for the majority of polar bears tracked in Baffin Bay during 1991-1997. Five of the polar bears that were instrumented in the Melville Bay area during spring 1992 and 1993 transmitted for more than a year. They all returned in consecutive years to the same general spring feeding area in Northwest Greenland – in one case up to four consecutive years (Born unpublished data).





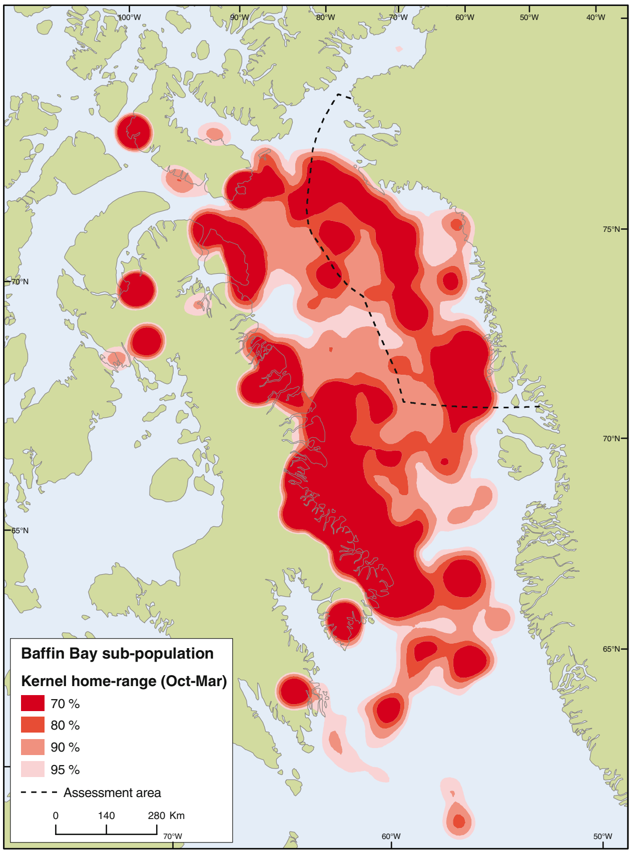


Figure 16. Home ranges (calculated as Kernel home range contours) of the Baffin Bay sub-population of polar bears based on satellite-telemetry tracking of 41 female polar bears 1991-1997. **October-March** (winter). **April-June** (spring). **July-September** (summer, or open water season). The definition of seasons relevant to polar bear ecology follows Born *et al.* (1997) and Wiig *et al.* (2003). Sources: Taylor *et al.* (2001), unpublished data from GINR, Nunavut Wildlife Management Division, University of Saskatchewan. This information on polar bear area use obtained from satellite-telemetry may not longer be representative, given the fact that sea ice conditions and polar bear occurrence have changed in Northwest Greenland.

The majority of satellite transmitters in the study by Taylor *et al.* (2001) were deployed during autumn along the western shores of Baffin Bay (Taylor *et al.* 2001, Figure 15). Due to logistical constraints satellite radios were not deployed offshore (i.e. in the western parts of the assessment area). This geographical bias in deployment sites and the fact that the sea ice conditions in the polar bear habitat inside

Box 5

Offshore densities of seabirds in the Baffin Bay assessment area

D. Boertmann, A. Mosbech, F. Merkel, M. Frederiksen and K.L. Johansen

Since the beginning of the 1990s, NERI has collected data on seabirds in the off-shore areas of Greenland. Both ships and aircrafts have been used as platforms, and the sampling methods (Distance Sampling, Buckland *et al.* 2001) allow for calculation of densities (individuals/km^2) of the different species. The surveys have been carried out by NERI, both on dedicated seabird surveys and on ships of opportunity, and also and with increasing intensity by the Marine Mammal and Seabird Observers (MMSO) on board the ships carrying out seismic surveys in the Greenland waters. These MMSOs are instructed to sample seabird data in the same way as NERI do, why the data can be incorporated into the database kept by NERI. These seismic surveys have in many cases covered waters, from where no previous information on seabirds was available. The information from NERIs seabird-at-sea database is available for companies preparing Environmental Impact Assessments in the Greenland waters. Figure 1 shows the seabird-at-sea survey effort in the Baffin Bay assessment. Note that the scales differ both between species and among seasons within species.

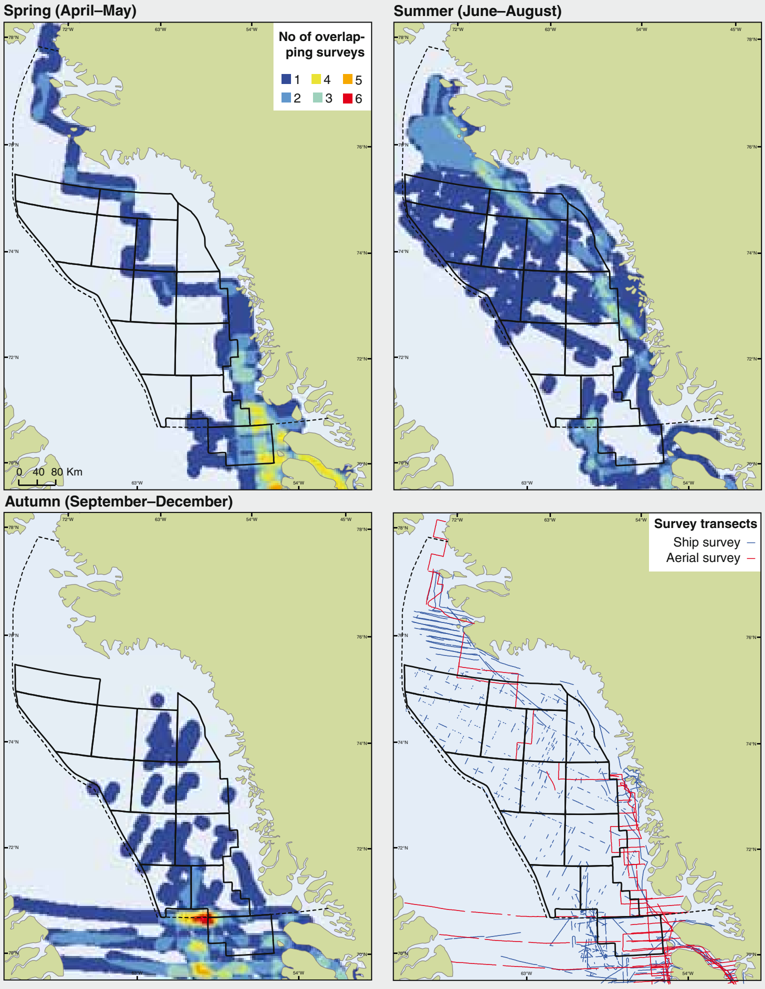


Figure 1. Effort of seabird-at-sea surveys in the Baffin Bay assessment area. Ship and aircraft based surveys combined, and shown for the three seasons with sufficient daylight to survey and with open waters present (in spring only open waters in the southern part and in the shear zone).

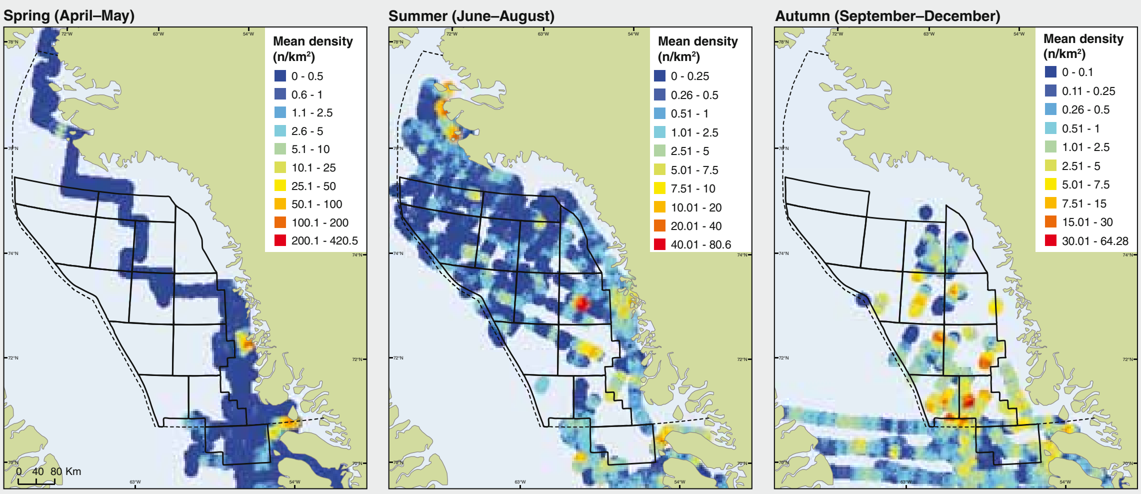


Figure 2. Off-shore densities of northern fulmar in three seasons as recorded on the surveys in the NERI seabird-at-sea database. In spring, when ice still is present generally very low densities were recorded. The few high-density spots are near large breeding colonies. In summer the fulmars are much more widespread, and high density spots were found at several sites – both near large breeding colonies and off-shore at feeding areas – often where shrimp trawlers operate. In the autumn season fulmars have been recorded widespread in the surveyed area, and the high densities are most likely at feeding sites, for example where shrimp-trawlers operate.

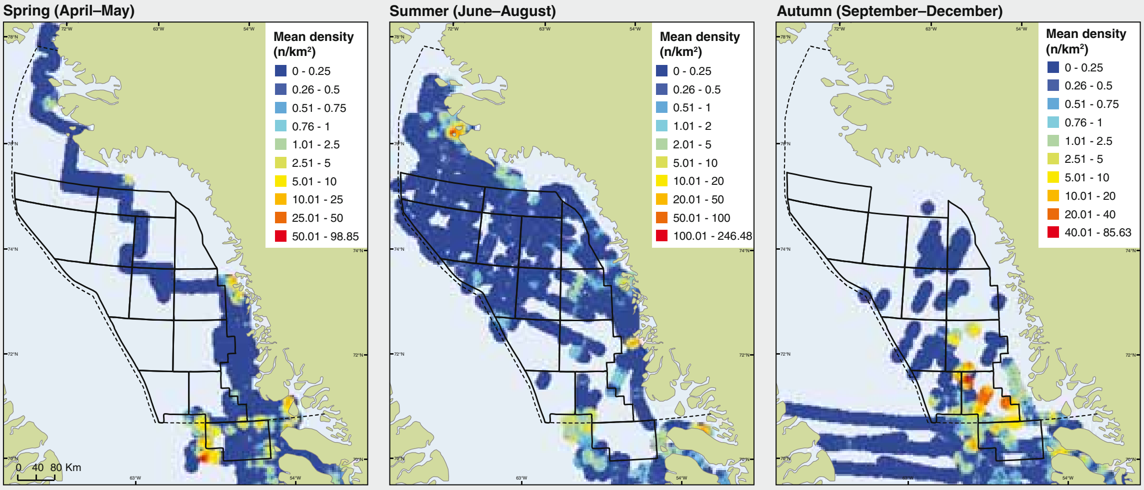


Figure 3. Off-shore densities of black-legged kittiwake in three seasons as recorded on the surveys in the NERI seabird-at-sea database. In spring high densities occur in some coastal sites, near large breeding colonies, and also in off-shore areas particularly in the southern part. These are migrating birds on their way towards north and staging in feeding areas. In summer off-shore densities are generally low, except for an area in the southern part which probably are non-breeding birds assembled at a feeding area. There are some high-density spots, which are close to large breeding colonies. In autumn high densities occur in large areas in the southern part, where also northern fulmars and thick-billed murres show high densities in autumn.

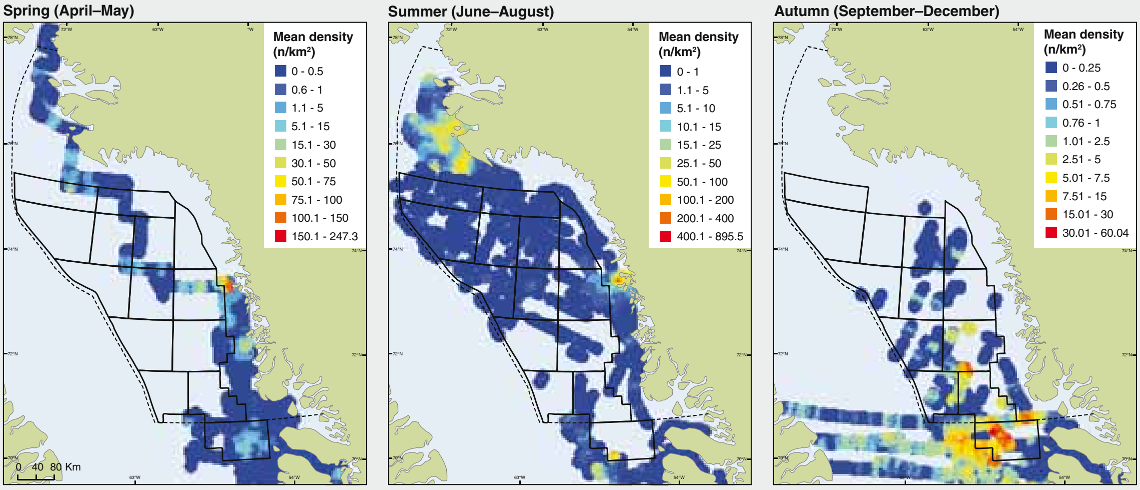


Figure 4. Off-shore densities of thick-billed murre in three seasons as recorded on the surveys in the NERI seabird-at-sea database. In spring low densities have been recorded in the leads and crack along the lead zone, while high densities have only been recorded near the large breeding colonies in northern Upernavik. Many birds are probably still to the south of the assessment area on the way north from the winter grounds. In summer the large breeding colonies in Thule and Upernavik are visible as high- density areas. A high density spot in the southernmost licence block may represent post-breeding birds on swimming migration away from the colony in Disko Bay *cf.* Box 4. In autumn, thick-billed murres occur widespread in the southern part of the assessment area, with very high densities in and near the southernmost licence block. Cf. the maps of kittiwake and fulmar densities in autumn, which also show high densities in this region.

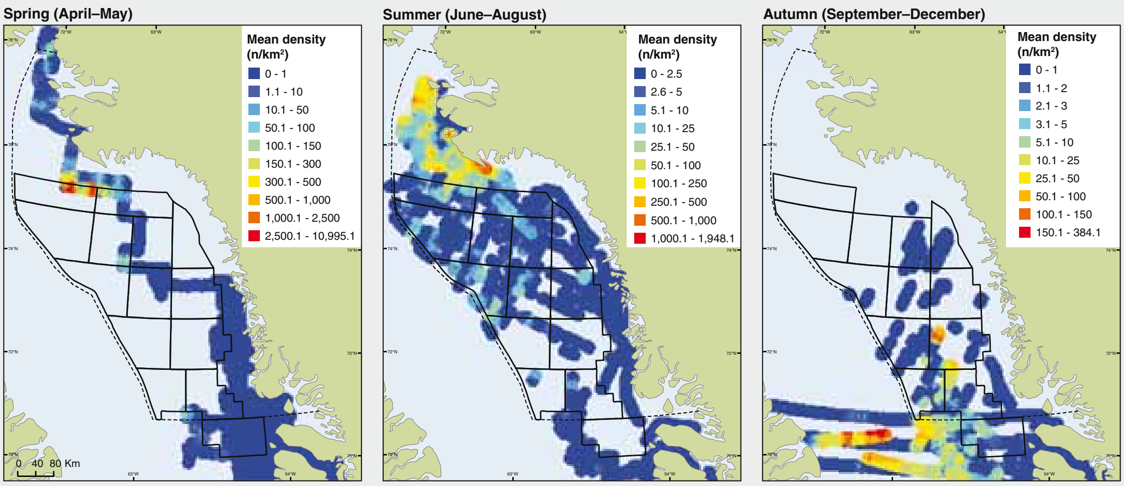


Figure 5. Off-shore densities of little auk in three seasons as recorded on the surveys in the NERI seabird-at-sea database. In spring there are very few records in the southern and central parts of the assessment area, but in the northern part very high pre-breeding densities occurred in the northern part in the shear zone to the south of the huge breeding colonies in Thule. In summer the huge breeding colonies in Thule also reflect the high densities recorded in the northern part for the assessment area. In autumn, the birds have left the breeding areas and congregate now in the deep off-shore parts of Baffin Bay.

the assessment area have changed markedly since the mid-1990s calls for caution when interpreting previously collected satellite data in relation to current and future polar bear habitat choice and oil activities.

Size of the subpopulations

On the basis of a large-scale mark-recapture population study, 1994 to 1997, Taylor *et al.* (2005) estimated the Baffin Bay subpopulation to number 2,074 bears (95% CI 1,544-2,604 bears) in 1997. Given the recorded catch from this population by Canadian and Greenlandic subsistence hunters (150-200+/year, Stirling & Parkinson 2006), the subpopulation was thought to be over-exploited and consequently decimated to approx. 1,600 in 2004 (Anonymous 2007).

The estimates of the size of the neighbouring subpopulations based on mark-recapture are: Kane Basin approx. 164 (95% CI 94-234 bears, Taylor *et al.* 2008) and Lancaster Sound approx. 2,541 polar bears (95% CI 1,759-3,323, Aars *et al.* 2006). Davis Strait numbers approx. 2,200 polar bears (Peacock 2008).

The catch

Traditionally the hunt of polar bears is of great cultural and economical importance to the subsistence hunting communities in Northwest Greenland (Born & Rosing-Asvid 1989, Rosing-Asvid & Born 1990, Rosing-Asvid 2002, Born *et al.* 2008). The Melville Bay area and adjacent pack ice in northeastern Baffin Bay (i.e. within the assessment area) are important areas for the hunting of polar bears from the Baffin Bay subpopulation, whereas polar bears from the Kane Basin subpopulation are taken in the former Qaanaaq municipality north of Savissivik (Rosing-Asvid & Born 1990, Rosing-Asvid 2002, Born *et al.* 2011, Figure 17). Typically, the catches during spring when dog sleds are used were concentrated at a shallow water bank about 100 km from the coast in Melville Bay ('Qoorfiit') and at offshore shallow water banks in the former Upernavik municipality. Polar bears are still taken offshore during spring, but due to the reduced extend of sea ice these catches have mainly been taken during boat trips in recent years (Born *et al.* 2008). During 1993-2005 (i.e. since the introduction of a new catch reporting system until introduction of quotas in 2006), the catch of polar bears in Greenland from the Baffin Bay population averaged 101/year (range: 60 (1994)-206 (2003) bears/year). Of these an average of 84 polar bears/year (range: 60 (1994)-188 (2003)) were taken inside the assessment area (i.e. reported for the former municipalities of Uummannaq, Upernavik and Qaanaaq (only north to Savissivik)). On average 69% of this catch was reported from the former Upernavik municipality (Born 2007). The Greenland take from the Baffin Bay population for the years 2007, 2008, 2009 and 2010 was 76, 73, 69 and 67 per year, respectively (Born *et al.* 2010, Ministry of Fishery, Hunting and Agriculture (APNN), Nuuk). Nunavut raised its quota for its take from the same population for the 2005/2006 hunting season from 64 to 105 polar bears.

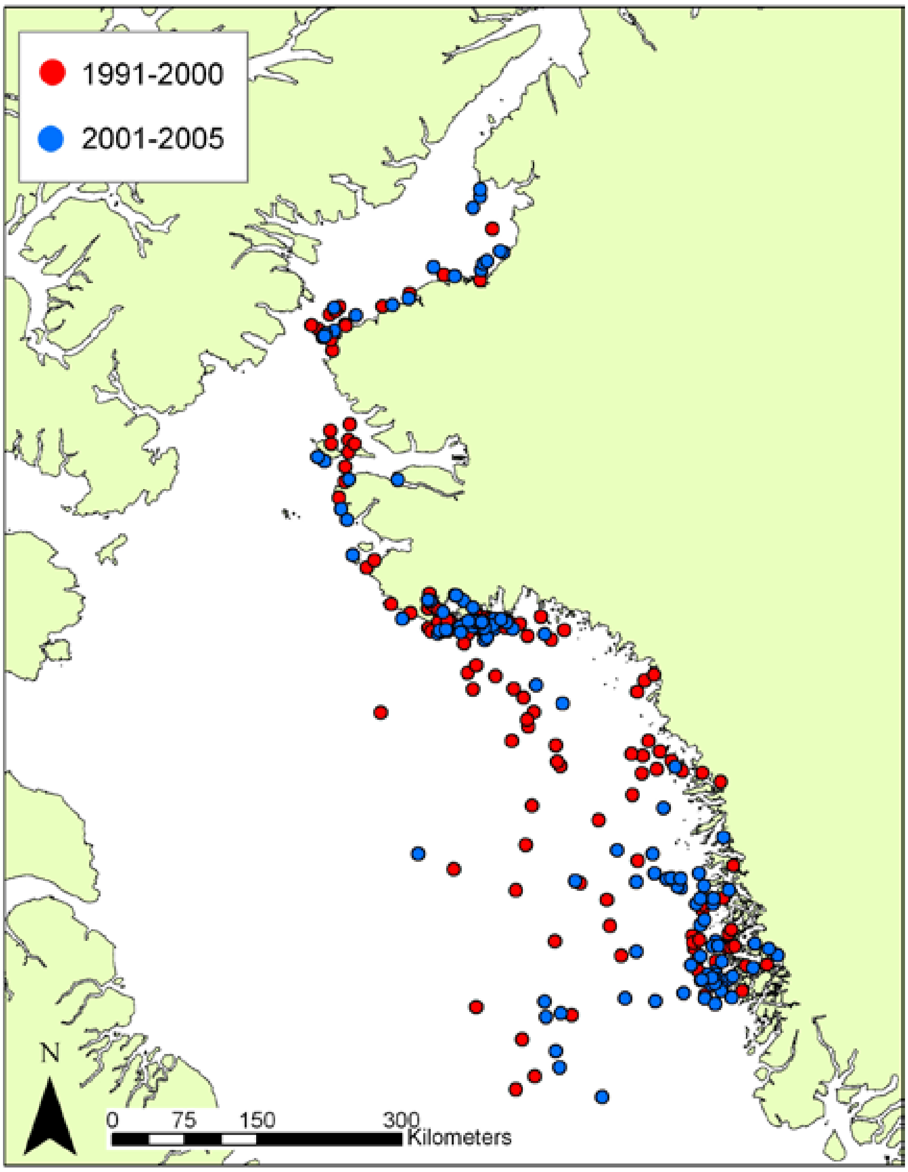
Critical and important areas

Polar bears may occur almost everywhere in the assessment area when ice is present. Some areas seem however, to be more important than others, e.g. the recurrent shear zone system south of Kap York and probably also the edges of the North Water Polynya.

Sensitivity

While moving on pack ice the polar bears enter the water to swim from one ice floe to another (Aars *et al.* 2007) thereby increasing their risk of becoming fouled in case of an oil spill. Polar bears also show a preference for the ice edge where a potential oil spill would accumulate thus increasing the chances of encountering oil. In Svalbard, three polar bears that were monitored for between 12 and 24

Figure 17. The distribution of 293 polar bear catches in the Qaanaaq and Upernavik municipalities shown for two periods (1991-2000: n=145; 2001-2005: n=148). Source: Born *et al.* (2008).



months with satellite-linked dive recorders had an average monthly percentage time in water ranging between 0.9 and 13.2 %. The maximum duration of swimming events ranged between 4.3 and 10.7 h, and dives reached 11.3 m depth (Aars *et al.* 2007). Polar bears are very sensitive to oiling as they are dependant on the isolative properties of their fur and also because they will ingest the toxic oil as part of their grooming behaviour (Øritsland *et al.* 1981, Geraci & St Aubin 1990). Polar bears have been shown to be especially sensitive to ingesting oil, why polar bears getting in contact with oil are likely to succumb.

If the fractions of the population occurring in the assessment area described above are representative of the overall subpopulation, a considerable proportion of the Baffin Bay subpopulation could be detrimentally affected by a large oil spill from activities in the assessment area, in particular during winter and spring. Even bears from the Kane Basin and Lancaster Sound subpopulations and to a lesser extent the Davis Strait and Viscount Melville Sound subpopulations could be affected.

Walrus *Odobenus rosmarus*

E.W. Born

A limited number of walruses winter in leads and cracks between the land-fast ice and the moving pack ice in the assessment area. An unknown number of walruses may also use the assessment area as a migration corridor during spring and perhaps also autumn.

Walruses have not been studied specifically within the assessment area; however extensive studies have been carried out both to the south and to the north of the assessment area.

Data sources

Information on the occurrence of Atlantic walruses in West and Northwest Greenland was summarised by Born (1990) and Born *et al.* (1994a, 1995). The following review of distribution and abundance in the assessment area between Illorsuit/ Ubekendt Ejland (approx. 71° 10' N) in the Uummannaq area and Iterlassuaq/ Granville Fjord (approx. 76° 47' N) in the Wolstenholme Fjord is based mainly on these sources. The movements of walruses in central western Greenland (south of the assessment area) were studied during spring 2005, 2006, 2007 and 2008 (Mosbech *et al.* 2007a, Dietz *et al.* 2010). Furthermore, the distribution and abundance of walruses between approx. 65° 30' N and approx. 74° N were determined during aerial surveys conducted in the spring of 2006 (Heide-Jørgensen *et al.* 2006a, Mosbech *et al.* 2007a) and 2008 (Heide-Jørgensen *et al.* 2010d). The status of the walrus subpopulation in West and Northwest Greenland (i.e. to the south and north of the assessment area) was evaluated by the North Atlantic Marine Mammal Commission in 2009 (NAMMCO 2009).

Biology

The following life history traits are relevant to the evaluation of the potential effects on walruses from oil-related activities. One 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 approx. 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 generally have an affinity for shallow water areas with suitable benthic food, traditionally used terrestrial haul-outs ('uglit', singular 'ugli') in the vicinity of these banks, and wintering areas without solid ice and access to food (Born *et al.* 1995 and references therein). In western and northwestern Greenland such habitats are mainly found between approx. 66° 30' N and approx. 70° 30' N and between approx. 76° N and approx. 78° 30' N (Born *et al.* 1994, 1995, Born 2005), which means that the main foraging grounds of walruses in West Greenland are mainly outside the Baffin Bay assessment area.

During the mating season (January-April, Born 2001, 2003 and references therein) male walruses engage in ritualised visual and acoustical displays in the water (Fay *et al.* 1984, Sjare & Stirling 1996, Sjare *et al.* 2003).

Walrus food

The shallow water benthic community in the assessment area was studied on a few stations in 1936 (Vibe 1939, 1950) and in 2008 on 41 stations (Box 1, Sejr *et al.* 2010a). In 2008, infauna including walrus food items (*Mya* sp. and *Hiatella arctica*) was found in variable abundance, but generally peaking between 10 and 50 m depth. Biomass decreased with increasing depth. According to Sejr *et al.* (2010a) average biomass of 200 g ww m^{-2} (including shells and skeletonnes) for depths < 150 m was comparable to that reported by Vibe (1939).

At approx. 72° N, the total average wet weight of the *Macoma* community, which mainly constituted walrus food components such as the bivalves *Macoma*, *Mya* and *Hiatella*, was 160-388 gww/m^2 (Vibe 1939). In this area, average benthic biomasses as high as 1,482 gww/m^2 were found locally (Vibe 1939), although such levels were considered exceptionally high (Vibe 1950). Hence, locally there is suitable walrus foraging habitat in the assessment area and not at least north of 76° N which is known to be wintering habitat for walruses (Vibe 1950). However, given the fact that the relatively narrow strip of shallow water areas along the coast between ca. 72° and ca. 76° N is generally covered with fast ice during winter, wintering conditions for walruses would appear not to be ideal in these parts of the assessment area.

Distribution and population size
It has not been determined whether walruses occurring in the southern and central part of the assessment area belong to the West Greenland wintering stock or to the North Water stock or whether they represent a mixture from both of these putative subpopulations (Born 2005). Walruses in the assessment area are basically transient (Born *et al.* 1994, 1995); therefore, the situation north and south of the assessment area where the transient animals may have their origin is described.

Generally, the historical and present distribution of walruses in the Uummannaq and Upernavik areas appear to be similar (Born *et al.* 1994). Judging from mainly catch statistics walruses are not numerous in these areas and they appear to be mainly transient (Figure 18). However, a limited number can occur during winter in cracks and leads in the shear zone between the fast ice and the Baffin Bay pack ice. Northward migrating walruses are observed along the edge of the fast ice in the Uummannaq area during spring, but they rarely enter Uummannaq Fjord, where the water is deep (Born *et al.* 1994).

Farther north, migrants occur along the ice edge at the outer archipelago of the Upernavik area during spring. Occasionally, walruses are also observed closer to the mainland coast. Walruses are most likely to be encountered in certain areas: Kiatassuup Qeqertarsui (Ryders Islands, approx. 74° 45' N), and between Kiatassuaq/Holms Island and Nuussuaq/Kraulshavn, and at Kitsissorsuit/Ederfugle Islands (Born *et al.* 1994, 1995).

Walruses were once reported to have hauled out occasionally near Eqqorleq and Tussaaq in the southern part of the Upernavik area. However, to our knowledge walruses no longer regularly haul out on land in the assessment area.

To the south of the assessment area walruses from the West Greenland wintering stock occur (e.g. NAMMCO 2009). From October-November until late-May the walruses are found on the pack ice, approx. 30 to 100 km off the coast between Sisimiut and Qeqertarssuatsiaq (Hareø). These walruses prefer areas with dense pack ice (usually more than 60% ice cover) in water that is less than 100 m deep. 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 have occasionally been reported from this area, most walruses observed during aerial surveys were either single or in pairs (Born *et al.* 1994, Heide-Jørgensen *et al.* 2010c, Dietz *et al.* 2010). Observations of newborn calves in this area are extremely rare (Born *et al.* 1994, 1995, Born 2005). Recordings of underwater sounds indicate that walruses mate in Central West Greenland (Born *et al.* 1994).

Box 6

The April 2009-April 2010 study of polar bear movements and habitat use in Northwest Greenland

E. W. Born, K. L. Laidre, R. Dietz and Ø. Wiig

A study initiated in April 2009 using satellite transmitters was intended to provide updated and supplementary information on distribution, movement and habitat use of polar bears in the Baffin Bay area.

During the 2009 field operation, 16 polar bears were tagged in April 2009 on the fast ice and the pack ice just to the south of the Baffin Bay assessment area between 70°14' N and 71°04' N (Figure 1). Fifteen of these bears were fitted with a satellite radio transmitter. Ten of these transmitters were small ear-tags which were applied to sub-adult polar bears of both sexes and adult males. Ear-tag transmitters had an expected life time of 3-6 months. Five adult female bears were fitted with satellite radio-collars with and expected life time of 2+ years.

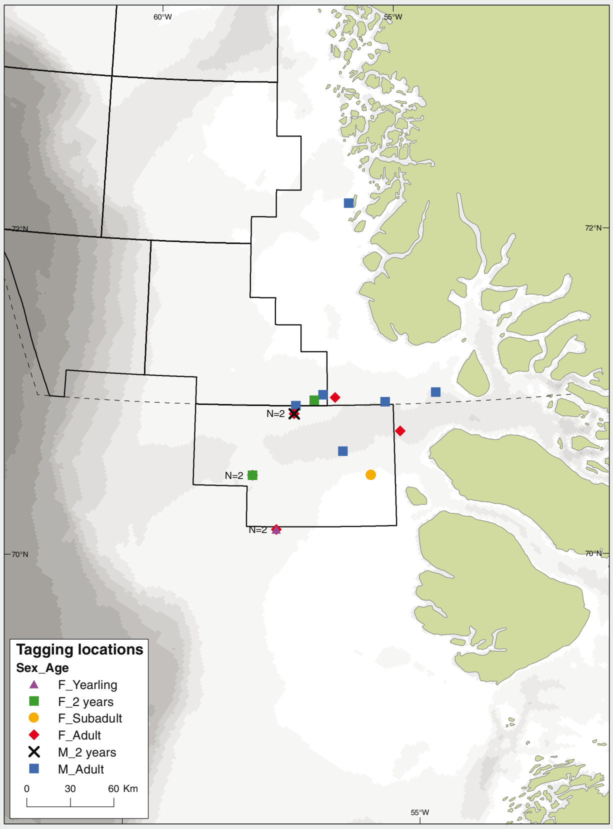


Figure 1. Locations where 16 polar bears were tagged during April 2009.

Movements, home ranges and focal areas

One of the bears with satellite radio-collars (D7273, 6 years old) dropped her transmitter shortly after deployment and another adult female (D7276, 17 years old) was shot in NW Greenland 13 February 2010. Adult males and sub-adult bears of both sexes experienced shorter tracking durations due to ear tag attachments (mean duration of transmission: 76.2 d, SD=44.9, range: 29-196 d, n=10). Hence, the annual cycle of movement can be described for four adult females only and three females after February 2010.

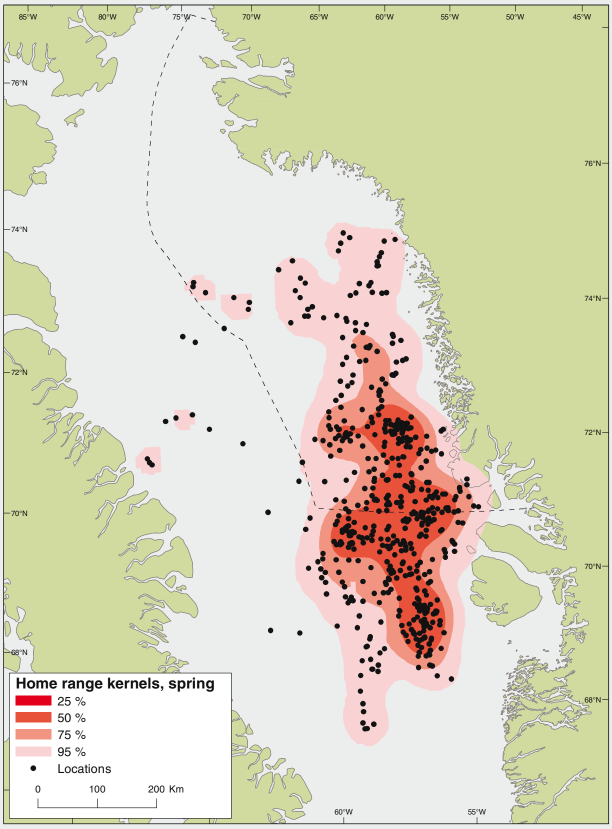


Figure 2. Spring (April-May) 95 %, kernel home range of polar bears in Baffin Bay. Home range is based on data from 16 individuals that were instrumented in the Disko West Assessment Area during April 2009 (see Figure 1). Sixteen of these transmitted during spring 2009 and 3 of these 16 also transmitted during April 2010. Kernel home range is explained in Box 3.

Tracking of four adult female polar bears for a single year between April 2009 and April 2010 (as stated one stopped in February 2010) confirmed previous information obtained from a telemetry study in the 1990s (Taylor *et al.* 2001), that polar bears are widely distributed over Baffin Bay sea ice in spring and summer with a more contracted land-based distribution in fall on Baffin Island, and dispersal from Baffin Island in winter once the sea ice forms again (Figures 2-5).

In spring 2009 (April-May), the polar bears (n=16) used a large area over the annual sea ice in Baffin Bay and were concentrated in the Baffin Bay assessment area and to the south hereof (Figure 2) from ca. 67° 30' N to offshore at ca. 75° N. The area of the 95 % kernel home range was approximately 198,400 km^2. As sea ice receded during early summer the range of the polar bears shifted west towards Baffin Island (Figure. 2).

In summer 2009 (June-August) the polar bear home range (n=13 bears) for the most part remained on the remaining sea ice, and shifted to the western side of Baffin Bay. Polar bears were found on the eastern edge of the Baffin Bay pack ice (i.e. in the western sector of the Baffin Bay assessment area). There was also some area use on the fast ice of Melville Bay (Figure 3). The summer 95 % home range was larger than during spring and the other two seasons, totalling approximately 349,000 km^2 (Figure 3).

In autumn 2009 (September-December), polar bears (n=5 bears, 4 F and 1 M) were located on the coast of Baffin Island (Figure 4). The total autumn range was the smallest of all the seasons and approximately 66,300 km^2. Adult female D7276 (PTT 68004) left Baffin Island around 3 November and moved towards Melville Bay in NW Greenland (Figure 4).

In winter 2010 (January-March), when the annual sea ice had formed, three adult polar bears (D7283, D7285, D7287) departed from the land on eastern Baffin Island where they had spent the open water season and moved offshore. Two of these bears moved

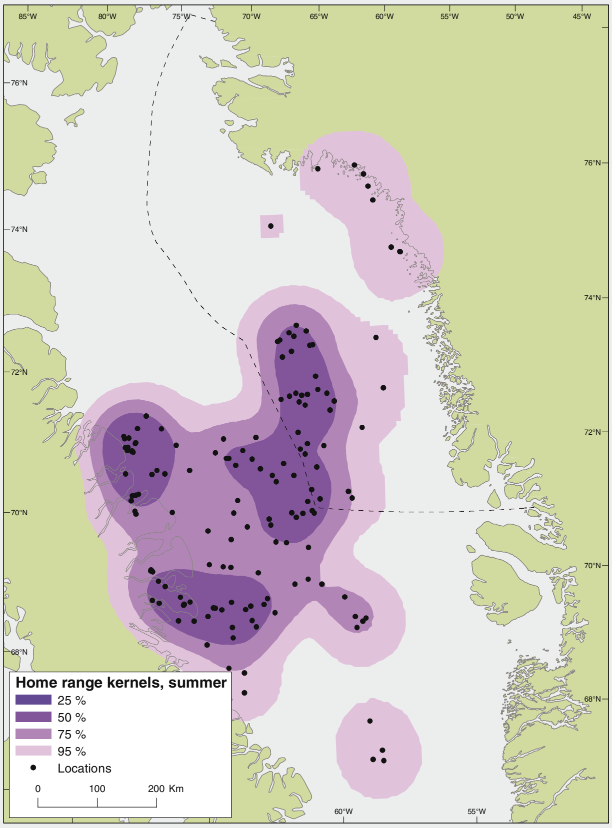


Figure 3. Summer 95 % home range of polar bears in Baffin Bay during June-August 2009. Home range is based on data from 13 individuals instrumented in the Disko West assessment area (Figure 1).

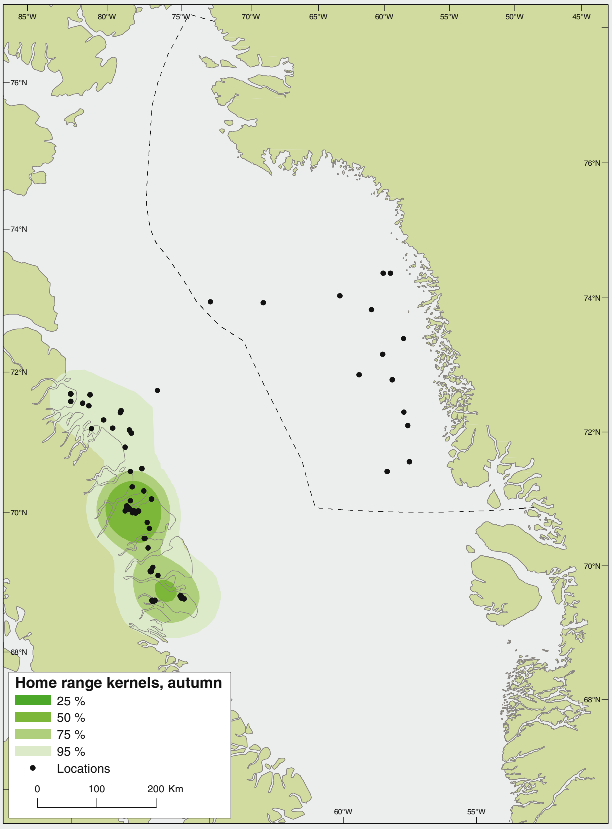


Figure 4. Autumn 95 % home range of polar bears in Baffin Bay during September-December 2009. Home range is based on data from 5 individuals (4 F, 1 M) and includes denning locations on Baffin Island at ca. 70° W of two adult females (see Figure 6). One bear (D7276) moved east and occurred in West Greenland after ca. 3 November 2009.

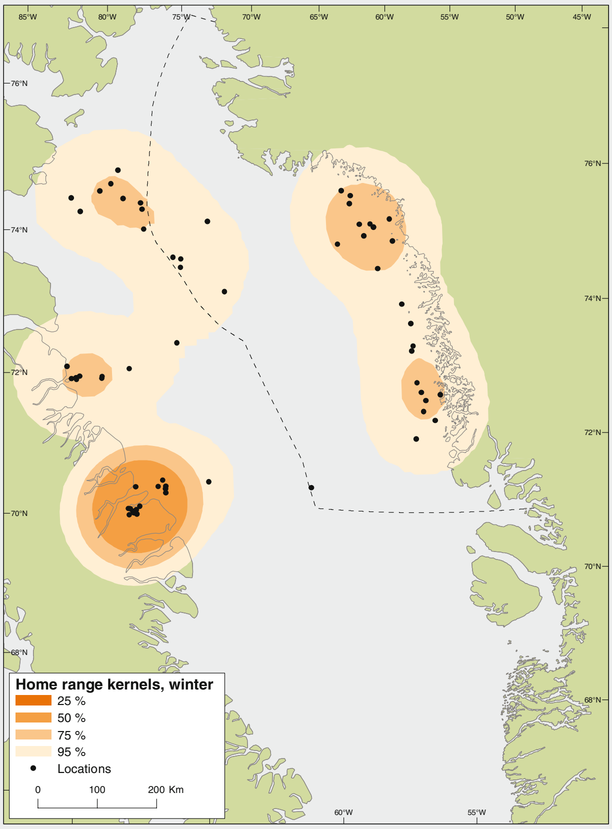


Figure 5. Winter 95 % home range of polar bears in Baffin Bay between January and March 2010. Home range is based on data from 4 individuals one of which one was shot in NW Greenland on 13 February 2010. Two adult female polar bears (D7276 and D7285) occurred in West Greenland after late January 2009.

from Baffin Island during late January 2010, whereas D7283 which had been in a maternity den on Baffin Island moved onto the sea ice sometime around 31 March 2010. Polar bears typically show fidelity to den and spring feeding areas (Wiig 1995). This tendency was confirmed by bear D7283 and bear D7285 which moved towards the West Greenland coast where they occurred in the shear zone between land fast ice and the offshore Baffin Bay pack ice between ca. 72° and ca. 76° N. D7283 was shot in Upernavik on 13 February 2010. Bear D7287 used the northern Baffin Bay in late winter (Figure 5 and 6). However, the two other adult female polar bears (D7283; D7287) were on the ice in the west side of Baffin Bay as of April 2010 (Figure 6).

Due to low sample sizes and the influence of denning locations on the probability distribution of the home range, the winter home range was divided in a western and eastern portion (Figure 5). The total combined winter home range was approximately 310,400 km^2.

Adult males and sub-adults of both sexes had shorter tracking durations due to ear tag attachments and all except bear D7286 (PTT 74781) remained on the Baffin Bay sea ice during the period they were tracked. Similar to adult females, there was a consistent movements westward by adult males and sub-adults as the Baffin Bay sea ice receded in late spring. Overall, the range of adult males was similar to that of adult females. Specific movement patterns were contrasted between male and female polar bears during the on-ice period in spring and early summer.

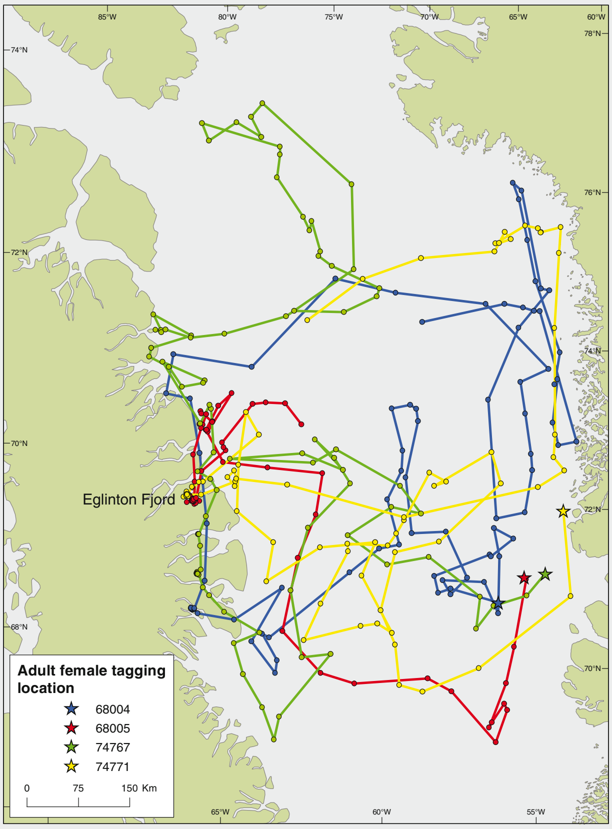


Figure 6. Movements of 4 adult female polar bears tracked in Baffin Bay between March 2009 and April 2010. A fifth instrumented adult female is not shown as the collar stopped transmitting shortly after tagging. Star indicates the tagging site in 2009. Denning site for two adult females on Baffin Island is shown (red and orange aggregations of dots).

The 2009-2010 study confirmed that polar bears in Baffin Bay move considerable distances during the year (Figure 6). Satellite telemetry studies in the 1990s showed that the home range size of individual polar bears exploiting Baffin Bay averaged 192,000 km^2 being considerably larger than the home ranges of bears inhabiting areas with more consolidated ice (Ferguson *et al.* 1999). It was suggested that the explanation for the large home ranges of bears in Baffin Bay was that these bears explore a habitat with large seasonal flux of annual ice in which the distribution of various prey in particular ringed seals is variable and patchy.

All polar bears that were instrumented in April 2009 chose to follow the receding ice and summer on the east coast of Baffin Island. Hence, their general movement was similar to that of 10 adult female polar bears that were instrumented with satellite collars on the sea ice in the Melville Bay area (74°-76° N, 58°-68° W) in the spring of 1992 and 1993 (Taylor *et al.* 2001, Nunavut Department of Environment, NDE, and Greenland Institute of Natural Resources, GINR, unpublished data).

Time spend on the West Greenland side

None of the 15 bears that were instrumented during April 2009 chose to spend the summer in West Greenland. Dates on which bears moved west of 60° W longitude varied within the months of May and June. The earliest departure date was May 6 and the latest was June 8. For the most part, dates of crossing 60° W were concentrated at the last 10 days of May. It should be noted that bears crossed this longitude threshold however many remained in the vicinity (between 60° and 63° W) for several more weeks until the sea ice had disappeared in central and western Baffin Bay.

Maternity denning sites

During the one year study period two maternal denning sites used by two different female bears were identified along the Baffin Island coast (Figure 6). Both dens were on land and located in the same fjord on Baffin Island (Eglinton Fjord north of Clyde Inlet). Female bear D7283 occupied her den in this fjord between approximately 14 October and 23 March (dates based only on geographic locations). She was 13 years old and accompanied with a 2-year old cub when marked in West Greenland on 15 April 2009. Apparently this female came into oestrus after having been instrumented, as at the time of capture she was not in oestrus. Bear D7285 (6 years old at capture) entered her den around 8 September. However, she emerged on 2 January 2010. She was in oestrus at the time of capture in 2009 therefore it is assumed this bear entered a maternal den. However the denning duration was too short to have resulted in a successful cub rearing. This bear may have left the maternal den prematurely due to some failure in pregnancy (intrauterine mortality or stillborn cubs).

The current study confirms previous information that polar bears from the Baffin Bay population prefer to den on eastern Baffin Island. Forty-one adult female polar bears that previously were tracked by use of satellite telemetry in Baffin Bay during 1991-1997 only entered maternity dens in the Baffin Island – Bylot Island areas (M.K. Taylor & E.W. Born unpublished data).

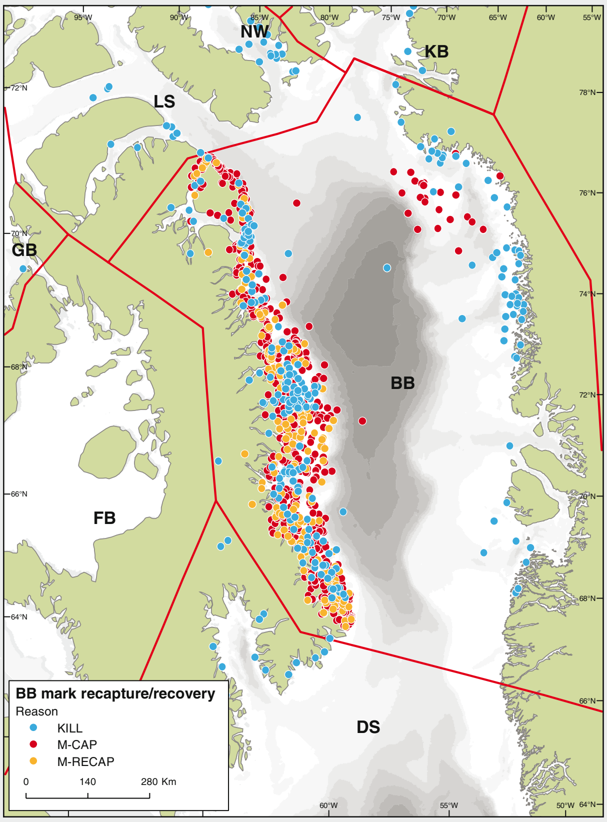
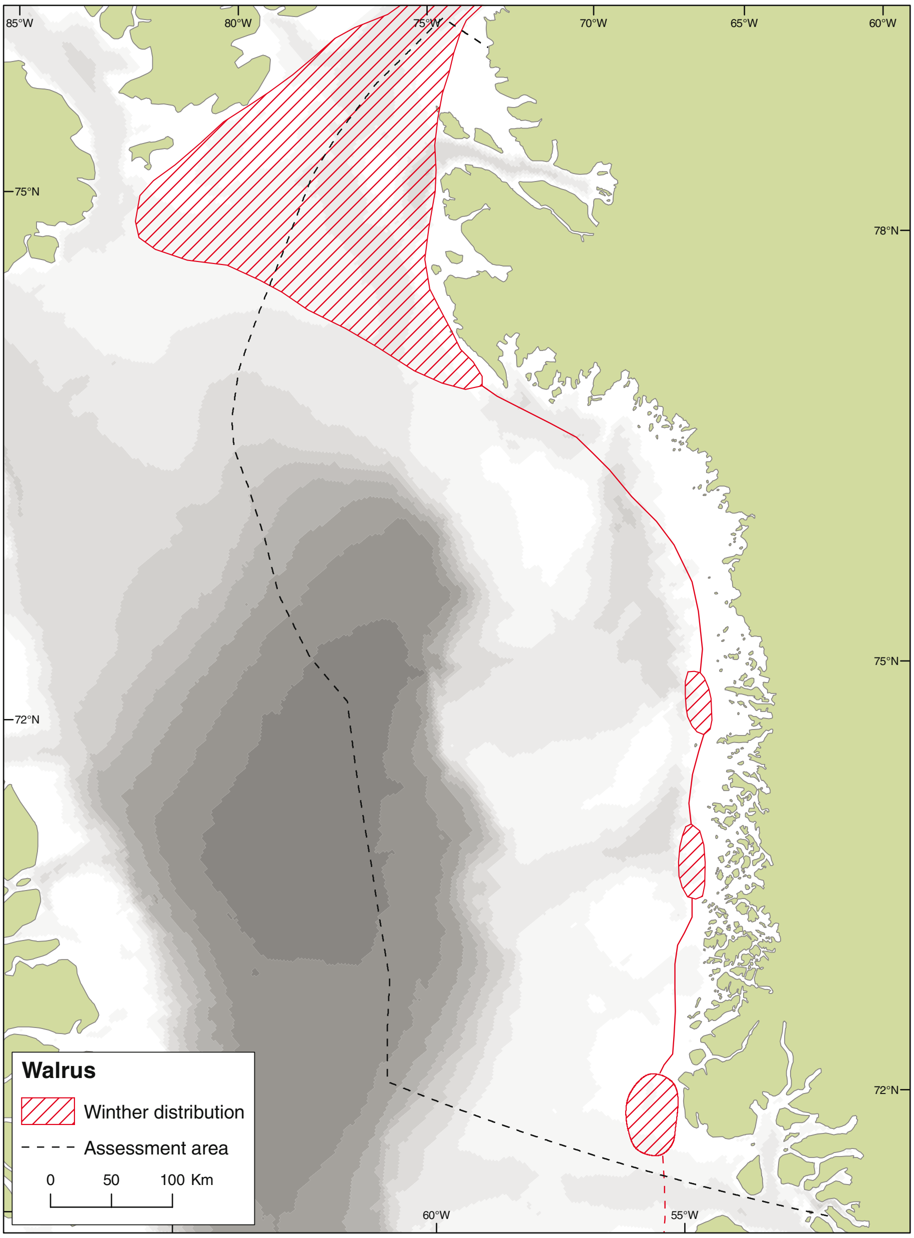


Figure 7. Map showing original tagging site (red, n=1266 bears) and sites of re-capture during scientific studies (yellow, n=230) and of hunter kills (blue, n=310) of polar bears that were marked in the Baffin Bay (BB) region during 1974-2009 (NDE and GINR unpublished data). These recoveries confirm the results of the telemetry study that polar bears range widely over the Baffin Bay region. The red limits indicate the different management areas.

Figure 18. The general distribution of walrus in the assessment area.



Several systematic aerial surveys conducted during 1981-2008 (Born *et al.* 1994 and references therein, Mosbech *et al.* 2007a, NAMMCO 2009, Heide-Jørgensen *et al.* 2010c) 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 ca. 69° 15' and 70° 30' N (Born *et al.* 1994, Mosbech *et al.* 2007a, 2009, Heide-Jørgensen *et al.* 2010c). However, during the aerial surveys in late March and April-May 2006 two small groups of walruses were observed further north within in the assessment area at approx. 71° 10' N (Mosbech *et al.* 2007a) and approx. 73° N (Heide-Jørgensen *et al.* 2006a). 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 the fully corrected estimates of abundance (2 methods for calculation and correction used) of ca. 2300 to 3000 walruses for these areas (Heide-Jørgensen *et al.* 2010c).

Some information exits on the abundance of walruses inside the southern parts of the assessment area. The 2006 survey resulted in an estimate corrected for animals out of sight of 69 walruses (90% confidence interval 14-334 animals) in the southern parts of the assessment area between 71° 30' N and 73° N (Heide-Jørgensen *et al.* 2006a).

Another aerial survey that focused on marine birds in April-May 2006 resulted in an uncorrected estimate of 46 walruses between 70° N and 71° 10' N (i.e. at the southern margin of the assessment area) (Mosbech *et al.* 2007a).

Walruses winter in the eastern parts of the North Water Polynya (NOW) between Qeqertarsuaq/Wolstenholme Island and Ullersuaq/Cape Inglefield (Freuchen 1921, Vibe 1950, Born *et al.* 1995 and references therein) i.e. inside the northernmost part of the assessment area. The population occurring in the NOW area is referred to the as the 'Baffin Bay' population (NAMMCO 2009). The thin ice there is frequently broken up by storms, giving the walruses access to shallow feeding banks (Vibe 1950). During winter walruses are hunted on the thin ice or from the edge of the fast ice, including the Savissivik and Wolstenholme Island areas (Born *et al.* 1995). Walruses in the eastern parts of the NOW area are segregated on the basis of sex and age class, with females and subadults generally occurring farther north than adult males (Born *et al.* 1995).

In the past, walruses arrived in the eastern parts of the North Water area from the south during spring (Freuchen 1921, Vibe 1950). These migrants joined the animals that had overwintered there. Although information from local people indicates that some walruses still do come from the south during spring (Born *et al.* 2008, Born unpublished data), it appears that the pronounced influx during June and July described by Freuchen (1921) and Vibe (1950) no longer takes place.

Today only occasional stragglers occur in the eastern parts of the North Water Polynya during summer (May-June until October-November), which contrasts to the situation earlier when walruses were apparently abundant in, for example, Murchison Sound during the open-water season (Born *et al.* 1995 and references therein).

They previously also occurred farther east in Wolstenholme Sound and also penetrated McCormick Fjord (Vibe 1950). Most likely, these changes have been caused by an increase in hunting pressure (Born *et al.* 1995).

An aerial survey conducted in late May 2009 in northern Baffin Bay to estimate the abundance of walrus, narwhal and beluga in the NOW area during late winter resulted in an estimate of total abundance (i.e. the estimate was corrected for walruses submerged and out of sight) of ca. 2700 animals (95% CI ca. 1100-ca. 5000). This estimate is suspected to be a slight overestimate of true abundance (NAMMCO 2009).

During summer the eastern parts of the NOW area are virtually devoid of walruses and at this time of the year they can be found along the coast and in the fjords of eastern Ellesmere Island (Canada). Aerial surveys conducted on 9 and 20 August 2009 over main concentration areas between 78° 35´ and 80° 11´ N along eastern Ellesmere Island resulted in a corrected estimate of abundance of the Baffin Bay population in the NOW area during the open water season 2009 of ca. 1600 (90% CI: ca. 1000-ca. 2700). Not all summering areas of the Baffin Bay population were covered why this estimate is considered a minimum (NAMMCO 2009, Born *et al.* 2009).

Hence, the 2009 surveys indicate that the Baffin Bay population of walrus numbers ca. 2000 individuals. How many of these occur inside the assessment area during the fall to spring season is not known.

There are no historical estimates of abundance of walruses in western and northwestern Greenland. Catches over several decades of many hundreds of animals indicate, however, that perhaps the Central West Greenland and the Baffin Bay population numbered several thousand walruses at the beginning of the 20th century (Born *et al.* 1994, 1995, Witting & Born 2005, NAMMCO 2009).

Delineation of population

Genetic analyses (Cronin *et al.* 1994, Andersen *et al.* 1998, Andersen & Born 2000, Born *et al.* 2001, Andersen *et al.* 2009b, NAMMCO 2009) indicate that three subpopulations exist in the Baffin Bay-Davis Strait region: Eastern Hudson Bay-Hudson Strait, West Greenland and the North Water (Baffin Bay population). Results indicated that (1) walruses in West Greenland and the Baffin Bay populations differ (i.e. north and south of the assessment area) genetically with some likely limited male mediated gene flow between these population, (2) walruses at southeastern Baffin Island and West Greenland do not differ genetically, (3) that walruses from Hudson Strait have some genetic input to this Southeast Baffin Island-West Greenland. The genetic evidence implies a direction of migration consistent with the suggestion by Freuchen (1921) and Vibe (1950, 1956) of a large-scale counter-clockwise migration of walruses in the Baffin Bay region.

The satellite telemetry study during 2005-2008 supported the notion that walruses in West Greenland and at southeastern Baffin Island constitute the same population which is hunted in both Greenland and Nunavut (NAMMCO 2009, Dietz *et al.* 2010).

Samples of walrus tissues for genetic analysis are not available from the assessment area and therefore the genetic affinity of walruses occurring in this area has

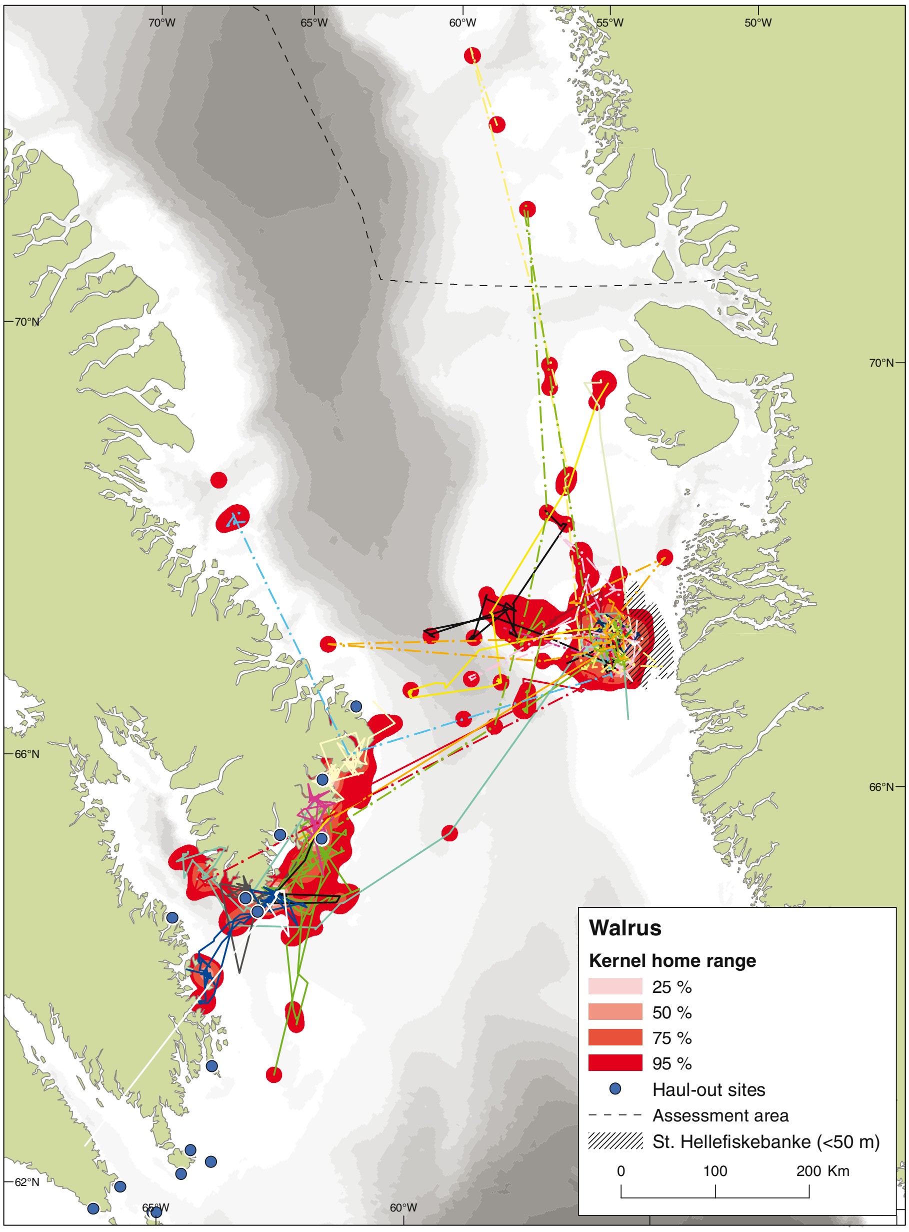


Figure 19. Track lines and home range (calculated as kernel home range polygons, KHR) of 31 walruses instrumented with satellite transmitters by the GINR and NERI at Store Hellefiskebanke during March-April 2005-2008 and at South East Baffin Island August-September 2007 (source: NAMMCO 2009, Dietz *et al.* 2010).

not been determined. Overall, the scarcity of information prevents a firm conclusion concerning the demographic affinities of the likely relatively few walruses occurring in the southern and central assessment area. Those occurring in the northern part of the assessment area (i.e. north of ca. 76° N) undoubtedly belong to the Baffin Bay population.

Movements

According to contacts in the town of Qeqertarsuaq/Godhavn walruses are never observed moving southward south of the town of Qeqertarsuaq during fall, whereas those wintering near the northwest coast of Disko Island are believed to move north in May. Observations made during aerial surveys along the coast between southwestern Disko Island and Svartenhuk during spring 1982 indicated that the walruses wintering along the west coast of Disko Island progressively moved north in the shear zone between the fast ice and the pack ice (Born *et al.* 1982).

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 (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).

According to Freuchen (1921) and Vibe (1950) the walruses crossed Melville Bay far offshore during their spring migration north into the Smith Sound region. Although there are indications that some walruses move north in the shear zone between the land-fast ice and the Baffin Bay pack ice during spring, a 'large-scale' spring migration north along the western coast of Greenland as indicated in Freuchen (1921) is not witnessed today.

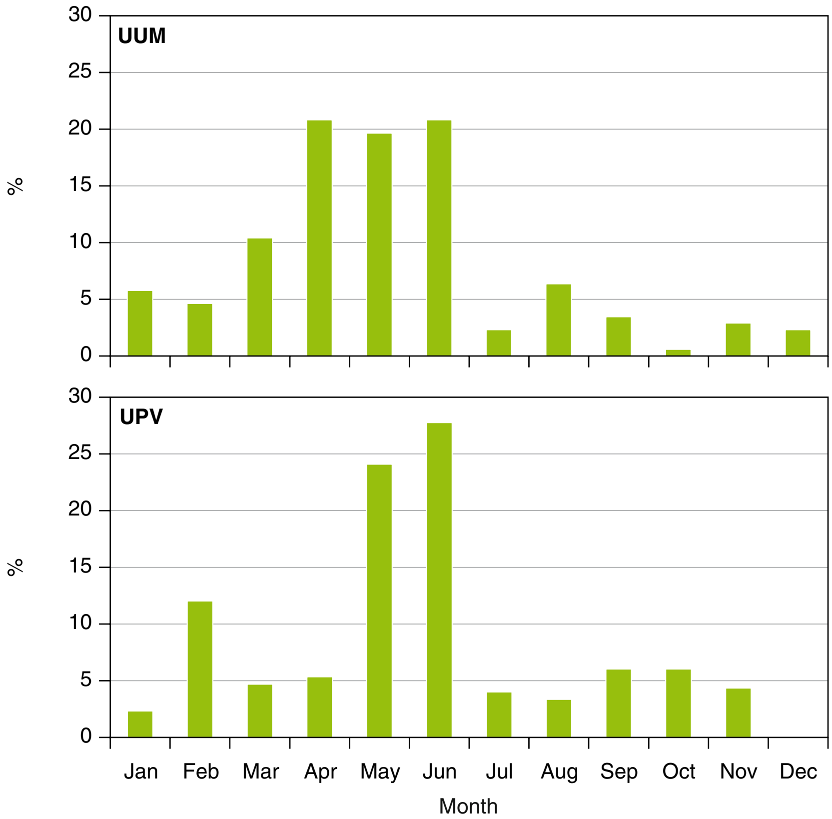
During spring 2005-2008, 23 walruses were fitted with satellite transmitters at their wintering grounds in at Store Hellefiskebanke, Central West Greenland in order to study movements and habitat choice (NAMMCO 2009, Dietz *et al.* 2010). Eight of the tags lasted long enough to document the migration from the wintering grounds in northern Davis Strait to southeastern Baffin Island. The westward migration occurred between 7 April and 25 May with the routes across Davis Strait being quite similar taking place at the most shallow and the narrowest part (ca. 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).

However, during 2008 two instrumented walruses first migrated north from Store Hellefiskebanke along the West Greenland coast 50-100 km offshore as far north as ca. 73° 27' N (Nutaarmiut) before turning south again (Figure 19). One of these walruses stopped transmitting on its way south along the coast whereas the other migrated to Baffin Island. This demonstrates that an unknown proportion of the West Greenland wintering stock of walruses may occur within the assessment area for an unknown period of time during May-June (NAMMCO 2009, Dietz *et al.* 2010).

Catch

The catch of walruses in the Uummannaq area peaks in March-June and in Upernavik in May-June (Figure 20). This seasonality may reflect the timing of a northward migration of walruses along the coast during spring. But it can also to some extent be explained by different hunting patterns as well as favourable weather and light conditions, and thereby favourable travelling and hunting conditions, arriving a little later in the spring in Upernavik compared to Uummannaq.

Figure 20. Seasonal distribution of the catch of walruses in the Uummannaq area (UUM, N=177) and the Upernavik area (UPV, N=300) during 1993-2006 (Source: APNN).



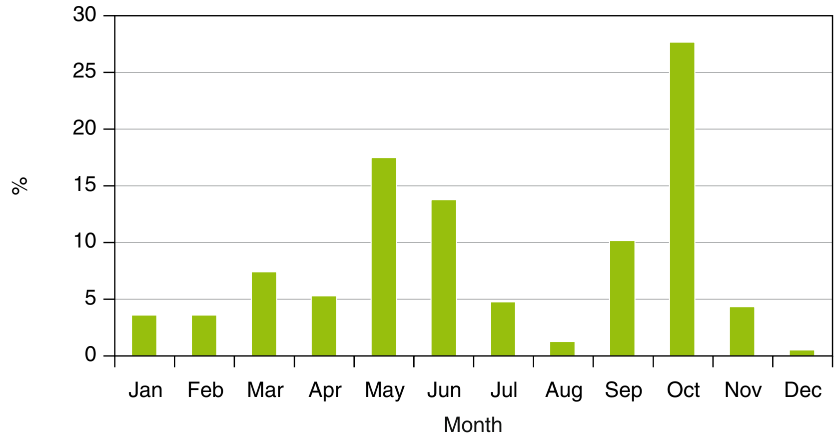
In the Uummannaq and Upernavik areas walruses are either caught when they winter in the shear zone between the fast ice and the Baffin Bay pack ice, or when they move along the ice edge in spring.

According to former, official game records the annual catch of walruses in the Uummannaq and Upernavik areas decreased between 1940 and 1987. The average annual catch in the period 1940-1959 in these two areas combined was around 22 walruses; between 1960 and 1987 the catch averaged 11 walruses per year. Over the entire period, the catch in the Uummannaq area comprised about 20% of the total catch of walruses in these two regions (Born *et al.* 1995). It must however be noted that for many years the catch records during the periods mentioned were insufficient. A new system of reporting catches (the '*Piniarneq*', i.e. '*The catch*') was introduced in 1993. During 1993-2006, the reported catch of walruses in the Uummannaq area averaged 12.6 per year (SD = 12.5, range: 0-38 animals (Ministry of Fishery, Hunting and Agriculture (APNN), Nuuk). The corresponding figures for the Upernavik area were 21.4 walrus per year (SD = 15.5, range: 7-58 walruses). The annual catch of walrus has not shown any trend in either of the two areas from 1993 to 2006. The seasonal distribution of the hunt reported in Piniarneq in the two municipalites is shown in Figure 20.

Annual quotas for the catch of walrus from the West Greenland population were 80, 65, 38 and 61 for 2007, 2008, 2009 and 2010, respectively. In 2010 the quota for the Uummannaq and Upernavik areas totalled 24 (http://dk.nanoq.gl).

Due to the more predictable and abundant occurrence in the eastern parts of the North Water area, the catch of walruses has always been of great importance in the former Qaanaaq municipality. The catch of walrus provides the local people with food for themselves and their sled dogs and the trade of walrus ivory is also a source of cash income (Vibe 1950, Born 1987, Born *et al.* 1995). Basically the walruses are caught during three types of hunt (Born 1987, Born *et al.* 1995): (1) Ice edge and thin ice hunt during winter and particularly spring. This hunting activity is

Figure 21. Seasonal distribution of the catch of walruses in the former Qaanaaq municipality (QAA, N=1,753) 1993-2006 (Source: APNN).



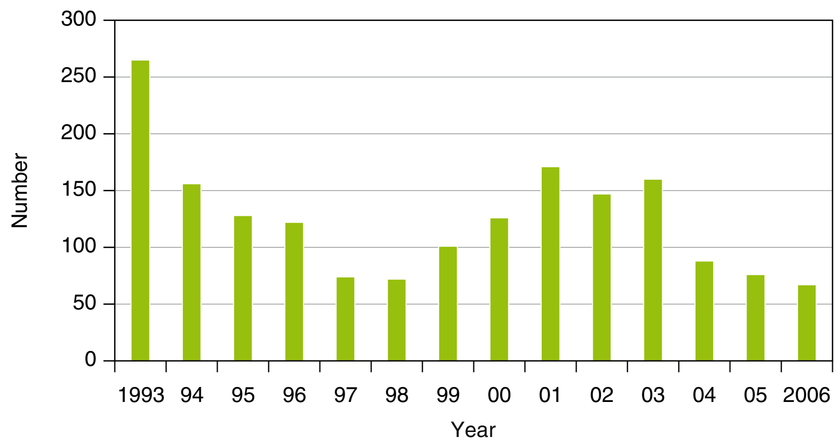
mainly conducted from February to April at western Wolstenholme Island and off Neqe at the northern entrance to Iluulerloq/Murchison Sound; (2) 'Summer' boat hunting (May-August) using skiffs. After an intense hunting activity from mid-May through June the walruses leave the area and go to eastern Ellesmere Island; (3) Boat hunt (September-November) when the walruses reappear in the Qaanaaq area in the fall when they are hunted by boat until formation of fast ice. These hunting patterns are reflected in the seasonal distribution of catches in the former Qaanaaq municipality (Figure 21).

Historically, the catch reports from Qaanaaq were inadequate. However, an estimated 100-300 walruses were landed annually between the 1940s and the late 1980s (Witting & Born 2005 and references therein). During 1993-2006 the reported catch of walruses in the entire Qaanaaq area has averaged 125.2 per year (SD=53.7, range: 67-265 walruses, source: APNN). In the southern part of the area, the catch reported from the two settlements Savissivik and Moriussaq has averaged 15.8 walruses per year (SD=14.3, range: 4-43 walruses) during the same period. However, since 1993 the reported catch in the former Qaanaaq municipality has decreased markedly – a decrease which has been nearly statistically significant (r^2=-0.240, F=3.783, P=0.073; df: 12/1), (Figure 22).

The Greenland walrus quotas for the Baffin Bay stock for the three-year period 2007-09 were 90, 80 and 75, respectively (Anon. 2006a, b).

The reason for the decrease in the catch of walruses is unclear. It may represent a general decrease in the number of hunters that are interested in hunting walruses and/or reflect that ice conditions have become more unsafe and unpredictable during the last decades due to global warming.

Figure 22. Number of walruses caught in the former Qaanaaq municipality during 1993-2006 (Source: APNN).



During the last approx. 15 years the sea ice has decreased and become more unstable in the Qaanaaq area. This development has in particular impeded or prevented the thin ice hunt of walruses during late winter and early spring, and has also made the summer walrus hunting season using skiffs shorter (Born *et al.* 2008). Hence, it cannot be excluded that the apparent decrease in the walrus catch reflects a decrease in hunting effort caused by environmental changes.

Important and critical areas

The preferred habitat for walrus is shallow waters with high densities of bivalves. The generally sedentary nature of walruses during winter and the inherent gregariousness of females appear to have been important factors influencing the evolution of the species' social behaviour and mating system (Sjare & Stirling 1996). Therefore wintering areas are important to the life history and survival of walrus subpopulations.

As the major part of the walruses in the assessment area are probably migrants or wintering at a number of places in the dynamic shear zone, it is not possible to designate important or critical areas. An exception is the mollusc banks at Qeqertarsuaq/Wolstenholme Ø and Appat/Saunders Ø in the former Qaanaaq municipality, where walruses are known to occur during autumn, winter and spring. Other critical habitats are the shallow waters at Kiataq/Northumberland Ø and the shallow water areas at the entrance to Iluleerloq/Murchison Sound.

Conservation status

The walrus populations occurring in the assessment area have an unfavourable conservation status, probably due to excessive hunt. The West Greenland population is red-listed as 'Endangered' (EN) and the North Water population as 'Critically Endangered' (CR).

Sensitivity

The effect of oil spills on walruses has not been studied in the field. Born *et al.* (1995) reviewed the information on potential negative effects on walruses of various anthropogenic activity including oil related activities.

An environmental impact assessment of shipping along the Northern Sea Route (the Northeast Passage) found the walrus populations could be negatively impacted by disturbance from traffic and by oil spills (Wiig *et al.* 1996). This will also apply to the assessment area.

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. Wiig *et al.* (1996) also pointed out that walrus feeding areas could be impacted resulting in the ingestion of toxic bivalves or by the reduction of available food supply. This latter effect could be critical for walruses wintering in limited open-water areas. The high level of gregariousness may also make walruses especially sensitive to oil spills – many individuals will be affected by oil spills hitting an assemblage and oil may be transferred between individuals.

Furthermore, the currents that are flowing north along the coast in the assessment area may bring oil slicks northwards into the important walrus wintering grounds in the Qeqertarsuaq/Wolstenholme Island-Appat/Saunders Island area and affect the North Water population.

However, walruses do not occur in high concentrations except in the northernmost part of the assessment area, and the most likely impact of disturbing activities inside the assessment area south of 76° N will therefore be displacement of a relatively few individuals.

4.8.2 Seals

A. Rosing-Asvid

Four species of seals are regularly seen in the assessment area; two species (harp- and hooded seals) are migrants occurring only during the open water season, whereas ringed seals maintain breathing holes in the area throughout the winter. Bearded seals can also make breathing holes, but only in relatively thin ice and many bearded seals that occur in the assessment area during spring-summer are likely to spend the winter elsewhere.

The effects of oil on seals were thoroughly reviewed by St. Aubin (1990). Seals are vulnerable to oil spills because oil can damage the fur, produce skin irritation and seriously affect the eyes as well as the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, and anal and urogenital orifices. In addition, oil can poison seals through ingestion or inhalation. Finally, oil spills can have a disruptive effect by interfering with normal behaviour 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) and oil will have a strong negative effect on the insulating properties of this fur. The mother seals recognize their pups by smell and a changed odour caused by oil might therefore affect the mother's ability to recognize its pup. Although the sensory abilities of seals should allow them to detect oil spills though 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).

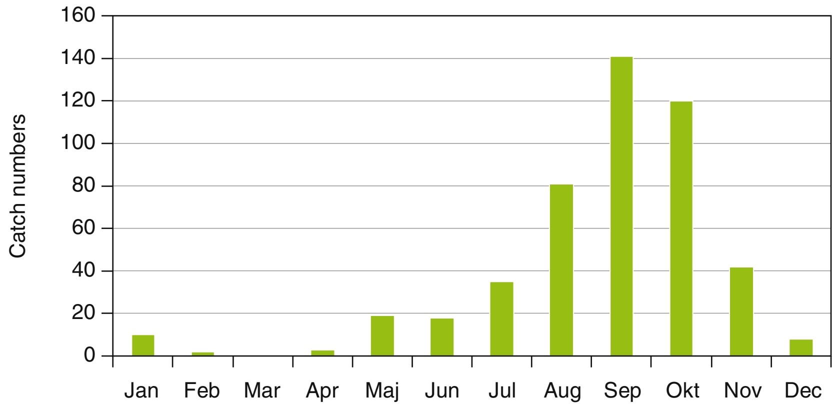
Hooded seal *Cystophora cristata*

Distribution: Hooded seals are migratory seals. The vast majority of the seals from the West Atlantic population concentrate in the whelping areas off Newfoundland and in Davis Strait during March-early-April (Stenson *et al.* 1996). In late April-May most of these seals swim toward Southeast Greenland and almost the entire population moult on the drift ice there during late June-July. Most juveniles stay near the drift ice off the Greenland east coast until they mature. The adult seals start a migration toward Davis Strait and Baffin Bay during the end of July (Andersen *et al.* 2009a). A large fraction of the adult seals move up into the Baffin Bay in September and until November they forage on the steep part of the shelf in the Baffin Bay (Andersen *et al.* 2009a). This means that a large fraction of the adult seals will forage in the deep parts of the assessment area, regularly diving below 500 m (down to 1500 m (Andersen *et al.* 2009a)), where they mainly take large fish and squids.

The catch: The annual catch in the assessment area is about 500/yr. The catch statistics show that some seals arrive in the assessment area when sea ice starts to break up in May, and a few will stay there throughout the open-water period May-November. Most hooded seals will, however, follow the migratory pattern described above, a fact also reflected in the seasonal distribution of the catches. The annual catch distributed on months is shown in Figure 23.

Conservation status: The population occurring in the assessment area has a favourable conservation status and the hooded seal is listed as of 'Least Concern' (LC) on the Greenland Red List. The seals are part of a very large population in the Davis Strait/Baffin bay region, which is managed internationally through a working group under ICES and NAFO and catches are sustainable (ICES 2006).

Figure 23. The number of hooded seals caught in the subsistence hunt in the assessment area by month in 2007.



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 (see above).

Important and critical areas: No particularly important areas are known for hooded seals within the assessment area.

Bearded seal *Erignathus barbatus*

Distribution: Bearded seals are widespread in the Arctic. Some bearded seals are stationary, but seasonal changes in their densities in some areas, indicate that part of the population 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 so seals that summer in areas with thick winter ice 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 parts of the assessment area and they are seen in the assessment area throughout the year, but they are most often seen (and caught) along the ice edge in the southern part of the assessment area during spring.

They are known mainly to feed on fish and benthic invertebrates found in waters down to 100 m depth (Burns 1981, Gjertz *et al.* 2000). Ongoing studies show that bearded seals in South Greenland spend considerable time at much deeper water (> 300m) and shrimps are found to be the most important prey in that area (GINR unpublished).

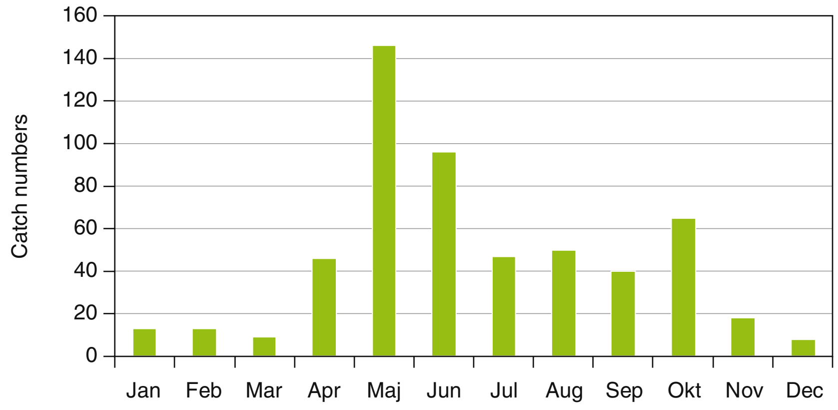
Birth takes place in April-May on drifting ice or on ice edges with access to open water and the lactation period is around 24 days (Gjertz *et al.* 2000).

The catch: Annual catches in the assessment area is about 5-600 seals/year, of which < 100 are caught during winter (December-March). The annual catch distributed on months is shown in Figure 24.

Conservation status: The bearded seal has a favourable conservation status. It is listed as 'Data Deficient' on the Greenland Red List due to lack of knowledge about population boundaries and numbers, but at global scale it is listed as 'Least Concern' (IUCN 2010).

Sensitivity: Bearded seals often vocalize, especially during the breeding season in spring (Burns 1981); and they may therefore be sensitive to acoustic disturbances (noise). The benthic feeding habits will also make them vulnerable to oil-polluted

Figure 24. The number of bearded seals caught in the subsistence hunt in the assessment area by month in 2007.



benthos and bearded seals can be affected by oil spills in the same way as all other seals (see introduction to seals, above).

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 ice cover limits the available habitats in the assessment area to feeding grounds in the NOW Polynya, the dynamic shear zone and in some mild winters open water along the southern ice edge.

Harp seal *Pagophilus groenlandica*

Distribution: 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.

The numbers of harp seals in the assessment area increases throughout the summer and early fall, but when the sea ice starts to form they initiate the migration back toward the whelping areas off Newfoundland. Most adult harp seals will during summer forage in pods typically consisting of 5-20 individuals. Juvenile seals forage alone, but all ages are mainly feeding on Capelin (*Mallotus villosus*), polar cod (*Boreogadus saida*), amphipods (*Parathemisto libellula*) and krill (*Thysanoessa* spp.) (Kapel 1995).

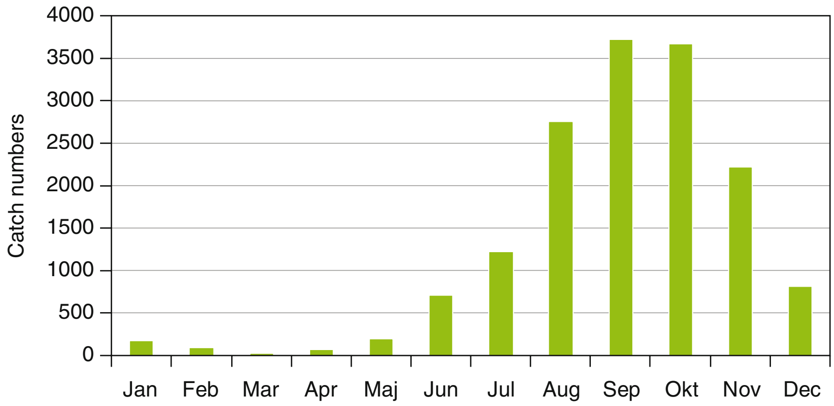
The West Atlantic population that whelp on the ice off Newfoundland in early March is estimated to have increased from around 1.8 million in the early 1970s to about 7-8 million individuals in 2010 (Hammill & Stenson 2010). The proportion of seals that enter the assessment area is unknown and probably also variable, but might be in the region of 10% of the population.

The catch: The catch in the assessment area has been steadily increasing from around 2,000/yr in the early 1970s to around 14,000-16,000/yr in recent years. The annual catch distributed by months is shown in Figure 25.

Conservation status: The population occurring in the assessment area has a favourable conservation status. Harp seals are the most numerous marine mammals on 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.

Critical and important habitats: No particularly important areas are known for harp seals within the assessment area, but the density of these seals is highest in the southern part.

Figure 25. The number of harp seals caught in the subsistence hunt in the assessment area by month in 2007.



Sensitivity: Non-breeding harp seals are not considered to be particularly sensitive to oil spills or to disturbance. Harp seals can be affected by oil spills in the same way as all other seals (see introduction to seals, above).

Ringed seal *Pusa hispida*

Distribution: Ringed seals are present in the assessment area in high numbers throughout the year. They give birth in March-April in lairs dug out in a snowdrift that is covering a breathing hole and many thousand pups are likely to be born in the assessment area each year. The pups lactate in up to 7 weeks (Hammill *et al.* 1991). The moulting period is mainly in June and during the moult, the seals will spend most of the day basking on the ice. They need to be near the ice in this period and their numbers therefore decline in some of the coastal areas in the southern part of the assessment area. Some move into ice filled glacier fjords and others follow the retreating sea ice north and westward to the high Arctic areas. When the sea ice expands again during early winter they spread out again. Ringed seals make breathing holes in the new ice and in fast ice areas or in consolidated pack ice, and they maintain the breathing holes throughout the winter. Adult seals establish territories in these areas, whereas the juvenile seals mainly spend the winter in areas with loose unconsolidated sea ice.

Aerial surveys in the 1980s revealed large concentrations of ringed seal in the Baffin Bay pack ice (Finley *et al.* 1983). These and other surveys found average densities of ringed seals on fast ice as well as on consolidated pack ice in the Baffin Bay area to vary between 1.3-2 seals/km^2 in June (Kingsley 1998 and references therein).

Ringed seals mainly prey on Polar cod (*Boreogadus saida*), Arctic cod (*Arctogadus glacialis*), *Liparis* spp. and amphipods (*Parathemisto* spp.) in near-shore waters in the assessment area (Siegstad *et al.* 1998). Prey selection is unknown for off-shore areas, but likely to consist of the same species.

Catch: Ringed seals are caught in high numbers in the assessment area. The catches decrease in the southern part and increase in the northern part when the sea ice disappears in south around June and *visa versa* when the sea ice spread out again in fall. Less than 10% of the seals caught are adults (Christiansen 1983). The sale of ringed seal skins is important for local hunters and the meat is of high importance in the household economy. The annual catch of ringed seals in the assessment area has in recent years been around 40.000/yr. The number of juvenile seals caught in the assessment area and further south along the Greenland west coast is higher than what can be produced locally, reflecting an influx from extra-limital populations from north or west (Christiansen 1983). The overall catch along the west coast has been relatively stable for many years and is therefore considered to be sustainable. The annual catch distributed on months is shown in Figure 26.

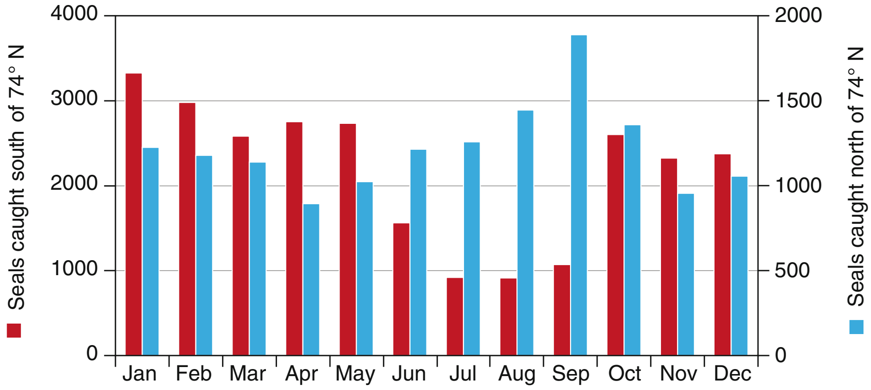


Figure 26. The number of ringed seals caught in the subsistence hunt in the assessment area by month in 2007 (divided by seals caught north and south of 74° N).

Conservation status: The ringed seal have a favourable conservation status, because of 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 two months when they give birth and nurse their pups. This stationary behaviour makes them vulnerable to disturbance and particularly to activities, which disrupt the stable ice. However ringed seals were not particularly shy towards seismic operation in Arctic Canada, where they showed only little avoidance to the ships (Lee *et al.* 2005). Ringed seals can be affected by oil spills in the same way as all other seals (see introduction to seals, above).

Critical and important habitats: Stable ice in the whelping and nursing period is the most critical factor to ringed seals. Such ice is widespread within the assessment area (both off-shore and in fjords and along the coast), why it is difficult to designate any especially important areas.

4.8.3 Baleen whales

F. Ugarte, L.M. Rasmussen and M.P. Heide-Jørgensen

Baleen whales occurring in the assessment area include five species of rorquals (family Balaenopteridae: minke, sei, fin, blue and humpback whale) and bowhead whale.

All the rorquals migrate between southerly calving and mating grounds during winter and northern feeding grounds during summer. Their summer distribution includes parts of the North Atlantic, including the seas around Greenland. There is very little information about these species in the assessment area. The rorquals undertake these long migrations to take advantage of the summer peak of productivity in northern waters. Climate change will likely impact these migratory species in terms of distribution changes due to geographic shifts in the locations of frontal and upwelling areas that concentrate their food. Such large-scale oceanographic changes are likely to affect most marine mammals, but they are currently very difficult to predict (Kovacs & Lydersen 2008). In the assessment area, new habitats for these migratory whales may open if the ice-edge retreats during the spring months, as most models predict. This may result in an increased importance of the Baffin Bay assessment area to these large whales.

Baleen whale sensitivity to oil activities

Oil activities that potentially can impact whales include seismic exploration, exploratory drilling, ship, helicopter and aircraft noise, discharges to water, dredging, and marine constructions.

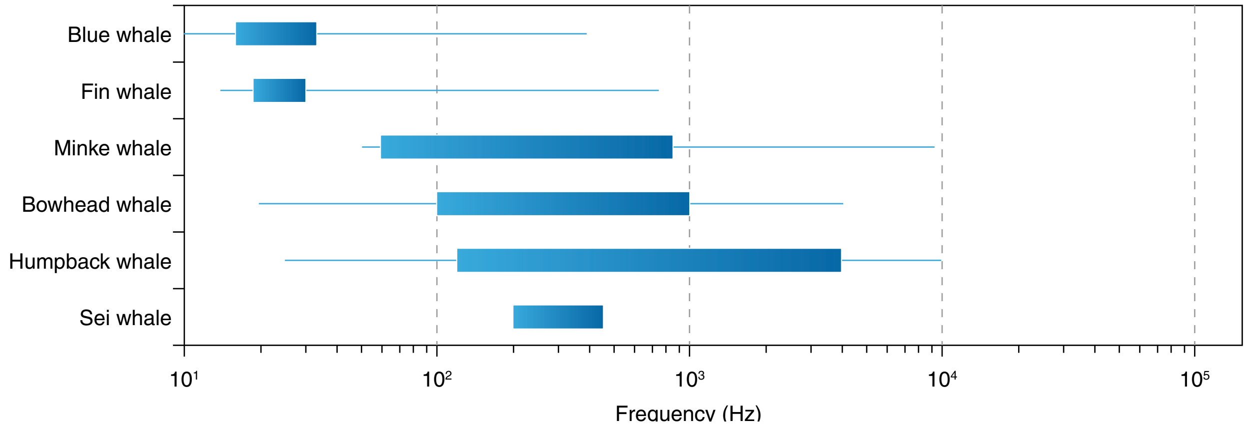


Figure 27. Known frequency ranges used by the baleen whales present in the Baffin Bay assessment area. The thick bar shows the range of the most common types of vocalisations, while the thinner line shows recorded extremes of frequency. Adapted from Mellinger *et al.* (2007).

Baleen whales produce low frequency calls, many of which are species-specific and can be detected over tens to hundreds of kilometres (Mellinger *et al.* 2007, Figure 27). Due to their potential ability to communicate acoustically over very long distances, the baleen whales may be sensitive to acoustic pollution from sources such as seismic airguns, drilling, offshore construction, aircrafts and vessel supply activities (see also Chapter 10).

The potential impacts of oil exploration or spills are relevant where spatial and temporal overlap between the whales and the activities occur. Seismic exploration is mainly conducted in the ice-free summer and autumn months, at times when rorquals are present in the Baffin Bay assessment area. The southern part of the assessment area could be a critical habitat for rorquals during summer.

Bowhead whale *Balaena mysticetus*

The bowhead whale is the only baleen whale that remains year round in Arctic and Sub-Arctic waters. Five populations of bowhead (Okhotsk Sea, Bering-Chukchi-Beaufort Sea (BCB), Foxe Basin-Hudson Bay (FBHB), Baffin Bay-Davis Strait (BBDS) and Spitsbergen) are currently recognized by IWC, although the FBHB and BBDS stocks delineation is currently being debated as they probably constitute one single population.

All the bowhead whale stocks were subject to commercial whaling before the 20th century, and a global ban on commercial harvest of bowhead whales was installed in 1932 after all stocks were greatly reduced. All populations except the one in Okhotsk Sea now show signs of recovery from the commercial harvest.

The bowhead whales that occur in the Baffin Bay assessment area primarily utilize the area for feeding and migration between spring concentration areas in the Disko Bay region and summer grounds in the Canadian arctic archipelago.

Bowhead whales are highly specialized filter feeders with many long baleen that are used to filter large amounts of water and capture small zooplankton prey (Burns *et al.* 1993). They are seasonally dependent on substantial concentrations of zooplankton, however their fat depots likely allow them to survive periods of famine.

Somatic growth of bowhead whales is known to be slow compared to other baleen whales and sexual maturity is estimated to be attained late in life (> 20 yrs of age) relative to other mammals. Calving intervals of 3-4 yrs (Burns *et al.* 1993) resembles production seen in right whales and other Arctic cetaceans (narwhals, and belugas). Calving is believed to take place in spring after a gestation period of just over one year which should give a conception-period in March (see also below). The maximum age of bowhead whales has recently been estimated by aspartic acid racemization of eye lenses to exceed 200 yrs (George *et al.* 1999).

Although recovering, the abundance of bowhead whales in West Greenland is still much below the pristine population size and bowhead whales in West Greenland remain threatened until a larger more viable abundance has been attained. This means that the population is particularly vulnerable to anthropogenic disturbances for example from oil exploration and exploitation.

Current distribution of bowhead whales

Today Bowheads are primarily spring and summer visitors along the west coast between Nordre Strømfjord and southern part of Qaanaaq (Box 7). The core area for bowhead whales today is the Disko Bay and offshore waters in Baffin Bay north of Disko Island. It is anticipated that the historical range of bowhead whales will at some point be re-inhabited with the increasing abundance over time.

However, a few bowheads also winter in the North Water Polynya or visit the polynya in early summer (Figure 28) and, depending of the ice conditions, occur within the northern part of the assessment area until at least July when they probably move westwards.

Migrations

The first bowhead whales appear in Disko Bay in February (2005, 2006, 2009 and 2010) at Kitsissuarsuit and Qeqertarsuaq. The whales remain in the bay until June where they are mainly concentrated in the northern section near the coast of Disko Island, but some whales have been observed in the eastern part of the bay towards Ilulissat or around the islands in the opening of the bay. The timing of the departure from the bay varies slightly, but usually occurs around mid May. The predominant migration route is taken in a northwest direction across the Baffin Bay assessment area, probably through leads and cracks in the pack ice (Heide-Jørgensen *et al.* 2003d, Heide-Jørgensen *et al.* 2006b). The traverse of Baffin Bay likely requires that whales move north along the West Greenland coast until they find a lead that intersect Baffin Bay running northwest to southeast, facilitating open water availability during the relatively short time span the whales use to cross the bay (Box 7).

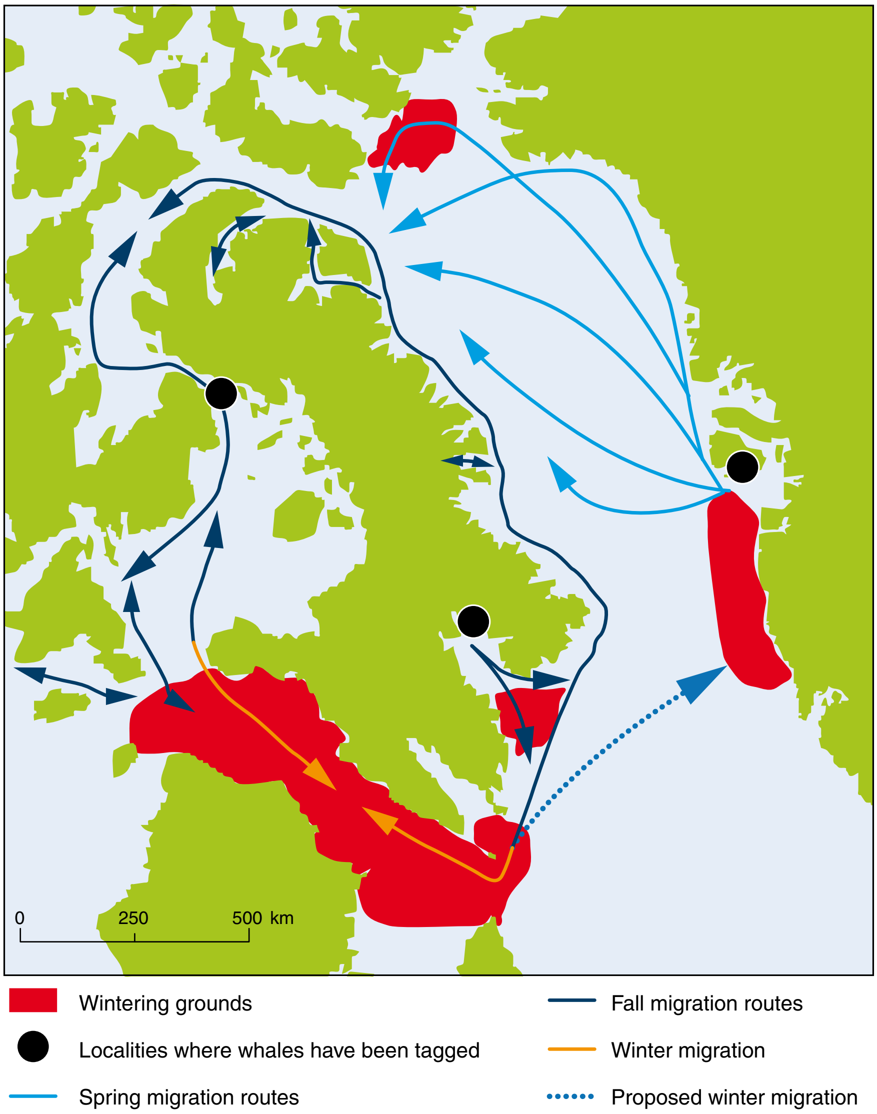
Stock identity

Recent satellite tracking studies in Canada and Greenland (Box 7) shows that bowhead whales that occur in West Greenland are part of a population that extends from Foxe Basin through the Canadian high-Arctic archipelago, Hudson Bay and Hudson Strait, and along the east coast of Baffin Island (Heide-Jørgensen *et al.* 2006b), i.e. the range of the two now debated stocks BBDS and FBHB.

Population segregation

Even though the bowhead whales in West Greenland are shared with those in Hudson Bay and Foxe Basin there is evidence for considerable age and sex segregation between the two areas. Females with calves and young immature whales are primarily found in Foxe Basin, whereas in Disko Bay (and the Baffin Bay assessment area) the population consists mostly of adult whales (Heide-Jørgensen *et al.* in press c). Skin biopsy samples of bowhead whales collected in Disko Bay between 2000 and 2010 show that 78 % (n=448) of the whales sampled are females based on genetic sex determinations (Palsbøll *et al.* 1997) and length estimates suggest all were mature exceeding 12-14 m of body length (Heide-Jørgensen *et al.* in press c). Very few calves have been seen in West Greenland, thus the large proportion of females must be either pregnant, resting or in oestrous (post-lactat-

Figure 28. Wintering grounds, spring and autumn movements of bowhead whales in Baffin Bay.



ing). Acoustic studies in Disko Bay indicate that the bay is also a mating ground. Mating is believed to occur in March and April (Reese *et al.* 2001). Intensive singing activity of bowhead whales with up to three unique songs were recorded in April 2007 (Stafford *et al.* 2008, Tervo *et al.* 2009). Singing is an activity that usually is attributed to male display in baleen whales and, given most singing activity was recorded during spring; mating between the relatively few males and the large fraction of females is assumed to occur in Disko Bay in March.

Current abundance in West Greenland

Abundance of bowhead whales in West Greenland was assessed from an aerial survey conducted in March and April 2006. The surveyed area included the region between Sisimiut and Upernavik and up to approximately 100 km offshore and resulted in an estimated abundance of 1229 (95% CI: 495-2939) bowhead whales for the surveyed area (Heide-Jørgensen *et al.* 2007b). These whales constitute a fraction of the total population moving through the Baffin Bay to the Canadian summer grounds, where the population in 2001-02 was estimated at 6,344 (95% confidence limits 3,119-12,906) (IWC 2008). Despite the recent signs of recovery (Heide-Jørgensen & Laidre 2010), numbers of bowhead whales in Baffin Bay are probably still much lower than the original population size (Allen & Keay 2006).

Diving and foraging ecology

Dive data collected from bowhead whales in Disko Bay indicate deep dives with great variability following the highly complex bottom contours of Disko Bay. These

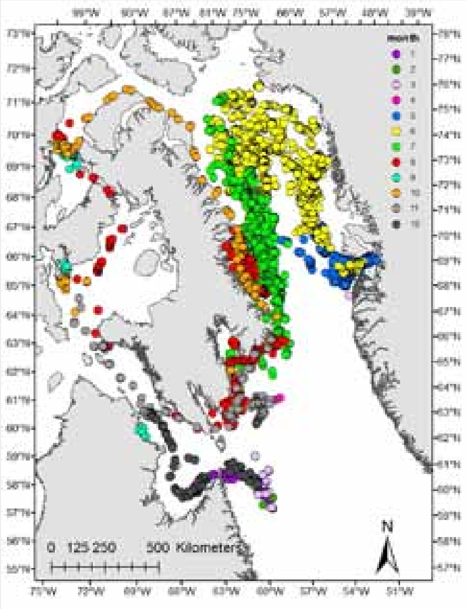


Figure 1. Tracks of all bowhead whales tagged in 2009 in Disko Bay and tracked through December 2009.

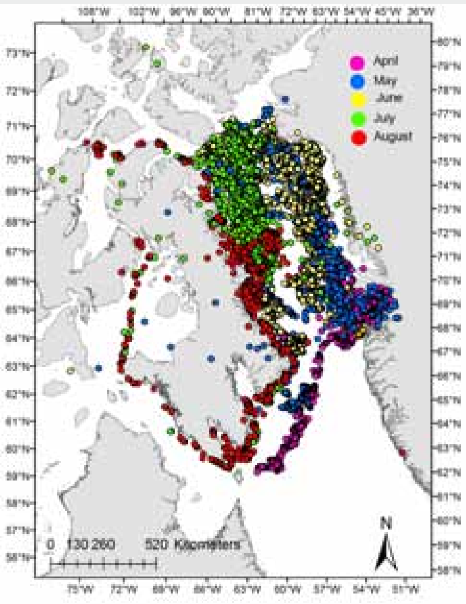


Figure 2. Tracks of all bowhead whales tagged in Disko Bay in 2010 and tracked through August 2010.

Box 7

Movements and space-use patterns of bowhead whales in the Baffin Bay, 2009 and 2010

M.P. Heide-Jørgensen and K.L. Laidre

A total of 78 bowhead whales have been instrumented with satellite-linked radio transmitters in Disko Bay in 2009 (n=28) and 2010 (n=50). Three types of transmitter configurations were used: cylindrical implantable SPOT 5 tags that provide only positions of the whales (n=33), cylindrical implantable Mk10 tags that collect and transmit compressed and binned dive data (n=16) and external SWING SPLASH tags secured with a spear with barbs that also collect dive data (n=29). All tags were deployed in Disko Bay between 15 February and 5 June with most deployments in April. Data from the tags have been collected for as long as 14 months and seven tags are still transmitting at the time of the completion of this report.

Kernel home ranges were calculated for 3 data subsets based on satellite telemetry collected from whales between spring 2009 and summer 2010. First, home ranges in autumn, winter, spring and summer were calculated only from whales tagged in 2009 (which had transmitted through 2010) (Figure 6). Second, home ranges for the spring and summer were calculated from whales tagged in 2010 (data for this report were available through August 2010) (Figure 7). Third, home ranges were calculated for the combined data sets for the spring and summer season using whales tagged in 2009 and 2010 (Figure 8). Currently, autumn home ranges are only available based on whales from 2009 because the tags from 2010 are still transmitting.

Winter: January – March

Two tags deployed on 27 April and one deployed on 17 May 2009 in Disko Bay provided positions in January-March 2010 and they were all located at the northern Labrador Coast at the entrance to Hudson Strait in January at a time when bowhead whales are not regularly seen in Disko Bay. In March-April two of the whales made a move towards Disko Bay where they were located in April in the very same areas where bowhead whales were located and tagged in 2010. The tracks of the two whales from Northern Labrador to Disko Bay in winter are the first actual demonstrations of the return migration of bowhead whales to West Greenland from the summer and fall grounds in Northern Canada. Although it was assumed that the route across Davis Strait constituted the most likely supply of bowhead whales to West Greenland it has also been proposed that whales could come from the north along the West Greenland coast or straight across from Baffin Island. The tracks of the two whales (one female and one unknown sex) that returned to Disko Bay also demonstrate that some whales return year after year to the bay and not necessarily follow a multi-annual cycle.

Spring: April – May

Most of the tagging effort on bowhead whales has taken place in April-May in Disko Bay. Generally the bowhead whales are concentrated in the western part of Disko Bay and in April-May but the northbound migration has been initiated in early May and bowhead whales can be found all along the West Greenland coast as far north as Melville Bay and the North Water, and they are also found in the eastern part of Disko Bay and in Vaigat.

The spring home ranges (Figures 6 and 7) demonstrate the concentration area of whales in the Disko Bay region during April and May (especially when compared to the expansive home range in summer). The combined spring area (Figure 8) was similarly concentrated in Disko Bay and only the 95% region showed small pieces of area use as whales began their northbound migration.

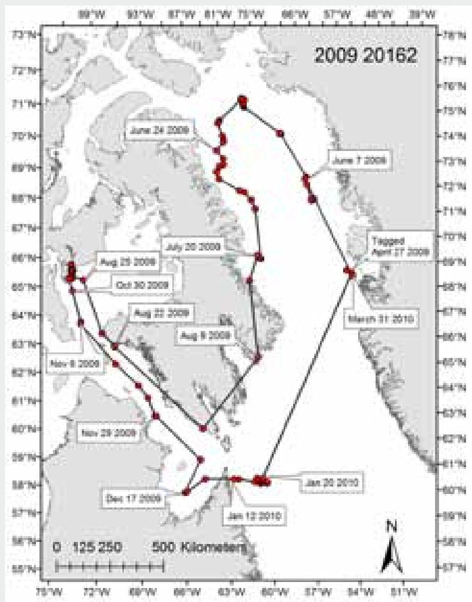


Figure 3. Track of one female bowhead whale (IDNO 20162) tagged on 27 April 2009 in Disko Bay and tracked through March 2010.

Summer: June – August

June is the month when bowhead whales migrate across Baffin Bay. Bowhead whales can still be found in Disko Bay in June, but they occur in lower numbers as many whales have departed. Most whales are located in the eastern part of Baffin Bay from Disko Island and north to the North Water. Some whales have however already crossed or circumvented the deep basin of Baffin Bay to be found on the western side of the bay.

In July almost all of the whales are on the western side of Baffin Bay and along the east coast of Baffin Island. Also offshore areas in the northern part of Baffin Bay and southern part of the North Water attract a large number of bowhead whales in July.

August is typically spent in coastal areas in the Canadian high Arctic archipelago and in northern Hudson Bay and Foxe Basin. Some bowhead whales circumvent Baffin Island in August but the largest concentrations of whales have been found in Prince Regent Inlet in late August.

The summer home range demonstrated the vast area over which the bowhead whales range during these months.

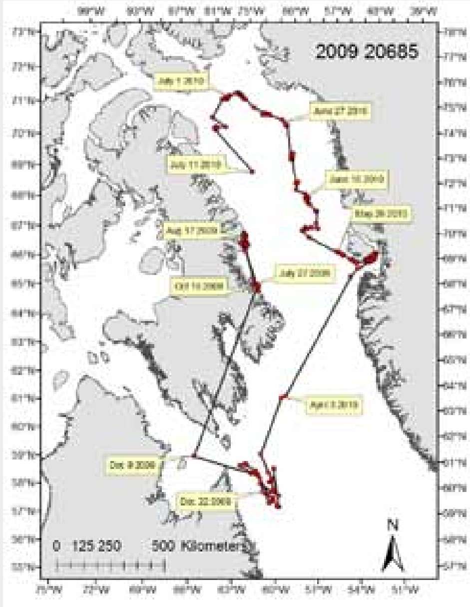


Figure 4. Track of one female bowhead whale (IDNO 20167) tagged 17 May 2009 in Disko Bay and tracked through 11 July 2010.

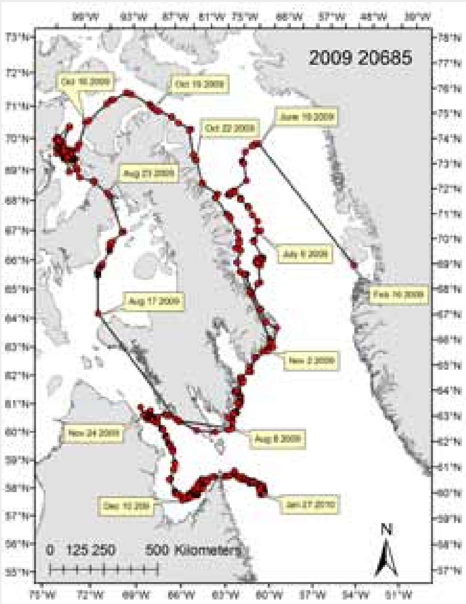


Figure 5. Track of one bowhead whale (sex unknown, IDNO 20162) tagged 27 April 2009 in Disko Bay and tracked through 27 January 2010.

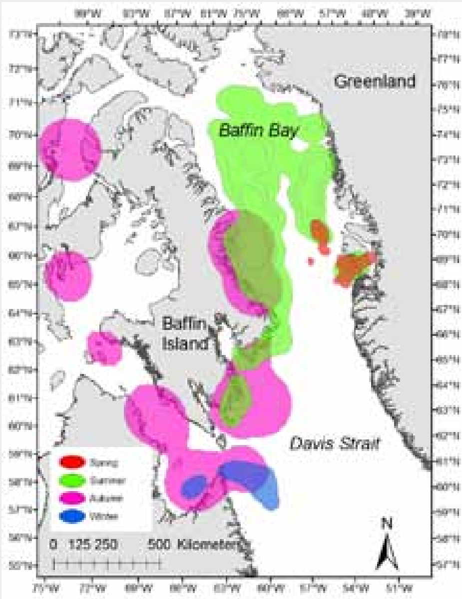


Figure 6. Seasonal home range distributions of bowhead whales from 2009.

Figure 7. Seasonal home range distributions of bowhead whales from 2010.

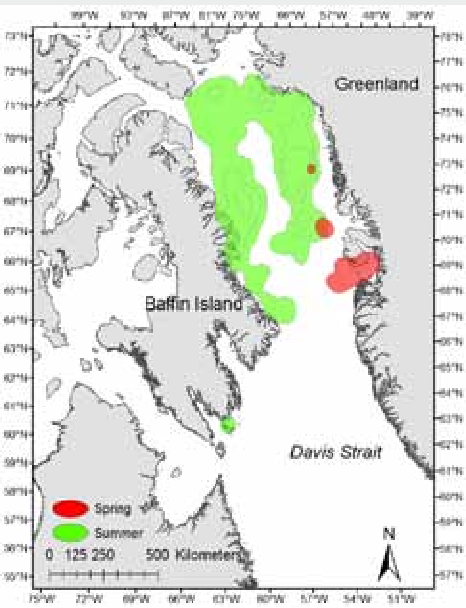
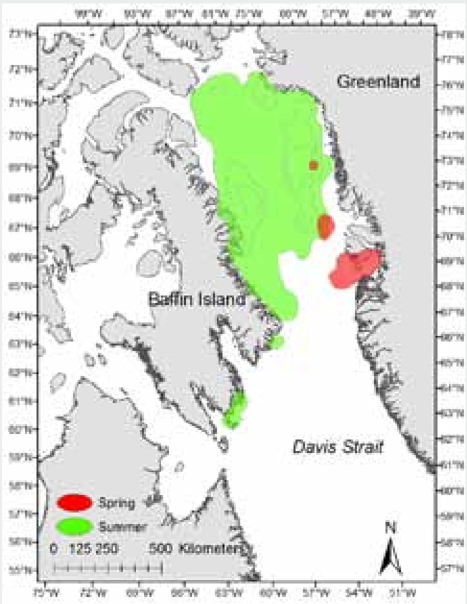


Figure 8. Combined home ranges spring and summer for whales tracked in 2009 and 2010.



Autumn: September - December

Bowhead whales are generally not present in West Greenland or the eastern part of Baffin Bay in the fall and early winter. In the fall whales from Disko Bay can be located in the Canadian Arctic Archipelago as far west as 90° W, but are primarily concentrated in Prince Regent Inlet, Foxe Basin and in fjords along the east coast of Baffin Island (e.g. Isabella Bay and Cumberland Sound) and Hudson Strait. At this time of the year the whales are also concentrated in coastal areas or move between coastal locations.

The 95, 75, and 50 % autumn kernel home range was concentrated in multiple smaller focal areas which included the east coast of Baffin Island (Isabella Bay and offshore from Cumberland Sound), Prince Recent Inlet, Repulse Bay, and multiple areas within Hudson Strait.

are area where epibenthic densities of copepods are very high (Laidre *et al.* 2007). Given the requirement to strain enormous quantities of water, bowhead whales likely have evolved to exploit their zooplankton prey in regions with high density aggregations. Near-seabed zooplankton in Disko Bay occur in dense concentrations, are calorically superior to surface zooplankton given they are far more concentrated than those in the upper 50 m of the water column and the concentrations are likely predictable on an inter-annual scale.

Feeding habits of bowhead whales in Disko Bay have been studied through examination of stomach contents of whales captured in the subsistence harvest for whales. Four stomach samples were collected in 2009 and 2010 and in all stomachs the prey items were > 99 % calanoid copepods > 3 mm long (Heide-Jørgensen *et al.* submitted). In one stomach, where species determination was possible, it was primarily *Calanus hyperboreus* that was found. The stomach content of the bowhead whales from Disko Bay indicate that they feed almost exclusively on calanoid copepods and that no other prey items contribute substantially to their diet. This is in agreement with observations of diving behaviour and area utilization by whales instrumented with time-depth-recorders and satellite transmitters (Laidre *et al.* 2007). The stomach contents of three whales (of the same stock) taken by the subsistence hunt in the Canadian archipelago in the period 1996-2008 surprised by containing high numbers of benthic and epibenthic organisms especially mysids (Pomerleau *et al.* 2011).

Critical and important areas

The assessment area is extensively used by bowhead whales during their spring migration between Disko Bay and Arctic Canada, from late May through June. Just to the south of the assessment area, the Disko Bay and the waters to the southwest of Disko must be classified as one of the most important bowhead whale habitats worldwide; it is used extensively for foraging by mature whales of both sexes and it is especially important for mature females that – aside from feeding – are also mating in the bay (Heide-Jørgensen *et al.* submitted).

The North Water Polynya is a winter and spring/early summer habitat, but it is not known how many whales occur there.

Conservation status and catch

The population occurring in the assessment area has now a favourable conservation status as it is increasing and is more numerous than previously believed. It is listed as 'Near Threatened' (NT) on the Greenland Red List and as 'Least Concern' (LC) the international Red List (IUCN 2010).

The Baffin Bay stock has been protected since 1910, but in recent years a few have been taken in Canada; and Greenland was permitted by the IWC to take two per year in 2008-2012. Three bowhead whales were taken in Disko Bay in 2009 and 2010 and the remaining part of the quota will be taken in 2011 and 2012.

Minke whale *Balaenoptera acutorostrata*

Minke whales are the smallest baleen whale in the northern hemisphere, with average lengths in the North Atlantic of 8-9 m and average weights of 8 tonnes. Because of their relatively small size, their inconspicuous blow, their extremely fast movements and the fact that they are usually solitary animals, minke whales are often difficult to survey.

Minke whales feed on a large variety of prey, including small schooling fish and krill, and migrate seasonally from boreal, Arctic and sub-Arctic waters in summer to warmer waters in winter. Summer feeding grounds extend from northern Europe and North America, including Iceland and Greenland, to the ice edge. Winter breeding grounds are unknown, but may include tropical waters off the Caribbean and West Africa. Some individuals remain although at high latitudes during winters.

Distribution

Minke whales occur as summer visitors mainly in the southern part of the assessment area (Figure 29). In recent years minke whales have been reported as far north as Siorapaluk in the former Qaanaaq Municipality, which most likely is an effect of climate change. There is no knowledge on specific, important areas for minke whales within the assessment area.

Conservation

The population occurring in the assessment area has a favourable conservation status. Both the global Red List (IUCN 2010) and the Greenland Red List categorise the minke whale as of 'Least Concern' (LC).

Stocks

For management purposes, the International Whaling Commission (IWC) recognizes four different stocks of minke whales in the North Atlantic (Figure 30). These management regions were established based on studies of catch statistics, biological characteristics and tagging. Newer molecular studies tend to confirm the established subdivisions (Andersen *et al.* 2003, Born *et al.* 2007).

Catch

Minke whales have been hunted in West Greenland since the middle of the 20th century. Quotas for West Greenland are set by the IWC. The Greenland government divides the quota among the towns. The annual quota for West Greenland in the period 2010-2012 is 175 minke whales. Most whales are taken south of Disko Island, where there are boats equipped with harpoon guns. Further north in the assessment area, minke whales are taken from dinghies with outboard engines, and several dinghies work as team, using hand held harpoons and high-powered rifles. This type of hunt is called the 'collective hunt'. In 2010, 18 minke whales were caught in the assessment area. Of these, 7 were caught in Upernavik and 11 in Uummannaq (Ministry of Fishery, Hunting and Agriculture, APNN). A minke whale was caught in Qaanaaq for the first time in 2009.

From 1968 to 1986, small-type whaling boats from Norway caught minke whales in the waters off West Greenland. During the early and mid-1970s, Norwegian catches off West Greenland averaged 175 minke whales annually. After 1977, following recommendations by the IWC, the Norwegian catches were reduced to 75 minke whales annually (Kapel & Petersen 1982). The Norwegian boats stopped catching minke whales in Greenland in 1986.

The Norwegians recorded data on each whale caught, including size, sex, reproductive status and location where the whale was caught. From this dataset, we can see that several minke whales were caught within the southern part of the assessment area (Figure 29).

The data also indicate that there is an excess of female minke whales in West Greenland, even though similar numbers of female and male offspring are born (Laidre *et al.* 2009). This indicates that only a portion of the population, with a majority of females, migrates to the summer feeding grounds off West Greenland. Females seem to prefer colder waters and move further north than males in warm years.

Several surveys of large whales in West Greenland, south of the Baffin Bay assessment area have been carried out since 1984, the most recent in 2007. Based on

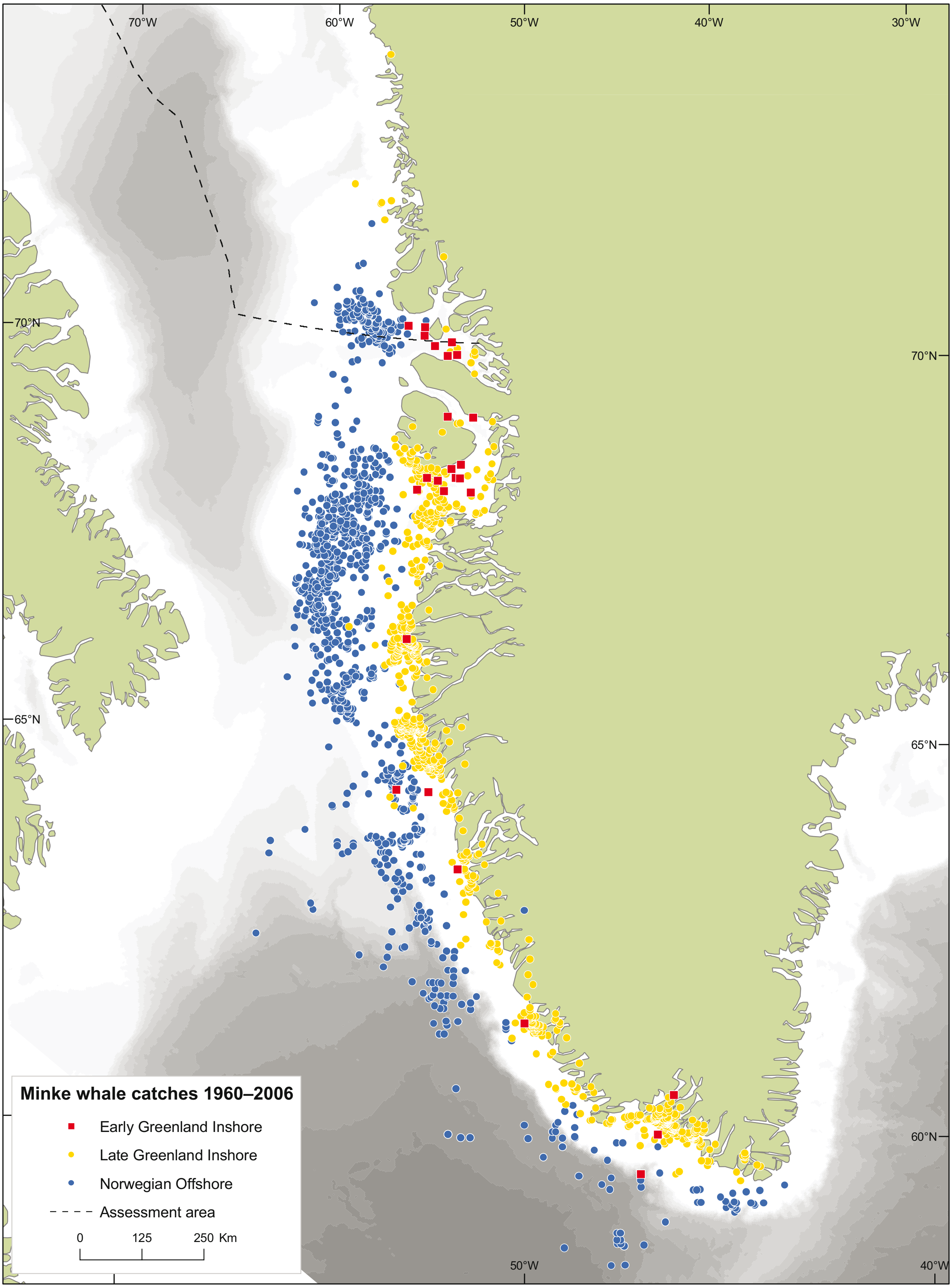


Figure 29. The distribution of minke whales in the assessment area (and West Greenland) shown by the reported catches in the period 1960 to 2006, distributed on three different hunting regimes. Only about 18 % of the minke whales taken by the collective hunt (from small boats) have been reported with accurate positions (Ugarte 2007). Therefore are catches from the assessment area under-represented in this figure.

the fluctuation of abundance estimates from eight different years, Heide-Jørgensen & Laidre (2008) concluded that a varying proportion of North Atlantic minke whales use the West Greenland banks as summer feeding grounds.

From a survey in 2007, the minke whale abundance for West Greenland was estimated to be 16,609 whales (95% CI 7,172-38,461; Heide-Jørgensen *et al.* 2010b). The actual number of minke whales in West Greenland is assumed to be higher because this survey did not cover the northernmost part of West Greenland (i.e. the assessment area), where minke whales also occur.

Sensitivity
Minke whales produce a variety of vocalisations, using frequencies that vary from a few kHz down to 60 Hz (review in Rankin & Barlow 2005). They may be affected by anthropogenic noise with in these frequencies.

See also the introduction to baleen whales on sensitivity to oil activities.

Sei whale *Balaenoptera borealis*

Sei whales are on average 14 m long and weigh 20-25 tonnes. They feed on small fish, krill, squid and copepods. Their distribution is worldwide, from subtropical or tropical waters to high latitudes of the sub-Arctic or sub-Antarctic. It is assumed that most populations move seasonally between high latitudes in summer to tropical waters in winter (IWC 2008).

The distribution of sei whales is poorly understood. They occur in apparently unpredictable patterns and can be seen in an area regularly for several years, after which they may largely disappear. Although they occur in polar areas, sei whales seem to be more restricted to mid-latitude temperate zones than other rorquals (Jefferson *et al.* 2008).

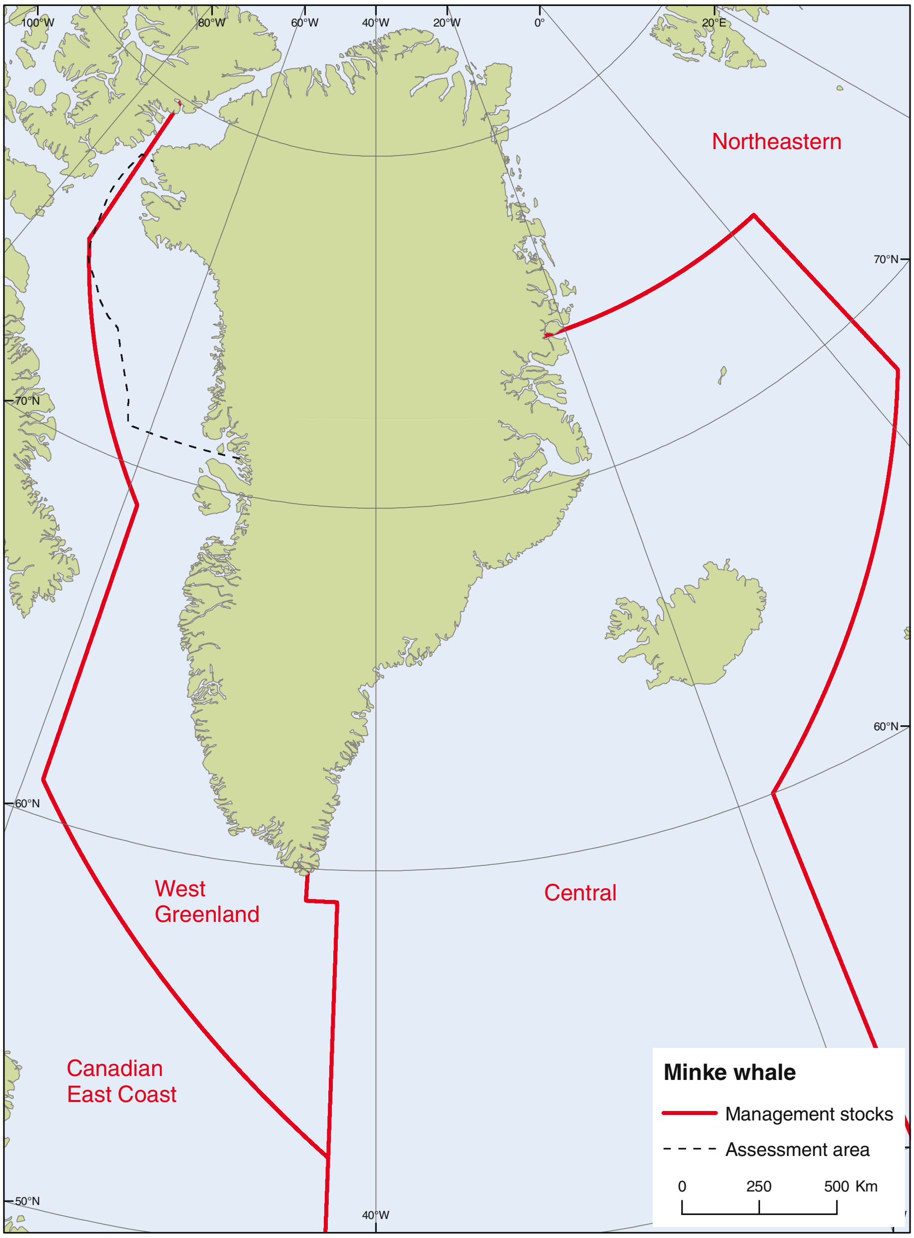
Distribution
Sei whales are probably rare within the assessment area, and have only been recorded in the southern part. According to local hunters, the occurrence of sei whales in Uummannaq Fjord, partly within the assessment area, has increased substantially during recent years.

As in other high latitude areas, the presence of sei whales in West Greenland fluctuates widely, and their occurrence has been linked to influx of relatively warm waters from the Atlantic (Kapel 1979). Sei whales in West Greenland are assumed to belong to a large, oceanic population of the mid-Atlantic that does not have pronounced site fidelity. It is not known to what extent sei whales actually make use of the assessment area.

Conservation
The population occurring in the assessment area probably has an unfavourable conservation status as commercial whaling in the 20th century depleted sei whale populations. After protection in the 1970s and 1980s, this species has been subject to relatively little research and the extent to which stocks have recovered is uncertain. Sei whales are classified as 'Endangered' (EN) in the global Red List (IUCN 2010) and as 'Data Deficient (DD)' in the Greenland Red List.

Surveys of cetaceans in West Greenland have been carried out at regular intervals since 1984. Sei whales were rarely observed in the earlier surveys, but appear relatively abundant in the most recent surveys of 2005 and 2007. Numbers of sei whales off West Greenland, calculated from a ship survey in 2005, were 1,529 (95% CI 660-3,540) (Heide-Jørgensen *et al.* 2007a). This is probably an underes-

Figure 30. The management stocks of minke whale in the North Atlantic. Only one stock occurs within the assessment area.



timation of the actual numbers because the survey did not cover all the potential habitat of sei whales off West Greenland and because animals underwater at the time of the survey, and animals missed by observers were not accounted for.

Sensitivity

See the introduction to baleen whales.

Blue whale *Balaenoptera musculus*

Blue whale is the largest animal in the world, with an average length of 25-26 m and average weight of 100-120 tonnes, females being larger than males.

Blue whales are globally distributed from the equator to polar waters, moving to high latitudes for feeding during summer and to low latitudes for breeding during winter. Their main prey is krill (*Euphausia* spp.).

Blue whales produce distinctive calls with low frequency and high intensity that can be detected over hundreds of kilometres (Širović *et al.* 2007).

Distribution
Due to lack of survey effort, their presence in the assessment area is almost unknown, but they have at least been reported form the southern part. However, in other areas as in the Eastern Atlantic and Antarctica, they are present in offshore waters up to the ice edge.

Winter calving grounds for the blue whales occurring in West Greenland are unknown. There are important known feeding grounds in eastern North America (St. Lawrence Bay, Newfoundland, Labrador) and in the Greenland Sea/Denmark Strait. Blue whales are also present west of Svalbard and in the Norwegian Sea/Barents Sea. Direct observations of blue whales in West Greenland are rare, but unpublished data indicates that blue whales frequently use the Davis Strait area, including the area immediately south of the assessment area.

A blue whale tagged with a satellite transmitter in Disko Bay in April 2009 moved north and entered the southern part of the assessment area during May, while the sea ice coverage was still substantial (GINR unpublished data).

Conservation status
The population occurring in the assessment area has an unfavourable conservation status, because it was heavily exploited by commercial whaling during the first half of the 20th century. The population shows some signs of recovery since global protection was applied in 1966, but population size remains at a very low level (IUCN 2010). There are roughly approximately 1,500 blue whales in the North Atlantic waters. Blue whales are categorised as 'Data Deficient' in the Greenland Red List. In the global Red List, blue whales are classified as 'Endangered' (IUCN 2010).

Sensitivity
Due to their low densities and their ability to communicate acoustically over very long distances, blue whales are probably especially sensitive to acoustic pollution. Blue whales synchronise their call sequences and display very fine pitch discrimination and control over their calling frequency (McDonald *et al.* 2009). The physical characteristic of their synchronous calls might allow blue whales to use the Doppler shift to navigate and to acquire information about the direction to other calling whales (Hoffman *et al.* 2010). Low frequency sounds may effectively mask blue whale calls, thus interfering with their social activities and/or navigation. Indeed, Di Iorio & Clark (2010) documented that blue whales changed their vocal behaviour during a seismic survey. They found that blue whales called more on seismic exploration days than on non-exploration days, and concluded that the observed response represents a compensatory behaviour to the elevated ambient noise from seismic survey operations.

Dunn & Hernandez (2009) acoustically tracked blue whales that were at 42-90 km from operating airguns and, at these relatively large distances were unable to detect changes in the behaviour of the whales.

See the introduction to baleen whales for sensitivity to oil spills.

Fin whale *Balaenoptera physalus*

Fin whales are the second longest animal on the planet next to blue whales, with average lengths in the northern hemisphere of 19-20 m and average weights of 45-75 tonnes. Fin whales are found worldwide from temperate to polar waters but are less common in the tropics.

Fin whales favour prey items such as krill (*Euphausia* spp.) and small schooling fish, such as herring (*Clupea harengus*) and capelin (*Mallotus villosus*). During summer they feed at high latitudes and are believed to migrate south to unknown breeding grounds during the winter. However, satellite tracking (Mikkelsen *et al.* 2008) and catch statistics (Simon *et al.* 2007a) indicate that at least some individuals remain at high latitudes year round. Recently (Simon *et al.* 2010), passive acoustic monitoring in the Davis Strait indicated that fin whales may mate during winter in West Greenland, and that fin whales remain in the Davis Strait until they are apparently excluded from the area by the advance of the sea ice. Fin whales have also been sighted throughout November in Uummannaq in recent years (GINR unpubl. data).

Distribution

Fin whales occur regularly during summer in fjords of the southern part of the assessment area, and may occur further north in offshore areas. However, the offshore waters in Baffin Bay have never been systematically surveyed for cetaceans, and there are no data on the distribution or numbers of fin whales in the assessment area. Local knowledge indicates that fin whale abundance has increased in recent years in coastal areas.

Conservation

Fin whales have an unfavourable conservation status on a global scale, and are categorised as 'Endangered' in the global Red List (IUCN 2010). This listing is based on the population decrease recorded in the southern hemisphere due to whaling. However in the North Atlantic fin whales are abundant and the population here have a favourable conservation status, and the species is listed as of 'Least Concern' (LC) on the Greenland Red List.

Fin whales are genetically similar in widely spread areas in the North Atlantic. Current genetic research (Pampoulie *et al.* 2008) is dealing with two likely scenarios. There could be separated populations that split from a common ancestry in a not too distant past (i.e. after the most recent glaciation), or there could be a single population comprised of individuals that move over very long distances and to different areas.

Satellite tagging data show that fin whales make extensive movements in West Greenland, suggesting that fin whales off West Greenland should be treated as one large management unit, rather than small separate populations or stocks (Heide-Jørgensen *et al.* 2003c).

Catch

In West Greenland, pelagic whalers from Norway and Denmark hunted fin whales from 1922 to 1958 (Kapel & Petersen 1982). The annual average catch was 109 whales, except during the Second World War (1940-45) when no European whalers operated in Greenland (Simon *et al.* 2007a).

Greenlanders started catching fin whales from fishing boats equipped with harpoon cannons in 1948, but as early as 1924 was a steam ship especially designated (by the Danish authorities) to catch large whales in West Greenland. Until the 1970s, this catch took 0-13 fin whales per year. The IWC aboriginal subsistence quotas have regulated fin whale takes in West Greenland since 1977. The quotas have ranged from 6 to 23 whales annually and remained stable at 19 whales from 1995 to 2009. The total quota is seldom used and the average catch is 10 fin whales per year (Kapel & Petersen 1982, Caulfield 1997, Witting 2008). The quota for 2010 was reduced to 10 fin whales per year. This provides however, 100 tonnes of meat, or approximately 30% of the total amount of meat from large whales consumed in Greenland.

Due to the lack of boats equipped with harpoon cannons in the northernmost parts of West Greenland, most fin whales are taken south of the assessment area. However, a few have been caught off Uummannaq, in the southernmost part of the region, by boats travelling from the towns of the Disko Bay area (Simon *et al.* 2007a).

Due to their economic importance, there have been considerable efforts to estimate the numbers and the abundance trends of large whales, including fin whales in West Greenland, south of Disko Island. The estimate from an aerial survey in September 2007 was 4,468 (95% CI 1,343-14,871) fin whales, and the population may be increasing (Heide-Jørgensen *et al.* in press a, Witting 2008). The actual number of fin whales in West Greenland must be larger because the survey did not cover the northernmost parts of the fin whale's range, including the assessment area.

Sensitivity
Fin whales produce distinctive low frequency calls that can be detected over tens of kilometres (Širović *et al.* 2007), and they can be sensitive to anthropogenic noise.

A recent study of the acoustic behaviour of fin whales during seismic surveys in the Mediterranean showed that fin whale vocalisations changed in the presence of air gun events: 20-Hz pulse duration shortened, bandwidth decreased, and center and peak frequencies decreased (Castellote *et al.* 2010). Furthermore, bearings to singing whales 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. The authors concluded that fin whales modify their acoustic behaviour to compensate for increased ambient noise and, under some conditions they will leave an area for an extended period (Castellote *et al.* 2010).

See also the introduction to baleen whales for sensitivity to oil spills.

Humpback whale *Megaptera novaeangliae*

Humpback whales are on average 12-14 m long and weigh 25-30 tonnes. They feed on a variety of small schooling fish and krill. Humpbacks are widely distributed and occur seasonally in all oceans from the Arctic to the Antarctic. Humpbacks migrate between mid- and high-latitude summer feeding grounds and tropical or subtropical winter breeding and calving grounds. Known calving grounds for humpbacks from the North Atlantic are in the Caribbean and at the Cape Verde islands (Wenzel *et al.* 2009 and references therein).

Distribution
Due to lack of survey effort, the distribution patterns and numbers of humpback whales in the assessment area are unknown. For West Greenland south of the assessment area, a series of eight line-transect surveys carried out between 1984 and 2007 was used to estimate a rate of increase of 9.4% per year (Heide-Jørgensen *et al.* in press b). This high rate of increase is consistent with the observed rate of increase at other feeding grounds in the North Atlantic. The abundance estimate for 2007 was 3,272 (95% CI 1,300-8,233). The actual abundance of humpback whales in West Greenland may be larger, since the survey did not cover important humpback whale habitats in the far north (including the assessment area) or offshore areas with depths exceeding 200 m.

It is likely that the range of humpback whales in West Greenland will expand as the population continues to increase. In recent years humpback whales are found more widely distributed in West Greenland and records of observations further north, inside the assessment area, are now frequent, and Uummannaq fjord may become an important feeding ground for humpback whales.

Humpback whales can be individually identified by the pattern on the fluke, which they often raise above the surface at the start of a deep dive. Movement patterns of thousands of humpbacks photographed across the North Atlantic show high levels of site fidelity with occasional long-distance movements between four main feeding aggregations (Figure 31): Gulf of Maine, eastern Canada, West Greenland and the eastern North Atlantic (Stevick *et al.* 2006).

Satellite telemetry suggests that humpback whales use much of the West Greenland waters by remaining relatively stationary at suitable feeding grounds for a period of days and then moving up to hundreds of kilometres to a different location, where they remain stationary again (Heide-Jørgensen & Laidre 2007). This pattern is consistent with an ongoing photo-identification study in a fjord of central West Greenland, where individual humpback whales seem to return year after year, remain in the fjord for several days and then leave (Boye *et al.* 2010).

The main prey items of humpback whales in West Greenland are probably capelin (*Mallotus villosus*), which is abundant in coastal and fjord waters; sand eels (*Ammodytes* sp.), abundant in offshore banks and krill (*Meganyctiphanes* sp.), which can be found both offshore and in the fjords. By moving between known feeding grounds, humpback whales target multiple sites for foraging and are able to exploit several species in a variety of environments during a single feeding season.

Conservation
The population occurring in the assessment area has a favourable conservation status as it is abundant and increasing. Whaling has seriously depleted all humpback whale stocks, and humpback whales received worldwide protection in the 1980s. Most populations have increased substantially since the cessation of commercial whaling and from 2008, Humpback whales were changed from 'Vulnerable' (VU) to 'Least Concern' (LC) in the global Red List (IUCN 2010). Their classification in the Greenland Red List is also 'Least Concern' (LC).

Catch
Until their protection in 1986, humpback whales were an important source of whale meat for the people in West Greenland, who caught on average 14 animals annually, yielding approximately 112 tonnes of whale meat (IWC 1991). In 2008, the Scientific Committee of the IWC advised that a catch of ten humpback whales per year would be sustainable (IWC 2008). On the basis of this advice, a quota of 9 humpback whales per year was installed by the IWC to Greenland for 2010-2012. All the humpbacks in 2010 were caught south of the assessment area.

Vocalization
Humpback whales are well known for the long and complex songs produced by males in the breeding grounds (recent review of humpback whale song in Parsons *et al.* 2008). Most knowledge about the sound produced by humpback whales in their feeding grounds comes from a few studies in the north pacific (D'vincent *et al.* 1985, Thompson *et al.* 1986) and the gulf of Maine (Stimpert *et al.* 2007), where cooperative feeding calls, as well as click-like sounds have been described. In West Greenland, humpback whales seem to be mostly silent during summer (Simon 2010). Humpback whale sounds are low to mid-frequency, usually 30 Hz to 8 kHz, although up to 24 kHz may be reached (Figure 27). Peak frequencies tend to be around 315 Hz and 630 Hz (Parsons *et al.* 2008).

Oil spill and noise vulnerability
See the introduction to baleen whales.

Figure 31. Feeding aggregations of humpback whales in the North Atlantic: Gulf of Maine, Eastern Canada, West Greenland and Eastern North Atlantic.

4.8.4 Toothed whales

F. Ugarte, L.M. Rasmussen and M.P. Heide-Jørgensen

Two species of toothed whales, the narwhal and the white whale or beluga, are specialised inhabitants of the Arctic and can seasonally be found in large numbers in the assessment area.

Five other species of toothed whales that are common in the northern North Atlantic are also regularly present in the assessment area; killer whale (*Orcinus orca*), sperm whale (*Physeter macrocephalus*), pilot whale (*Globicephala melas*), white-beaked dolphin (*Lagenorhynchus albirostris*) and bottlenose whale (*Hyperoodon ampullatus*). Harbour porpoise (*Phocaena phocaena) also occur, but as a rare visitor and will not be dealt with further. These* species are also found in boreal waters and sperm whale and killer whales occur in all oceans. All avoid densely ice-covered waters, so their use of the assessment area is restricted to the ice-free months. With the expected reduction of sea-ice cover due to climate change, their occurrence in the assessment area may however be extended.

Toothed whale sensitivity to acoustic pollution

Toothed whales produce clicks for echolocation[2] and communication. In addition, killer whales produce pulsed calls made of clicks in very rapid succession. Narwhals, white whales, white-beaked dolphins, pilot whales and killer whales produce whistle-like sounds. Pulsed calls serve several purposes, including long-range communication and transmission of information about kinship and group

[2] Echolocation is the ability of finding (i.e. locating) objects by listening to the reflections (echoes) of echolocation clicks.

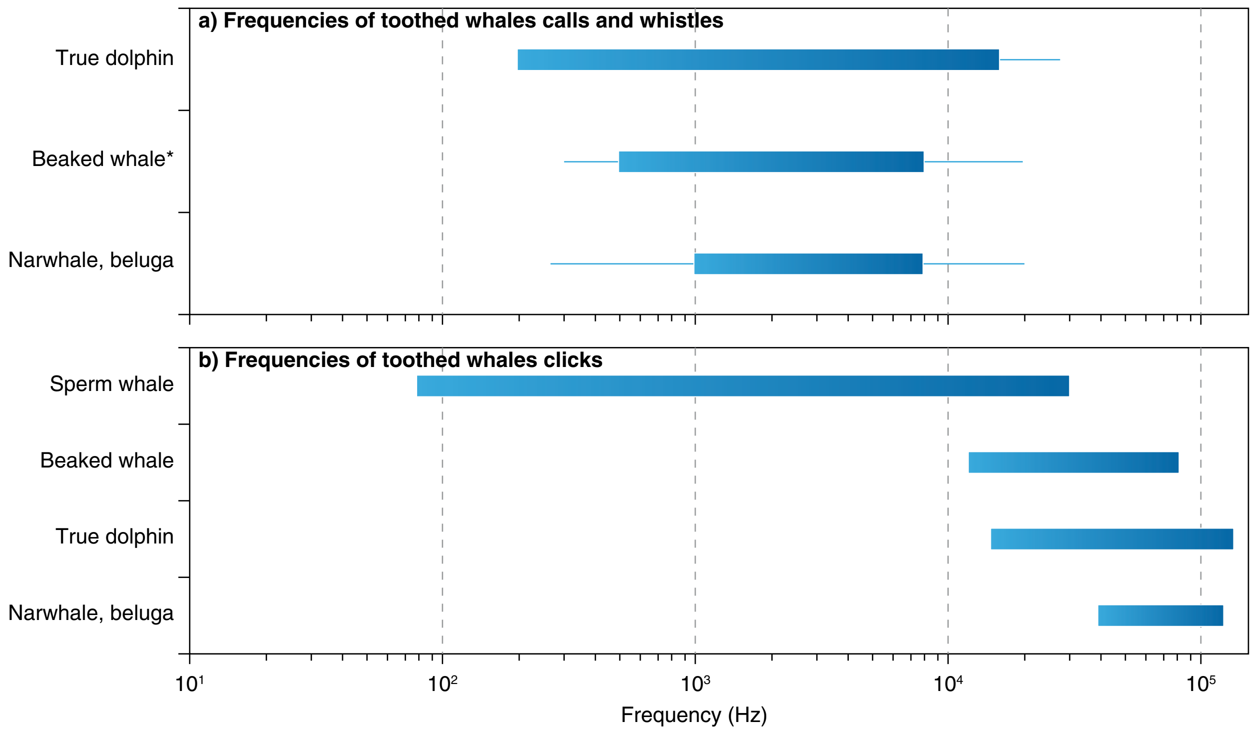


Figure 32. Known frequency ranges of pulsed calls and whistles (**a**) and echolocation clicks (**b**) made by toothed whales in the Baffin Bay assessment area. True dolphins (family Delphininae) include killer whale, pilot whale and white beaked dolphin. Beaked whales (family Ziiphidae) include bottlenose whale. Figure modified from Mellinger *et al.* (2007).

cohesion. Whistles are important during short-range social contacts and may include information about the identity of the whistler. Figure 32 shows the frequency ranges of echolocation clicks, calls and whistles produced by toothed whales in the assessment area.

Masking by anthropogenic sounds, including noise from ships, oil exploration and development, can reduce the active space of sounds produced by toothed whales. Whales can also be displaced from noisy areas, and extremely loud sounds may physically damage their hearing organs (review in Nowacek *et al.* 2007). In addition, there may be indirect effects of underwater noise associated with altered prey availability (Gordon *et al.* 2003).

Toothed whale sensitivity to oil spills

The effect of oil spills on killer whales has been well described by Matkin *et al.* (2008). They monitored the demographics and group composition of killer whales from Prince Williams Sound 5 years prior to and 16 years after the 1989 *Exxon Valdez* oil spill. Two killer whale groups in the proximity of the spill did not avoid the oil; they suffered losses of up to 41 % in the year following the spill and 16 years later and had not recovered at all or had recovered at rates lower than those for groups not affected by the oil.

Smultea & Würsig (1995) tracked dolphins swimming toward oil slicks and concluded that the animals detected the oil but did not avoid travelling through it.

Long-finned pilot whale *Globicephala melas*

Distribution

The long-finned pilot whale occurs in temperate and sub-polar zones and, according to most literature ranges from Disko Bay and Ungava Bay in the north west, from 68° N in eastern Greenland across Iceland and the Faroe Islands to mid-

Norway, and south to North Carolina, the Azores, Madeira and Mauritania (e.g. Jefferson *et al.* 2008). Greenlandic catch statistics (Ministry of Fishery, Hunting and Agriculture APNN, unpublished data) show, however, that pilot whales occasionally occur as far north as Uummannaq and Upernavik in the southern part of the assessment area and in late summer or early autumn.

Biology
Long-finned pilot whales are social and generally found in groups of 20-100 individuals, where they frequently associate with other marine mammals. In the western North Atlantic they concentrate in areas over the continental slope in winter and spring, and move over the shelf in summer and autumn (Jefferson *et al.* 2008).

Diet consists primarily of squid, but also small to medium-sized fishes are taken, such as cod and herring.

Catch
Pilot whales are caught opportunistically in West Greenland. Annual catches in West Greenland vary between 0 and 300, where most animals are caught south of Disko Bay. Their occurrence is probably correlated with the influx of relatively warm Atlantic water (Heide-Jørgensen & Bunch 1991).

Population
Pilot whales occurring in the assessment area (and the rest of Greenland) probably represent vagrants from a single large North Atlantic population. Abundance of pilot whales on the banks of West Greenland was estimated in 2007 to be 7,440 (95 % CI 3,014-18,376) (Hansen 2010b). The surveys only covered part of the range of pilot whales in West Greenland and it must be considered a minimum estimate.

Conservation
Long-finned pilot whale is listed as of 'Least Concern' according to both the global Red List (IUCN 2010) and the Greenland Red List.

Sensitivity
Pilot whales are probably as sensitive as other toothed whales to noise, disturbance, and oil spills, cf. also the introduction to toothed whales.

White-beaked dolphin *Lagenorhynchus albirostris*

White-beaked dolphins inhabit the North Atlantic Ocean in the cold temperate zone and the southern part of the Arctic. According to several published sources, Disko Bay is the northern limit of their distribution in West Greenland (e.g. Reeves *et al.* 1999, Kinze 2008). However, unpublished and unverified catch statistics may indicate that white-beaked dolphins occur as far north as Upernavik, well into the assessment area.

White beaked dolphins primary habitat is waters less than 200 m deep, especially along the edges of continental shelves.

The species has been very little studied why little is known about its biology and ecology. The diet of white-beaked dolphins in West Greenland is unknown. In other areas, they feed mainly on a variety of small schooling fishes such as herring, capelin, sand eel and cod, but may also eat squid and crustaceans (Jefferson *et al.* 2008).

White-beaked dolphins are most often found in groups of 5-10, but are commonly found in larger groups and occasionally in their hundreds (Rasmussen 1999). When feeding, the dolphins often associate with other species of whales.

Catch

White-beaked dolphin is not a target of commercial fisheries, but occasionally drowns as by-catch in fishing gear. The rate of by-catch is however low, compared to other dolphin and porpoise species, and incidental catches are not thought to be high enough to represent a serious threat for white-beaked dolphins (IUCN 2010).

In Greenland, white-beaked dolphins are caught for subsistence. There are no catch statistics for this species previous to October 2005. For the Baffin Bay assessment area, catches of white-beaked dolphins were at least reported from September 2007 (six dolphins in two locations).

Abundance of white-beaked dolphins on the banks of West Greenland was estimated in 2007 to be 11,801 (95% CI 7,562-18,416) (Hansen 2010b). The surveys only covered part of the range of white-beaked dolphins in West Greenland and it must be considered a minimum estimate.

Conservation

The global status of the white-beaked dolphin is 'Least concern' (IUCN 2010). On the Greenland Red List, the white-beaked dolphin is listed as 'Data Deficient'.

Sensitivity

See the introduction to toothed whales.

Killer whale *Orcinus orca*

Killer whales are top predators that occur in all oceans, but tend to concentrate in colder regions with high productivity. They feed on prey that varies in size from herring to adult blue whales. Different killer whale populations tend to specialise and feed on locally abundant prey species. Across populations the movements and behaviour of the prey influence killer whale behaviour, movements and social organisation. As a result of these specialisations, there are different ecotypes of killer whales. Examples of such ecotypes include killer whales that feed seasonally on sea lion and elephant seal pups in Patagonia (Lopez & Lopez 1985), herring in Norway and Iceland (Simon *et al.* 2007b), sharks in New Zealand (Visser 2005) and tuna fish in the Gibraltar Strait (Guinet *et al.* 2007). In some cases, up to three different ecotypes are known to overlap in one area, such as in the northeastern Pacific where the ecotypes called 'residents', 'transients' and 'offshores' feed on salmon, marine mammals and sharks, respectively (Ford & Ellis 2006, Baird & Dill 1995, Herman *et al.* 2005). In Antarctica, three ecotypes are feeding on tooth-fish, seals or large whales, respectively (Pitman & Ensor 2003). Sympatric ecotypes (i.e. with overlapping ranges) seldom interact and do not interbreed.

Killer whales are typically found in groups of 3-30 animals, but group size may vary from one to more than 100 animals. Large groups are temporary associations of smaller, more stable groups with long-term associations and limited dispersal (review in Baird 2000).

Killer whale populations tend to be small, often numbering in the hundreds, rather than thousands (e.g. Bigg *et al.* 1990, Similä & Ugarte 1997, Ford & Ellis 2002, Visser 2001). Based on genetic analyses of killer whales from several locations in the North Pacific, Hoelzel *et al.* (2007) suggested that killer whale populations in the

North Pacific had small effective sizes and that there was ongoing low-level genetic exchange between populations.

Killer whales produce calls and whistle-like sounds for communication and clicks for echolocation (Simon *et al.* 2007a). Calls serve several purposes and group-specific call repertoires play a fundamental role in the social organisation and mating system of killer whales (Barrett-Lennard 2000). Whistles are important during short-range social contact (Thomsen *et al.* 2002).

Distribution

Killer whales are not common in the assessment area but are occasionally observed or caught by hunters.

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. Observations occurred in all areas of West Greenland, and sightings were most frequent in Qaanaaq, Disko, Nuuk and Qaqortoq.

Norwegian small-type whalers caught 13 killer whales at four locations in Southwest Greenland from 1968 to 1972 (Øien 1988). Norwegian catches of killer whales in Greenland stopped when the market for meat from toothed whales for pets and fur animals was much reduced (Jonsgård 1977 in Øien 1988).

Large groups of killer whales were observed in Disko Bay in the winter 2001, when over 30 animals were taken by hunters within a few days, offshore west of Uummannaq in 2005 and in Upernavik in 2008.

Catch

Killer whales are hunted in Greenland, partly for human subsistence and partly to feed dogs, but also because they are considered as a pest (i.e. as competitors to seal and whale hunters). Since 1996, when the current reporting system was established, killer whales have been taken three times in the assessment area. A large group of 20-40 killer whales was hunted in Upernavik in September 2008. Six whales were landed.

Conservation

Killer whales are listed as 'Data Deficient' (DD) on the global IUCN Red List (IUCN 2010) and as 'Data Deficient' (DD) on the Greenland Red List (Boertmann 2007).

Sensitivity

A recent study indicates that killer whales are more sensitive to oil spills than hitherto believed for toothed whales (Matkin *et al.* 2008), see the introduction to toothed whales.

White whale (beluga) *Delphinapterus leucas*

The white whale is a medium-sized toothed whale up to 5 m long and up to 1,500 kg in weight. The closest relative is the narwhal. Nursing times of two years have been observed. Their main prey is polar cod and other fish but also squid and shrimps (Heide-Jørgensen & Teilmann 1994). White whales usually travel in groups of two to ten whales, although larger pods often occur.

Distribution

White whales migrate through the assessment area, where they occur in October-November and again in April-June. They may also occur in winter as one population spends the winter in the North Water and as the central West Greenland wintering grounds occasionally range as far north as the southern assessment area (Figure 33, 34). In recent years they seem to winter and migrate further out from the coast than previously, probably due to the reduced amounts of sea ice (Heide-Jørgensen *et al.* 2010a).

The summer grounds of white whales are in the Canadian Arctic archipelago, where they often occur in extensive estuaries.

Movements

The migration has been documented by two white whales equipped with satellite transmitters in Canada and tracked to the winter quarters south of Disko Bay (Heide-Jørgensen *et al.* 2003b). Generally the knowledge on the migrations of white whales in West Greenland is limited compared to that on narwhal migrations.

White whales are expected to acquire the major part of their annual food intake in their winter quarters in West Greenland and in the North Water.

Abundance

Aerial surveys flown in West Greenland between 1981 and 1994 found that white whale numbers decreased by 62 % during that period, because of overharvesting (Heide-Jørgensen & Reeves 1996).

Further surveys in 1998 and 1999 confirmed the decline and found 7,941 (95 % CI: 3650-17,278) white whales in West Greenland, including whales missed by the observers and whales that were submerged during the survey (Heide-Jørgensen & Acquarone 2002).

In 2006, the total abundance of white whales in West Greenland was estimated to be 10,595 (95 % CI 4,904-24,650) again corrected for missed and submerged animals. The greatest abundance of white whales in 2006 was found in the areas south of Disko Bay at the northern portion of Store Hellefiskebanke, a pattern similar to that found in surveys of white whales conducted since 1981. The whales were mainly observed at the eastern edge of the pack ice that covers Baffin Bay and Davis Strait. The survey from 2006 suggested that the population is increasing after a period with severely reduced catches (Heide-Jørgensen *et al.* 2010a).

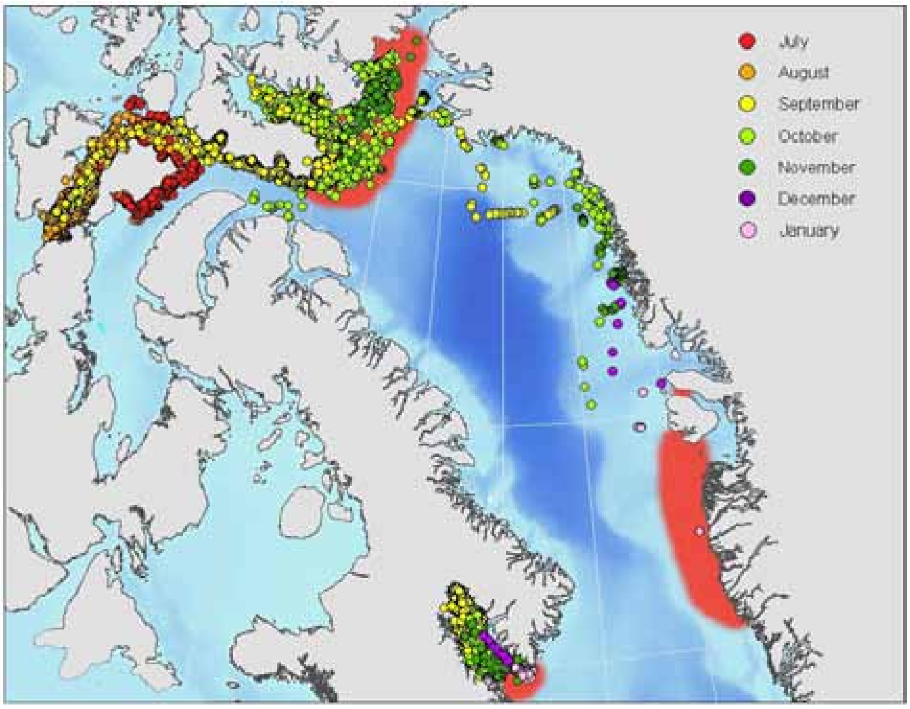
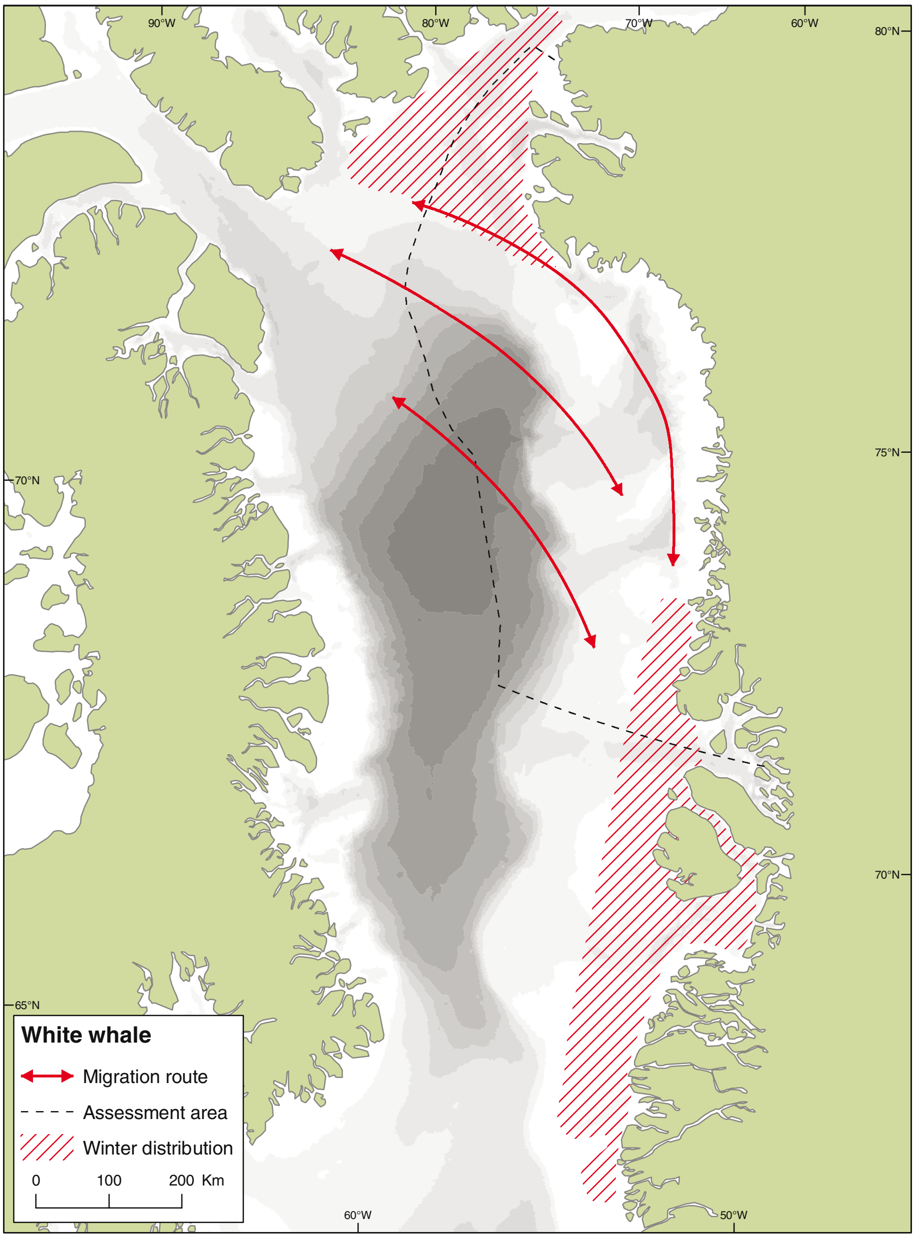


Figure 33. Positions of satellite-tracked white whales distributed according to month. Red areas indicate winter quarters (GINR unpublished).

Figure 34. White whale winter grounds and migration routes.



Catch and population trends

Commercial harvesting of white whale in West Greenland and Baffin Bay began in the late-1800s (NAMMCO 2008). After a period with large catches in Nuuk (from 1906-22) and in Maniitsoq (1915-29), white whale disappeared from the area south of 66° N (Heide-Jørgensen & Acquarone 2002). Between 1927 and 1951, large catches were reported in the southern part of the former municipality of Upernavik, and since 1970 in the northern part. In the early 1990s catches in this area were about 700 whales per year. In the period 1993-2003 the annual total catch in West Greenland was on average 550 whales.

As the number of white whale wintering off West Greenland has declined since 1981, the Canada/Greenland 'Joint Commission on Conservation and Management of Narwhal and Beluga' (JCNB) concluded that the West Greenland stock was substantially depleted and advised that delay in reducing the catch to approximately 100 animals per year would result in further population decline and further delay the recovery of this stock (NAMMCO 2001). In 2004, a quota of 320 white whales per year was established for West Greenland. This quota has been gradually reduced and in the 2007/2008 season it was 160. In accordance with the new biological advice from JCNB, the quota increased to 310 in 2009.

Conservation status
The population occurring in the assessment area has an unfavourable conservation status, because it has declined due to excessive catch. It is therefore listed as 'Critical Endangered' (CR) on the Greenland Red List. In Canada it is listed as 'Threatened/Special Concern' depending on the stocks. In the Global Red List, the white whale was moved from 'Vulnerable' (VU) to 'Near Threatened' (NT) in 2008 (IUCN 2010), although with the notification that the white whale is 'unquestionably a conservation dependent species'.

Critical and important habitats
As white whales mainly are transient in the assessment area, no specific important or critical areas are known. The migration corridor is a critical habitat, but no particularly important summering or wintering areas are known in the assessment area, other than the NOW polynya. There are, however, traditional hunting grounds especially in Qaanaaq, at Savissivik, along Upernavik and in Disko Bay.

Sensitivity
White whales are generally believed to be sensitive to noise from seismic surveys and drilling (Lawson 2005). In Arctic Canada white whales avoided seismic operations by 10-20 km (Lee *et al.* 2005). See also the introduction to toothed whales.

Narwhal *Monodon monoceros*

Narwhals have high site fidelity to migration routes and summering and wintering grounds, and generally use the same areas year after year (Heide-Jørgensen *et al.* 2003a). In summer months, narwhals visit inshore bays and fjords in the Canadian Arctic archipelago and Greenland (Figure 36). In the autumn, upon the formation of fast ice, narwhals are forced to move east and south out of these regions and spend the winter in areas covered by dense offshore pack ice (Dietz & Heide-Jørgensen 1995, Dietz *et al.* 2001, Heide-Jørgensen *et al.* 2002, Heide-Jørgensen *et al.* 2003a, Dietz *et al.* 2008). During winter months, narwhals are widely dispersed in Baffin Bay and Davis Strait with high concentrations between 55°-64° W and 68°-71° N and off Disko Bay (Koski & Davis 1994, Heide-Jørgensen *et al.* 1993, Dietz *et al.* 2001, Heide-Jørgensen & Acquarone 2002, Dietz *et al.* 2008, Laidre & Heide-Jørgensen 2011). During spring, concentrations of narwhals are seen along ice edges on the east coast of Baffin Island, at the entrances of Lancaster and Jones Sound, and in Smith Sound (e.g. Bradstreet 1982, Koski & Davis 1994). Narwhals are also known to move along the ice edges off West Greenland and to concentrate in the North Water Polynya in spring before entering Inglefield Bredning (Born *et al.* 1994b, Heide-Jørgensen 2004, GINR unpubl. data).

Current distribution of narwhals
Figure 35 shows the global distributing range of the narwhals. In Greenland, Narwhals occur at two summer concentration sites in the Baffin Bay assessment area; Melville Bay and Inglefield Bredning. Both are visited by significant numbers of narwhals from June through October.

Narwhals are regularly seen and caught along the coasts of the assessment area from October through May. Aerial surveys conducted in 1981 and 1982 demonstrated that narwhals are widespread in the offshore in the pack-ice in central Baffin Bay in winter, and an important winter (late November through March) concentration area 'the Northern Wintering Ground' is located in the southern part of the assessment area (Figure 36).

Stock identity

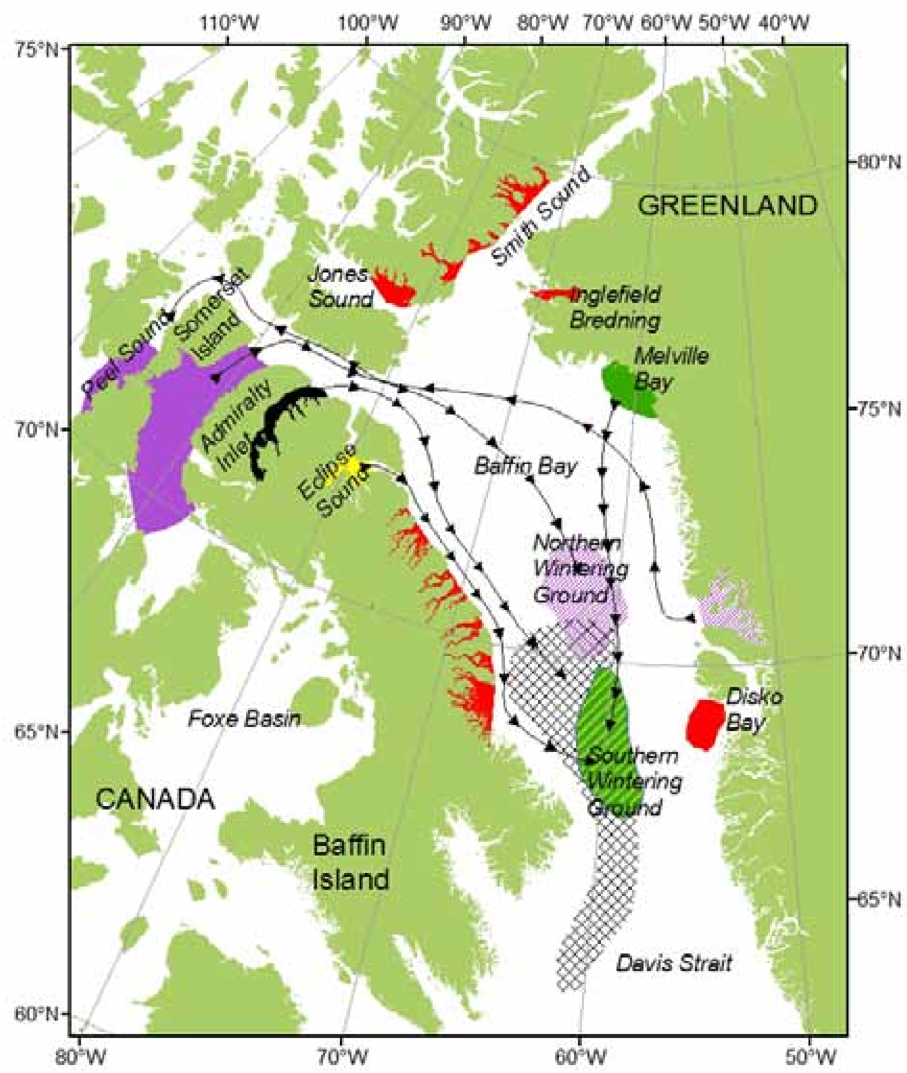
Figure 35. Overall distribution of narwhals, with indication of important summer grounds. The assessment area is indicated with hatched line.

Narwhals stocks or management units of narwhals are traditionally identified based on the summer aggregations (Dietz & Heide-Jørgensen 1995, Dietz *et al.* 2001, Heide-Jørgensen *et al.* 2002, Heide-Jørgensen *et al.* 2003a, Dietz *et al.* 2008).

Judging from the satellite tracking data, the three summer stocks in the Canadian high Arctic: Eclipse Sound (including Pond Inlet and Navy Board Inlet with adjacent fjords), Admiralty Inlet and Somerset Island (including Prince Regent Inlet and Peel Sound) have limited exchange during summer (Figure 36). Other Canadian summer aggregations exist along the east coast of Baffin Island and their stock identity is unknown (Figure 36). Jones Sound and Smith Sound also have smaller aggregations that likely constitute stocks.

In November an aggregation occur in Uummannaq, West Greenland. This is not a wintering ground because the whales are forced to leave the fjord in late December to winter offshore once the fast ice forms. These narwhals essentially winter in the eastern part of Baffin Bay in the same general area where whales from other stocks are found. Two whales tagged in Uummannaq in November departed at

Figure 36. Population units of narwhals in West Greenland and the Eastern Canadian Arctic with migration routes and main wintering grounds indicated. Red areas inshore Canada and NW Greenland indicate areas where important summer concentrations occur, but their relationships to other concentration areas are not known. The red area at Disko Bay in Greenland indicates an important winter concentration area, where the stock identities of the whales have not been established.



the same time and took a similar route north into the Baffin Bay assessment area (Figure 37); a more detailed account is presented below.

The winter aggregation in Disko Bay has been visited by whales from both Melville Bay, Tremblay Sound and Admiralty Inlet (Figures 38 and 40, Richard *et al.* unpubl. data), many of which pass through the Baffin Bay assessment area in autumn and again in spring. Apparently Disko Bay is a mixing ground for narwhals from several summering stocks.

Current abundance in West Greenland

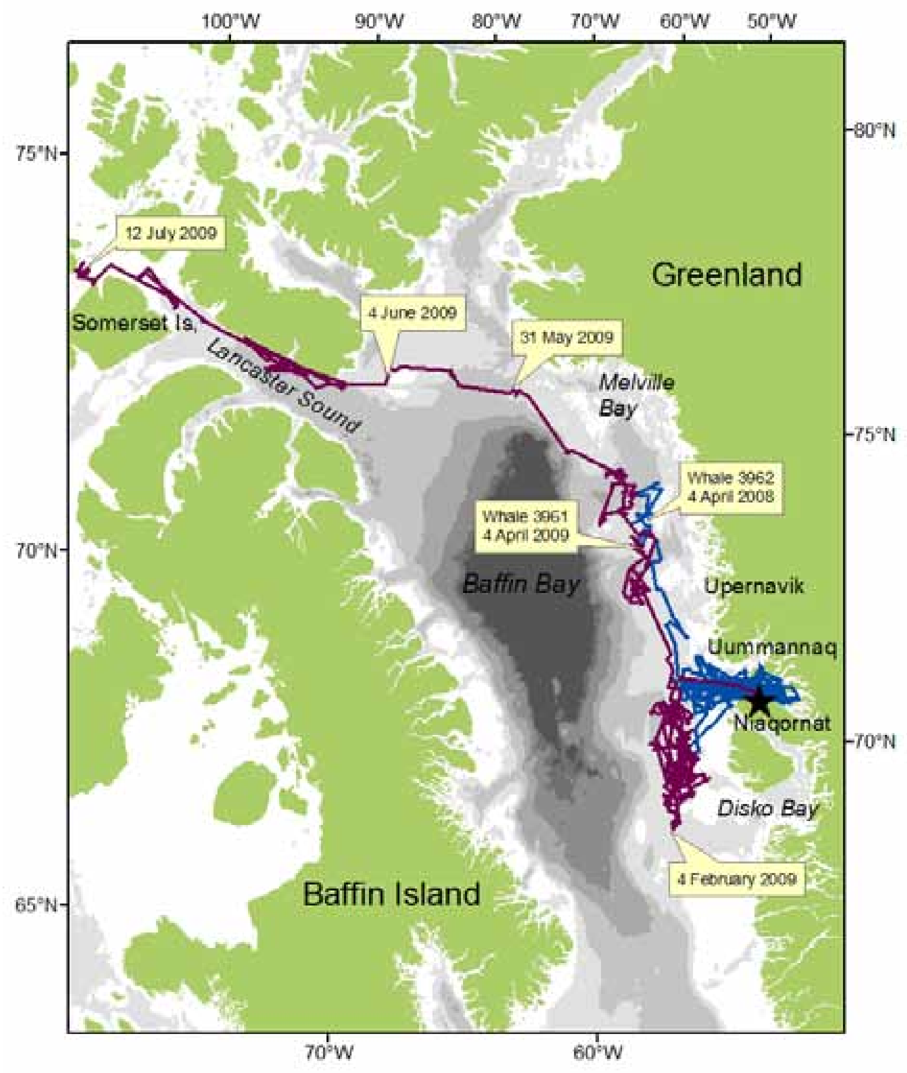
Abundance of narwhals off West Greenland was assessed from an aerial survey conducted in March and April 2006. The surveyed area included the region between Sisimiut and Upernavik and up to approximately 100 km offshore and the resulting abundance estimate was 7,819 (95% CI: 4,358-14,029) narwhals for the surveyed area (Heide-Jørgensen *et al.* 2010c).

Abundance of narwhals at the summering grounds in Inglefield Bredning and Melville Bay was estimated in 2007 and were 8,368 (95% CI 5,209-13,442) and 6,024 (95% CI 1,403-25,860) respectively.

Migrations

Narwhals leave their summering grounds at about the same time each year and they follow similar routes during their autumn migration. Narwhals also use the same gen-

Figure 37. Tracks of two narwhals tagged in Uummannaq in 2007 and 2008.

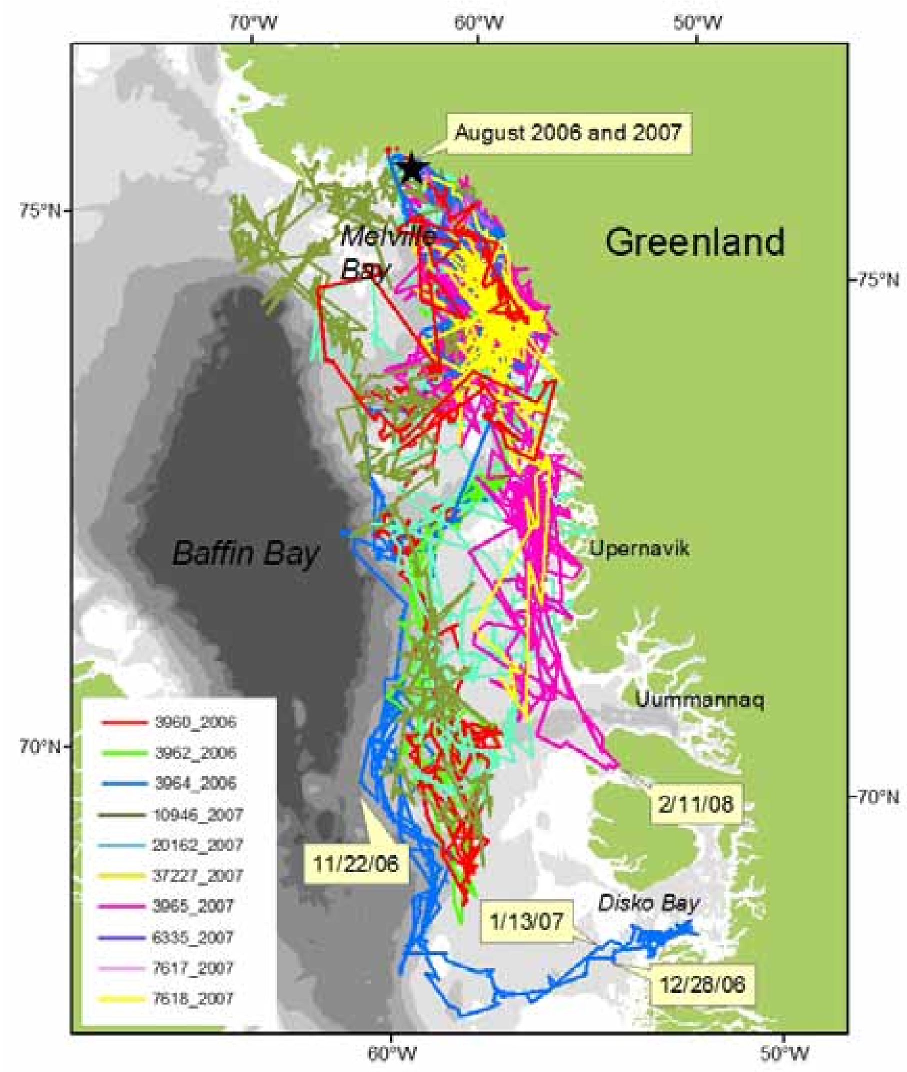


eral areas for wintering and they are somewhat stationary on their wintering grounds from late November through March. Whales from different stocks have similar timing for abandoning their wintering grounds and initiation of the spring migration.

Data on migrations are available from satellite tracking of 85 individual narwhals from five different coastal localities in Arctic Canada (n=3) and West Greenland (n=2). Published results from tagging before 2005 are summarized in Figure 39, whereas recent tracking results from 2005-2008 are presented in the Figures 37, 38 and 40.

- **Eclipse Sound.** Tagging data from Eclipse Sound in 1997-1999 demonstrated how narwhals from Eclipse Sound departed on their autumn migration and moved east through Pond Inlet and south along the east coast of Baffin Island and visited some of the fjords. In November, they arrived on the wintering grounds in central Davis Strait which were in the same general vicinity as the wintering grounds of narwhals from Melville Bay. This 'Southern Wintering Ground' is centered on 69° N and 60° W. In 2010 one male narwhal from Eclipse Sound entered the southern part of Disko Bay in December.
- **Somerset Island.** In September and October narwhals from Peel Sound and Prince Regent Inlet moved east along the southern and the northern coast of Lancaster Sound. The whales moved toward West Greenland across or on the northern side of the deep basin in Baffin Bay and continued south to the 'Northern Wintering Ground' centered on 71° N and 62° W, a wintering area distinct

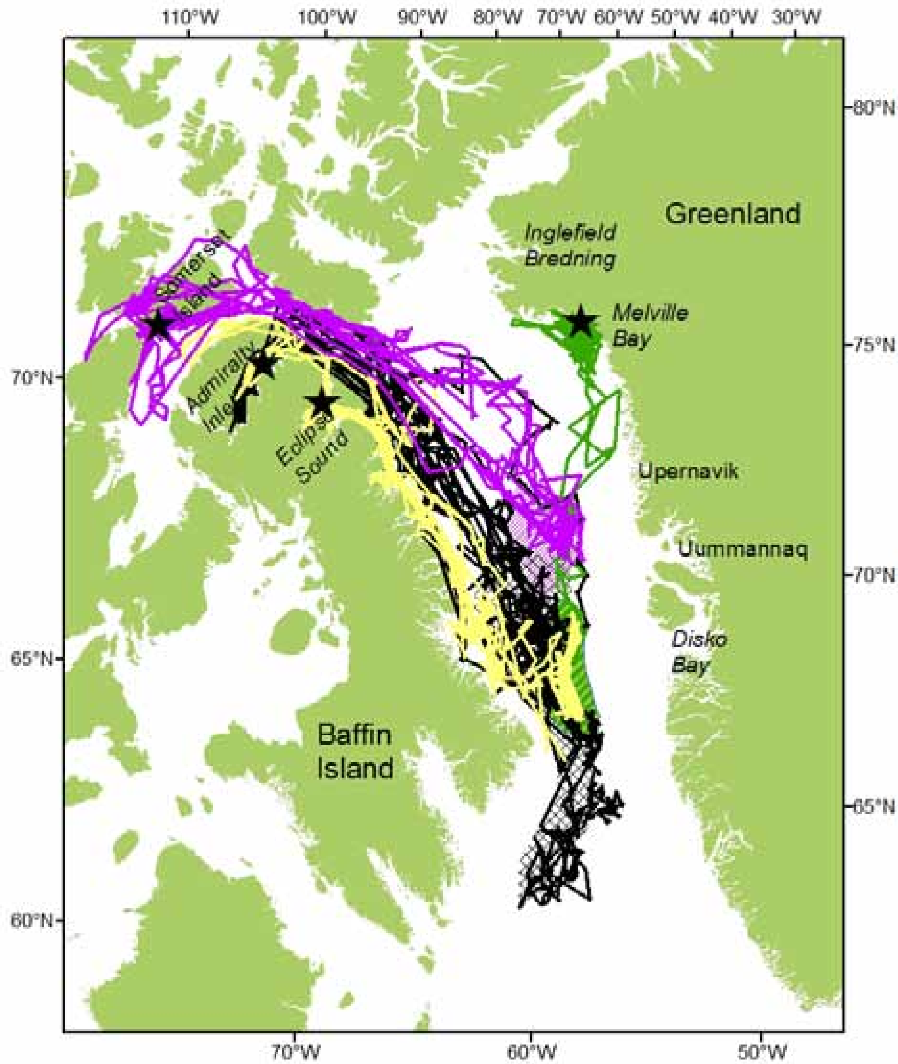
Figure 38. Tracks of narwhals tagged in Melville Bay in 2006 and 2007.



from the wintering area used by whales from the Eclipse Sound and Melville Bay stocks and within the Baffin Bay assessment area. The Somerset Island whales remained stationary on the 'Northern Wintering Ground' through March when they started the return migration through Lancaster Sound along the southern shoreline of Devon to the Somerset Island summering ground (Heide-Jørgensen *et al.* 2003a, Dietz *et al.* 2008).

- **Admiralty Inlet.** When leaving Admiralty Inlet the narwhals moved south along the east coast of Baffin Island and spread out in the western part of Baffin Bay, ranging widely from Cumberland Sound to north of Home Bay. The range of the wintering ground varied between 2004 and 2005 (Dietz *et al.* 2008). A total of 13 narwhals were tagged in Admiralty Inlet in 2005. All whales left Lancaster Sound in September-October for a southbound migration either along the east coast of Baffin Island or somewhat east of Baffin Island at the edge of the continental shelf (Figure 40). Some of the whales extended their southbound migration to the northern part of Davis Strait where they have also been located to winter in 2004 and 2005. One male from Admiralty Inlet moved to the coastal areas of West Greenland in January 2006 close to Disko Island and Uummannaq (Figure 40).
- **Melville Bay.** Narwhals tracked from Melville Bay during the autumn of 1993-94 (n=2) took an offshore southward migration route along the 1000 m depth contour. They did not visit any other coastal aggregations of narwhals on the West Greenland coast. They reached central Davis Strait in mid-November and presumably spent the winter in this region. Narwhals tracked from Melville Bay in 2006 and 2007 (n=7) followed a similar migration pattern as those tracked in

Figure 39. Tracks of narwhal from Canada and Greenland tagged before 2005. Asterisks indicate tagging sites. Each whale indicated by a colour.



1993-1994; after spending September and beginning of October with movements inside Melville Bay, they made a southbound migration route towards the wintering grounds. In 2006 the whales took a more coastal route after departing from Melville Bay (south of 74° N) on 18-25 October (Figure 38). Wintering took place in the same area used by the whales from Melville Bay tracked in 1993-1994 (cf. Dietz & Heide-Jørgensen 1995). After arriving at the offshore wintering ground in December, one of the whales (a male of 437 cm) left the offshore wintering ground and went to the southern part of Disko Bay. The whale left Disko Bay on 13 January and returned to the offshore wintering ground. In 2007, a more diverse movement pattern was observed, both in the summer period when the whales were more widespread in Melville Bay and in the fall where some whales remained close to Upernavik (Figure 38). In 2007, the whales departed from Melville Bay between 26 October and 16 December and spent considerable time in the Upernavik and Uummannaq area before wintering a bit further north than the traditional 'southern wintering ground' used in previous years (Dietz & Heide-Jørgensen 1995, Heide-Jørgensen & Dietz 1995). One whale was tracked for 13 months and it returned to Melville Bay the year after it was tagged.

- **Uummannaq.** Two narwhals were tagged in Uummannaq (south of the assessment area) in November 2007 and 2008. The male tagged in 2007 spent the entire winter inside Uummannaq Fjord or just outside the Uummannaq area after freeze-up (Figure 37). On 13 March 2008 it headed north (< 72° N) along the West Greenland coast however contact was lost on 4 April 2008. The female narwhal tagged in 2008 immediately left Uummannaq Fjord and spent December through mid-February 2009 off the banks of Disko Island. On 24

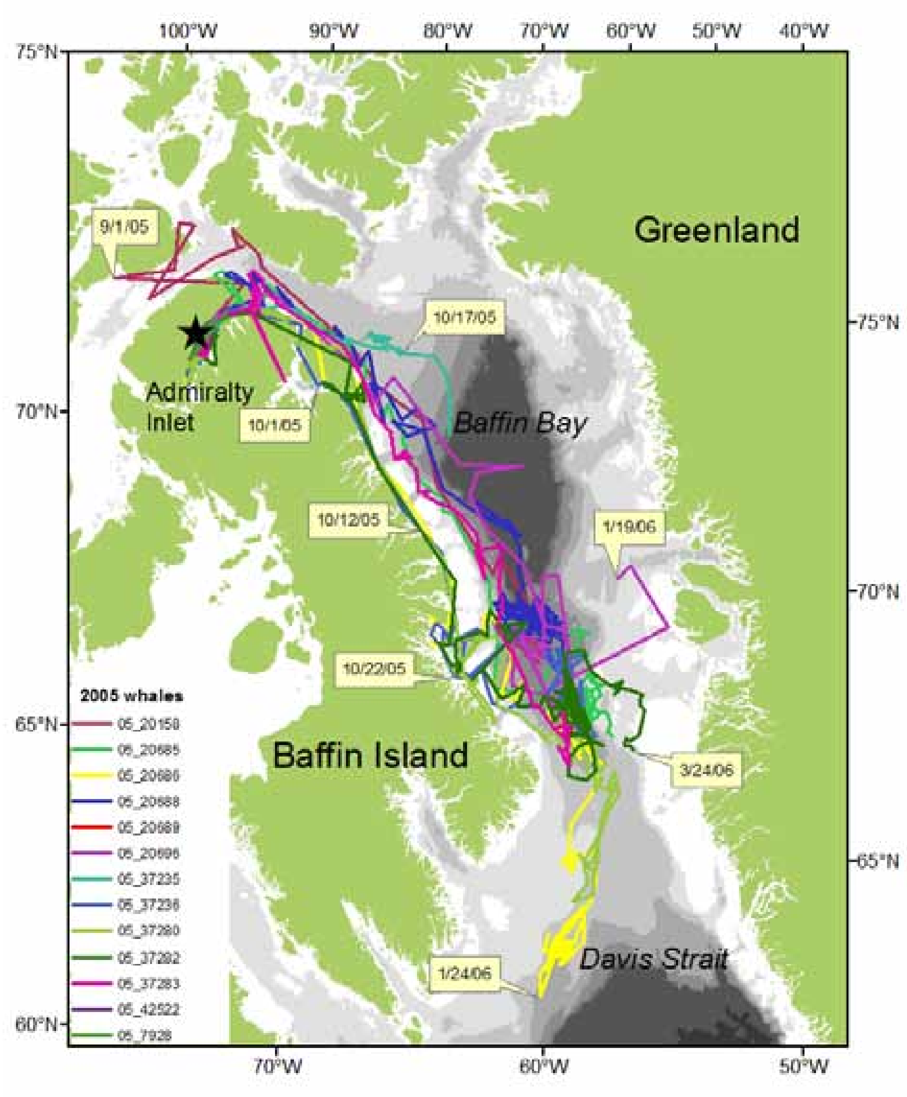
March it initiated a northward migration along West Greenland and into the assessment area. It halted the migration in the northern part of Baffin Bay in April and May and continued the migration in late May where it reached the eastern entrance of Lancaster Sound on 6 June where after it followed the northern coast of the sound close to the southern shore of Devon Island and reached Barrow Strait on 3rd July. The whale moved south into Peel Sound where contact was lost on 24 July.

Diving and foraging ecology

Feeding habits of narwhals have been studied in Disko Bay where fresh stomach samples from narwhals can be obtained from the Greenlanders subsistence harvest. Greenland halibut (*Reinhardtius hippoglossoides*), the squid *Gonatus fabricii*, and *Pandalus* shrimp spp. are the dominant prey items. Greenland halibut is an important winter resource, observed in 64% of stomachs collected in winter and the only prey species detected in almost half of all stomachs in the 49 samples (Laidre & Heide-Jørgensen 2005b). Greenland halibut taken by narwhals were on average 36 cm (SD 9) and 430 g (SD 275) and *Gonatus* prey were on average 35.6 g (SD 31.1) with mean mantle lengths (mm) of 95.1 (SD 36.2).

There is no direct information on the prey selection on the offshore winter feeding grounds in Baffin Bay, but observations of the diving behaviour suggest that the narwhals target depth (> 1000 m) where halibuts are known to be abundant. The availability of this important prey is the most likely explanation for the occurrence of narwhals in these ice covered offshore areas (Laidre *et al.* 2003). Other species

Figure 40. Tracks narwhals tagged in Admiralty Inlet in 2005.



like polar cod and squids may also contribute to the offshore diet as they seasonally do in inshore waters in both Canada and West Greenland (Laidre & Heide-Jørgensen 2005a). Compared to the summer feeding habits it is obvious that the major food intake takes place during the > 6 months stay on the fall and winter feeding grounds.

Importance of the assessment area to the narwhals

Narwhals occur within the assessment area throughout the year. In summer are Melville Bay and Inglefield Bredning are important areas (Figure 36). In autumn, the shelf break along the 1000 m contour seems to be important as migration corridor for whales form from Melville Bay stock. In winter the 'Northern Wintering Ground' is an important aggregation area for whales from the Somerset Island stock (Figure 36). Narwhals from the other Canadian summer grounds at least move through the assessment area on their migrations (Figure 37). The wintering areas are especially important to the whales because their main food intake takes place in winter, and especially the southern part of the assessment area must be regarded as critically important to wintering narwhals.

The world's largest abundance of narwhals occurs within the assessment area in winter and any exploitation and exploration for resources could potentially impact a major proportion of the global population of narwhals.

Conservation concern

The population in West Greenland is redlisted as 'Critically Endangered' (CR), while the global population is listed as 'Data Deficient' (DD). I light of the most recent survey results from Melville Bay and Baffin Bay the status in the Greenland Red List should be revised.

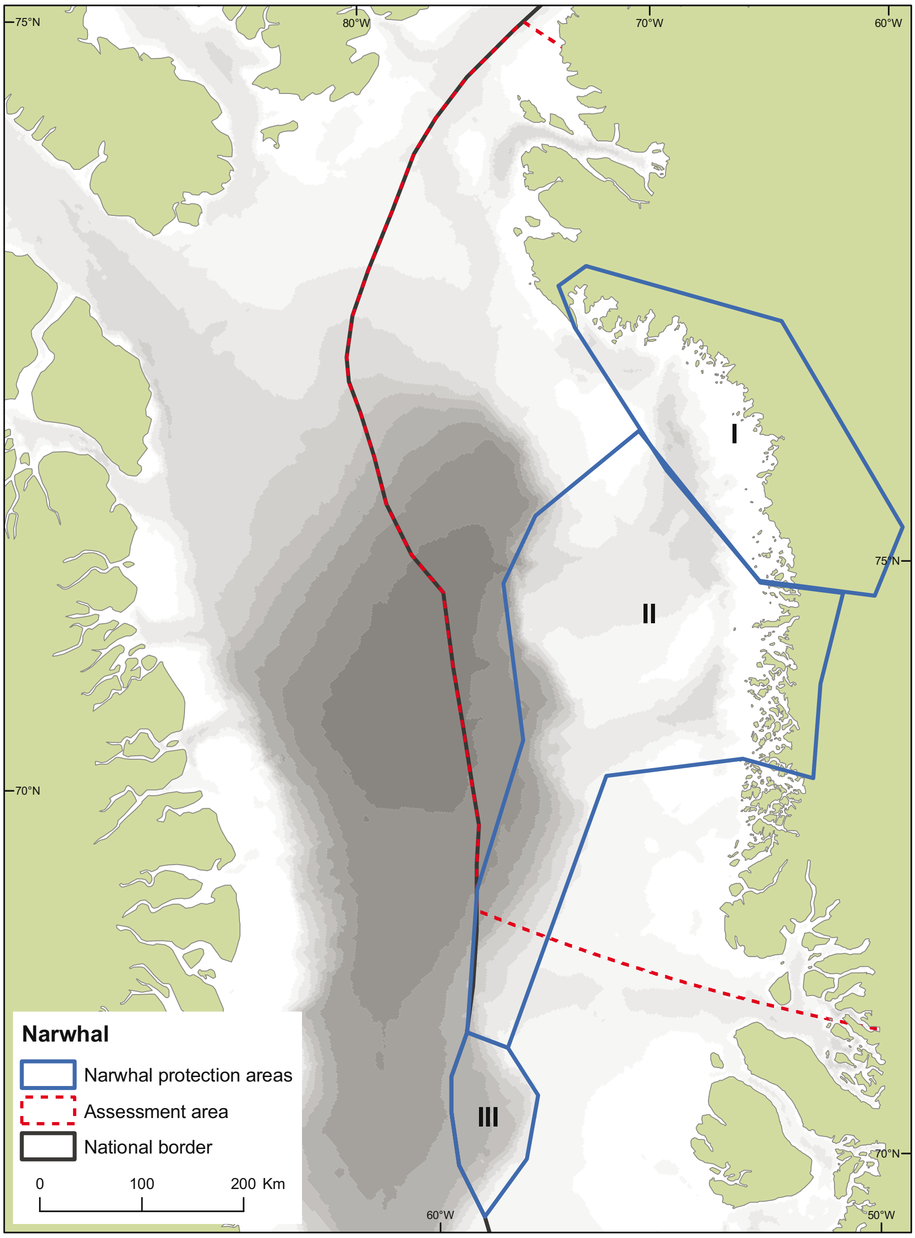
I relation to seismic activities some protection areas for narwhals have been designated (Boertmann *et al.* 2010). These are shown in Figure 41.

Sperm whale *Physeter macrocephalus*

With males reaching lengths of 18 m and weights of 50 tonnes, sperm whales are the largest toothed whale. On average, male sperm whales are 15 m long and weigh 45 tonne, while females are 11 m long and weigh 20 tonnes. As in the case of bottlenose whales, sperm whales are found in deep waters, often seaward of the continental shelf and near submarine canyons. Sperm whales are found in all oceans, from the ice edges to the equator. Females and calves remain in tropical and sub-tropical waters year round, while males segregate to high latitudes at the onset of puberty, aged between 4 and 15 years (Best 1979, Mendes *et al.* 2007). The larger males, in their late twenties or older migrate occasionally to lower latitudes in search of mating opportunities. When in lower latitudes, males move between different groups of females and their offspring, sometimes engaging in physical combat with other males (Whitehead & Weilgart 2000).

Sperm whales forage on a wide variety of deep-sea cephalopods and fish. Prey size ranges from a few centimetres long fish to 3-metre long sharks and even giant squids of the family Architeutidae that weigh up to 400 kg (reviews in Rice (1989) and Whitehead (2003)). Sperm whales in the northeastern Atlantic feed heavily on the deep-water squid *Gonatus fabricii* (Santos *et al.* 1999), favouring mature squid with mantle length of approx. 19-26 cm (Simon *et al.* 2003). Male sperm whales off northern Norway tagged with multi-sensor instruments feed both at shallow depths of approx. 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). In some areas, sperm whales take fish from long-line fisheries (e.g.

Figure 41. The narwhal protection areas in relation to seismic operations in the assessment area. Area 1 is the summer habitat, where seismic operation should be avoided or limited 15 July to 25 October. Area 2 is the migration corridor, where seismic operations should be minimized 15 October to 1 December. Area 3 is the winter habitat where seismic operations are impossible to conduct.



Roche & Guinet 2007) or approach trawlers in search of discarded fish (e.g. Karpouzli & Leaper 2003).

Stomach samples from sperm whales caught between Iceland and Greenland were dominated by fish, squid being a secondary food item (Roe 1969, Martin & Clarke 1986). The most important fish species in the diet was lumpfish (*Cyclopterus lumpus*), but redfish (*Sebastes marinus*), anglerfish (*Lophius piscatorius*), cod (*Gadus morhua*) and blue whiting (*Micromesistius poutassou*) were also common.

Distribution

Berzin (1971) reviewed captures of sperm whales in the Davis Strait as far back as 1812, including a mention from 1870 about sperm whales being relatively scant in the region, and a report of 181 males caught by a fleet of seven boats in 1937. Sperm whales are still regularly reported in ice-free areas in the Davis Strait and in Baffin Bay as far north as Upernavik (unpublished data).

Offshore boat traffic further north in the Baffin Bay assessment area is rare, and there have been no dedicated surveys for cetaceans in this area. The presence of sperm whales could be expected 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 that all sperm whales in the North Atlantic belong to a single stock (Donovan 1991). This assumption is supported by genetic analyses (Lyrholm & Gyllensten 1998).

Conservation
Sperm whales were the target of commercial whaling during over two centuries. By the second half of the 20th century, sperm whales were still numerous but several populations were depleted. Commercial whaling of sperm whales stopped with the moratorium on whaling at the end of the 1980s. At the present time, sperm whales are not caught anywhere in the North Atlantic. In the Greenland Red List, sperm whale is listed as 'Not Applicable' (NA) and globally as 'Vulnerable' (VU) (IUCN 2010).

Sensitivity
The echolocation clicks of sperm whales have a source energy flux density of up to 193 dB re 1 μPa2s. These clicks are the loudest sound known to be produced by any animal (Møhl *et al.* 2003), and therefore sperm whales may be more tolerant to loud noises than other whales.

During a controlled exposure experiment in the Gulf of Mexico, sperm whale horizontal movements were not noticeably affected by a seismic survey, but foraging effort seemed to diminish when airguns were operating (Miller *et al.* 2009).

Northern bottlenose whale *Hyperoodon ampullatus*

Next to the sperm whale, the northern bottlenose whale is the largest toothed whale in the North Atlantic, with adult females measuring up to 9 m in length and males up to 11 m. They are found in deep waters, often seaward of the continental shelf and near submarine canyons, from the ice edges south to approximately 30° N. They have a fission-fusion social system (i.e. live in groups that join and split), with group sizes from about 4 to 20 animals. Groups may be segregated by age and sex and males may form long-term companionships with other males (Wimmer & Whitehead 2004).

The main prey of the bottlenose whale is squid (*Gonatus* spp.), but prey items also include fish (herring *Clupea harengus*, redfish *Sebastes* spp., etc.), and invertebrates, such as sea cucumbers, starfish and prawns (Hooker *et al.* 2001). Prey is often caught near the bottom at depths greater than 800 m (Hooker & Baird 1999). Bottlenose whales are known to take Greenland halibut from long-line fisheries.

Northern bottlenose whales have only been studied in detail in an area surrounding the Gully, an underwater Canyon off Nova Scotia, in the southern part of the species' range. Based on boat surveys, photo-identification and molecular analyses, it has been established that these northern bottlenose whales live in a small population of about 150 animals that is rather stationary and isolated from other populations (Wimmer & Whitehead 2004, Whitehead & Wimmer 2005, Dalebout *et al.* 2006). It is not known whether northern bottlenose whales in other parts of their range also form relatively small, isolated and stationary populations.

Distribution
There is no survey data for bottlenose whales in the study area. Bottlenose whales are frequently observed from fishing boats operating in deep waters of the Davis

Strait and Southern Baffin Bay. In the North East Atlantic, bottlenose whales were caught by Norwegian whalers as far north as the ice edge west of Svalbard (Benjaminsen & Christensen 1979).

Catches

Northern bottlenose whales were heavily hunted during the 19th and 20th century throughout the North Atlantic, south of the assessment area. They are not caught in Greenland.

Conservation

The Red List status of the northern bottlenose whale is 'Data Deficient' (DD) on the global list, and 'Not Applicable' (NA) on the Greenland list (IUCN 2010, Boertmann 2007).

Critical and important habitats

None are known from the assessment area.

Sensitivity

Hooker *et al.* (2008) found increasing levels of persistent contaminants and CYP1A1 protein expression (signal of stress) in biopsy samples from bottlenose whales following the onset of gas and oil development in Eastern Canada. The authors conclude that the change in contaminant levels over time in these whales was likely to reflect a temporal change in contaminant levels in the water and/or in prey species, and speculated that the proximity of oil and gas drilling activities may have influenced contaminant patterns through remobilization of persistent contaminants from sediments on the sea bed.

See also text about toothed whales and acoustic disturbance above.

4.9 Summary of VECs from the Baffin Bay assessment area

The VEC (Valued Ecosystem Component) concept is explained in Section 9.1.2. It must be underlined that the designation of VECs will always be constrained by the availability of data. In the present assessment area, data on wildlife and other ecosystem components are rather limited, and more species, such as blue whale and killer whale, may in fact be VECs.

Primary productivity

Due to lack of data and large variability it is not possible to point out particularly important, recurrent areas for primary productivity, except for a general designation of polynyas and ice edges.

Zooplankton

It is not possible to designate specific important areas for zooplankton. The key species *Calanus hyperboreus*, *C. glacialis* and *Parathemisto libellula* are definitely VECs.

Benthic flora

It is not possible to designate specific important species of or areas for macroalgae.

Benthic fauna

There are many areas with high densities of benthos, and sites in shallow waters are often important feeding grounds for walrus, bearded seal and eiders. The results of the investigations in 2008 indicate that the benthic communities are widespread, but it was not possible to identify areas especially vulnerable, mainly because the spatial coverage was incomplete.

Northern shrimp is an important species as it forms the basis of the most important fishery in Greenland. In 2007-2009 10% of total landings were taken within the assessment area. The amount is expected to increase in the future if water temperatures increase.

Ice flora and fauna

Due to lack of data and wide variability it is not possible to point out particularly important, recurrent areas for sympagic flora and fauna.

Fish

VECs among the fish include the Greenland halibut (the only species utilised on a commercial basis), polar cod (ecological key species), capelin (ecological key species) and Arctic char. The fishing grounds for Greenland halibut, the rivers utilised by Arctic char and the near-shore habitat used by capelin to spawn are important VECs; however, it is not possible to designate important areas for polar cod or other fish species due to lack of data.

Birds

Great cormorant occur in the southern part of the assessment area. A significant part of the Greenland population is estimated to occur here, and cormorants are generally vulnerable to oil spills.

Common eider is an important species, breeding in colonies throughout the coastal parts of the assessment area. The population has been decreasing throughout the past century but in the recent decade this trend has been reverted. Common eider is an important quarry species for the hunters of the assessment area. Concentrations, including the breeding colonies and moulting flocks, are vulnerable to oil spills and disturbance.

King eider occurs in late summer in large moulting concentrations along the coasts. These flocks are particularly vulnerable to oil spills and disturbance.

Kittiwake breeds in large and dense colonies, where high proportions of the population may be exposed to oil spills and disturbance. It is also an important quarry species for the hunters of the assessment area.

Ivory gull migrates through the assessment area, and occurs as summer visitor. The major part of the birds belongs to the Canadian breeding population, which recently has decreased by more than 80%.

Arctic tern breeds in large and dense colonies along the coast, where they are vulnerable to oil spills and disturbance.

Thick-billed murre. The population breeding in the assessment area is of high international conservation value and of very high national conservation value as 15% of the global population and > 90% of the Greenland population is found there in summer. The Greenland population is assessed as 'Vulnerable' (VU) on the national Red List. Murres are particularly vulnerable to oil spills (Wiese & Ryan 2003).

Atlantic puffin. The population breeding in the assessment area is of national conservation value as approx. 25% is estimated to breed there (mainly in the former Upernavik municipality). It listed as 'Near Threatened' (NT) on the Greenland Red List, and it is vulnerable to oil spills.

Little auk. The population breeding within the assessment area is of extremely high international conservation value as well as of national conservation value as more than 80% of the global population is found there in the summer. This species is vulnerable to oil spills and it is utilised by the inhabitants of the former Qaanaaq municipality.

Marine mammals

Polar bear. A significant part of the global population occurs within the assessment area and it is of high international and national conservation value. Polar bears are globally and nationally red-listed due to an expected population decline due to climate change. Polar bears are important quarry for hunters of the assessment area. Particularly important areas include ice edges, shear zones, polynyas, areas with high densities of ringed seals and coasts with available denning habitats. However, concentrations rarely occur and when they do, they are not predictable.

Walrus occur mainly as migrants in the assessment area. The numbers probably constitute a low proportion of the total population, but both are red-listed and both are hunted. The shear zone off the outer coast is their primary habitat within the assessment area.

Bearded seal. This species is abundant in the assessment area, where a significant part of the Greenland population is found. Its biology in Greenland is poorly understood, but in other areas bearded seals are known to feed at or close to the bottom, with benthic organisms being an important part of their diet. As benthic feeders they may be ecologically affected by oil spills. They are very active acoustically and therefore may be affected by anthropogenic noise related to oil exploration and development.

Ringed seal is an ecological key species due to its abundance and its role as main prey for the polar bear (Figure 10). It is moreover the most important marine mammal to the hunters of the assessment area. No particularly important areas are known.

Bowhead whale. This whale has a high international conservation value due to its rarity. A large proportion of the Baffin Bay population moves through the assessment area, and some also winter and spend part of the spring and summer in the northern part. Their primary habitat is the marginal ice zone.

Narwhal. A significant part of the global population occurs within the assessment area – summering, migrating or wintering – and its conservation value is therefore of international importance. There is also concern for the population as it is decreasing, and it is red-listed as 'Critically Endangered' (CR). In summer, narwhals aggregate in Melville Bay, during migration they move along well-defined routes, and they winter in well-defined areas. Narwhals are important quarry for the hunters of the assessment area.

White whale. The population occurring in the assessment area has a high national conservation value as it makes up the entire West Greenland winter population. It is listed as 'Critically Endangered' (CR) on the Greenland Red List due to reduced population size because of past unsustainable harvest. The white whale is an important species for the subsistence hunters in the area. The primary habitats are the shelf waters – in winter and spring between land and the drift ice, often in the shear zone.

Other ecological features

Key habitats which are VECs in the assessment area include recurrent ice edges, polynyas (often in combination), recurrent shear and lead zones and probably also the marginal ice zone. Besides these many small islands are important as breeding grounds for seabirds.

5 Natural resource use

5.1 The commercial fisheries

H. Siegstad and O.A. Jørgensen

Commercial fisheries represent the most important export industry in Greenland, underlined by the fact that fishery products accounted for 91 % of the total Greenlandic export revenue (2.3 billion DKK) in 2006 (Statistics of Greenland 2009). Very few species are exploited by the commercial fisheries in Greenland, and this is especially true in the assessment area. The three most important species on a national scale are northern shrimp (export revenue in 2006: 1,200 million DKK), Greenland halibut (510 million DKK), Atlantic cod (128 million) and snow crab (53 million DKK) (Statistics of Greenland 2009).

Greenland halibut and shrimp are the main commercially exploited species within the Baffin Bay assessment area, accounting for 18 % and 1 % of the total Greenland catch, respectively.

Greenland halibut fishery

In the assessment area the fishery for Greenland halibut (*Reinhardtius hippoglossoides*) has both inshore and offshore components. The inshore fishery is conducted in the former municipalities of Uummannaq and Upernavik where landings in 2006 amounted 5,500 tonnes taken within the assessment area (this was approx. 18 % of the total Greenland landings of Greenland halibut). The fishery takes place throughout the year in fjords with deep water and the fish are caught on long-lines either from small vessels or from the winter ice (Figure 42).

The offshore fishery for Greenland halibut takes place in summer and autumn on the shelf slope of Baffin Bay (Figure 42). In the past years the offshore catches north of 68° 50' N (mainly to the south of the assessment area) increased from 575 tonnes in 2001 to 3,500 tonnes in the years 2003-2005. Catches increased again in 2006 to 6,220 tonnes and stayed at that level in 2007 and 2008 to increase slightly to 6,700 tonnes in 2009. No catches were taken inside the assessment area in 2009 (north of 71°), but Greenland halibut from the assessment area are believed to a large extend to recruit to the fishing grounds south of the assessment area.

The distribution of the catches is shown in Figure 42.

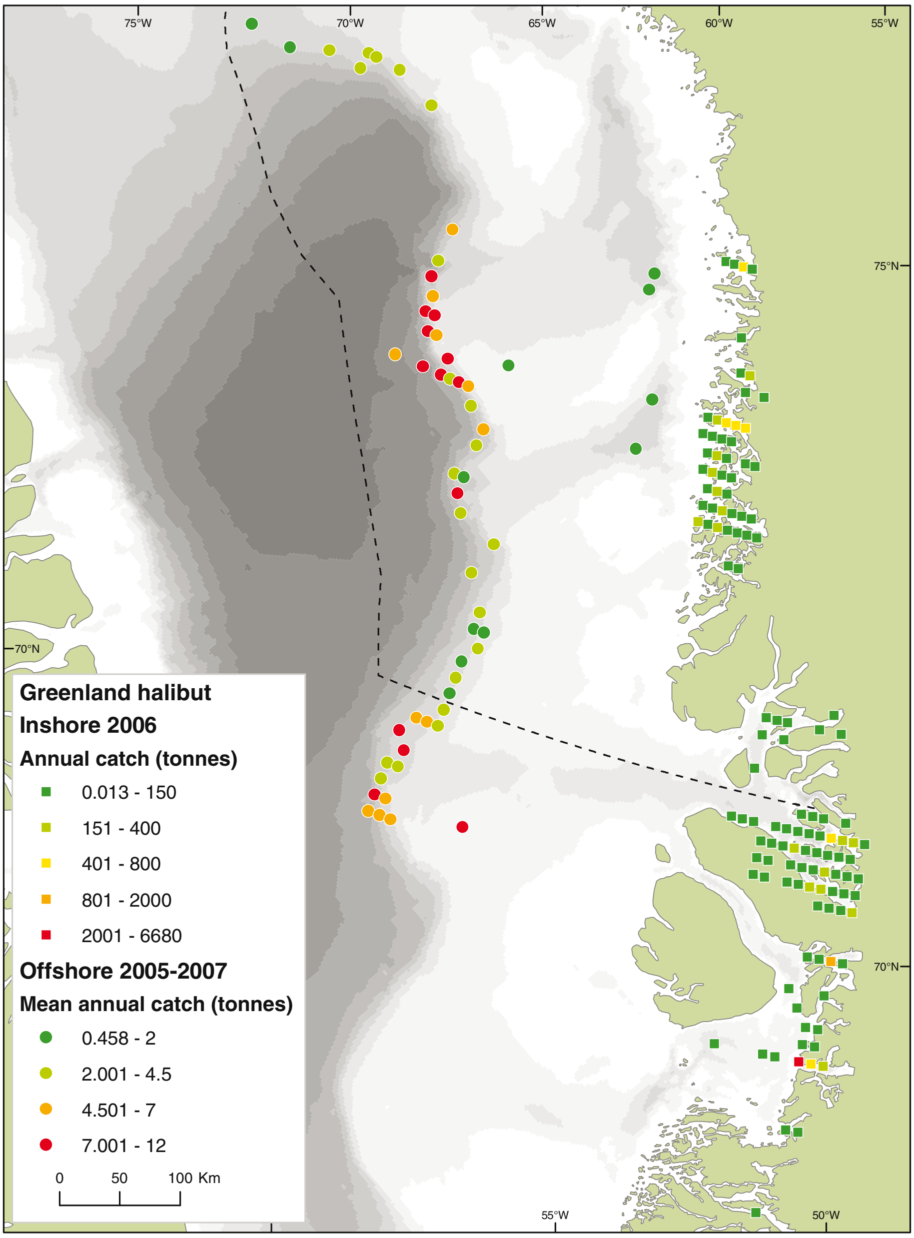
Northern shrimp fisheries

The fishery for northern shrimp (*Pandalus borealis*) has in recent years been conducted in a small area offshore Upernavik. In 2004-2006 less than 1 % of the total Greenland shrimp catch was taken in that area (Figure 43). However, in previous years (1985-1988) the area north of 71° N was very important and accounted for up to 30 % of the total catch. As a response to climatic changes with higher temperatures in Southwest Greenland it is likely that the area could regain its importance as the stock is moving further north. The biological surveys has shown an increased biomass in the area offshore Upernavik since 2003.

Other species

The commercial fishery for snow crab (*Chionoecetes opilio*) was initiated in 1996. Total landings peaked in 2002 at approximately 15,000 tonnes, and the snow crab at that time represented the third most important export for Greenland in terms of income. The stock has been decreasing since 2004 and total catch in 2007 was only 2,000 tonnes. In the assessment area a catch of 65 tonnes (less than 1 % of

Figure 42. Distribution of Greenland halibut fishery and size of landings from the assessment area. Note the different scales on inshore and offshore landings. Inshore catches are illustrated by a single year: 2009, off-shore by annual average over the period 2008 to 2009. However, the off-shore fishery inside the assessment area had character of surveys and investigations than actual commercial fishery.



total catch) was noted in 2004. Since then no fishery has been reported from the area. It is unlikely that a new fishery for snow crab will develop in this area.

Iceland scallop (*Pecten islandica*) is caught in rather shallow water where currents are strong. Total catch in Greenland has been around 2,000 tonnes/year. In the assessment area almost no fishery (1 %) has taken place, with only 4 tonnes in 2000 and 53 tonnes in 2003. No fishery has taken place since then.

5.2 Subsistence and recreational fisheries and hunting

A. Rosing-Asvid

Besides the commercial fishery, subsistence fishery and recreational fishery take place in the region. Hunting on subsistence basis and also as recreational activity also is important in the assessment area. Both fishing and hunting are important for the income of many families, particularly in the small settlements, and many are still dependent on these activities for their living. The catches are either used or manufactured by families themselves or sold at local outdoor markets (Kapel & Petersen 1982, Pars *et al.* 2001, Rasmussen 2005).

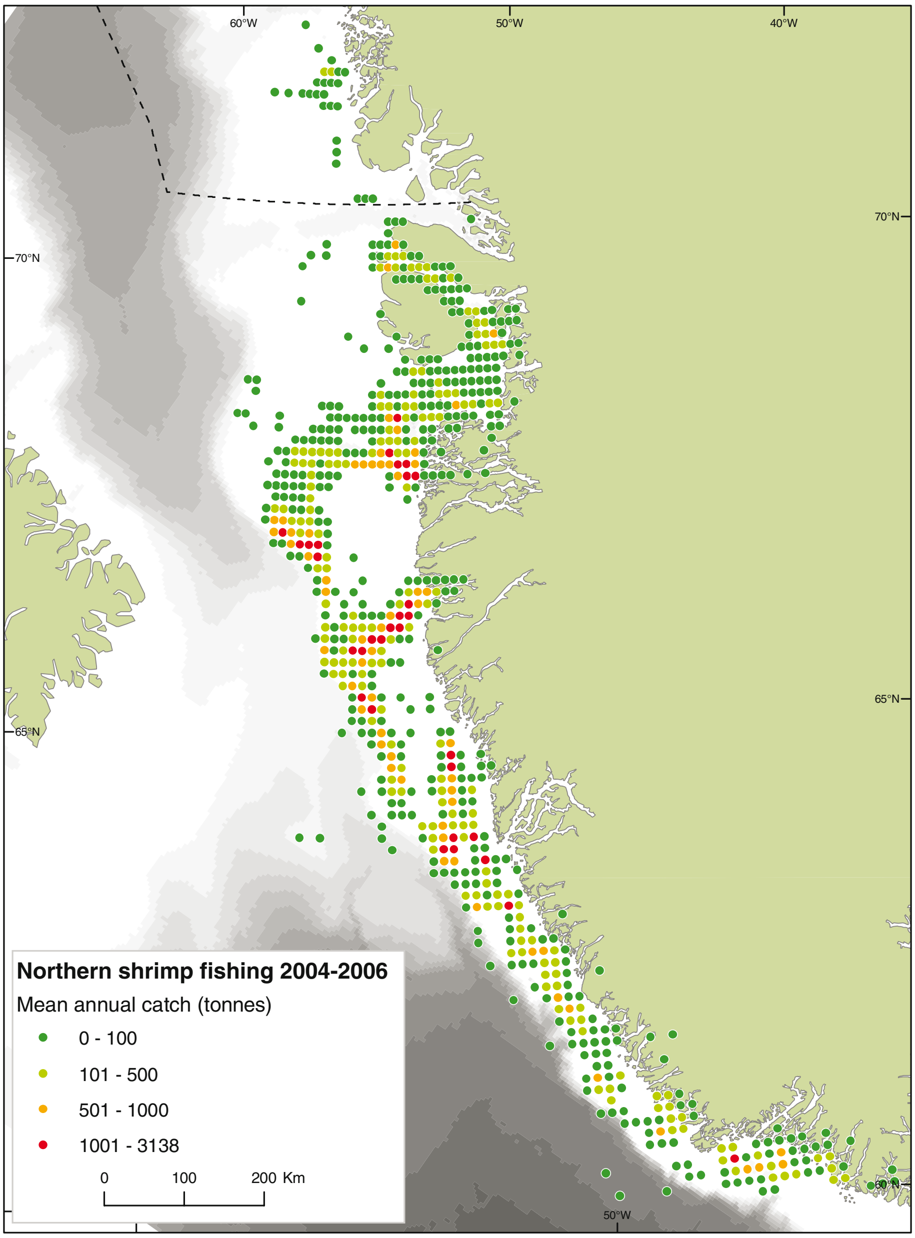


Figure 43. Distribution and size of northern shrimp catches in West Greenland. The fishing grounds cover only the southernmost part of the assessment area. Catch size calculated as annual mean over the period from 2004 to 2009.

Fishery

Many fish species are utilised in these fisheries. The species that will be most vulnerable to an oil spill are those caught close to the shoreline: capelin (*Mallotus villosus*), lumpsucker (*Cyclopterus lumpus*) and Arctic char (*Salvelinus alpinus*). Fisheries for these species are restricted to spring and summer. Capelin and lumpsucker occur only in the southernmost part of the assessment area, although their ranges are moving northwards in these years. Arctic char occur throughout the assessment area, see Section 4.6.2.

Many other species of fish are utilised on subsistence basis: spotted wolffish (*Anarchichas minor*), Greenland halibut (*Reinhardtius hippoglossoides*), redfish (*Sebastes* spp.), Atlantic cod (*Gadus morrhua*), polar cod (*Boreogadus saida*), Greenland cod (*Gadus ogac*), Greenland shark (*Somniosus microcephalus*), etc.

Important areas for fishery of capelin, lumpsucker and Arctic char were mapped by the oil spill sensitivity mapping project covering west Greenland as far north as 72° N (Svartenhuk Peninsula), but this overlaps only the southernmost small part of the assessment area (Olsvig & Mosbech 2003, Mosbech *et al.* 2000b, 2004a).

Table 5. The quotas in 2010 for marine mammals in North and West Greenland (APNN).

		2010		
Walrus	**Baffin Bay population**	**Upernavik, Uummannaq & Disko Bay**	**Rest of West Greenland**	
	64	27	34	
Polar bear	**Kane Basin population**	**Baffin Bay population**		
	6	50		
White whale	**Qaanaaq**	**Upernavik**	**Uummannaq**	**Rest of West Greenland**
	20	115	19	156
Narwhal	**Inglefield Bredning & Smith Sound**	**Melville Bay**	**Uummannaq**	**Rest of West Greenland**
	85	81	85	59

Hunting

The marine mammal species that are regularly hunted within the assessment area include four seal species, walrus, white whale, narwhal, minke whale, fin whale and polar bear. In 2008, the following numbers of seals were reported to the official catch statistics for Ummannaq, Upernavik and Qaanaaq: ringed seal 40,745; harp seal 19,325; hooded seal 479 and bearded seal 551 (Ministry of Fishery, Hunting and Agriculture APNN, unpublished data).

The catch of walrus, white whale, narwhal, polar bear and minke whale is regulated by quotas (Table 5). Seven minke whales were caught in Upernanvik and 11 in Uummannaq during 2010 (Ministry of Fishery, Hunting and Agriculture (APNN), unpublished data).

There are no quotas on the seal hunt. Ringed seal and harp seals are important quarry especially in the Upernavik-area, where they make up a large part of the catch for the subsistence hunters. Also hooded seal is of a relative high importance being a larger animal (Table 6).

The seasonal distribution of the seal catches are described in Section 4.8.2.

Narwhals, white whales and walrus to the south of Melville Bay are caught when they migrate in spring and/or autumn, while in Qaanaaq and Melville Bay narwhals are caught in summer. In the Qaanaaq-area walruses are caught mainly in May-June and September-October. Minke whales are caught in the open-water season in the southern part of the assessment area. Polar bears are caught during the period 1 September to 30 June.

In 2008 about 2,809 thick-billed murres and 3,944 eiders (mainly common eider) were reported to the official bag record system from the region to the north of Disko Bay (≈ the assessment area and southern part of the former Uummannaq Municipality). Reported catches of eiders and murres were considerably reduced after a reduction in the hunting period in spring, following new legislation in 2001. Catches of little auk are important in the Qaanaaq area during the whole breeding season, were a catch of 23,166 were reported from 2008 (Ministry of Fishery, Hunting and Agriculture (APNN), unpublished data).

Table 6. Catches of seals in North West Greenland in 2008 (APNN, unpublished data).

	Uummannaq	Upernavik	Qaanaaq
Harp seal	5854	13223	238
Ringed seal	5999	37805	3886
Hooded seal	167	458	11

5.3 Tourism

D. Boertmann

The tourist industry is one of three major sectors within the Greenland economy, and the industry is increasing significantly in importance both nationally and locally in the assessment area. The most important asset for the tourist industry is the unspoiled, authentic and pristine nature.

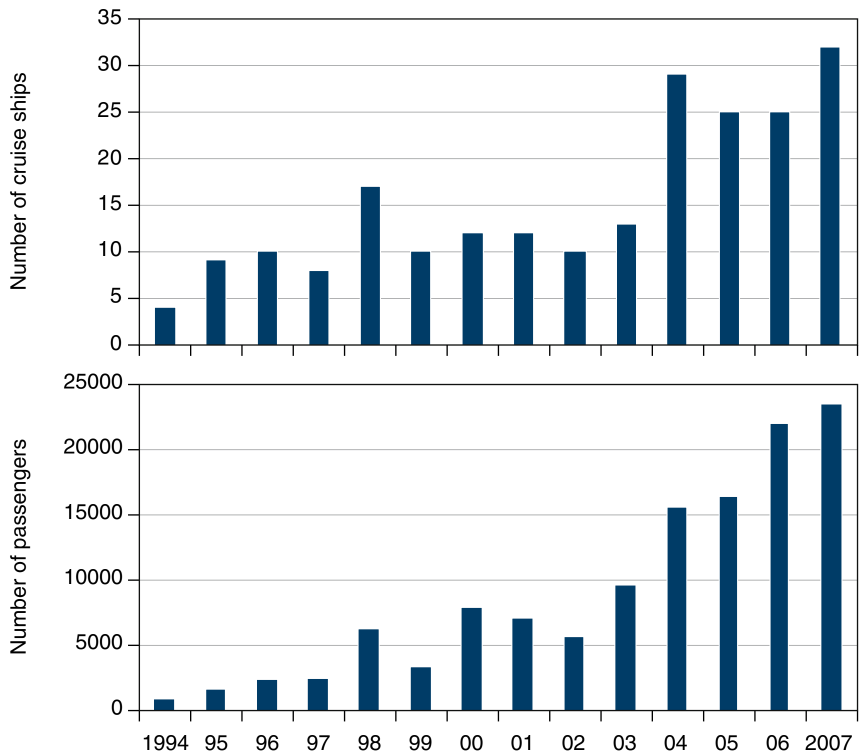
There are no statistics on the number of tourists and their regional distribution in Greenland available, but hotels report the number of guests they have accommodated and how many 'bed nights' they have sold. Overall figures for Greenland as a whole in 2006 were approx. 82,000 guests and approx. 250,000 'bed nights' (Statistics of Greenland 2008). By far the major part of these were in West Greenland outside the assessment area and only 5-10% of the total number of 'bed nights' were in Northwest and East Greenland (= former municipalities of Qaanaaq, Upernavik, Uummannaq, Scoresbysund and Tasiilaq).

Besides the tourists staying in hotels and other accommodation on shore, cruise ships bring an increasing number of tourists to Greenland. According to the Statistics of Greenland (2010), the number of visitors from cruise ships increased from 15,700 in 2004 to 23,500 in 2007 (Figure 44). 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 sightings of 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 on scientific expeditions (natural history) (Figure 45).

Figure 44. Number of cruise ships and number of passengers 1994-2007 in Greenland overall. There is no data on the cruise ship activity available for the assessment area, but the trends are similar (Statistics of Greenland 2010, Greenland Tourism pers. comm.).



Tourist activities

The activities are centred in the main towns of the assessment area: Uummannaq (just outside the assessment area), Upernavik and Qaanaaq, where there are accommodation and tourist operators. The season starts in early spring when there are opportunities for dog sledding on the sea ice, but the main season is summer when it is possible to sail from the towns to attractions such as archaeological sites, bird cliffs, whale habitats, glaciers, small settlements, hiking areas and areas with scenic views.

In Upernavik the following activities take place (Bo Albrechtsen, Director of Museum and Tourism in Upernavik, pers. comm.):

- Dog sledge trips. Takes place year round. Sled trips are mostly on sea ice in the coastal zone.
- Boat trips with local hunters. Summer season
- Kayaking. June to August. Kayakers explore the coastal zone and bring equipment and provisions on their own
- Cruise ships. Mainly August and September. Visitors in Upernavik town mostly walk around for sightseeing and visit the museum
- Fishing and hunting. Seal hunt on the ice in spring
- Hiking. Summer season. Land-based

In 2007 the number of visitors was in total approx. 800. Of this figure, 700 arrived from cruise ships, 50 were there specifically for kayaking, and the last 50 were independent travellers.

Due to the remoteness, Qaanaaq receives only a few independent travellers and these often as sport or scientific expeditions. The activities include dog sledge trips, hiking, kayaking and hunting. Most of the activities are related to the sea or the ice. A few of the independent travellers go there in winter. Cruise ships also bring an increasing number of tourists to Qaanaaq in the summertime.

Much of the tourist activity within the assessment area takes place in the coastal zone, which potentially is exposed to oil spills. As the most important asset of the tourist activity in the area is the unspoiled nature, an extensive oil spill has the potential to seriously impact the local tourist activity and industry.

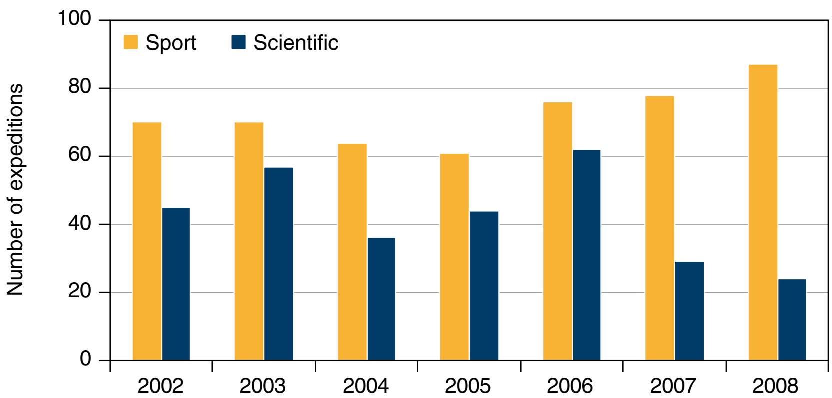


Figure 45. Number of expeditions in Greenland by year. Data provided by the former Danish Polar Centre (DPC). It is not possible to filter out the expeditions visiting the assessment area.

6 Protected areas and threatened species

D. Boertmann

6.1 International nature protection conventions

According to the Convention on Wetlands (the Ramsar Convention), Greenland has designated eleven areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, this is only the case for one of the Greenland Ramsar sites. No Ramsar sites are found within the assessment area (Egevang & Boertmann 2001a).

6.2 National nature protection legislation

The Melville Bay Nature Protection Area is situated within the assessment area (Figure 46). This was designated primarily to protect polar bears. Although a nature protection area, traditional hunting is allowed in an outer part and exploration for petroleum and minerals is allowed throughout (Boertmann 2005).

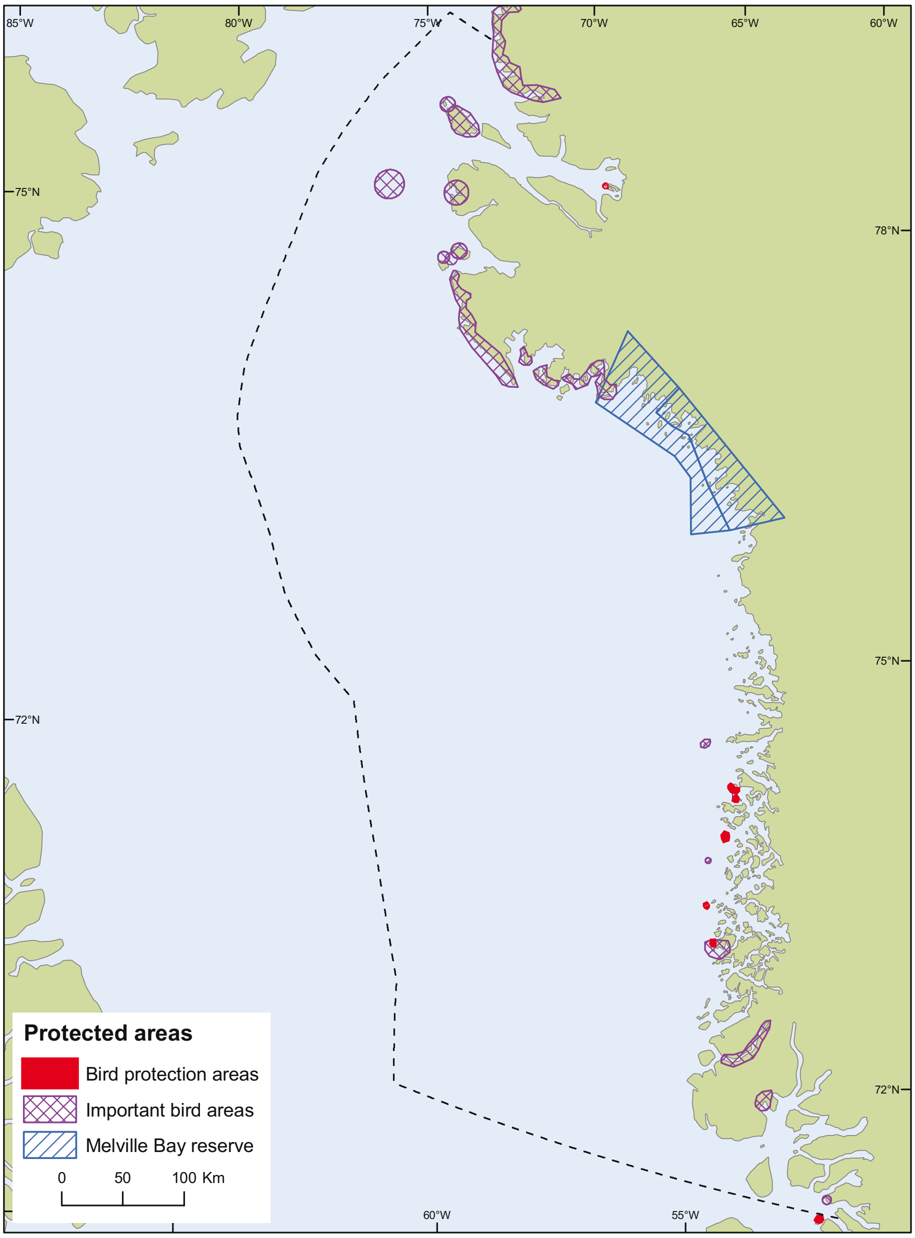


Figure 46. Areas protected according to the Greenland Nature Protection Law (Melville Bay reserve and Bird Protection areas) and areas designated as Important Bird Areas (IBAs) by BirdLife International. There are no Ramsar-areas within the assessment area.

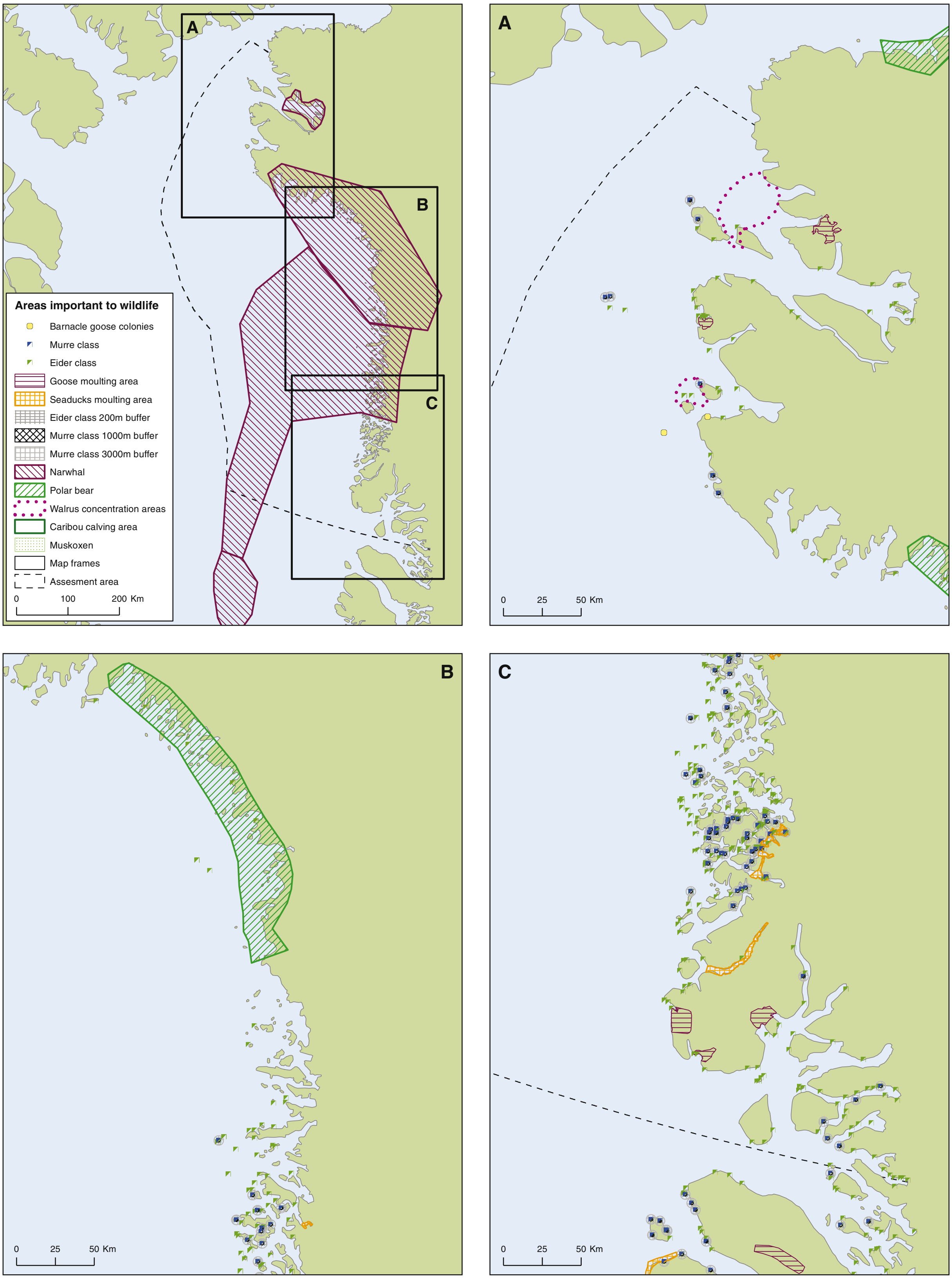


Figure 47. Areas designated as 'important to wildlife' by Bureau of Minerals and Petroleum as a part of the field rules for prospecting and exploration activities. The protection areas for narwhals (related to seismic surveys) are shown on the overview map. These are now under revision.

There are six specific sites within the assessment area, protected as seabird breeding sanctuaries according to the Bird Protection Executive Order (Figure 46). 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

Table 7. Nationally red-listed species occurring in the Baffin Bay assessment area.

Species	Red List category
Polar bear	Vulnerable (VU)
Walrus	Critically endangered (CR)
Bowhead whale	Near threatened (NT)
White whale	Critically endangered (CR)
Narwhal	Critically endangered (CR)
Great northern diver	Near threatened (NT)
Greenland white-fronted goose	Endangered (EN)
Common eider	Vulnerable (VU)
Gyr falcon	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)
Atlantic puffin	Near threatened (NT)

assessment area (Figure 15). According to the Mineral Extraction Law, a number of 'areas important to wildlife' are designated and, in these, mineral exploration activities are regulated in order to protect wildlife. There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies (Figure 47). Moreover some important narwhal-areas in the assessment area have been designated as narwhal-protection areas (Figure 47) in relation to seismic surveys (Boertmann *et al.* 2010). These are however, presently under revision.

6.3 Threatened species

Greenland has red-listed (designated according to risk of extinction) five species of mammals and eleven species of birds (Table 7) occurring in the assessment area (Boertmann 2007).

A few species have been categorised as 'Data Deficient' (DD) and they may become red-listed when additional information is available (Table 8).

Globally threatened species occurring in the assessment area include some marine mammals and a single bird (Table 9).

Within the assessment area there are some hot-spots for threatened species (Figure 48) – particularly in the coast of the former municipality of Upernavik and the coasts of central part of the former Qaanaaq municipality.

Table 8. National responsibility species (defined as more than 20 % of the global population in Greenland), species with isolated population in Greenland and species listed as 'Data Deficient' (DD) occurring in the assessment area. Only species which may occur in marine habitats included.

National responsibility species	Species listed as Data Deficient (DD)	Species with isolated population in Greenland
Narwhal	Bearded seal	Great cormorant
Walrus	Harbour porpoise	Red-breasted merganser
Polar bear	Blue whale	Harlequin duck
Light-bellied brent goose	Sei whale	
Greenland white-fronted goose (endemic)		
Mallard		
Common eider		
Iceland Gull		
Black guillemot		
Little auk		

Table 9. Species occurring in the assessment area and listed as globally threatened (IUCN 2010).

Globally threatened species occurring in the assessment area include some marine mammals and a single bird (IUCN 2010)	
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)
White 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 eighteen are located within the assessment area (Figure 46). 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 (Link). Some of the IBAs are included in or protected by the national regulations e.g. as seabird breeding sanctuaries, but many are without protection or activity regulations.

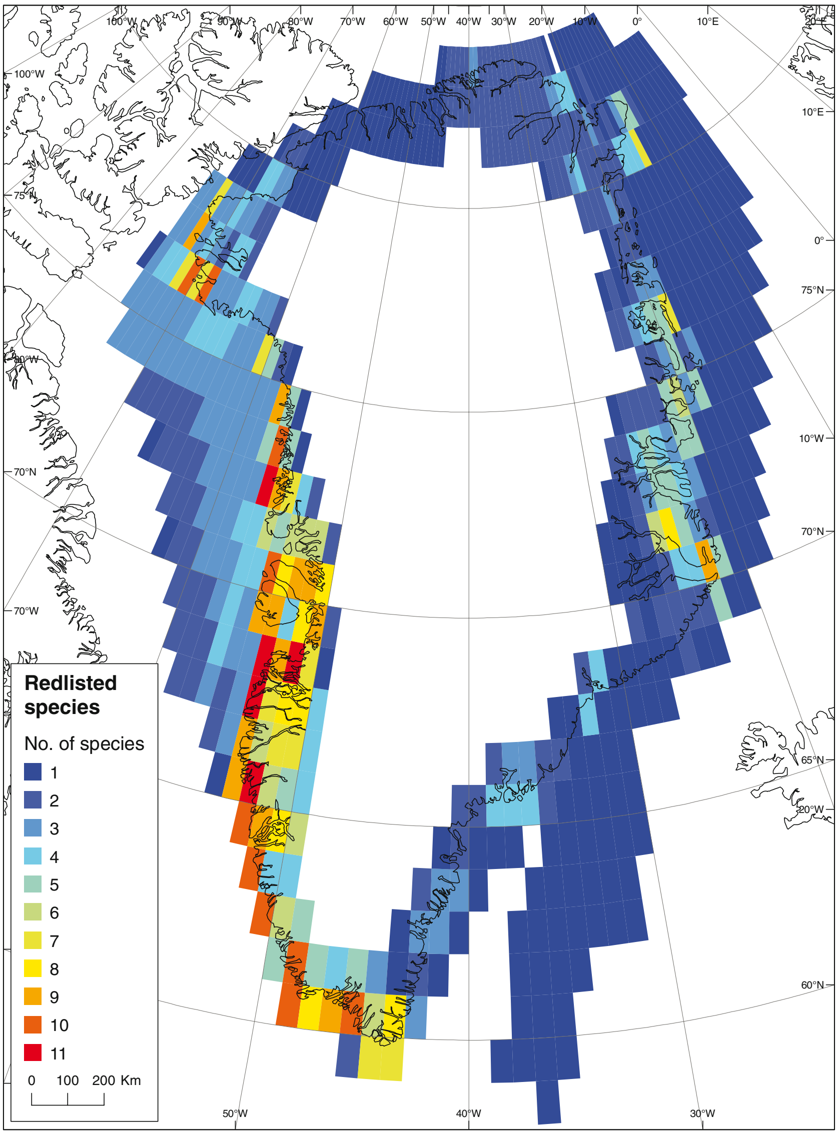


Figure 48. Distribution of Redlisted species in Greenland shown as number of species in 1°×1° squares.

7 Background levels of contaminants

D. Schiedek

Knowledge on background levels of contaminants in areas with hydrocarbon exploration and exploitation is important mainly as a baseline for monitoring the potential contamination of the environment from the 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 the following sections, with focus on studies with relevance for the 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 have been included for animals not affected by local pollution sources, i.e. former mine sites. The overall conclusion was that lead levels in marine organisms from Greenland were low, whereas cadmium, mercury and selenium levels were high, in some cases exceeding Danish food standard limits. No clear conclusions could be drawn in relation to geographical differences concerning lead, mercury and selenium concentrations. In general, cadmium levels were higher in biota from Northwest Greenland compared to southern areas.

Studies on specific pollution sources have not been carried out in the assessment area, but at two sites close to the area contamination from point sources have been surveyed and monitored. At Maarmorilik (near Uummannaq, just to the south of the assessment area) lead and zinc ore was mined from 1973 to 1990. Environmental studies have been conducted at the mine since 1972 by measuring lead and zinc in seawater, sediments and biota in the fjords at Maarmorilik (Larsen *et al.* 2001, Johansen *et al.* 2006, 2010). At Thule Airbase, pollution impacts on the marine environment on a local and regional level studied were in 2002 (Glahder *et al.* 2003).

7.1 AMAP Monitoring Activities

In 1991, the Arctic Monitoring and Assessment Programme (AMAP) was established to monitor identified pollution risks and their impacts on Arctic ecosystems. The Arctic is a region with almost no industry or agriculture, why the origin of the pollution mainly is from off-regional areas. Most of the persistent organic pollutants (POPs) and a substantial part of the mercury (Hg) 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. The air provides a fast transport route – bringing contaminants from Europe to the Arctic within days. Ocean transport is slower, but more important for contaminants that partition into water and sediments rather than air and aerosols (AMAP 2004). Once in the Arctic, contaminants can be taken up in the lipid rich food chains, in particular in the marine food webs. In general, 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 Hg (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 and different trace metals, i.e. cadmium (Cd), mercury (Hg), selenium (Se) in selected species. In the following an overview is given concerning the contaminant levels and temporal trends in the monitored species based on Riget (2006, updated 2007) and results from the latest AMAP assessment in 2009.

7.1.1 Heavy metals

Heavy metal content has been measured in the liver of shorthorn sculpins, ringed seals, and polar bears. An increase, though not significant, in the mercury levels was found in shorthorn sculpins and ringed seals from 1999 to 2006. Cadmium, on the other hand showed a decreasing trend in shorthorn sculpins and ringed seals. Nevertheless, the cadmium concentrations found in shorthorn sculpins and ringed seals where highest when compared to biota from other Arctic regions (Riget *et al.* 2000, 2005). The patterns observed appear mainly to be related to natural geological differences in the occurrence of the minerals (Riget *et al.* 2005).

As summarised by Dietz (2008), marine mammal populations from Northwest Greenland and the Central Arctic show the highest concentrations of mercury. The highest cadmium concentrations were found in mammals from Central West Greenland and Northwest Greenland.

Temporal trends of mercury (Hg) in West Greenland gyrfalcons (*Falco rusticolus*), peregrine falcons (*Falco peregrinus*) and white-tailed eagles (*Haliaeetus albicilla*) were determined over 150 years from 1851 to 2003. Hg was measured in the fifth primary feather. It was shown that Hg levels increase in the order gyrfalcon (lowest) < peregrine falcon (intermediate) < white-tailed eagle (highest). All species showed significant age-related accumulations. The comparisons of Hg 10-year medians for adult peregrine falcons, and juvenile and adult white-tailed eagles indicated a continued increase during recent decades. However, low levels of Hg in a few recent collections among gyrfalcons and peregrine falcons could indicate a change in the increasing trend (Dietz *et al.* 2006).

Temporal trends in mercury concentrations for the last two to three decades were also determined in different species from Northwest Greenland (NWG, 77° N) and central West Greenland (CWG, 69° N). For shorthorn sculpin from CWG and NWG and walrus from NWG no temporal trend was found. In ringed seals from NWG, an increase in mercury of 7.8 % per year was observed. In ringed seals from CWG no trend in mercury concentrations was found during the period 1994-2004 (Riget *et al.* 2007a).

Bio-magnification of mercury and methyl mercury (MeHg) in the West Greenland marine ecosystem has been studied in fourteen species including invertebrates, fish (e.g. Greenland halibut) and seabirds (sampled from 62° to 69° 30' N) and marine mammals (62° to 71° 30' N). Bio-magnification was clearly visible with a bio-magnification factor similar to those found in other marine systems (Riget *et al.* 2007b).

7.1.2 Persistent Organic Pollutants (POPs)

The substances belonging to this group include polychlorinated biphenyls (PCBs), various organohalogenes (OHCs) (such as the organochlorine pesticides DDTs, dieldrin, hexachlorocyclohexane (HCHs) and toxaphene), brominated flame retardants (BRFs) or perfluorinated compounds (PFCs). All of them are known to accumulate in organisms, preliminary in fat storage tissues. Furthermore, bio-magnification towards the upper end of the food web has been documented (Riget *et al.* 2004).

POP levels are generally lower in the Arctic environment than in more temperate regions; however, they could be of concern particularly for higher trophic predators such as polar bears (Dietz 2008).

Levels of certain POPs have also been measured in a range of marine fish collected in West Greenland and in the northern Baffin Bay (AMAP 2004). Concentrations were relatively consistent across species with the exception of the Greenland shark (*Somniosus microcephalus*) and Greenland halibut, which displayed higher levels. The Greenland halibut is a large, predatory, benthic fish, which may account for the higher levels. PCBs were the predominant compounds in these two fish species followed by ΣDDTs and chlordanes, reflecting their generally higher trophic level (AMAP 2004). Concentrations of organic chlorines in Greenland sharks collected in the Davis Strait and Cumberland Sound region in 1997 and 1999 were in the range of other top Arctic marine predators, i.e. polar bear and glaucous gull (AMAP 2004). Concentrations were 10-100 times higher than those observed in Greenland halibut and 3-10 times than those in ringed seals, suggesting a very high trophic position.

As part of the monitoring programme, the concentrations of different POPs were measured in black guillemot eggs, ringed seal blubber and polar bear adipose tissue. The content of POPs increases with age; therefore ringed seals and polar bears were divided into two groups, juveniles and adults. If possible a distinction was also made between males and females.

PCB concentrations showed a decreasing trend for ringed seals; for black guillemot eggs no clear trend was visible, but the time series only started in 1999. DDT levels have decreased significantly in all species monitored.

The effects of biological and chemical factors on trophic transfer of organochlorines (OC) were measured in six zooplankton species, the benthic amphipod, *Anonyx nugax*, Polar cod, seabirds (six species) and ringed seals in the North Water Polynya. Strong positive relationships were found between organochlorine concentrations and trophic level, providing clear evidence of OC bio-magnification in Arctic marine food webs (AMAP 2004).

For hexachlorobenzene (HCB), a significant non-linear decrease was observed for ringed seal since 1994. Concentrations have clearly decreased, particularly from 1994-1999. HCB levels in guillemot eggs showed a slight increase since 1999. In general, a similar trend as for PCBs was found.

In 2009, the latest AMAP assessment was performed. The results showed still decreasing trends for PCBs, sum DDT, α, β and γ- and sum-HCH in ringed seals from West Greenland (Riget *et al.* 2010).

7.1.3 Brominated flame retardants (BFRs)

Brominated flame retardants (BFRs) are chemicals used in materials to make them more fire-resistant, e.g. in polyurethane foam, plastics used in electric and electronic equipment, various textiles used in public environments (curtains, furniture coverings, carpets), rubber for coating wire, etc. Many countries have legislated high fire safety standards, which has led to an increase in the use of flame retardants (de Witt *et al.* 2010). Polybrominated diphenyl ethers (PBDEs) represent the most widely used flame retardants. PBDEs have similar physical and chemical properties as PCBs. PBDEs and other BFRs were analysed in blubber of ringed seals, partly retrospectively since the measurements were performed on the same samples used for the PCB analyses. BDE-47 was the only congener consistently found above the detection limit. It showed a significantly increasing trend of approx. 5% annually (Vorkamp *et al.* 2008). However, these levels were about 10 times lower than those observed in ringed seals from East Greenland (Riget *et al.* 2006, Letcher *et al.* 2009). Different PBDEs were also found in the eggs from the thick-billed murre and black guillemot north of Disko Bay. The measured concentrations were, however, also clearly lower than those found in eggs from East

Greenland. The general higher concentrations of these compounds in East Greenland indicate Western Europe and eastern North America as important source regions of these compounds via long range atmospheric transport and ocean currents (de Witt *et al.* 2010).

7.1.4 Perfluorinated compounds (PFCs)

Compounds belonging to this group, e.g. perfluorooctane sulfonate (PFOS), are used in a variety of consumer products and in industrial materials. They have been identified as global pollutants and are also known to bio-accumulate within marine food webs. The sources and transport routes of PFCs to the Arctic are not well understood. The two major supposed pathways are: atmospheric transport and oxidation of volatile precursors and the direct transport via ocean currents (Butt *et al.* 2010). In Greenland, an number of PFCs were analyzed in liver samples of polar bear, minke whale, ringed seal, black guillemot and shorthorn sculpin from various locations. PFOS was the dominant PFC detected in all species, except minke whale in which PFOSA levels were higher than PFOS. Indication for bio-magnification of PFOS was also found in species from East Greenland with the following trends: shorthorn sculpin < ringed seal < polar bear. West Greenland polar bears were not analyzed (Butt *et al.* 2010).

An increasing trend of PFCs has been observed since 1980 in ringed seals with an annual rate between 5.7% and 12.1. Generally, PFC levels were significantly lower in ringed seals from West Greenland compared to those from East Greenland (Bossi *et al.* 2005).

7.1.5 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, TBT levels are usually low, except close to harbours 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 even though the concentrations are rather low (Jacobsen & Asmund 2000, Strand *et al.* 2005).

Presence of TBT and the related compound triphenyltin (TPhT) has also indirectly been shown for the area around Thule Airbase in Northwest Greenland during a study performed in 2002 (Strand *et al.* 2006). Occurrence of imposex, a sensitive indicator for the presence of TBT, was found in the Arctic whelk *Buccinum fumarkianum* at several locations around Thule Airbase (Strand *et al.* 2006).

7.2 Polycyclic Aromatic Hydrocarbons (PAH)

PAHs are aromatic hydrocarbons from the crude oil and they are released to the environment through oil spills and discharge of produced water.

Levels of oil 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).

In Greenland, various studies on hydrocarbons, their patterns and sources have been performed mainly in Southwest Greenland (Mosbech *et al.* 2007b).

PAHs originate from two main sources: combustion (pyrogenic) and crude oil (petrogenic). PAHs represent the most toxic fraction of oil, and sixteen PAHs are included on lists of priority chemical contaminants by the World Health Organization and the U.S. Environmental Protection Agency (EPA).

7.2.1 PAH studies in Greenland

Total petroleum hydrocarbons (TPH) and PAH levels were measured at possible natural seeps in the Disko Bay area in 2005. Sediments and biota (blue mussels, shorthorn sculpins, Greenland cod) were taken from the coast of Nuussuaq Peninsula from onshore and offshore areas (Mosbech *et al.* 2007b). TPH levels in the sediments were relatively low and therefore gave no real indication of oil seeps or other local petrogenic sources. The PAH levels ranged from low values up to approx. 1600 µg/kg dry weight but there was no clear spatial pattern. However, samples from greater depths (200-400 m) and further away from the coast showed 3-4 times higher levels than those closer to the coast. The reason for this is presently not clear (Mosbech *et al.* 2007b).

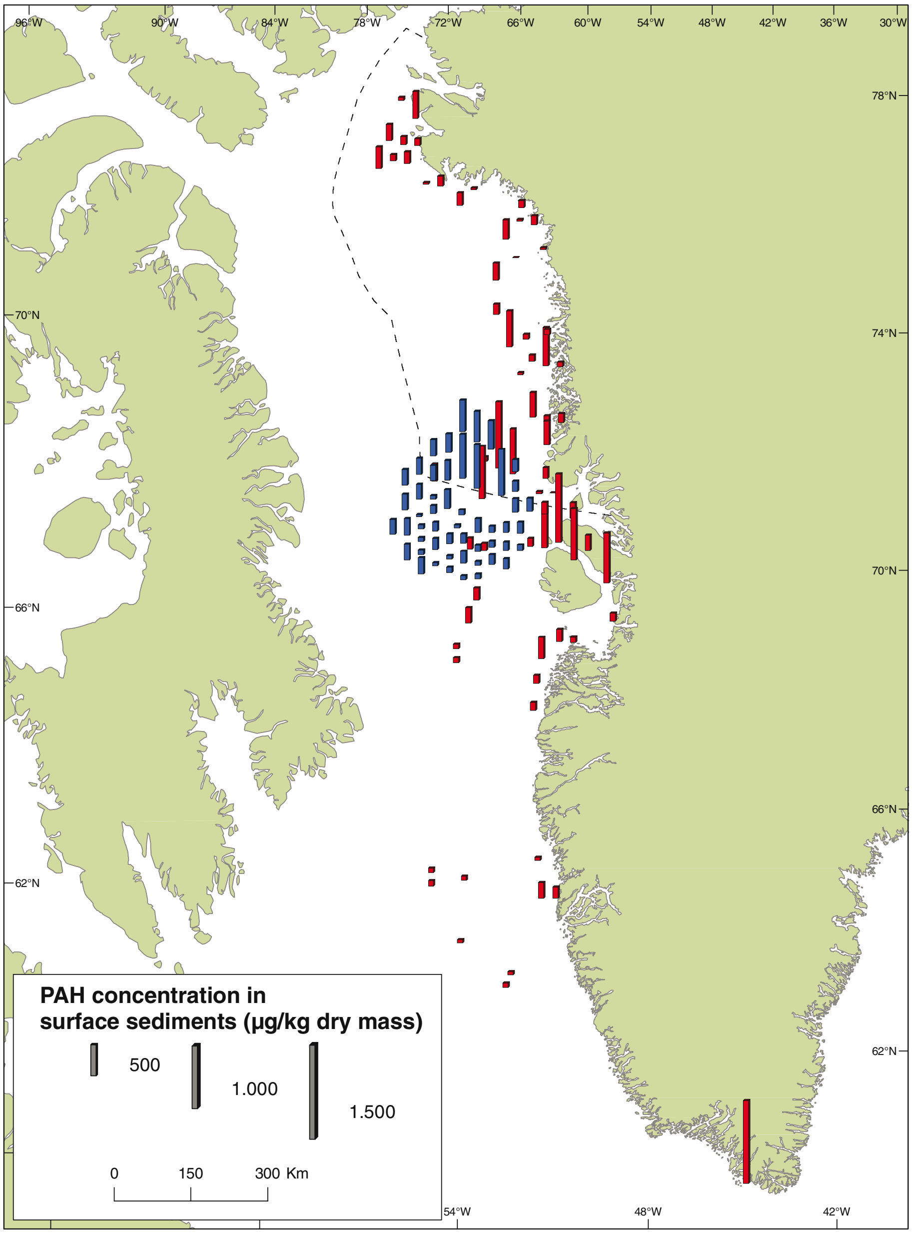
PAH levels in sediments, bivalves (Iceland scallop, Greenland cockle) and shorthorn sculpins were measured at dumpsites and reference sites around Thule Airbase in 2002. The PAH concentrations found in the bivalves were in the same range as in blue mussels from temperate marine environments, but higher than in blue mussels from Disko Bay previously studied. PAH concentrations in shorthorn sculpins did not differ between dumpsites and reference locations. The levels were, however, only about half of those measured in specimens at the Disko Bay area (Mosbech *et al.* 2007b).

In 2006, sediment samples were taken off West Greenland between (64° N and 71° N). Based on dry weight most samples were close to or slightly above background levels regarding the sum of all measured PAHs. Only three samples from Aasiaat Bay and two from Nuussuaq Basin clearly displayed higher concentrations.

In 2008, sediment samples were taken at 15 coastal locations in the eastern Baffin Bay. A set of 28 different polycyclic aromatic hydrocarbons (PAH) were analysed in the surface sediment layer (0-1 cm depth) (Sejr *et al.* 2010a, Box 1). At locations where PAH content was found to be elevated, additional samples from deeper layers within the sediment were processed. In general, PAH levels were low and could be regarded as background levels (Figure 49). A general trend was found showing that total PAH content decreased with increasing latitude, while two PAH chemical species (1- and 2-Methylnapthalene) showed a similar trend. All other PAH species showed no spatial patterns. Additionally, total PAH content decreased with increasing water depth, furthermore, specific PAHs, C1- and C2-Phenanthrener, also attenuated with depth. The reasons for these trends are currently not clear. An exception to the low PAH content was Kangersuatsiaq/Prøven harbour which showed a total PAH concentration of 621 µg/kg dw in the top sediment layer which decreased with depth to 385 and 397 µg/kg (9-10 and 10-15 cm respectively). This station was close to a small fish processing factory with some boat traffic to and from the harbour supporting the Kangersuatsiaq/Prøven settlement. This most probably explains the observed elevated concentrations. The concentrations found in this harbour are still about 10 times lower than those measured in the harbour of Sisimiut in 2006-2008 (Bach *et al.* 2009). Despite the elevated PAH concentrations at Kangersuatsiaq/Prøven harbour, which is slightly polluted, the surveyed area can be regarded as unpolluted.

In another study performed in 2008, PAH levels from offshore locations in the Baffin Bay have been analysed in surface sediments. PAH levels were usually very low,

Figure 49. 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 done by different companies/institutions: red bars: sampled by NERI (Aarhus University, Denmark) and blue bars by Capricorn (Cairn, Edinburgh). Note: Data is based on 23 PAH values which is included in The United States Environmental Protection Agency (EPA) compounds as priority pollutants.



except for one station (Figure 49). The higher PAH concentrations at this location could probably be attributed to the Marrat oil seep, which was studied some years ago (Mosbech *et al.* 2007b).

As part of a baseline study performed by Capricorn, PAH content in surface sediments was analysed offshore Disko Bay to document background level prior drilling. PAH content in the analysed sediment was usually low (Figure 49).

From the studies performed so far in the assessment area and in other parts of Greenland regarding PAH levels in biota and sediment (including sediments from offshore areas, municipal waste dump sites 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 level concentrations.

7.3 Conclusions on contaminant levels

In general, the AMAP studies have revealed that levels of organochlorines in Arctic biota are generally highest in the 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 for bio-magnification of PCBs and DDT. AMAP activities have also shown a decrease in the levels of some POPs (e.g. PCBs and DDT), as result of the introduction of bans and restrictions relating to their use in other parts of the world (AMAP 2004, Muir & de Witt 2010). At the same time, however, new persistent pollutants, currently produced in large quantities, are increasing (AMAP 2004, Muir & de Witt 2010). These substances have also been detected in animals from Greenland. Two brominated flame retardants (hexabromocyclododecane (HBCD) and tetrabromobisphenol A (TBBPA)) are produced in large volumes. In recent years, their presence has been reported in sediments and biota from the marine environment (Frederiksen *et al.* 2009). Concentrations of HBCDs in animals from West Greenland are generally lower than in the same species and tissues from East Greenland. The same effect has previously been described for other halogenated compounds such as PBDEs (Vorkamp *et al.* 2007).

The short overview given in this section, which is based on available data and information, documents that our present knowledge on contaminant levels in marine organisms from the Baffin Bay assessment area is still limited. Most of the studies have been carried out in certain areas, only covering the south and very north of the Baffin Bay assessment area.

Further studies are needed to fill in the gaps in order to better understand the extent to which biota in the potential oil exploration area might be impacted by contaminants and to serve as baseline for a future monitoring and assessment.

There are also major gaps concerning the potential impact of oil related pollution in relevant species living in the assessment area which might already be affected by POPs or metals.

In this respect we also need to know if the present contaminant loads have any biological impact, involving sublethal health effects or impairments.

7.4 Biological effects of contaminants

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 the 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 temperate regions, e.g. North Sea or Baltic Sea. The relevant questions therefore are whether the levels found in the Arctic are sufficiently high to cause biological effects and what the threshold level of impact might be.

Arctic species have very specific life strategies and population dynamics as a result of adaptation to the harsh environment. Moreover, their high fat content and seasonal turn over differs compared to temperate species (AMAP 2004). The lower temperatures in the Arctic are also likely to have an impact on the toxicity of contaminants.

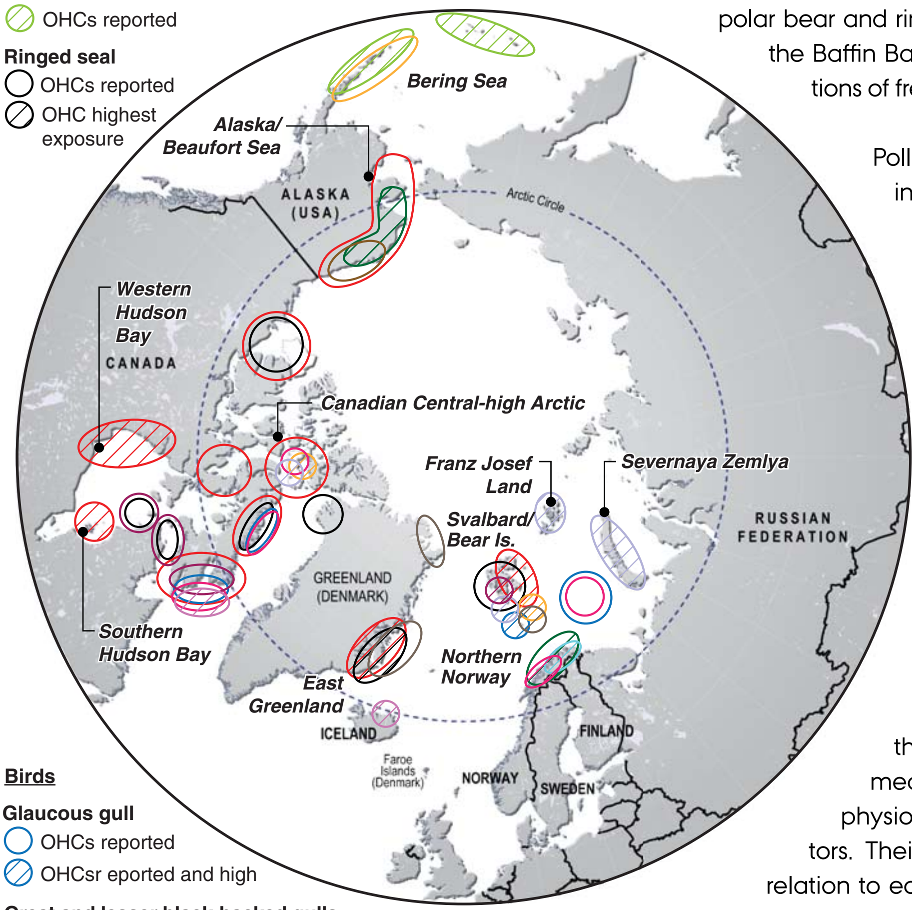
Limited data are available to determine whether polar species are more (or less) sensitive to contaminants than temperate species and hence whether the relationships between contaminant concentrations and impacts derived from temperate species can be applied to the sub- and high Arctic environment.

Recently, it has been demonstrated that the measured contamination levels in Arctic organisms may cause sub-lethal biological effects. Based on laboratory and field studies performed at Bear Island (Bjørnøya), western part of the Barents Sea, and in Svalbard it has been demonstrated that the present level of certain POPs found in polar bears and glaucous gulls have an influence on behavioural-, biochemical-, physiological- and immunological parameters affecting the health of these species (Gabrielsen 2007).

As part of the AMAP (2009) assessment, the most recent studies (post-2002) have been reviewed and summarized in regard to biological effects and how they are related to organohalogen contaminants (OHC) exposure (Letcher *et al.* 2010). Based on the 'weight of evidence' found in different studies performed on Arctic wildlife and fish, several key ('hotspot') species and populations have been identified (Letcher *et al.* 2010). Among those are East Greenland polar bear and ringed seals, Greenland shark from the Baffin Bay/David Strait and a few populations of freshwater Arctic char (Figure 50).

Pollution effects have been especially investigated on polar bears (*Ursus maritimus*) since this species exhibit the highest levels of certain contaminants in the Arctic. In particular the populations from East Greenland and Svalbard (Norway) have high levels (Kirkegaard *et al.* 2005, Sonne *et al.* 2004, 2005, 2006, 2007, 2009, Basu *et al.* 2009, Sonne 2010).

The response of marine animals to petroleum exposure via water, food or sediment has also been studied extensively in the laboratory and in the field by means of a number of biochemical, physiological and histological indicators. Their applicability and limitations in relation to ecological risk assessment after an oil spill has been assessed (Anderson & Lee 2006). However, as pointed out before, most of these studies have been performed in temperate regions.



Map source: UNEP

Figure 50. Based on the 'weight of evidence' found in different studies performed on Arctic wildlife and fish, several key ('hotspot') species and populations have been analysed. Among those are East Greenland polar bear and ringed seals, Greenland shark from the Baffin Bay/David Strait and a few populations of freshwater Arctic char (Source: Letcher *et al.* 2010).

8 Impact of climate change on the Arctic marine environment

D. Schiedek

8.1 Introduction

The Arctic marine environment has changed over the past several decades, and these changes are part of a broader global warming that exceeds the range of natural variability over the past 1,000 years as documented in the Arctic Climate Impact Assessment (ACIA 2005).

Since the publication of the ACIA, several indicators have shown further and extensive changes at rates faster than previously anticipated. Air temperatures are increasing, sea ice extend has decreased sharply with record low in 2007 and ice-free conditions were present in 2008 in both the Northeast and Northwest sea passage for the first time in recorded history (AMAP 2009). As multi-year ice is replaced by newly formed (first-year) ice, the Arctic sea-ice is becoming increasingly vulnerable to melting.

Global climate models indicate an additional warming of several degrees Celsius in much of the Arctic marine environment by 2050. Based on two different emissions scenarios (A2 and B2) and five global climate models it is projected that mean annual Arctic surface temperatures north of 60° N will be 2 to 4° C higher, compared to the present, by mid-century and 4 to 7° C higher toward the end of the 21st century (ACIA 2005, Walsh 2008). Other changes predicted for 2050 are a general decrease of sea level pressure and an increase of precipitation (ACIA 2005, Walsh 2008).

Ongoing and future warming will have an impact on the marine ecosystem and its biota in many ways (ACIA 2005, Moline *et al.* 2008), (Figure 51). An increase in water temperature has a direct influence on metabolism, growth and reproduction of organisms. Whether organisms remain in the area and adapt or relocate further north will depend on their acclimation capacity. Thus, potential long-term ecological effects will include changes in species distribution and diversity, affect-

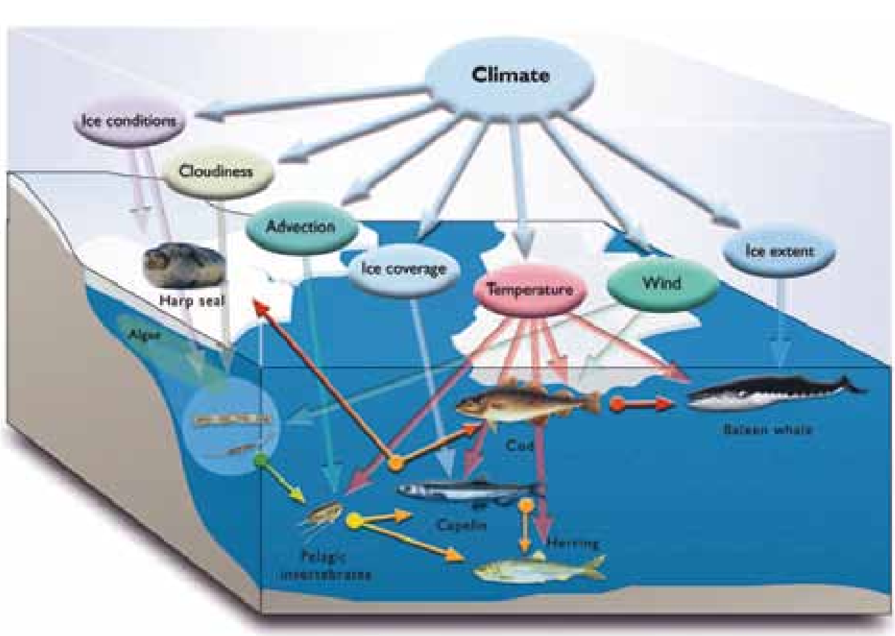


Figure 51. Different climate parameters that may impact the marine food chain, both directly and indirectly. From ACIA (2005).

Table 10. Summary of types of footprints of responses of Arctic marine organisms to climate change (Wassmann *et al.* 2011).

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

ing community composition and production and influencing ecosystems on local and regional scales. Reduction in sea ice, changes in snow cover, and rise in sea level will cause main habitat changes with severe consequences for marine mammals and seabirds. Changes in sea ice, water temperature, freshwater input and wind stress will also affect primary production and thus the timing, location and species composition of phytoplankton blooms. This will in turn affect the zooplankton community and the productivity of fish; e.g. 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. However, generalist predators are likely to be more adaptable to changed conditions than specialist predators.

It is already apparent that the Arctic marine ecosystem is changing in response to a warming climate. In reviewing published literature, Wassmann *et al.* (2011) found clear evidence for documented changes in Arctic marine biota for almost all components of the marine ecosystems, from planktonic communities to large mammals.

The evaluation is based on several types of footprints of responses of Arctic marine organisms to climate change, such as range shifts, including poleward range shift of subarctic species, changes in abundance, growth/condition, behaviour/phenology and community/regime shifts (Table 10).

Most information is available for marine mammals, particularly polar bears, and fish. The number of well-documented changes in planktonic and benthic systems was much lower, probably due to lack of relevant studies. It was also concluded that evident losses of endemic species in the Arctic Ocean, and in ice algae production and associated community remained difficult to evaluate due to the lack of quantitative reports of its abundance and distribution.

Some of the ongoing and expected changes are described below. In general, there is concern about the fate of Arctic species, particularly those in ice-associated communities.

8.1.1 Primary production and zooplankton

Climate change is likely to change primary production from strongly pulsed to a more prolonged and unpredictable production of diatoms (rich in polyunsaturated fatty acids) with consequences for the higher trophic levels (Kattner *et al.*

2007). Presently, Arctic ecosystems are dominated by two diatom-feeding copepod species (*Calanus glacialis* and *Calanus hyperboreus*). Both are favoured food for specialised Arctic seabirds and marine mammals, such as the little auk and bowhead whale. A prolonged production period could favour a mixed diatom-dinoflagellate community which could result in a food chain based on *Calanus finmarchicus/Metridia longa* (Weslawski *et al.* 2009), which are less valuable as food for Arctic planktivorous species (e.g. bowhead whale and little auk).

Arctic 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 Arctic ecosystems (McGuire *et al.* 2009).

Projections of future primary production for the Canadian Beaufort Shelf were used to describe the impacts of a reduction in sea ice cover duration and thickness and an increase in surface freshwater fluxes. The results of the model runs show, that the relative contribution of the ice algal and spring phytoplankton blooms to the annual primary production is reduced in the future owing to reduction in the length of the ice algal growth season (resulting from earlier snow and ice melt) and in the replenishment of nutrients to the mixed layer in winter. The model runs showed also an increase in the duration of the summer subsurface phytoplankton bloom, which favours the development of the main copepod species. This leads to an increase in export production that is greater than the increase in primary production (Lavoie *et al.* 2010).

8.1.2 Benthic ecology and diversity

Changes in zoobenthic communities due to climate change will mainly depend on the temperature tolerance of the present species and their adaptability. If warming continuous, sub-arctic and boreal species will become more frequent, causing changes in the zoobenthic community structure and probably its functional characteristics, especially in coastal areas.

There are already indications for changes in distribution, including northward range expansion of temperate species (Berge *et al.* 2005), change in productivity (Sejr *et al.* 2009), biomass or communities (Grebmeier *et al.* 2006). Similar changes have previously been observed during an intrusion of unusual warm water along the West Greenland coast and the Barents Sea in the 1920s and 1930s (Jensen 1939, Jensen & Fristrup 1950).

The pattern of occurrence and recent changes in the distribution of macrobenthic organisms in fjords and coastal (nearshore) Arctic waters has also been reviewed and future changes have been hypothesized (Weslawski *et al.* 2011). The predicted temperature rise in itself, will likely cause minor problems for coastal benthos, since nearshore living organisms are often adapted to a wide temperature range. More important for the coastal benthos are variables associated with temperature rise: increase of coastal turbidity and sedimentation, changes in ice cover, increase in storminess, increasing coastal erosion and freshening of surface waters.

The review by Weslawski *et al.* (2011) also revealed that coastal and fjordic diversity in the Arctic does not show a uniform pattern, and the expected changes will differ regionally and across ecosystem compartments. Two major areas of biotic advection have been indicated (the North Atlantic Current along Scandinavia to Svalbard and the Bering Strait area) where larvae and adult animals are transported from the species-rich sub-Arctic areas to species-poor Arctic areas (Weslawski *et al.* 2011). For these two areas it is expected that increased temperature associated with increased advection will increase the number of boreal-subarctic species and thus increase local biodiversity. However, local cold-water species might be suppressed. Two other large coastal areas, i.e. the Siberian shores and the coasts of the Canadian Archipelago are likely to be little influenced by advected waters. Here, the local Arctic fauna has to cope with increasing ocean temperature, decreasing salinity and a reduction in ice cover with unpredictable effect for biodiversity. On the other hand, the innermost basins of Arctic fjords are able to maintain pockets of very cold, dense, saline water and thus may act as refugia for coldwater species.

The complex environmental changes described here will reshape coastal communities and likely drive them to a new state, possibly close to or beyond a point of no return.

8.1.3 Fish and Fisheries

Fish form an essential link in Arctic food chains and they are also prey for many seabirds and mammal species in the Arctic. Temperature changes may influence fish populations both directly, through shifts to areas with preferred temperature, and indirectly through the food supply and the occurrence of predators. Changes in the distribution and abundance of fish populations will, therefore, have consequences for both fish prey as well as for predators depending on fish species.

Poleward extension in the distribution range of many fish species is very likely under the projected climate change scenarios. Some of the more abundant species likely to move northward due to the projected warming include Atlantic herring (*Clupea harengus*), Atlantic mackerel (*Scomber scombrus*) and Atlantic cod (*Gadus morhua*). The southern limits of colder water fish species, such as polar cod (*Boreogadus saida*) and capelin (*Mallotus villosus*) are likely to move northward. Greenland halibut (*Reinhardtius hippoglossoides*) possibly shifts its southern boundary northward or restrict its distribution more to continental slope regions (ACIA 2005).

Fish recruitment patterns are strongly influenced by oceanographic processes such as local wind patterns, mixing, and prey availability during early life stages; climate change impacts on these are difficult to predict. Recruitment success could be affected by changes in the timing of spawning, fecundity rates, larval survival rates, and food availability.

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, and temperature changes may have different effects for the different life stages of a species. If a change in temperature causes a species to shift its spawning areas, its continued success will depend on factors such as whether current systems in the new area take the eggs and larvae to suitable nursery areas, and whether the nursery areas are adequate in terms of temperature, food supply, depth, etc. Changes in spawning and nursery areas caused by climatic changes may, therefore, also lead to changes in population or species abundance (Dommasnes 2010).

Changes in the distribution of polar cod, during the next 30 years, have been modelled. Polar cod is a small, pelagic gadoid fish (less than 20 cm) which lives in the Arctic seas. It feeds on zooplankton and is not itself a target for large fisheries, but it is an important prey species for larger fish, seabirds and marine mammals. The modelling results indicate that both distribution and abundance of Arctic cod may be dramatically reduced (Cheung *et al.* 2008).

The loss of multi-year ice cover will profoundly affect Arctic ecology and will probably lead to positive fisheries effects. Positive effects of warming expected in the Arctic have already been documented for the Arcto-Norwegian cod distributions and abundance (MacNeil *et al.* 2010). This population shows stronger year classes in warm years and poor year classes in cold, and warming has led to a northern range expansion in Norway (Drinkwater 2006, 2009). As a result of warming, yields are predicted to increase by approximately 20 per cent for the most important cod and herring stocks in Iceland, and approximately 200 per cent in Greenland over the next 50 years (Arnason 2007). Climate-driven fish invasions into the Arctic are expected to exceed those of any other Large Marine Ecosystem (Cheung *et al.* 2010).

Despite the loss of the current marine ecosystem and positive effects of climate warming predicted for Arctic fisheries, it is still not clear how invading species interact with native species and how this effects food web interactions.

8.1.4 Marine mammals and seabirds

The impacts of climate change on marine mammals and seabirds are likely to be profound, but not so easy to estimate since patterns of changes are non-uniform and highly complex (ACIA 2005). There is a limit to how far north High Arctic species can shift to follow the sea ice. If the loss of sea ice is as dramatic, temporally and spatially, as has been projected by ACIA-designed models, negative consequences for Arctic animals that depend on sea ice for breeding and foraging can be expected within the next few decades.

Laidre *et al.* (2008a) compared seven Arctic and four sub-Arctic marine mammal species in regard to their habitat requirements and evidence for biological and demographic responses to climate change. Sensitivity of the different species to climate change was assessed using an 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}). Based on the index, the hooded seal, the polar bear, and the narwhal, appear to be the three most sensitive Arctic marine mammal species, primarily due to their reliance on sea ice and specialised feeding behaviour. The least sensitive species were the ringed seal and bearded seal, primarily due to large circumpolar distributions, large population sizes, and flexible habitat requirements. In using a conceptual model, Moore & Huntington (2008) estimated the impacts and resilience of marine mammal species to changes in sea ice in combination with follow-up changes in benthic and pelagic communities. The response of the mammals on habitat loss (sea ice) and change in food sources will differ depending on whether they are ice-obligate (e.g. polar bear, ringed seals), ice-associated (certain seals, white whale, narwhal, bowhead whale and walrus) or seasonally migrant species (i.e. fin and minke whales).

Polar bears appear to be at risk since their habitat is changing and there is limited scope for a northward shift in distribution. According to Derocher *et al.* (2004) spatial and temporal sea-ice changes will lead to shifts in trophic interactions involving polar bears through reduced availability and abundance of their main prey: seals. In the short term, climatic warming may improve polar bear and seal habitat at higher latitudes over continental shelves if currently thick multi-year ice is replaced by annual ice with more leads, making it more suitable for seals. A cascade of impacts beginning with reduced sea ice will be manifested in reduced adipose stores, leading to lowered reproductive rates. As sea ice thins, it is likely to be more fractured and labile and more reactive to winds and currents. As a result, polar bears will need to walk or swim more and thus use greater amounts of energy to maintain contact with the remaining preferred habitats (Derocher *et al.* 2004).

The increased fragmentation and loss of sea ice habitat, as a consequence of climate change, is the single most critical conservation concern for polar bears. Global warming has been amplified at high latitudes in the northern hemisphere and a number of studies have documented significant reductions in extent and duration. Recent predictions of continued climate warming show unidirectional, negative changes to sea ice, although the timing and rate of change will not be uniform across the circumpolar Arctic. However, because of their dependence on sea-ice habitat, the impacts of continued climate change will increase the vulnerability and risk to the welfare of all polar bear subpopulations. Population and habitat modelling have projected substantial future declines in the distribution and abundance of polar bears, thickness and age of sea ice (Lunn *et al.* 2010).

Projections of polar bear sea ice habitat distribution in the polar basin during the 21st century were developed to understand the consequences of anticipated sea ice reductions on polar bear populations. Location data from satellite-collared polar bears and environmental data (e.g. bathymetry, distance to coastlines, and sea ice and collected from 1985 to 1995) were used to describe habitats that polar bears preferred in summer, autumn, winter and spring (Durner *et al.* 2009). Monthly maps of 21st-century sea ice concentration projected by 10 general circulation models (GCMs) used in the Intergovernmental Panel of Climate Change Fourth Assessment Report, indicated habitat losses in the polar basin during the 21st century. Mean loss of optimal polar bear habitat was greatest during summer; from an observed 1.0 million km^2 in 1985-1995 (baseline) to a projected multi-model mean of 0.32 million km^2 in 2090-2099 which presents a reduction of 68 %. Projected winter losses of polar bear habitat were less: from 1.7 million km^2 in 1985-1995 to 1.4 million km^2 in 2090-2099 (−17 % change). Durner *et al.* (2009) concluded that reduction in the total amount of optimal habitat will likely reduce polar bear populations, but exact relationships between habitat losses and population demographics are not known. The projected change in habitats will probably affect specific sex and age groups differently and may ultimately preclude bears from seasonally returning to their traditional ranges.

For widely distributed seabirds, such as the thick-billed murre, changes in the extent and timing of sea-ice cover over the past several decades are leading to changes in phenology and reproduction with adverse consequences for nestling growth (Gaston 2010). The direct response of common eiders, another important seabird for the Arctic ecosystem, to climate change is currently under investigation in several countries. In Iceland, local weather conditions appear to affect nesting dates and clutch sizes, although not consistently between colonies. The North Atlantic Oscillation Index was found to have no effect on the survival of eider females in Finland. The management of human harvest of eiders or their products, and the management of introduced predators such as foxes (*Vulpes* spp.) and mink (*Mustela vison*), will remain important (Merkel & Gilchrist 2010). In East Greenland common eiders have expanded their breeding range over several 100 km towards north in recent decades as a response to more open waters along the coasts (Boertmann & Nielsen 2010).

The ivory gull is a sea ice obligate species, which face the same threats as the polar bear and there is serious concern for the future of the species (Gilg *et al.* 2009, 2010).

More and more information has been gathered in the past years to provide evidence that change in Arctic climate has a large potential to modify the marine ecosystems, either through a bottom-up reorganization of the food web by altering the nutrient or light cycle, or top-down reorganization by altering critical habitat for higher trophic level (Macdonald *et al.* 2005). At present, we have only started to understand the possible impacts and consequences of climate change for the Arctic marine environment. Complexity arising from alterations to the density, distribution or abundance of keystone species at various trophic levels, such as polar bears and polar cod, 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 Arctic biodiversity (CAFF 2010).

8.2 Interactions between climate change and other stressors

Climate change will have profound impacts on the ecosystems and their components in the Arctic, and it will act on populations in combination with the human induced stressors such as oil spill, contaminants (see below) and hunting. Most true Arctic species populations such as polar bears, ivory gulls and little auks, will most likely suffer from the changes and become much more sensitive to the other human induced stressors. This fact makes it important to consider all the stressors in combination when assessing impacts of especially major oil spills in the future.

8.2.1 Climate change and contaminants

The Arctic environment is now clearly affected by climate change, but also by human releases of contaminants as indicated in Chapter 7 of this SEIA.

Climate change will affect contaminant exposure and toxic effects (Macdonald *et al.* 2005) and both forms of stress will impact aquatic ecosystems and biota in many ways (Schiedek *et al.* 2007, Noyes *et al.* 2009). An overview of possible changes and consequences is given in Table 11.

Pathways, distribution patterns and/or toxicity of certain contaminants are likely to change; native organisms are likely to become less tolerant to contaminant exposure due to higher temperatures (Macdonald *et al.* 2005, Schiedek *et al.* 2007). Species distribution ranges will change, and some will be displaced by temperate species which might differ in their contaminant tolerance. Additional possible risks could be caused by oil contamination due to offshore oil and gas resources be-

Table 11. Climate change-induced toxicological effects of contaminants on wildlife (Noyes *et al.* 2009 and references therein)

Climate change-induced effect	Relationships/Interactions	References
Altered uptake and elimination	• ↑ temperature = ↑ uptake of toxicants • ↑ temperature = ↑ elimination • ↑ temperature = remobilization of bioaccumulated POPs	(Buchwalter et al., 2003; Lydy et al., 1999; Maruya et al., 2005)
Increased toxicity	• ↑ temperature = ↑ toxicity • ↑ temperature = ↑ metabolism and potentially altered metabolite profiles • Toxicant exposure may limit capacity of species and populations to acclimate to altered temperatures. • Pollutant-exposed ectotherms and species at the edge of their physiological tolerance range may be especially sensitive to temperature increases.	(Anderson and Peterson, 1969; Boone and Bridges, 1999; Brian et al., 2008; Broomhall, 2002, 2004; Buckman et al., 2007; Capkin et al., 2006; Gaunt and Barker, 2000; Gordon, 2003; Heath et al., 1994; Lydy et al., 1999; Monserrat and Bianchini, 1995; Patra et al., 2007; Silbergeld, 1973)
Altered environmental salinity	• ↓ solubility and ↑ bioavailability of pesticides/POPs ("salting out effect") • ↑ salinity + ↑ POP/pesticide exposure may alter osmoregulation due to altered enzymatic pathways	(Fortin et al., 2008; Heugens et al., 2001; Moore et al., 2003; Schiedek et al., 2007; Schlenk and El-Alfy, 1998; Schwarzenbach et al., 2003; Song and Brown, 1998; Tachikawa and Sawamura, 1994; Wang et al., 2001; Waring and Moore, 2004)
Altered ecosystems	• Altered POP sequestration and/or remobilization through shifts in food sources and starvation events • Shifts in disease vector range and severity coupled with toxicant exposure inhibiting immune response may leave wildlife more susceptible to disease • Low level exposures may impair organism acclimation to ecosystem alterations induced by climate change • Climate change induced changes in trophic food webs may alter POP bioaccumulation and biomagnification	(AMAP, 2004; Braune et al., 2005; Furnell and Schweinsburg, 1984; Jenssen, 2006; Macdonald et al., 2005, 2003; Olafsdottir et al., 1998; Ramsay and Stirling, 1982; Schiedek et al., 2007, Stirling et al., 1999)

ing developed as well as increased ship traffic (Skjoldal *et al.* 2007, Arctic Council 2009). Climate change may also lead to increased pollution loads resulting from an increase in precipitation bringing more river borne pollution northward (Macdonald *et al.* 2005).

Bio-magnification of many persistent organic pollutants (POPs) is particularly high for higher trophic levels (i.e. mammals); these animals are also among the most vulnerable to climate change as described above. Relationships between various POPs and hormones in Arctic mammals and seabirds imply that these chemicals pose a threat to the endocrine systems of these animals, in particular the thyroid hormone system (TH), but effects have also been seen in sex steroid hormones and cortisol (Jenssen 2006). Different endocrine systems are important for enabling animals to respond adequately to environmental stress, and endocrine-disrupting chemicals (EDCS) may interfere with the adaptation to increased stress, e.g. that induced by climate change (Jenssen 2006). Presently, possible interactions between climate change and contaminants have not been studied in great detail and therefore our knowledge is still very limited.

Climate change is expected to alter environmental distribution of contaminants and their bio-accumulation due to changes in transport, partitioning, carbon pathways, and bio-accumulation process rates. Magnitude and direction of these changes and resulting overall bio-accumulation in food webs is currently not known. In a study performed by Borgå *et al.* (2010) a first attempt has been made to quantify the effect of climate change (i.e. increased temperature and primary production). It was assumed that there were no changes in food web structure and in total air and water concentrations of organic contaminants. To determine the effect of climate change, a bio-accumulation model was used on the pelagic marine food web of the Arctic, where climate change is expected to occur fastest and to the largest magnitude. The effect of climate change on model parameters and processes and on net bio-accumulation, were quantified for three substances (g-hexachlorocyclohexane (HCH), polychlorinated biphenyl (PCB)-52, and PCB-153) and for two possible climate scenarios. It was found that increased temperature and primary production reduced the overall bio-accumulation of organic contaminants in the Arctic marine food web, with the largest change being for PCB-52 and PCB-153 (Borgå *et al.* 2010). In future studies other aspects such as altered contaminant transport or food web structure have to be addressed.

The influence on recent changes in feeding ecology (1991-2007) in polar bears from the western Hudson Bay subpopulation on the exposure and accumulation of contaminants was reported by McKinney *et al.* (2009). Differences in timing of the annual sea ice breakup explained a significant proportion of the diet variation among years which resulted in increases in the tissue concentrations of several chlorinated and brominated contaminants. The increased levels coincided with an increase in the consumed proportions of open water-associated seal species compared to ice-associated seal species in years of earlier sea ice breakup. This demonstrate that climate change is a modulating influence on contaminants in this polar bear subpopulation and may pose an additional and previously unidentified threat to northern ecosystems through altered exposures to contaminants (McKinney *et al.* 2009).

Climate change may also alter patterns of POP bio-accumulation and bio-magnification by altering bottom-up or top-down mechanisms controlling trophic food webs (Braune *et al.* 2005, Macdonald *et al.* 2005, Schiedek *et al.* 2007). Climate change-induced alterations in bottom-up controlling mechanisms, such as altered nutrient and primary production, may lead to the addition or removal of trophic levels (Macdonald *et al.* 2005). This in turn could shift predators higher or lower in the aquatic food web, leading to a respective increase or reduction of POPs. Top-down alterations in trophic structures elicited by the changing climate, for example, could involve the loss or diminished populations of higher trophic level species leading to consumption further down the food chain and reduced POP bio-magnification potential.

Increased temperature and salinity linked to climate change could enhance the toxicity of some POPs and other pesticides in aquatic biota. Altered bio-transformation of contaminants to more bioactive metabolites appears to be an important mechanism by which climate change enhances chemical toxicity. Moreover, these climate change and contaminant interactions could compromise homeostasis and physiological responses, potentially impairing species fitness, reproduction, and development (Brian *et al.* 2008, Heugens *et al.* 2001, Schiedek *et al.* 2007).

The complex interactions between climate change and pollutants may be particularly problematic for species living at the edge of their physiological tolerance range. For most species, there are optimum ranges of temperature, salinity, pH, moisture, etc., and organisms living under conditions that approach their tolerance limits are often more vulnerable to additional stressors, such as climate change and chemical pollution (Noyes *et al.* 2009 and references therein). Species with narrow ranges of tolerance to changing environmental conditions may have difficulty acclimating to climate change.

Altered habitats caused by the rapidly changing climate also could trigger species migrations that ultimately push populations into suboptimal regions where they may experience reduced overall fitness and diminished tolerance to toxicant exposures (Schiedek *et al.* 2007).

8.3 Climate change implications for the Baffin Bay area

Many of the aspects in relation to ongoing climate change, described in the previous sections are of relevance for the assessment area and will be discussed in the following.

Annual mean temperatures for selected stations in West Greenland, reaching back to 1873, document that there has been a warming period in the first three decades of the twentieth century, followed by cooling until the mid-1970s before temperatures increased again (Stendel *et al.* 2008).

According to Parkinson & Cavalieri (2008), the Baffin Bay/Labrador Sea region experienced a cyclical rise and fall in winter sea-ice extent through two cycles of about 10 years each from 1979 through 1998. Continuation of this cyclical pattern would have yielded a rise in ice extent over the next several years; however, this did not occur. Instead, the overall decrease in the extent of the ice has been by continued. The net result includes statistically significant negative trends in the monthly deviations, yearly averages, and all four seasonal averages (Parkinson & Cavalieri 2008).

Based on a regional study using the HIRHAM4 model a clear increase in temperature has been projected for Greenland, with greatest warming in winter and spring (Stendel *et al.* 2008). Simulated mean near-surface (2 m) temperature change projected a general temperature increase of 3° C in winter, 4° C in spring and 2° C in summer and autumn for the period 2021-2051 compared to a modelled present day situation (1961-1990). For the later period (2051-2080), winter temperature increases accelerate considerably, reaching 7-8° C throughout the Arctic and

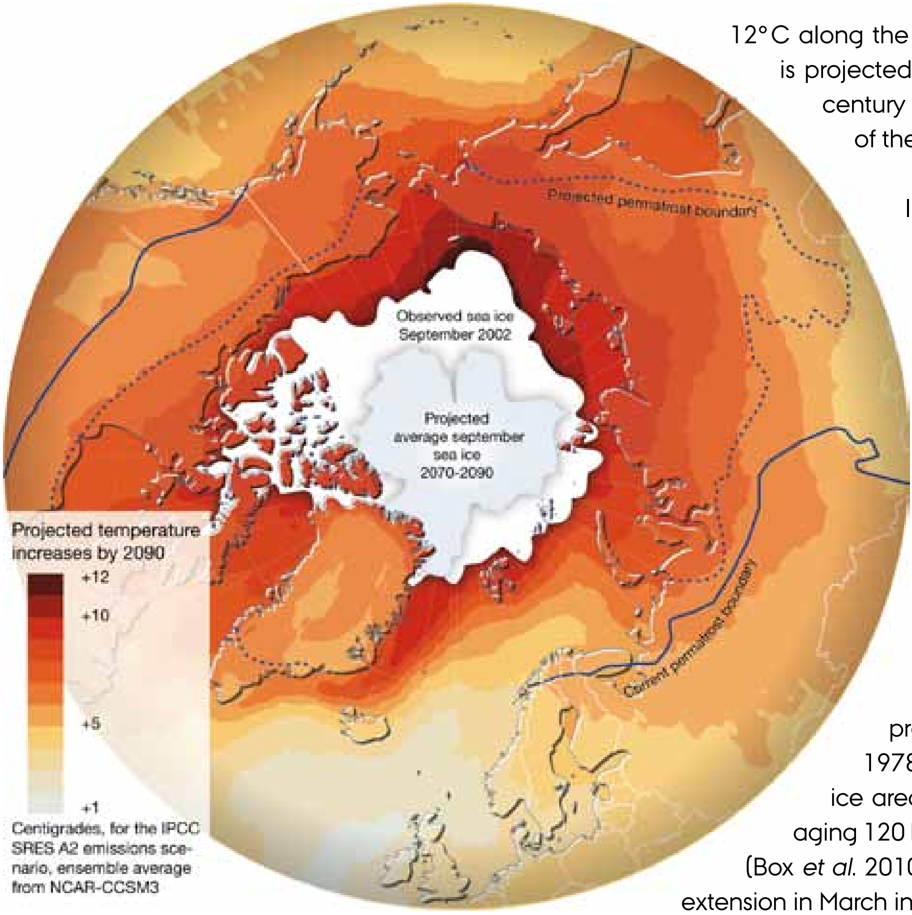


Figure 52. Projected temperature increases in the Arctic due to climate change, to 2090 (NCAR-CCM3, SRES A2 experiment). UNEP/GRID-Arendal Maps and Graphics Library 2008. Available at: http://maps.grida.no/go/graphic/projected-temperature-increases-in-the-arctic-due-to-climate-change-2090-ncar-ccm3-sres-a2-experimen

12°C along the east coast (Figure 52). Precipitation is projected to increase by approx. 8 % by mid-century and by about 20% towards the end of the 21st century.

In 2010, climate in Greenland was marked by record-setting high air temperatures, ice loss by melting, and marine-terminating glacier area loss. Summer seasonal average (June-August) air temperatures around Greenland were 0.6 to 2.4°C above the 1971-2000 baseline and were highest in the west. A combination of a warm and dry 2009-2010 winter and the very warm summer resulted in the highest melt rate since at least 1958 and an area and duration of ice sheet melting that was above any previous year on record since at least 1978. There is now clear evidence that the ice area loss rate of the past decade (averaging 120 km^2/year) is greater than before 2000 (Box *et al.* 2010). From 1953 and until 2001 sea ice extension in March in West Greenland increased by about 1.4% per decade (Stern & Heide-Jørgensen 2003). After 2001, rapid declines in mid-March sea ice extension has been observed in West Greenland, and the smallest March sea ice extension was reached in 2005 (Heide-Jørgensen & Stern unpubl. data). After 2005 some recovery in sea ice extension has been observed and in 2008 the sea ice had almost recovered to normal values for the period 1980-2000. After 2008 the sea ice extension dropped again and reached another low level in 2009. Over the period 2000 to 2008 the winter sea ice extent along West Greenland declined from approx. 81.000 km^2 to 56.000 km^2, i.e. a loss of about 1/3 (Heide-Jørgensen & Stern unpubl. data).

8.3.1 Zooplankton

Direct information concerning the impact of climate change on the zooplankton in the assessment area is not available. The influence of temperature on *Calanus* distribution has been studied experimentally. It was concluded that depending on the species, a future warmer climate will cause a shift in the zooplankton community structure towards the smaller less energy rich *C. finmarchicus* (Kjellerup *et al.* submitted). This scenario will presumably cause a trophic cascade due to less energy content per individual (Falk-Petersen *et al.* 2007). In addition, the share in biomass accounted for by *C. finmarchicus* will increase (Hirche & Kosobokova 2007) due to its higher growth rate and short life cycle (Scott *et al.* 2000). Thus, a regime shift towards *C. finmarchicus* will very likely also impact the little Auk negatively (Karnovsky *et al.* 2003) and favouring certain intermediate species like herring (Falk-Petersen *et al.* 2007).

The influence of temperature on copepod life history has also been analysed. Depending on the species, reproductive success improved due to increased food availability and higher temperature, resulting from reduced ice cover. It was predicted that a climate-induced reduction in the duration of ice cover will favour the population growth of the predominant large calanoid copepods and *Pseudocalanus* on Arctic shelves (Ringuette *et al.* 2002).

8.3.2 Benthos

Composition of the benthic community, its diversity and biomass in the Baffin Bay must be regarded as dynamic parameters that not only show variability in space but also temporal, i.e. during the coming decades.

Exactly how climate change will impact the benthos in eastern Baffin Bay in the future is difficult to predict. In general, reduction of the annual sea ice cover is expected to increase marine productivity in general also in the high Arctic (Blicher *et al.* 2007, Sejr *et al.* 2009). At present it is difficult to predict how increased productivity might influence the species composition and diversity. Owing to the northward flowing coastal currents influenced by Atlantic water along the West Greenland cost (Weslawski *et al.*2011), a potential transport and northward range expansion of sub-arctic species is possible if temperatures and productivity increase in the future. The Greenland West coast might thus be more prone to changes in range expansion compared to the East Greenland coast dominated by the south flowing East Greenland Current.

8.3.3 Fish and Fisheries

The interaction between changing climate and distribution of certain fish species has been documented for previous warming period off Greenland with consequences for the abundance of Atlantic cod and Greenland halibut (Horsted 2000, Stein 2007, Drinkwater 2006), and distribution of other species (Jensen 1939, Jensen & Fristrup 1950). Ecosystem changes associated with the warm period during the 1920s and 1930s included a general northward movement of fish. Boreal species, such as cod, haddock and herring expanded farther north while colder water species such as capelin and polar cod retreated northwards. Higher recruitment and growth led to increased biomass of important commercial species (i.e. cod and herring). During a period of decreasing air and ocean temperatures, cod abundance (including cod larvae) declined again in this region (Rätz 1999, Horsted 2000, Drinkwater 2006). Coinciding with the decrease in cod was an increase in northern shrimp (*Pandalus borealis*) and Greenland halibut (Buch *et al.* 2004). Meanwhile, the shrimp fishery has replaced cod as a dominant industry in West Greenland (Hamilton *et al.* 2003).

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

During the warming period in the 1920-1930, Jensen (1939) and Tåning (1949) documented changes in many other fish species (e.g. spotted wolffish and herring). Also benthic species such as blue mussels (*Mytilus edulis*) and common starfish (*Asterias rubens*) spread northward during the warming period 1920-1930. Some of these more temperate species including herring, coalfish and redfish reproduced successfully in areas north of their previous range. On the other hand, colder water species such as capelin no longer migrated as far south along the West Greenland coast and their abundance in southwestern Greenland decreased while it increased northward as far as Thule. Greenland shark (*Somniosus microcephalus*) retreated from the region off south-western Greenland while densities in the colder, more northern regions increased. New immigrants came to Greenland including tusk (*Brosmius brosme*), ling (*Molva vulgaris*), witch (*Pleuronectes cynoglossus*) and the jellyfish *Halopsis ocellata*. It was suggested that most of these new species probably arrived through advection from Iceland (Tåning 1949).

8.3.4 Marine mammals

Vibe (1967) made the first quantitative observations of the impacts of climate change on the distribution and abundance of different types of sea ice and some of their consequences for Arctic marine mammals in the early 1900s. He noted that multi-decadal environmental fluctuations during 1810-1960 influenced the density and distribution of top predators such as eider, ringed seals, polar bears, harp seals, walrus or different whale species (narwhal, white whale, Bowhead whale) in West Greenland.

Polar bears

Amstrup *et al.* (2007) incorporated projections of future sea ice in four different 'ecoregions' of the Arctic, based on 10 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 region') – including the Baffin Bay – 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 populations in the seasonal ice ecoregion ca. 45 years from now (22-32% decline ca. 100 years from now), whereas the other model (quasi-quantitative 'Bayesian network population stressor model') predicted extinction of bears in this ecoregion – including Baffin Bay and Davis Strait – by the mid-2100 century.

Since 1979 the spring break-up of the sea ice in Baffin Bay has occurred significantly earlier in the season and the total amount of sea has decreased since ca. 2000 (Stirling & Parkinson 2006).

Also of note are the significant trends in loss of sea ice on the banks of West Greenland which are an important spring foraging habitat for polar bears. Between 1979-2010 the average sea ice concentration on the banks of western Greenland (0-300 m) in April, May and June within the boundaries of the Baffin bay polar bear population has decreased by ca. 25% (Laidre, unpubl. data).

Bowhead whales and narwhals

Both are important species in the assessment area. They congregate in large numbers in spring in Disko Bay and eastern Baffin Bay, which are subject to great climatic variability. Within the past decade dramatic physical changes have been detected along West Greenland including increased sea surface temperatures and reduced extension of sea ice. Climate change will affect the bowhead whales and the narwhals both directly by the physical changes in the sea ice conditions in Disko Bay and along West Greenland, but also by changes in both primary production and composition and productivity of the secondary production.

The recent massive reduction of the sea ice makes it easier for the narwhals to cross the Baffin Bay and reach the foraging grounds in Eastern Baffin Bay and in Disko Bay. It also provides new foraging opportunities in coastal areas of Disko Bay that previously were covered with landfast ice until late in spring. To some extent the narwhals seem to benefit from these changes by using ice free coastal areas of West Greenland extensively for feeding in spring but there is also a tendency for the narwhals to stay in close proximity of the sea ice in Baffin Bay for an extended period in spring.

Bowhead whales feed intensively in the Disko Bay area and they primarily feed on calanoid copepods that occur in dense aggregations in pre-ascending stages at depths of 100-200 m (Heide-Jørgensen *et al.* submitted). They primarily target *Calanus hyperboreus* and *C. glacialis* and but also the more Atlantic *C. finmar-*

chicus is part of the diet. As indicated in the previous section, the distribution of *C. finmarchicus* is increasing in the Arctic and if temperature changes continue likely to outcompete the two Arctic copepods. *C. finmarchicus* is a smaller and faster reproducing copepod species and its lipid content is only 4 to 10% of the lipid content of the two other species (Scott *et al.* 2000). At present, it is impossible to predict what the effects would be on the bowhead whales if there is a shift in the copepod community towards the more temperate *C. finmarchicus.*

One factor that supports the resilience of bowhead whales to climate changes is their ability to explore large areas of the Arctic and move considerable distances over short time. This plasticity in migration patterns may allow the bowhead whales to abandon unsuitable habitats and focus on areas where foraging conditions are optimal. At present the conditions, particular in and west of Disko Bay are however of outstanding importance to the bowhead whales and there are no signs that climate changes negatively impacts their use of this area. On contrary, Disko Bay must be classified as one of the most important bowhead whale habitats worldwide; it is used extensively for foraging by mature whales of both sexes and it is especially important for mature females that – aside from feeding – are also mating in the bay (Heide-Jørgensen *et al.* submitted).

Narwhals feed intensively on Greenland halibut at depths of 500-1000 m (Laidre & Heide-Jørgensen 2005b). Halibuts spawn in southern Davis Strait and the larvae drift north and settle on the banks of West Greenland. Presently, it is not possible to predict what the effects would be on the narwhals if the recruitment and dispersal of halibut from Davis Strait north to the shelves in Baffin Bay is affected by climate change, but changes in density of halibut on the feeding grounds in Baffin Bay could negatively affect the growth and reproduction of narwhals.

At present the conditions in the eastern part of Baffin Bay are however of outstanding importance to the narwhals and there are so far no signs that climate change negatively have impacted their use of this area.

8.4 Concluding remarks

The examples given in this chapter clearly document that ongoing climate change is likely to result in a clear, radical shift in the abundance and occurrence of certain species with significant impact on community structure and thus functioning of the ecosystem off West Greenland/Eastern Baffin Bay.

Changes in species composition on all trophic levels and occurrence of fish species with relevance for commercial fisheries are likely, resulting in increased fishing activities in the area.

Presently, we do not know the adaptation capacity of native species and the extent to which they might be more sensitive to potential impact of oil exposure under these changing environmental conditions. This has to be taken into account when environmental impact assessments are conducted in relation to ongoing and future oil exploration activities.

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. Boertmann *et al.* 1998, Mosbech 2002, Mosbech *et al.* 1996, 1998, 2007a), information from the oil spill sensitivity atlases prepared for the region (Mosbech *et al.* 2004a, Stjernholm *et al.* 2011) and from information collected by the Marine Mammals and Seabird Observers (MMSO) on the ships carrying out seismic and other geophysical studies for the oil companies. All summarised in the previous Chapters 3 to 8. Moreover several studies were initiated specifically for the present assessment, see Section 13.

9.1.1 Boundaries

The assessment area covers the area described in the introduction (Figure 1). It is the region which potentially can be impacted by activities related to oil exploration and exploitation. However a large and long-lasting oil spill deriving from one of the licence areas, has the potential to impact much further, including coasts both north and south of the assessment area and also areas within the Canadian EEZ. An oil spill from a tanker transporting crude oil from a future production site have the potential to impact areas far from Greenland depending on where oil is spilled.

The assessment includes, as far as possible, all activities associated with an oil field, from exploration to decommissioning. Exploration activities will take place in the summer and autumn months due to ice cover in winter and autumn. Production activities will, if decided and initiated, take place throughout the year. But how production facilities eventually will be established is presently not known. A setup could 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 ecological components in the area both in time and space. Interactions are then evaluated for their potential to cause impacts.

Since it is not possible to evaluate all ecological components in the area, the concept of Valued Ecosystem Components (VEC) has been 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 include important flora and fauna, habitats (also temporary and dynamic like the marginal ice zone and polynyas) and processes such as the spring bloom in primary production.

The VECs selected here give a fair impression of the ecosystem and are species and events which potentially can be impacted by oil activities in the assessment area, and also species and events where changes can be detected (see Section 4.9).

The spatial extent of effects is indicated as local, regional, national or global. Local refers to impacts in the nearby environment (up to ~ 100 km^2). Regional encompasses effects on wider areas including the entire assessment area. The extent of the national or global scale is evident.

The nature and extent of environmental impacts from petroleum activities can be evaluated on different scales (or a combination of these):

- from individuals to populations
- temporal scale – from immediate over short term to long term
- spatial – from local to global

However, quantification of the potential impacts on ecosystem components is difficult. Many factors contribute to the uncertainty of the assessment: For example is the location of specific sites for activities only known in a few cases. The physical properties of oil eventually discovered and potentially spilled are also unknown, and there still lack of knowledge concerning important ecosystem components and how they interact. Finally, climate change complicate the assessment of impacts.

In order to assess impacts many sources have been drawn upon. Especially important in this context are the Arctic Council Oil and Gas Assessment (Skjoldal *et al.* 2007), the extensive literature from the *Exxon Valdez* oil spill in Alaska in 1989 and the Norwegian EIA of hydrocarbon activities in the Lofoten-Barents Sea (Anonymous 2003). Relevant research results on toxicology, ecotoxicology and sensitivity to disturbance have also been included.

Many uncertainties still remain and expert judgement or general conclusions from research and EIAs carried out in other Arctic or near-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 related to exploration are temporary and will be terminated after a few years if no commercial discoveries are made. Another important aspect in relation to exploration is that activities only can take place during the few months when the sea is more of less free of ice. However in 2010 a company carried out 2D-seismic surveys in lightly ice covered waters off Northeast Greenland, aided by a large ice breaker.

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 below, 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 concerns to the sound generation from the seismic sound sources 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 2004a). 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 which 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, the sound pressure may be significantly higher than expected 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, peak to peak) more than 10 km from a seismic array (Madsen *et al.* 2006).

Another issue rarely addressed is that airgun arrays generate significant sound energy at frequencies many octaves higher than the frequencies of interest for geophysical studies. This increases concern regarding the potential impact particularly on toothed whales which can detect the high frequency sounds (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 1992).

It has been estimated that adult fish react to an operating seismic array at distances of more than 30 km, and that intense avoidance behaviour can be expected within 1-5 km (see below). Norwegian studies measured declines in fish density at distances more than 10 km from sites of intensive seismic activity (3D). Negative effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during 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 air-gun (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 level 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 (C-starts), 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 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 sand eel (*Ammodytes marinus*) (Hassel *et al.* 2004). No immediate lethal effect on the sand eels 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 sub-lethal 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 (Anonymous 2003). However, in Norway, specific spawning areas in certain periods of the year may have very high densities of fish larvae in the uppermost water layers, and the Lofoten-Barents Sea area is closed for seismic activities during the cod and herring spawning period in May-June (Anonymous 2003). It was concluded in an assessment of seismic activities in the Disko West Area that it was most likely that impacts of seismic activity (3D) were negligible on the recruitment to fish stocks in West Greenland waters. Because densities of fish eggs and larvae generally are low in the upper 10 m and because most fish species spawn in a dispersed manner in winter or spring, with no temporal overlap with seismic activities. There is very limited data on fish egg and larvae densities as well as zooplankton from the assessment area, but it can be assumed that the density will not be higher than in other Greenland waters. It is therefore most likely that impacts of seismic activity (even 3D) on zooplankton and on the recruitment to fish stocks are negligible in the assessment area.

Impact of seismic noise on fisheries

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

A recent study of 3D seismic survey impacts on gillnet and longline fisheries showed some contradicting results (Løkkeborg *et al.* 2010): Gillnet catches of Greenland halibut (*Reinhardtius hippoglossoides*) and redfish (*Sebastes* sp.) increased during seismic shooting and remained higher in the period after shooting. Longline catches of Greenland halibut, on the other hand, decreased. Saithe (*Pollachius virens*) catches in gillnet showed a tendency to decrease (but not statistically significant) during the shooting. However also acoustic surveys of fish densities indicated that saithe left the shooting area.

An analysis of the official catch statistics from an area with seismic surveys in Norway in 2008 also showed very varying results (Vold *et al.* 2009): Catch rates of Atlantic cod (*Gadus morhua*), ling (*Molva molva*), tusk (*Brosme brosme*) and Atlantic halibut (*Hippoglossus hippoglossus*) were not changed significantly. Catch rates of redfish and monkfisk (*Lophius piscatorius*) seemed to increase, while catch rates of saithe and haddock caught in gillnet decreased and catches with other gear was not affected. The majority of the seismic surveys included in the analysis was 2D and scattered in time and space, why major influences on the fisheries was not expected.

A Canadian review (DFO 2004a) concluded that the ecological effect of seismic surveys on fish is low and that changes in catchability are probably species dependent.

The commercial fisheries which may overlap with the seismic surveys in Greenland waters are primarily the offshore trawling for Greenland halibut (*Reinhardtius hippoglosoides*).

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 abilities are reduced compared to fish with 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. It is therefore not advisable to apply results from studies on these species to Greenland halibut.

The only studies including Greenland halibut is the Norwegian mentioned above. They concerned gill net fishery and not trawl, why the results can not be applied to Greenland offshore conditions.

This is also supported by a Norwegian review (Dalen *et al.* 2008), which concluded that the results described by Engås *et al.* (1996) and mentioned above cannot be applied to other fish species and to fisheries taking place in other water depths as for example the Greenland halibut fishery in Greenland.

To sum up, there will be a risk of reduced catches of Greenland halibut in areas with intensive seismic activity. The effect will probably affect specific fisheries only for a period. The trawling grounds within and just to the south of the assessment area are, however, spatially restricted (Figure 42); they are found at specific depths at approx. 1,500 m and on the narrow continental slope; thus alternative fishing grounds may be limited.

It should be mentioned that the Norwegian studies showed an increased catch of Greenland halibut in gillnets. There are also other examples of this trend (Hirst & Rodhouse 2000), and it it most likely result of changed behaviour (more moving around) of the fish.

In general there is very little knowledge on the effects of seismic shooting on invertebrates, why studies and reviews express the need for research in this field and concern for long-term effects is also expressed (Christian *et al.* 2003, DFO 2004a, Chadwick 2005). E.g. emphasizes a Canadian review (DFO 2004a) that there is lack in information to evaluate the effects on crustacean during their moult, a period when crustaceans are particularly vulnerable.

A study has shown that the shrimp species *Palaemon serratus*, is responsive to sounds from 100 to 3000 Hz, and that the responsive organ is the statocyst (balance organ) in the basal segment of the antennule (Lovell *et al.* 2005). Behaviour associated with hearing has so far not been demonstrated. Future research may reveal shrimp reactions to seismic sound pulses. A Canadian study (DFO 2004b) addressed impacts on snow crabs. The study was set up with short notice and did not find short term effects, but it raised questions relating to long term effects.

The few other field studies on crustaceans (Norwegian lobster (La Bella *et al.* 1996), Australian rock lobster (Parry & Gason 2006), three shrimp species off Brazil (Andriguetto-Filho *et al.* 2005), snow crab (Christian *et al.* 2003)) did not find any short term reduction in catchability, why it is likely that the limited shrimp fisheries within the assessment area (Figure 43) will not be affected by seismic surveys during the exploration phase.

The Norwegian EIA of hydrocarbon activities in the Barents Sea does not assess impacts on northern shrimp or fishery on this resource, because the species is considered relatively robust to external impacts (Østby *et al.* 2003).

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 (from the presence and activity of the ship) breeding and moulting congregations.

Next to nothing is known about underwater hearing in diving sea birds and none has attempted to assess possible impact of exposure to airgun sounds during diving. Their hearing abilities underwater are 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 air gun array, but unlike the case for mammals, the sensory cells of the inner ear of birds can regenerate after damage from acoustic trauma (Ryals & Rubel 1988) and hearing impairment, even after intense exposure, is thus temporary.

Impact of seismic noise on marine mammals

Responses of marine mammals to noise fall into three main categories: physiological, behavioural and acoustic (Nowacek *et al.* 2007). Physiological responses include hearing threshold shifts and auditory damage. Behavioural responses include changes in surfacing, diving and heading patterns, and may result in displacement from the affected area or reduced feeding success. 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.* 2004).

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 damages. Under experimental conditions temporary elevations in hearing threshold (TTS) have been observed (National Research Council 2005, Southall *et al.* 2007). Such temporary reduced hearing ability is considered unimportant by Canadian researchers; unless it develops into permanent threshold shift (PTS) or it occurs in combination with other threats normally avoided by acoustic means (DFO 2004a).

In the USA a sound pressure level of 180 dB re 1µPA) (rms) or higher has been adopted by the US National Marine Fisheries Service as a mitigation standard to protect whales from exposures considered capable of inducing temporary or permanent damage to their hearing (NMFS 2003, Miller *et al.* 2005a). This exposure criterion is poorly defined from a measuring point of view and with little experimental support. Thus Southall *et al.* (2007) have proposed a reorganisation of exposure criteria, allowing more room for differences in sensitivity between different taxa and different sound types. They also implement a dual criterion, one being based on maximum instantaneous sound pressure, the other being total acoustic energy accumulated over the complete duration of exposure. The suggestions of Southall *et al.* (2007) have been challenged from various sides and it is yet to be seen how they will be implemented in legislation in the USA and elsewhere.

Research on the Alaskan Beaufort Sea has shown that bowhead whales do change behaviour when exposed to low frequency sound from airgun arrays (e.g. Reeves *et al.* 1984, Richardson *et al.*1986, Ljungblad *et al.* 1988). Humpback whales have been observed to consistently change course and speed in order to avoid close encounters with operating seismic arrays (McCauley *et al.* 2000). An analysis of sightings of marine mammals, including minke and fin whale during seismic surveys in UK documented a reduction of observations during periods of shooting compared with non-shooting periods, on surveys with large airgun arrays (Stone & Tasker 2006). Di Iorio & Clarck (2010) documented that blue whales increase their calling rate during seismic surveys, probably as a compensatory behaviour to the elevated ambient noise. Fin whales can also change the acoustic characteristics of their sounds and move away from active airgun sources, leaving the area for time periods that extend well beyond the duration of the airgun activity (Castellote *et al.* 2010).

Displacement is a behavioural response, and there are many documented cases of displacement from feeding grounds or migratory routes of marine mammals exposed to seismic sounds. The extent of displacement varies between species and also between individuals within the same species. For example, a study in Australia showed that migrating humpback whales avoided seismic sound sources at distances of 4-8 km, but occasionally came closer. In the Beaufort Sea autumn migrating bowhead whales avoid areas where the noise from exploratory drilling and seismic surveys exceeds 117-135 dB and they may avoid the seismic source by distances of up to 35 km (Reeves *et al.* 1984, Richardson *et al.* 1986, Ljungblad *et al.* 1988, NMFS 2002, Brewer *et al.* 1993, Hall *et al.*, 1994, 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). In the Mediterranean, bearings to singing fin whales estimated with passive acoustic monitoring indicated that whales moved away from the airgun source and out of the area for a time period that extended well beyond the duration of the airgun activity (Castellote *et al.* 2010).

In contrast, minke whales have also been observed as close as 100 m from operating airgun arrays (NERI unpublished), potentially close enough to sustain physical damage.

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

In coastal areas noise from seismic activities might deflect the course of the bowhead migration routes and could, in case of extensive seismic activities in early winter, potentially force the whales to change their migratory destinations. Noise from exploratory and production drilling, offshore constructions, aircraft and vessel supply activities will add to create an environment that could displace the whales to more offshore areas possibly into unfavourable ice conditions and reduce the use of specific coastal sites for feeding (National Research Council 2003).

In West Greenland waters satellite tracked humpback whales utilised extensive areas and moved between widely spaced feeding grounds (Dietz *et al.* 2002, Heide-Jørgensen & Laidre 2007); they would therefore most likely still have access to alternative foraging areas if they were displaced from one area by a seismic activity. However, given the extent of oil exploration in Greenland, there is a risk of cumulative effects if multiple surveys occur at the same time in adjacent areas, and marine mammals are thus 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 distances within which some cetaceans are likely to be subject to behavioural disturbance (NMFS 2005 in Dunn & Hernandez 2009). 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.* (2006) found no reaction of sperm whales to a distant seismic survey operating at tens of kms 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).

A behavioural effect widely discussed in relation to whales and seismic surveys is the masking effect of communication and echolocation sounds. There are, however, no studies which document such effects, mainly because the experimental setups are extremely challenging. Masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures. The whales and seals in the assessment area use a wide range of frequencies (from < 10 Hz to > 100 kHz), why the low frequency sounds (< 300 Hz) of seismic surveys are likely to overlap in frequency with at least some of the sounds produced by these whales (Figure 27).

Whether sound pressures could be high enough at the animals to mask biologically significant sounds is another uncertainty. Masking is more likely to occur from the continuous noise from drilling and ship propellers and this effect have been demonstrated for white whales and killer whales in Canada (Foote *et al.* 2004, Scheifele *et al.* 2005). Furthermore, if the direction from which the noise arrives differ from the direction of the (for the animal) relevant sound, as will most often be the case, there will be a pronounced release of masking.

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.* 2004), and it has been demonstrated that blue whales increase their calling rate during seismic surveys, probably as a compensatory behaviour to the elevated ambient noise (Di Iorio & Clarck 2010).

Sperm whales showed diminished forage effort during air gun emission. 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.* 2005b in Jochens *et al.* 2008).

The most noise-vulnerable whale species in the assessment area will be white whale, narwhal and bowhead whale, and both white whales and bowhead whales are mostly absent from the area when seismic surveys usually are carried out (summer and autumn). There is however a risk of overlap with seismic operations in late autumn in some specific areas: Narwhals have a an important summer ground in Melville Bay, well-defined migration routes and winter quarters within the assessment area, and here there is a risk of displacement especially caused by 3D surveys. The summer and autumn grounds are those which may be exposed to seismic noise, whereas the winter quarters are the most critical; however no seismic surveys will take place in winter. Seismic activities are currently regulated in the assessment area in order to minimise overlap with the occurrence of narwhals, see Figure 41 (Boertmann *et al.* 2010).

Other whales occurring in summer and autumn will also be vulnerable, but their occurrence in the assessment area is less regular and no concentration areas are known.

In general, seals display considerable tolerance to underwater noise (Richardson *et al.* 1995), confirmed by a study in Arctic Canada, where ringed seals showed only limited avoidance to seismic operations (Lee *et al.* 2005). In another study, ringed seals had habituated to industrial noise (Blackwell *et al.* 2004). However, walruses (especially when hauled out on ice or land) may be disturbed and displaced by seismic activity and not so much by the seismic noise. Therefore seismic activities are regulated in a number of important habitats in the northern part of the assessment area (Boertmann *et al.* 2010).

Mitigation of impacts from seismic noise

Mitigation measures generally include a soft start or ramp up of the airgun array each time a new line is initiated (review by Compton *et al.* 2008). Although not verified by experiments or observations, this approach is commonly considered 'best practice'. A soft start will allow marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals.

Secondly it is recommended to bring skilled marine mammal observers 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) from the array. The detection of nearby whales in sensitive areas can be more efficient, depending on species, if supplemented by the use of hydrophones for recording whale vocalisations (Passive Acoustic Monitoring – PAM), although whales not necessarily emit sounds, when present. 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 day light.

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 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 (Figure 41; Boertmann *et al.* 2010). A similar protection zone for bowhead whales should be considered in the Disko Bay waters in spring.

Finally it is recommended that local authorities and the hunters' organisations be informed before seismic activities take place in their local area. This may help hunters 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 was applied to minimise impacts from seismic surveys on marine mammals and the subsistence hunting on these (Miller *et al.* 2005a). Some were identical to those mentioned above. The most important was a delay in the start of seismic operations until the end of the white whale hunt and when important white whale habitats were utilised by the whales. Some particularly important white whale areas were even completely closed for surveys.

In the NERI-guidelines to seismic surveys (Boertmann *et al.* 2010), some important issues to consider when the impacts of a seismic surveys have to be assessed were listed. These guidelines are presently under revision, and a new version is planned to be issued in 2012.

Important points to consider in such an assessment would be:
- Species likely to be affected. Some species apparently are more tolerant to seismic surveys than others.
- Natural behaviour of animals in the shooting area at time of survey. Disturbance of mating and calving is considered to have a higher impact than disturbance of feeding behaviour. Feeding behaviour is again considered of higher importance than migration, given that migration routes are not obstructed.
- Severity and duration of impact. Even a strong startle reaction to an approaching survey vessel may have only a small total impact on the animal whereas a small, but prolonged (days or weeks) disturbance to feeding behaviour could have a much larger impact.
- Total number of animals likely to be affected. It is not possible to conduct seismic surveys in the arctic without affecting marine mammals at all. The number of animals likely to be affected should be judged in relation to the size of the population, local densities and season.

- Local conditions for sound transmission. Local hydrographic and bathygraphic conditions may result in highly unusual sound transmission properties, in particular in polar waters, which may result in a very uneven sound field, with no clear relation between distance to source and received level. Potential consequences of these effects should be included in the assessment.

When planning surveys the overall exposure should be sought minimised to the degree possible in using the smallest airgun array to get the data needed. The total exposure is a complex function of number of animals exposed, the time each animal is exposed and the sound level each are experiencing. Nevertheless, reducing any of the three parameters will also reduce the total exposure and thus the possibility of reducing one or more factors should be considered in the planning.

Conclusions on disturbance from seismic noise (Table 12)

The most sensitive VECs in the assessment area are bowhead whales, narwhals, white whales and walruses. The occurrence of bowhead whale, white whale and walrus do however not usually overlap with the season for normal seismic surveys and, if they do so it is only for a short period in the late autumn (October/November). However, the narwhal summer grounds in Melville Bay are accessible to seismic operations, and here there is a risk of displacement from critical habitats. Icebreaker facilitated seismic surveys have recently been conducted in ice covered waters off Northeast Greenland, and such may overlap in time with the presence of both narwhals and bowhead whales in the assessment area.

There is also a risk of displacement of other species, such as fin, blue, humpback and especially minke whale from important, if not critical habitat, especially in the southern part of the assessment area.

Table 12. Summary of potential impacts from a single seismic survey on VECs in the Baffin Bay assessment area. Displacement indicates spatial movement of animals away from an impact, and is classified as none, short term, long term or permanent. Sublethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. 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. Several surveys either simultaneously or consecutive have the potential to give more pronounced cumulative impacts. (L) = local extend, (R) = regional extend.

VEC	Overlap	Risk of impact on critical habitats	Potential impacts – worst case with current regulation			
			Displacement 2D	Displacement 3D	Sublethal effects	Direct mortality
Prim. production	no	no	–	–	–	–
Zooplankton	small	yes	–	–	insignificant	insignificant
Benthic fauna	no	no	–	–	–	–
Greenland halibut	pot. large	no	short term (L)	short term (L)	none	none
Arctic char	no	no	–	–	–	–
Polar cod	small	no	short term (L)	short term (L)	none	none
Fish egg and larvae	small	yes	–	–	insignificant	insignificant
Seabirds	small	no	–	–	–	–
Walrus	small	yes	short term (L)	short term (L)	insignificant	none
Ringed seal	small	no	short term (L)	short term (L)	insignificant	none
Narwhal	pot. large	yes	short term (L)	long term (L)*	insignificant	none
White whale	pot. large	yes	short term (L)	short term (L)	insignificant	none
Bowhead whale	pot. large	yes	short term (L)	short term (L)	insignificant	none
Polar bear	small	no	short term (L)	short term (L)	insignificant	none
Comm. fisheries	pot. large	yes	short term (L)	short term (L)	–	–
Hunting	small	no	short term (L)	short term (L)	–	–

*specifically in Melville Bay

A temporary displacement will impact the availability of whales, walrus and seals to hunters if the affected habitats include traditionally hunting grounds. More severe impacts – with the risk of displacement for perhaps a whole season – are expected from 3D seismic surveys if they are carried out near critical habitats for walruses, narwhals, bowhead whales and blue whales.

As seismic surveys are temporary, the risk for long-term impacts from single surveys is low. But long-term and cumulative impacts have to be assessed if several surveys are carried out simultaneously or in the same potentially critical habitats during consecutive years.

The only fishery which is at risk of impacts from seismic surveys is the Greenland halibut fishery in the southern part of the assessment area, however these impacts may also extend to the more important fishing ground just to the south of the assessment area. There is a risk of a temporary displacement of fish and consequently reduced catches from the trawling grounds.

Noise from drilling rigs

This noise has two sources, the drilling process and the propellers (cavitation) keeping the drill ship/rig in position (dynamic positioning). The noise is continuous in contrast to the pulses generated by the 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 used within the assessment area, due to water depths and the collision risk from drift ice and icebergs.

Whales are estimated to be the organisms most sensitive to this kind of underwater noise, because they depend on the underwater acoustic environment for orientation and communication, and it is likely that this communication can be masked by the noise. 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 estimated that whales are more tolerant to fixed noise than noise from moving sources (Davis *et al.* 1990). In Alaskan waters migrating bowhead whales avoided an area with a radius of 10 km around a drill ship (Richardson *et al.* 1990) 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). Also white whales are considered sensitive to noise from drilling operations (Lawson 2005).

As described in Section 4.8.3 and Box 7 bowhead whales occur in the assessment area mainly during spring migration and in early summer (June) in the assessment area. The migration corridor across Baffin Bay seems to be wide enough to provide alternative routes (Figure 28, Box 7), and displacement of single animals similar to that described from the Beaufort Sea probably has no significant effect here.

White whales and walrus may occur in the assessment area when exploration activities takes place, but the overlap will be brief, and no effects are expected. It should be mentioned that the 2010-drillings in the Disko West area should be terminated on 1 October, in order to have a sufficiently long ice free window to carry out a relief well in case of a blow out. A similar or even earlier termination in the Baffin Bay will reduce the overlap.

Narwhals on the other hand occur throughout the year in the assessment area (Section 4.8.4). Displacement from critical habitats will therefore be a risk if drilling takes place in the Melville Bay area in the summer period.

Table 13. Summary of potential impacts from noise and discharges from a single exploration drilling on VECs in the Baffin Bay assessment area. Several drillings either simultaneously or consecutive have the potential to give increased cumulative impacts. The assessment of potential impacts assumes the application of current (2011) mitigation guidelines, see text and Table 12 for details and explanation.

VEC	Overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Displacement	Sublethal effects	Direct mortality
Prim. production	neglig.	no	–	insignificant	insignificant
Zooplankton	neglig.	no	–	insignificant	insignificant
Benthic fauna	small	pot. yes	no	minor (L)	minor (L)
Greenland halibut	minor	no	no	no	no
Arctic char	no	no	no	no	no
Polar cod	neglig.	no	no	no	no
Fish egg and larvae	neglig.	no	no	insignificant	insignificant
Seabirds	neglig.	no	short term (L)	insignificant	no
Walrus	small	yes	short term (L)	no	no
Bearded seal	small	no	short term (L)	no	no
Ringed seal	small	no	short term (L)	no	no
Narwhal	small	yes	short term (L)	no	no
White whale	small	yes	short term (L)	no	no
Bowhead whale	small	yes	short term (L)	no	no
Polar bear	small	no	short term (L)	no	no
Comm. fisheries	small	yes	no	–	–
Hunting	small	no	short term (L)	–	–

Conclusion on noise from exploration drilling rigs (Table 13)

Exploration activities are temporary, and displacement of marine mammals caused by noise from drilling rigs will also be temporary. The most vulnerable species in the assessment area are narwhal, white whale, bowhead whale and walrus. Of these species the narwhal probably has the highest risk of exposure, as there is a critical summer area for the species within the assessment area. If alternative habitats are available only slight effects may be expected, but if several rigs operate in the same region, there is a high risk for cumulative effects and displacement even from alternative habitats.

10.1.2 Drilling mud and cuttings

Drilling creates substantial quantities of drilling wastes composed of rock cuttings and the remnants of drilling mud (cf. Section 2.3). Cuttings and mud have usually been 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 been almost completely eliminated due to environmental concerns. OBMs may be used for special drillings, but then the mud is injected into wellbores or brought to land for treatment.

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

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

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. However, use of WBM potentially moves effects on the seafloor to the water column, where dilution is a major factor in reducing impacts. In Norway the change to WBM has resulted in a marked decrease of the level of impacts on the seafloor (Renaud *et al.* 2007).

Cold water corals and sponges are sensitive to suspended material in the water column (Freiwald *et al.* 2004, SFT 2008). But the especially sensitive habitats for these organisms (reefs and sponge gardens) have not been documented (so far) from the assessment area and as the seabed at all drill sites in Greenland is surveyed for these organisms, it is possible to avoid impacts on them.

Multiple drilling carried out when a field is developed may cause more widespread effects on the benthos.

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). Biological effects from the particles in the water based mud have been observed on fish and bivalves under laboratory conditions (Bechmann *et al.* 2006).

A further risk from discarding cuttings polluted with oil residues is tainting of commercial fish (see Section 11.2.6), although such discharges are not allowed in Greenland.

Despite the results reported in Box 1, the seafloor fauna in the assessment area is still poorly known, why it is difficult to assess the impact of discharges of drilling mud and cuttings. However, a way to minimise such impacts is to re-inject or bring to land the cuttings and the mud, as is the case in the Lofoten-Barents Sea areas of Norway (Anonymous 2003). This on the other hand increases the amount of ship transport and the emission of CO_2; moreover, impacts at disposal sites on land have to be considered and evaluated (Oljedirektoratet 2011).

Mitigation of impacts from the release of drilling mud and cuttings

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

It is generally assessed that the impacts from water based muds are limited if only environmentally safe drilling chemicals are used. Therefore they usually are released to the marine environment when the drilling is over. Environmentally safe chemicals can be those which are classified as 'green' (PLONOR) or 'yellow' by OSPAR. But in general, these chemicals have not been evaluated under Arctic conditions regarding degradation and toxicity, why 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 % during 1997-2007 by applying international standards, BAT and BEP (SFT 2008).

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

Conclusion on discharges from exploration drilling (Table 13)
Within the assessment area only very local effects on the benthos may be expected from discharging the water-based muds from the drilling of an exploration well. In any case, baseline and monitoring studies at drill sites shall be conducted to document effects and assess if there are unique communities or species that could be harmed.

10.2 Appraisal activities

The activities during the appraisal phase are similar to the exploration activities (see Chapter 2.4) and the impacts are the same. However, there is an increased risk of cumulative impacts as the phase takes place usually over several years.

10.3 Development and production activities

In contrast to the temporary activities of the exploration phase, the activities during development and production are usually long lasting, depending on the amount of producible petroleum products and the production rate. The activities are numerous and extensive, and the effects on the environment can be summarised under the 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 and have to be disposed of in one way or the other. Produced water is by far the largest contribution from an oil field (see Section 2.7).

Generally is it assessed that the environmental impacts from produced water discharged to the sea are small due to dilution. For example, the discharges during the 5 % 'off normal time' in Lofoten-Barents Sea has been assessed not to impact stocks of important fish species. But in the same assessment it is also stated that the long-term effects of the release of produced water are unknown (Rye *et al.* 2003). There is particularly concern for the PAHs, the hormone-disrupting phenols, the radioactive components and the nutrients in relation to toxic concentrations, bio-accumulation, 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 then international standards (OSPAR) at least must be applied: 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 (Oljedirektoratet 2011).

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 fertiliser, which could impact especially the composition of primary producers (planktonic algae) (Rivkin *et al.* 2000 in 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 either Atlantic cod or blue mussels were positioned at various distances (0-5000 m) and different directions from oil platforms in Norway. In addition, two reference locations were used, both 8000 m away from the respectively platform. PAH tissue residues in blue mussels ranged between 0-40 ng/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 found biological effects 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 constituents which cause endocrine disruptive effects in fish (Lie *et al.* 2009). In another study the genotoxic potential of water-soluble oil components on Atlantic cod have been documented (Holth *et al.* 2009).

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

Table 14 gives an overview of potential impacts from discharges during exploitation activities.

10.3.2 Other discharged substances

Besides produced water, discharges of oil components and different chemicals occurs in relation to 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 at least should be applied to minimise impacts. Sanitary waste water is usually also released to the sea. The environmental impacts of these discharges are generally small from a single drilling rig or production facility, but releases from many facilities and/or over long time periods may 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 are ways in which the effects can be reduced. It should be mentioned that the release of environmentally hazardous substances from the oil industry to

Table 14. Summary of potential impacts on VECs in the Baffin Bay assessment area from discharges (primarily of large quantities of produced water) to the marine environment in relation to production activities. Regulation and mitigation measures will be dealt with when future EIAs of the activities are to be approved by the BMP. See Table 12 and text for details and explanation.

VEC	Overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Displacement	Sublethal effects	Direct mortality
Prim. production	pot. large	yes	–	no	no
Zooplankton	pot. large	yes	–	perhaps (L)	no
Benthic fauna	small	no	–	minor	no
Greenland halibut	small	no	–	no	no
Arctic char	small	no	–	no	no
Polar cod	pot. large	yes	–	pot. moderate (L)*	no
Fish egg and larvae	pot. large	yes	–	pot. major (L)*	perhaps (L)*
Seabirds	pot. large	yes	–	perhaps	possible

*under ice

the marine environment in Norwegian areas have been reduced by 99 % over 20 years by applying these measures (SFT 2008).

Ballast water from ships poses a special biological problem. That is the risk of introduction of non-native and invasive species (also termed as Aquatic Nuisance Species –ANS) to the local ecosystem (Anonymous 2003). This is generally considered as a severe threat to marine biodiversity and, for example, blooms of toxic algae in Norway have been ascribed to release of ballast water from ships. There are also many examples of introduced species which have impacted fisheries in a negative way (e.g. the comb jelly *Mnemiopsis* in the Black Sea (Kideys 2002)).

Presently, the Arctic Ocean is 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, and the IMO ballast water management convention has developed guidelines for this task (IMO 1998). The international convention has not yet been ratified by a sufficient number of states (incl. Denmark/Greenland) to enter into force. This is expected to occur in 2011, and within a few years the convention will apply to all ships. Ships involved in hydrocarbon activities in Greenland have to follow the IMO guidelines or the canadian regulation on this issue.

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

10.3.3 Placement of structures

The construction of subsea wells and pipelines has the potential to destroy parts of important habitats on the seafloor. In other regions especially sponge gardens and reefs of cold water corals are considered as sensitive, but such features have not yet been located in the assessment area. This could be due to lack of knowledge, as the survey effort is low (Box 1). In the waters southwest of Maniitsoq (700 km to the south of the assessment area) areas are now considered to be closed for trawling fishery to protect such habitats and fishermen shall also report catches of corals and sponges. Other important habitats are feeding grounds for bearded seal, walrus and king eider, which live on benthic mussels and other invertebrates (Figures 14, 18). 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. This is discussed below (Section 10.3.4).

Illumination and flaring attract birds during the 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 2010a). 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 2010a).

A related problem occurs in the North Sea, which millions of song birds cross on their night time 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 night-time migrating little auks has recently been expressed (Fraser *et al.* 2006), and this species occurs in very large densities within the assessment area. One method to mitigate the attraction of birds is to change the colour of the illumination to colours not attracting birds e.g. green (Poot *et al.* 2008).

Placement of structures will affect the fisheries due to exclusion (safety) zones. These areas, however, are 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 as 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 allowing 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 (Anonymous 2003).

Another effect of the exclusion zones is that they act as sanctuaries and in combination with the artificial reefs created by the subsea structures 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. Another potential conflict is with denning polar bear females. Denning areas are critical to polar bear populations. Dens are apparently very rare in the assessment area and their location varies between seasons.

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 rendered much less attractive by the buildings, infrastructure and other facilities.

Table 15. Summary of potential impacts from placement of structures on VECs in the Baffin Bay assessment area. Regulation and mitigation measures will be dealt with when future EIAs of the activities are to be approved by the BMP. See text and Table 12 for details and explanation.

VEC	Overlap	Risk of impact on critical/ importanthabitats	Potential impacts – worst case		
			Displacement	Sublethal effects	Direct mortality
Prim. production	neglig.	no	–	–	–
Zooplankton	neglig.	no	–	–	–
Benthic fauna	small	yes	long term (L)	no	insignificant (L)
Benthic flora	small	yes	long term (L)	no	insignificant (L)
Greenland halibut	small	yes	long term (L)	no	no
Arctic char	small	yes	no	no	no
Polar cod	neglig	no	no	no	no
Fish egg and larvae	neglig.	no	–	–	–
Seabirds	small	yes	long term (L)	no	pot. major*
Walrus	pot. large	yes	long term (L)	no	no
Ringed seal	small	no	long term (L)	no	no
Bearded seal	small	no	long term (L)	no	no
Narwhal	small	yes**	long term (L)	no	no
White whale	small	no	long term (L)	no	no
Bowhead whale	pot. large	no	long term (L)	no	no
Polar bear	small	yes	long term (L)	no	no
Com. fisheries	pot. large	yes	long term (L)	–	–
Hunting	small	yes	long term (L)	–	–
Tourism	pot. large	yes	long term (L)	–	–

*from lights and flaring during dark hours, **summer population in Melville Bay

Table 15 gives an overview of potential impacts from placement of structures.

10.3.4 Noise/Disturbance

Noise from drilling and the positioning of machinery is described under the exploration heading (Section 10.1.1). 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 Upernavik town – the impacts of noise particularly on the migration of narwhals and white whales must be addressed. Bowhead whales in the Beaufort Sea avoided close proximity (up to 50 km) to oil rigs, which resulted in significant loss of summer habitats (Schick & Urban 2000). This will probably not be a problem in the assessment area as the bowheads here are passing by on migration towards their summer grounds in Canada. The other species especially at risk for displacement from critical habitats is the walrus.

One of the more significant sources of noise during development and production is ships and helicopters used for intensive transport operations (Overrein 2002). Ships and helicopters are widely used in the Greenland environment today, but the level of these activities is expected to increase significantly in relation to development of one or more oil fields within the assessment area. Supply ships will sail between offshore facilities and coastal harbours. Shuttle tankers will sail between crude oil terminals and the trans-shipment facilities on a regular basis, even in winter. The loudest noise levels from shipping activity result from large icebreakers, particularly when they operate in ramming mode. 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 white whales, narwhals and walruses which are hunted from motor boats will be expected to be particularly sensitive. 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.

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 off from their breeding ledges they often push egg or small chick off the ledge, resulting in a failed breeding attempt (Overrein 2002). By far the majority of the Greenland breeding population of thick-billed murre is found within the assessment area (Figure 13C). Also concentrations of feeding birds can be sensitive, as they may lose feeding time due to the disturbance.

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

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

Concentrations of moulting seaducks occur at several sites along the coasts of the assessment area (Figure 14). The effects of disturbance 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.

Offshore construction activities such as blasting have potential to produce behavioural disturbance and physical damage among marine mammals, particularly whales (Ketten 1995, Nowacek *et al.* 2007). Off Newfoundland, Ketten *et al.* (1993, 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 sound. Such impacts are, however, local and will mainly be a threat on an individual level.

Table 16 gives an overview of potential impacts from disturbing activities during development.

Table 16. Summary of potential impacts from disturbing activities during development and production in the Baffin Bay assessment area. More pronounced cumulative impacts must be expected if several production facilities are established. Regulation and mitigation measures will be dealt with when future EIAs of the activities are to be approved by the BMP. See text and Table 12 for details and explanation.

VEC	Overlap	Risk of impact on critical/ important habitats	Potential impacts – worst case		
			Displacement	Sublethal effects	Direct mortality
Fulmar	pot. large	yes	long-term (L)	no	no
Great cormorant	pot. large	yes	long-term (L)	no	no
Common eider	pot. large	yes	long-term (L)	no	no
King eider	pot. large	yes	long-term (L)	no	no
Long-tailed duck	small	yes	long-term (L)	no	no
Arctic tern	pot. moderate	yes	long-term (L)	moderate (L)	no
Thick-billed murre	pot. large	yes	long-term (L)	major (L)	no
Atlantic puffin	pot. large	yes	long-term (L)	moderate (L)	no
Little auk	pot. moderate	yes	long-term (L)	moderate (L)	no
Walrus	pot. large	yes	long-term (L)	major (L)	no
Ringed seal	small	yes	long-term (L)	minor	no
Bearded seal	moderate	yes	long-term (L)	minor	no
Narwhal	pot. large	yes	long-term (L)	major (L)	no
White whale	pot. large	yes	long-term (L)	minor	no
Bowhead whale	pot. large	yes	long-term (L)	minor	no
Polar bear	moderate	yes	long-term (L)	minor	no
Comm. fisheries	small	no	no	–	–
Hunting	pot. large	yes	long term (L)	–	–

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

Emissions of SO_2 and 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 it was concluded that NOx emissions even from a large-scale scenario would have insignificant impact on the vegetation on land, but also that there was no knowledge about tolerable depositions of NOx and SO_2 in Arctic habitats where nutrient-poor habitats are widespread (Anonymous 2003). 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. This is, however, not allowed in Greenland waters in relation to oil activities, where only low-sulphur (< 1.5 % by weight) gas oils may be used.

The international Convention on Long-Range Transboundary Air Pollution (LRTAP) includes all these 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. The impacts are summed up from single activities both in space and time. Impacts from a single activity can be insignificant, but the sum of impacts from the same activity carried out at many sites at the same time and/or throughout time can develop to be significant. Cumulative impacts also include interaction with other human activities impacting the environment, such as hunting and fishing; moreover, climate change is also often considered in this context (National Research Council 2003).

An example could be many seismic surveys carried out at the same time in a restricted area. A single survey will leave many alternative habitats available, but extensive activities in several licence blocks may exclude, for instance, baleen whales from the available 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 oil concentration in the discharged produced water is low. But the amounts of produced water from a single platform are considerable and many platforms will release even more.

Bio-accumulation 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 bio-accumulate in fauna on the seafloor and in the water column. This may occur in benthic populations 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. Tightened hunting regulations were introduced in 2001, which was followed by reduced numbers of birds reported to the hunting bag record. In particular, common eider and thick-billed murre colonies in and near the assessment area have decreased in numbers over the past decades. Both species rely on a high adult survival rate, giving the adult birds many seasons to reproduce. The common eider population has been recovering since 2001 (Merkel 2010b), while the murre population is still decreasing in most of the colonies in West Greenland. Extra mortality due to an oil spill or sub-lethal effects caused by contamination from petroleum activities have the potential to be additive to the hunting impact and thereby enhance the population decline (see also Figure 55) (Mosbech 2002). Within the assessment area the breeding colonies of thick-billed murres in the southern part of the former Upernavik municipality have declined considerably and a few have been completely exterminated. 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 (Box 4). This migration was studied in the Disko Bay in 2005 and 2006, and similar studies have been initiated in Qaanaaq in 2007 (Box 4).

10.3.7 Mitigating impacts from development and production

As a consequence of previous experience, e.g. from the North Sea, the Arctic Council guidelines (PAME 2009) recommend that discharges are as far as possible prevented. When water-based muds are used, additives containing oil, heavy metals, or other bio-accumulating substances should be avoided or criteria for the maximum concentrations should be established (PAME 2009). In Greenland only chemicals registered in HOCNF and the Danish product register PROBAS will be allowed and only those which by OSPAR are classified as 'green' (PLONOR) or 'yellow'. Moreover, wherever possible 'zero discharge of drilling waste and produced water' should be applied. This can be obtained by application of new technologies, such as injection and cuttings re-injections (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 at least shall follow the standards described by OSPAR, applying a sound environmental management based on the Precautionary Principle, Best Available Techniques (BAT) and Best Environmental Practice (BEP).

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 (Anonymous 2003), which on the other hand give 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.

As an example, activities impacting polar bear areas could be regulated according to guidelines provided by Linnell *et al.* (2000) in a review of the vulnerability of denning bears (modified to suit oil activities):

- Den concentrations should be indentified
- Winter activity should be minimised in suitable or traditional denning areas
- If winter activities are unavoidable, they should be around the time when bears naturally enter dens, so they can choose to avoid disturbed areas
- Winter activity should be confined to regular routes as much as possible; activity on level areas should generally have less effect than activity on slopes and steep snow covered hillsides
- Activity should avoid known bear dens by at least 1 km
- The slightest degree of off-road activity is likely to cause greater effects than any degree of fixed-point or predictable-route activity and should therefore be minimised

10.3.8 Conclusions on development and production activities (Tables 14, 15, 16)

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

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

There will be a risk of release of non-native and invasive species from ballast water and ship hulls, and this risk will increase with the effects of climate change.

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 are the colonial seabirds, bowhead whales, narwhals, white whales and walruses. 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. The biological impacts include mainly permanent displacement from critical habitats – walrus is the most sensitive. The aesthetic impacts primarily include impacts on the pristine landscape, which again may impact on the local tourism industry.

The commercial fishery may by effected by closure zones if rigs, pipelines and other installations are placed in the Greenland halibut fishing ground. But the impact on the fishery will probably be relatively low.

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 as OSPAR and HOCNF can do much to reduce emissions to air and sea. And a discharge policy, as for example planned for the Barents Sea, can contribute substantially to minimise impacts. Furthermore is monitoring of effects on the sites essential.

10.4 Decommissioning

The impacts from decommissioning activities are mainly from noise at the sites and from traffic, assuming that all material and waste are taken out of the assessment area and deposited at a safe site. There will also be a risk of pollution from accidental releases. However, the activities are short term and careful planning and adoption of BAT, BEP and international standards would minimise impacts.

An important issue to address in the planning phase is to design installations for easy removal when activities are terminated.

11 Impacts from accidental oils spills

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11.1 Oil spill properties

The main 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 spilled amounts of oil is decreasing (Schmidt-Etkin 2011). But the impacts from a large spill can be severe and long lasting especially in Arctic areas.

Several circumstances enhance the potential for severe impacts of a large oil spill in the assessment area. The Arctic conditions reduce the degradation of oil, prolonging potential effects. The occurrence of ice during most of the year may influence the distribution and conservation of oil (see below), but will also make oil spill response almost impossible at least in the winter period. The winter darkness, harsh weather and lack of infrastructure in large parts of the assessment area also contribute to the difficulties associated with oil spill response.

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 the tanker spill, are continuous and may last for many days. For example, the deep-water blow-out from the *Macondo*-well lasted 85 days before it was stopped by relief-drilling. Blowouts usually have their origin on the platform, but it may also be from the wellhead on the seafloor (subsea blowout).

11.1.1 Probability of oil spills

Large oil spills are generally very rare incident. However, the risk is there, and in a frontier area, such as the Baffin Bay license area it is difficult to calculate the risk based on experience from more developed areas. Contributing to increase the risk in Baffin Bay is the presence of icebergs. In relation to oil drilling in the Barents Sea it has been calculated, that statistically, 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 (Anonymous 2003). The likelihood of a large oil spill from a tanker ship accident is generally estimated to be higher than for an oil spill from a blowout (Anonymous 2003).

Drilling in deep waters (between 1000 and 5000 feet ~ 305-1524 m) and ultra deep waters (> 5000 feet ~ 1524 m) increase the risk for a long lasting oil spill, due to the high pressures encountered in the well and due to the difficulties of operating at in such deep waters. The water depth was among the many factors contributing to the long time it lasted (almost 3 months) to cap the *Macondo*-well in 2010 (Graham *et al.* 2011).

The only known oil spill in the assessment area was the result of a tanker accident in Melville Bay in August 1977. The U.S. Navy ship Potomac lost approx. 400 m^3 bunker-C fuel from a ruptured tank at a position of 74° 52' N, 61° 13'W (Grose *et al.* 1979). An effect study was carried out during the following weeks, and only very slights effects were detected on the biota studied, e.g. ingested oil in 4% of sampled copepods (*Calanus*) in a single sample (Grose *et al.* 1979).

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 vary considerably. 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). In Greenland waters drift and fate have been modelled by DMI at several occasions in relation to the preparation of strategic environmental impact assessments: Disko West (Nielsen *et al.* 2006), Baffin Bay (Nielsen *et al.* 2008) and also when the preliminar version of this SEIA was prepared (Nielsen *et al.* 2008). DMI is presently working on simulation of drift and fate of subsurface spills in the deep waters off South Greenland.

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.

Surface spills

Oil released to open water 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). However, oil dispersed at the source of a sub-sea blowout, may accumulate at any depth.

The oil spill simulations generally have addressed the drift of oil on the sea surface (except the Statoil simulations). However oil may also sink to the seabed, depending on the density of the spilled oil. Even light oil may sink if it adsorbs onto sediments particles in the water (Hjermann *et al.* 2007), a condition frequently seen in Greenland coastal waters where the melt water 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 riser from the wellhead collapses. The risk of a collapse is higher in deeper water. The oil in a subsurface blowout may float to the surface or remain for a longer time in the water column. If oil remains in the water column it will typically be dispersed in small droplets. Whether oil in a subsea blowout remains in the water column as a dispersed plume or float to the surface depends mainly 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 can not be predicted with any certainty. Therefore, the oil in the DMI models of subsurface spills in West Greenland, quickly floated to the surface (Nielsen *et al.* 2006) while SINTEF's models estimated that oil would not reach the surface at all, but rather form a subsea plume at a depth of 300-500 m (Johansen 1999). The SINTEF model also indicated high total hydrocarbon concentrations (> 100 ppb by weight) close to the outflow.

The *Macondo*-well oil spill in the Mexican Gulf in 2010 was unusual in size, location and duration (but much like the Ixtoc blow out in 1979 also in the Mexican Gulf) and revealed new and un-described ways spilled oil could be distributed in the environment, although this probably also happened during the Ixtoc spill (Jernelöv 2010).

The unusual dispersion of the oil was mainly caused by the spill site on the seabed in waters more than 1500 m deep. Dispersants were applied at the well head 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 oil spill from the Macondo-well has been estimated at 840,000 tonnes, making it the largest recorded peace time spill. The oil dispersed at the well head had a very slow buoyant migration towards the surface, which allowed volatile hydrocarbon to be dissolved in the water column. Adding dispersants at the well head contributed to the formation of huge plumes of dispersed oil in different depths ranging between 800 and 1200 m (Hazen *et al.* 2010, Valentine *et al.* 2010). It was estimated that 50% of the oil 'remained' dispersed, sank to the seabed or degraded in the water column (Kerr 2010).

Studies of deepwater blowout events have predicted that a substantial fraction of the released oil and gas will be suspended in pelagic plumes, and this may occur even in the absence of added dispersant agents (Johansen *et al.* 2001b). The fate of oil in the deep water is likely to be very different from that of surface oil because processes such as evaporative loss and photo-oxidation 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 estimated 140,000 tonnes oil annually (Kvenvolden & Cooper 2003), why there should be an intrinsic potential for microbial degradation (presence of the responsible organisms). This was confirmed by bio-degradation rates faster then expected in the deep plumes at 5°C (Hazen *et al.* 2010).

However, microbial degradation of oil may have derived effects such as oxygen depletion, which in the deep water persist for long periods of time, because deep water oxygen is not replenished *in situ* by photosynthesis, as is the case for surface waters (Joye & MacDonald 2010).

There are indications of severe and unexpected deep sea impacts (Schrope 2011), but as far as the environmental impacts of the *Macondo*-spill are not yet really understood or described (Graham *et al.* 2011), it is not possible to include any experiences in this SEIA. A natural resource damage assessment is under preparation (Graham *et al.* 2011), and the consequences of the *Macondo* subsea blowout will be discussed in more detail in a later version of this assessment.

11.2 The DMI oil spill simulations

As part of the ongoing SEA of oil activities in the Baffin Bay assessment area, DMI prepared a number oil drift and fate simulations for hypothetical oil spills (Nielsen *et al.* 2008).

The simulations were carried out for four hypothetical spill events located on the shelf areas in Baffin Bay. They were selected by GEUS to represent potential sites for offshore well drilling. The crude oil, Statfjord, a medium-type crude (API density 886.3 kg/m^3), was selected by GEUS from eight types in the DMI database, as the most representative oil potentially to be discovered in the assessment area. This is a medium oil type, lighter than seawater, which will evaporate by around one third during the first 24 hours of a surface spill period.

For continuous spills oil is released at a constant rate during the first ten days of the simulation period. The amount of oil released is fixed at a rate of 3,000 tonnes/day (in total 30,000 tonnes). For instantaneous spills the amount of oil released is 15,000 tonnes. These are relatively large spills.

Three one-month wind periods have been selected within the design year July 2004-June 2005. The five first periods represent a predominant wind from different directions at moderate wind speeds; the sixth period has spells of a strong southerly wind.

A total of 24 one-month oil drift simulations have been carried out: four release sites, three simulations periods and two release depths. Additionally and for comparison one simulation of an instantaneous surface spill has been carried out for each spill site.

Shores affected
By tracking all particles, the relative amount of oil settling on the shore is calculated. Oil end up on the shore in only three spill situations, while in the other 21 situations the oil remains offshore under all of the selected wind conditions (Figure 53). No nearshore spills from where the risk of shoreline pollutions is much higher, have been modelled.

Sea surface area covered
The slick area after 10 days is 100-110 km², equivalent to a disc with a radius of 5-6 km in the case of a continuous spill, and 10-12.5 km in the case of an instantaneous spill. After 30 days, the slick radius has increased to 22 km, and the slick typically covers an area of 1,400-1,500 km² of very irregular shape.

In practice, the oil will form isolated patches within this area, with regions of high concentration interspersed with regions with no oil at a given time. This means that the area actually covered with oil is smaller than figured. The model gives no indication of how much smaller the actual oil covered area is.

Subsurface concentrations
Quantification of subsurface concentrations based on output from the DMI model is complicated. In the Disko West assessment this issue is discussed further with reference to the oil spill simulations in southern Baffin Bay (Nielsen *et al.* 2006, Mosbech *et al.* 2007b). DMI (*in prep.*) elaborates further on this issue, when modelling subsurface spills in the waters off South Greenland.

11.3 Oil spill in ice-covered waters

Due to the roughness of the subsurface of the ice, oil will not move as far away from the spill site in ice-covered waters as in open waters. If an oil slick is 1 cm thick on average, a spill of 15,000 m^3 will cover only approx. 1.5 km^2 below the ice, and less if thicker. This also means that very high oil concentrations may occur and persist for prolonged periods. Fauna under the ice or in leads and cracks may therefore risk exposure to highly toxic hydrocarbon levels.

11.4 Dissolution of oil and toxicity

Total oil concentration in water is a combination of the concentration of small dispersed oil droplets and the oil components dissolved from these and the surface slick. The process of dissolution is of particular interest as it increases the bio-availability 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) of 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.

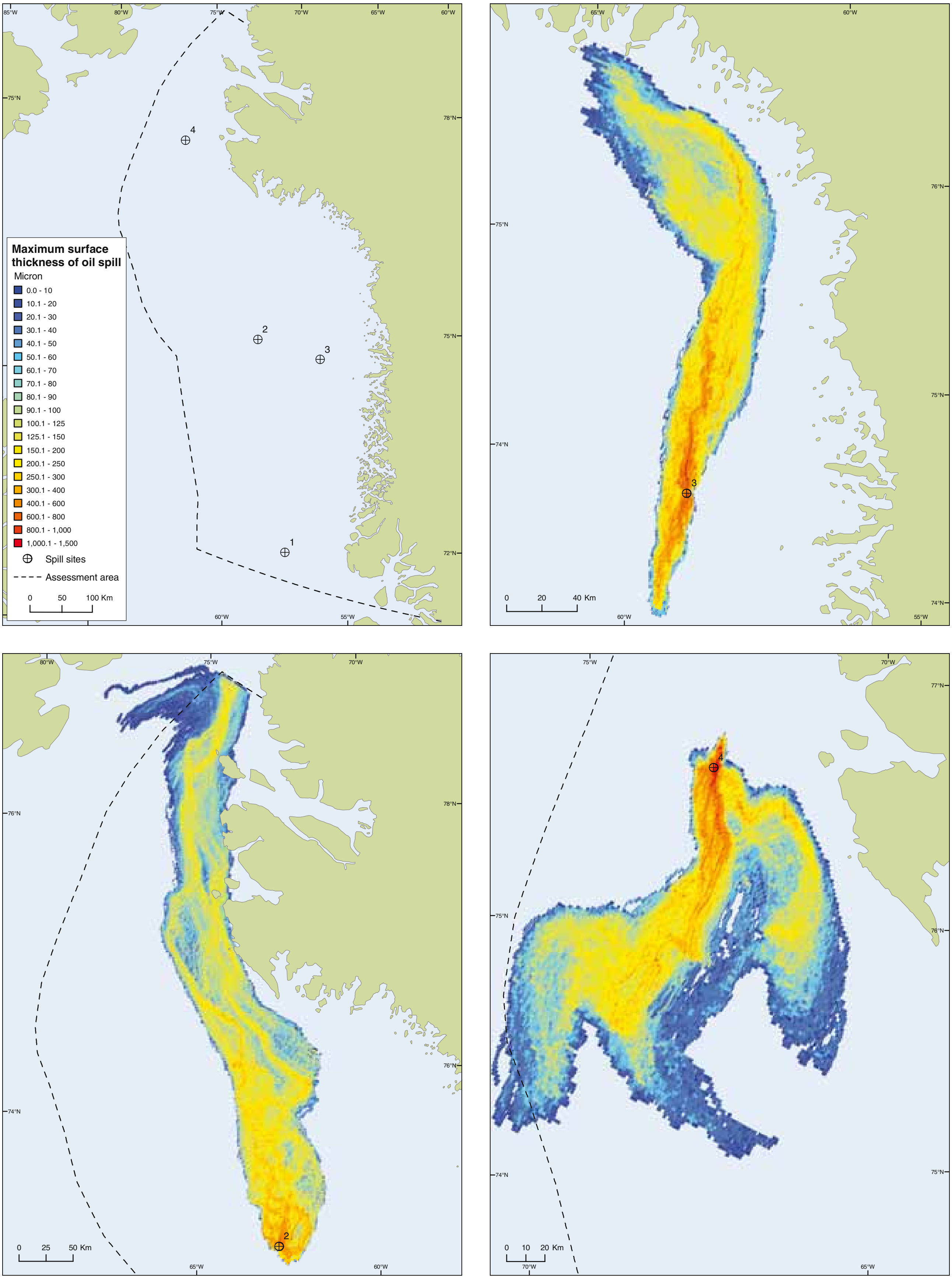


Figure 53. Examples of the DMI oil spill trajectory simulations (Nielsen *et al.* 2008). The maps B-D show the entire area swept by three different surface spills. The scale indicates the maximum thickness of the sea surface oil layer attained in the different cells during the 30 day simulation periods. Map A shows the four spill sites. B is a continuous spill from site 3 in August 2004. Map C is a continuous spill from site 2 in April 2005. Map D is a continuous spill from site 4 in October 2004. Note that the oil spill in map C hits the coasts, the spill in map B almost does and that oil spill in map D is far from any coasts.

PAHs are among the toxic components of crude oil (see Section 7.2). The highest PAHs concentration found in the water column in Prince William Sound within a six-week period after the *Exxon Valdez* spill was 1.59 ppb, at a 5 m depth. This is well below levels considered to be acutely toxic to marine fauna (Short & Harris 1996).

SINTEF (Johansen *et al.* 2003) reviewed available standardised toxicity studies and found acute toxicity down to 0.9 mg oil /l (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. Later, the weathered oil will be less toxic.

The so far published concentrations of oil components in the waters at the *Macondo*-well blowout in the Mexican Gulf in 2010 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 well head.

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, the exposure time was long (nearly four months). This might indicate that the ice fauna could be exposed to a substantial dose of toxic water-soluble components, and at least in laboratory experiments with sea-ice amphipods sub-lethal effects have been demonstrated (Camus & Olsen 2008, Olsen *et al.* 2008). Leakage of water-soluble components to the ice is of special interest, because of a high bio-availability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

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 easily metabolised by invertebrates and generally efficiently metabolised by vertebrates such as fish (review Hylland *et al.* 2006). Therefore, and in contrast to most persistent organic pollutants, PAHs are not bio-magnified 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). Bivalves and filter-feeding zooplankton can be exposed to high levels through filtering out oil droplets containing PAHs from the surrounding water.

11.5 Oil spill impacts on the environment

There are generally two types of effects from oil in the marine environment: physical contact (e.g. of birds 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) effets.

Table 17 gives an overview of potential impacts from a large oil spill.

Table 17. Summary of potential impacts from a large surface oil spill on VECs in the Baffin Bay assessment area. See Table 12 and text for explanation.

VEC	Potential overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Duration	Sublethal effects	Direct mortality
Prim. prod.	large	yes	short term	minor	minor
Zooplankton	large	yes	short term	minor	minor
Benthic fauna	large	yes	long term	major (L)	major (L)
Benthic flora	large	yes	long term	major (L)	major (L)
Ice flora and fauna	large	yes	short term	major (L)	major (L)
Greenland halibut	small	yes	short term	minor (L)	none
Arctic char	large	yes	long term	major (L)	minor (L)
Polar cod under ice	large	yes	short term	major (L)	major (L)
Fish egg and larvae	large	yes	short term	major (L)	major (L)
Fulmar	large	yes	long term	major (R)	major (R)
Common eider	large	yes	long term	major (R)	major (R)
King eider	large	yes	long term	major (R)	major (R)
Ivory gull	large	yes	long term	major (R)	major (R)
Arctic tern	large	yes	long term	major (R)	minor (R)
Thick-billed murre	large	yes	long term	major (R)	major (R)
Little auk	large	yes	long term	minor (R)	major (R)
Walrus	large	yes	long term	major (R)	moderate (R)
Ringed seal	small	no	long term	moderate (R)	minor (R)
Bearded seal	small	no	long term	moderate (R)	minor (R)
Narwhal	large	yes	long term	major (R)	minor (R)
White whale	large	yes	long term	major (R)	minor (R)
Bowhead whale	large	yes	long term	major (R)	minor (R)
Polar bear	large	yes	long term	moderate (R)	major (R)
Com. fisheries	large	yes	long term	–	–
Hunting	large	yes	long term	–	–
Tourism	large	yes	long term	–	–

11.5.1 Oil spill impact on plankton and fish incl. larvae of fish and shrimp

Adult fish and shrimp

In the open sea, an oil spill 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). Whether a subsea blowout may cause high concentrations in the water column near the shrimp habitats is not known, but a simulation study concluded that high oil concentrations would most likely occur only in a limited area (*cf.* Johansen 1999). However, the lessons learned from the deep sea blowout from the *Macondo*-well in the Mexican Gulf in 2010, where large subsea oil plumes occurred in the water column down to more than 1200 m, indicate that this conclusion is too restricted and that shrimp population could be impacted over much larger areas.

Fish and shrimp larvae

Eggs and larvae of fish and shrimp are more sensitive to oil than adults. Theoretically impacts on fish and shrimp 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, the individual oil exposure and population mortality has been calculated. 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 2 weeks, while very long-lasting blowouts could give losses of eggs and larvae in excess of 25 %. A 20 % loss in recruitment to the cod population is estimated to cause a 15 % loss in the cod spawning biomass and to take approx. eight years to recover fully (Figure 54).

However, Hjermann *et al.* 2007 reviewed the impact assessment of Barents Sea stock of Atlantic cod, herring and capelin by Johansen *et al.* (2003) and suggested improvements by emphasising more on oceanographic and ecological variation in the modelling. They also concluded that it is not possible to assess long-term effects of oil spills due to variation in the ecosystem. At best, ecological modelling, can give quantitative indications of the possible outcomes of oil spills in the eco-

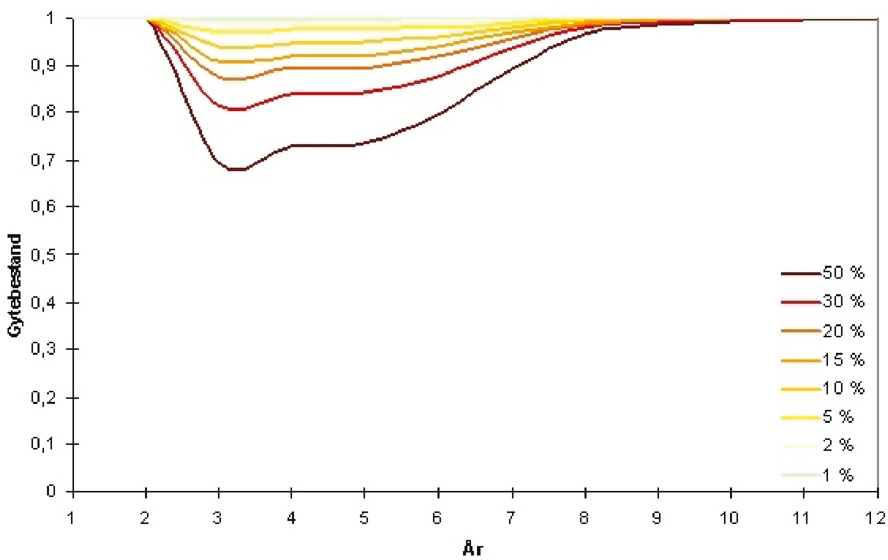


Figure 54. Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of egg and larvae due to large 'worst case' oil spills. Gydebestand = spawning stock, År = year. Sources: Anonymous (2003), Johansen *et al.* (2003).

system context. Qualitatively, modelling can assess at which places and times an oil spill may be expected to have the most significant long-term effects.

Compared to the Lofoten Barents Sea-area, there is much less knowledge available on concentrations of eggs and larvae from West Greenland and particularly in the assessment area. However, the highly localised spawning areas with high concentrations of egg and larvae for a whole stock near the surface as seen in the Lofoten-Barents Sea have not been reported from the assessment area. The overall picture here is that fish larvae are widespread, although occurring in patches which may hold relatively high concentrations. Another factor of importance is the vertical distribution of eggs and larvae. Eggs of Atlantic cod concentrate in the upper 10 m of the water column, whereas larvae of shrimp and Greenland halibut also are found deeper and would therefore be less exposed to harmful oil concentrations from a surface oil spill.

The above implies that an oil spill will most likely impact a much smaller proportion of a season's production of eggs and/or larvae for Greenland halibut and northern shrimp than modelled for cod in the Barents Sea, and that impacts on recruitment to Greenland halibut and northern shrimp stocks will most likely be insignificant. However, a subsea blowout with the properties and quantities of the *Macondo*-well 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 cause impact on the recruitment and stock size of these bottom-living species.

Polar cod eggs accumulate just below the ice. The eggs have a long incubation time and they hatch when the ice starts to disintegrate and melt. As oil spilled under ice will tend to accumulate in the same space, there is a potential risk for overlap and impacts on the recruitment to the polar cod population. Presently, we have no knowledge on possible aggregations of spawning polar cod and subsequent accumulation of eggs and larvae. But if it occurs, an oil spill may have the potential to impact recruitment and stock size. This could have effects up through the trophic web, as polar cod is an ecological key species.

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 and the wider depth distribution of the copepods this 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 (Anonymous 2003). Recent studies showed negative effects of pyrene (PAH) on reproduction and food uptake among *Calanus* species (Jensen *et al.* 2008) and on survival of females, feeding status, and nucleic acid content in *Microsetella* spp. from Western Greenland (Hjorth & Dahllöf 2008). The pyrene concentrations applied were however difficult to compare to actual spill situations. Negative effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *Calanus finmarchicus* and *C. glacialis* have also been demonstrated (Hjorth & Nielsen 2011).

Again, the lessons learned from *Macondo*-well oil spill, where huge subsea plumes of dispersed oil were found at different depths, may change these conclusions of relatively mild impacts from a surface spill to more acute and severe impacts in case of a large sub-surface spill.

Important areas for plankton including fish and shrimp 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. There is, however, very little information 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 April to June 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 (in the Disko West SEIA; Mosbech *et al.* 2007a) 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. This may, however, not apply to an oil spill of the *Macondo*-well type, due to the huge subsea plumes of dispersed oil, but no information is yet available on such impacts in the area.

11.5.2 Oil spill impacts on benthic flora

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

There are different reports on the impact of oil contamination on macroalgal vegetation and communities. After the *Exxon Valdez* oil spill in 1989 in Alaska the macroalgae cover in the littoral zone (mainly *Fucus gardneri*) was lost. It has taken many years to fully re-establish these areas with years of fluctuations in the *Fucus* cover, and some areas are still considered as recovering (NOAA 2010). These fluctuations may be a result of the grazer-macroalgae dynamics as was shown after the *Torrey Canyon* accident at the coast of Cornwall, UK (Hawkins *et al.* 2002). Regarding Prince William Sound, the fluctuations were considered as a result of homogeneity of the 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), thus resulting in a longer time span to restore *Fucus* population heterogeneity (Driskell *et al.* 2001).

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

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

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

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

11.5.3 Oil spill impacts on benthic fauna

Bottom-living organisms (benthos) are generally very sensitive to oil spills and high hydrocarbon concentrations in the water. The sensitivity of many benthic species have been studied in the laboratory and a range of sub-lethal effects have been demonstrated from exposures not necessarily comparable to actual oil spill situations (Camus *et al.* 2002a, b, 2003, Olsen *et al.* 2007, Bach *et al.* 2009, 2010, Hannam *et al.* 2009, 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, 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 sediment particles, a condition frequently seen in Greenland waters, where melt water runoff from glaciers may disperse widely into the open sea.

Effects of the sub-surface spill from the *Macondo*-well have been demonstrated on benthic fauna (Schrope 2011), but it is too early to draw any conclusions.

Many benthos species, especially bivalves, accumulate hydrocarbons, which may cause sub-lethal effect (e.g. reduced reproduction). Such bivalves may act as vectors of toxic hydrocarbons to higher trophic levels, particularly bearded seals and walruses. Knowledge on benthos in the assessment area is too fragmentary to assess impacts of potential oil spills.

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 as eiders and walrus. 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 indicate 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 specimens also suggest that mortality induced from disturbance from oil spills or exploration potentially can cause a significant reduction in the total species richness for a long time.

11.5.4 Oil spill impacts on ice habitats

There is very little knowledge available on oil spill impact on the sea-ice ecosystem (Camus & Dahle 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 11.1.4 above.

At least in laboratory experiments with sea-ice amphipods sub-lethal 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 field and in laboratory, and several sub-lethal effects were demonstrated and moreover polar cod seems to be a suitable indicator species to monitor pollution effects caused by oil (Nahrgang *et al.* 2009, 2010a-d, Christiansen *et al.* 2010, Jonsson *et al.* 2010).

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.

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 will accumulate (Skjoldal *et al.* 2007) (see also Section 10.3.1).

11.5.5 Oil spill impacts in coastal habitats

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

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 (Table 18). Many coasts in the assessment area are similar in morphology to those of Prince William Sound where oil was trapped below the surface after the *Exxon Valdez* oil spill.

In a study performed 12 years after the oil spill it was estimated how much oil remained on the beaches of Prince William Sound. Oil was found on 78 of 91 beaches, randomly selected according to their oiling history. The analysis revealed

Table 18. Peterson *et al.* 2003.

Old paradigm	Emerging appreciation
Physical shoreline habitat	
Oil that grounds on shorelines other than marshes dominated by fine sediments will be rapidly dispersed and degraded microbially and photolytically.	Oil degrades at varying rates depending on environment, with subsurface sediments physically protected from disturbance, oxygenation, and photolysis retaining contamination by only partially weathered oil for years.
Oil toxicity to fish	
Oil effects occur solely through short-term (~4 day) exposure to water-soluble fraction (1- to 2-ringed aromatics dominate) through acute narcosis mortality at parts per million concentrations.	Long-term exposure of fish embryos to weathered oil (3- to 5-ringed PAHs) at ppb concentrations has population consequences through indirect effects on growth, deformities, and behavior with long-term consequences on mortality and reproduction.
Oil toxicity to seabirds and marine mammals	
Oil effects occur solely through short-term acute exposure of feathers or fur and resulting death from hypothermia, smothering, drowning, or ingestion of toxics during preening.	Oil effects also are substantial (independent of means of insulation) over the long term through interactions between natural environmental stressors and compromised health of exposed animals, through chronic toxic exposure from ingesting contaminated prey or during foraging around persistent sedimentary pools of oil, and through disruption of vital social functions (care giving or reproduction) in socially organized species.
Oil impacts on coastal communities	
Acute mortality through short-term toxic exposure to oil deposited on shore and the shallow seafloor or through smothering accounts for the only important losses of shoreline plants and invertebrates.	Clean-up attempts can be more damaging than the oil itself, with impacts recurring as long as clean-up (including both chemical and physical methods) continues. Because of the pervasiveness of strong biological interactions in rocky intertidal and kelp forest communities, cascades of delayed, indirect impacts (especially of trophic cascades and biogenic habitat loss) expand the scope of injury well beyond the initial direct losses and thereby also delay recoveries.

that over 90% of the surface oil and all of the subsurface oil originated from the *Exxon Valdez* (Short *et al.* 2004). Today (2010) oil still lingers in buried patches on the affected shores, and their presence may be a source for continued exposure to oil for sea otters and birds that seek food in sediments (NOAA 2010).

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

11.5.6 Oil spill impacts on fish and fisheries

Tainting (unpleasant smells or tastes) of fish flesh is a severe problem related to oil spills. Fish exposed even to very low concentrations of oil in the water, in their food or in the sediment where they live may be tainted, leaving them useless for human consumption (GESAMP 1993, Challenger & Mauseth 2011). The problem is most pronounced in shallow waters, where high oil concentrations can persist for longer periods. Flatfish and bottom-living invertebrates are particularly exposed. Tainting has, however, not been recorded in flatfish after oil spills in deeper offshore waters, where degradation, dispersion and dilution reduce oil concentrations to 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 on 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, Graham *et al.* 2011, Challenger & Mauseth 2011). This problem may apply to the northern shrimp and Greenland halibut fisheries within and close to 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. In offshore areas suspension usually will last 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 (Law & Moffat 2011). During the *Macondo*-well spill 230,000 km^2 were closed for both commercial and recreational fishing, in September 2010 c. 83,000 km^2 were still closed (Graham *et al.* 2011) and in April 2011, the last of the closed areas was reopened for fishery (NOAA 2011).

Both commercial fishery and subsistence harvest and fishery in the Prince William Sound are still considered as 'recovering' since the oil spill in 1989 (NOAA 2010).

The offshore fishery for Greenland halibut within the assessment area is small compared to the total for Greenland as a whole. The main fishing grounds in the Baffin Bay are, however, located immediately south of the assessment area (annual catch on app. 13.000 tonnes, equally split between Canada and Greenland). Preliminary results of tagging experiments indicate that Greenland halibut from the assessment area migrate though these fishing grounds towards the spawning area in the Davis Strait. If tainted fish show up in the commercial catches it will have severe economical consequences. Greenland halibut at West Greenland often migrate over long distances in short time (unpublished GINR) and it is not unlikely that tainted fish also could show up in the commercial catches further south in the Davis Strait (where the annual catches constitute approx. 14.000 tonnes).

A closure of the offshore fishing grounds will mainly impact the single fishing ships operating the area. But an oil spill hitting the inshore fishing grounds will have much more severe impacts if the fishery is closed. The fishery here is much larger and takes approx. 11.000 tonnes annually ~ 18 % of the total Greenland halibut catch (in 2006).

Some interesting studies have been carried out with Atlantic cod (*Gadus morhua* L.) from the Barents Sea. Hydrocarbon uptake, metabolites, and enzymatic and genotoxic biomarker type of effect responses were measured. Elimination of PAHs was demonstrated to be slower at the lowest temperatures. For some biomarkers the response was lower than in cod from the North Sea. The results show that several factors have to be taken into account when performing risk assessment for cold water fish species. Recovery from exposure may also take longer than in temperate fish (Skadsheim *et al.* 2009).

11.5.7 Oil spill impacts on tourism

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. In this context it is notable that recreation and tourism are still considered as 'recovering' from the effects of the *Exxon Valdez* oil spill in 1989 in Alaska (NOAA 2010).

11.5.8 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 dive from the sea surface, such as auks, seaducks, cormorants and divers (loons), are most exposed to floating oil, compared with birds which spend more time flying than 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, sticks the feathers together destroying their insulation and buoyancy properties. 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, kidneys and salt glands and causes anaemia. Sub-lethal and long-term effects may be the result. However, the main cause of seabird losses following an oil spill is direct oiling of the plumage.

Many seabirds aggregate in small and limited areas for certain periods of their life cycles. Even small oil spills in such areas may cause very high mortalities among the birds present. The high concentrations of seabirds found at coasts, e.g. breeding colonies, moulting areas (Figures 13, 14) or in offshore waters at important feeding areas (Box 5) are particularly vulnerable.

Oiled birds which have drifted ashore are often the focus of the media when oil spills occur, witnessing the high individual sensitivity to oil spills. However, the concern must be the case where populations suffer from oiling. To assess this issue, extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem are necessary (Figure 55).

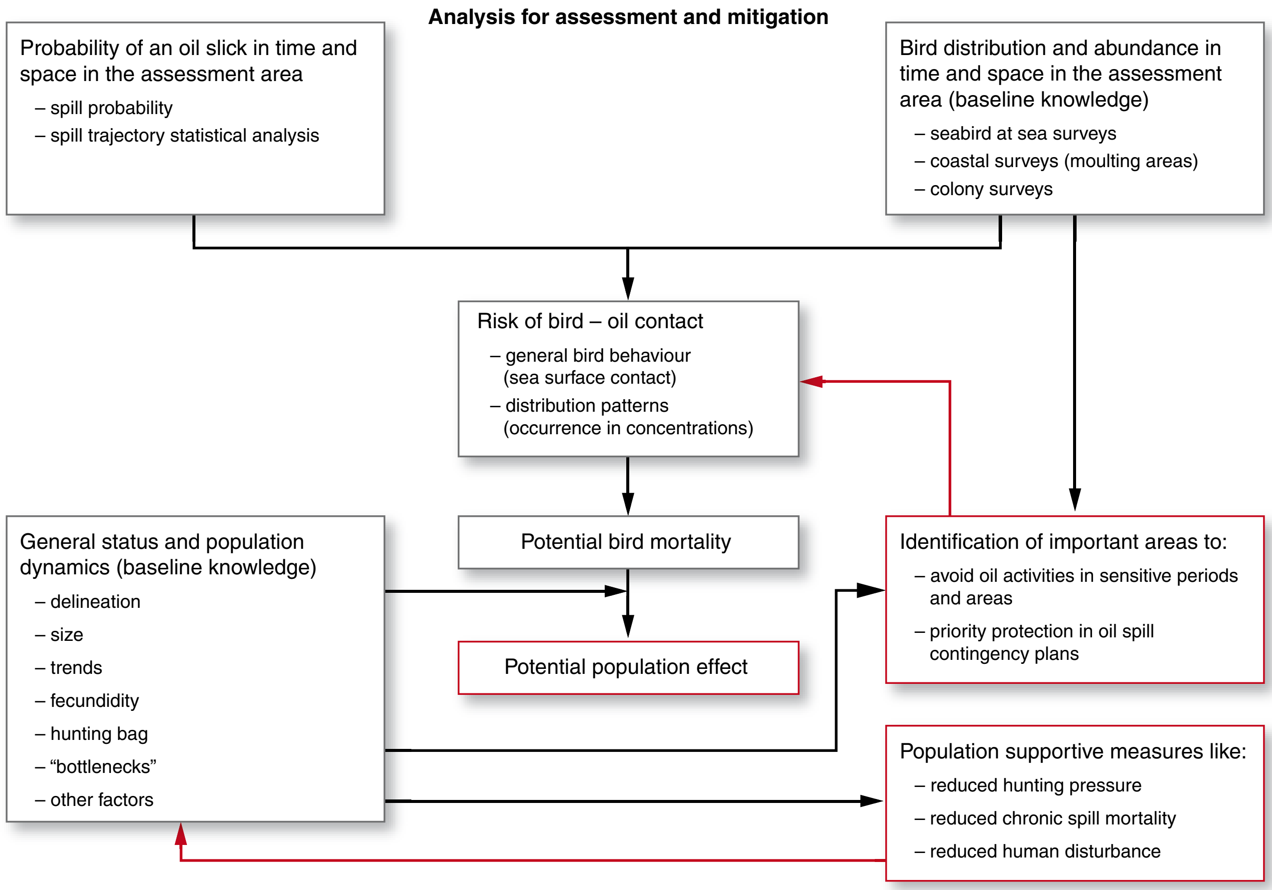


Figure 55. Basic principles of assessing a seabird populations vulnerability to oil spills. Black lines indicate main analysis of effects on bird populations, red lines analysis of potential mitigative measures. Indirect effects not included for simplicity.

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 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 adult mortality caused, for example, by an oil spill.

If a breeding colony of birds is completely wiped out by an oil spill it must be re-colonised from neighbouring colonies. Re-colonisation is 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 as in the former municipalities of Upernavik and Uummannaq, there will be no or only few birds available for re-colonisation of a site.

The breeding population of common murres (close relative of thick-billed murre) in Prince William Sound was assessed as recovered after 8 years following the impacts of the oil spill in 1989 (NOAA 2010). This is in an area with several neighbouring colonies and no hunting.

Several breeding colonies of thick-billed murre are known from the assessment area (Figure 13C). They are all situated at or close to the outer coast where they are exposed to oil spills from activities associated with the Baffin Bay licence areas. Moreover, adult birds often feed in concentrations far from the breeding site (Box 3), and also at these areas there is a high risk for contamination of many birds. A further risk situation is when the chicks and flightless adults leave the colony on a swimming migration. The satellite tracking studies of birds from a colony in Qaanaaq and another colony just south of the assessment area showed that these swimming birds move offshore towards the likely licence areas, but that they also disperse over extensive areas (Box 4). The population of thick-billed murres in southern Upernavik is most vulnerable to oil spills as all the colonies here have decreased due to excessive hunting. The colonies in Qaanaaq are not declining, and moreover there are several very large colonies within a relatively small area, increasing the regeneration potential.

There are several other important seabird colonies within the assessment area where the population could be severely impacted by oil spills. The most significant are the substantial little auk colonies in Qaanaaq, where millions of birds breed each summer (Figure 13C).

In central Melville Bay and west off Qaanaaq there are some very important seabird colonies on small islands. The fauna on these islands is diverse, and such colonies are very vulnerable to oil spills. They are in addition almost inaccessible to oil spill response due to their remoteness and the presence of sea ice during a large part of the year.

Moulting areas

Moulting seaducks are found along the coasts throughout the entire assessment area, and concentrations of primarily common and king eiders are shown in Figure 14. Moulting seaducks are highly vulnerable to oil spills in the moulting period from mid-July until September.

Migration concentrations

Large numbers of thick-billed murres have been located south of the assessment area in April/May (Mosbech *et al.* 2007a). These birds most likely proceed northwards through the assessment area to breeding sites in Upernavik and perhaps further north. Such concentrations are particularly vulnerable to oil spills because they will rest and stage in the restricted (by ice) open-water area, where oil also will tend to accumulate in case of a spill.

The considerable numbers of seabirds migrating through the Baffin Bay in autumn (Box 4) are also very vulnerable to oil spills, and significant numbers may be affected by a large oil spill. The satellite tracking showed that birds from the northern colonies tended to stage in areas in northern Baffin Bay before heading towards the winter quarters, and in such areas many birds may be exposed to oil spills. They subsequently moved rather rapidly towards their wintering grounds off Newfoundland. Murres from the colony in Disko Bay also staged before their winter migration southwards. At least some of the tracked birds were then located with the southern part of the assessment area.

Some of the bird populations which utilise the assessment area are particularly important and vulnerable (VECs): these include the king eiders moulting in the late summer and autumn, the thick-billed murres, little auks, razorbills, great cormorants, Atlantic puffins, common eiders, etc breeding in colonies holding significant proportions of the entire population. A large oil spill has the potential to severely deplete such assemblages of seabirds, which in the case of the little auk, for instance, could amount to millions of birds. Small and localised breeding colonies may be wiped out, and Atlantic puffin and razorbill are the most vulnerable in this respect. Healthy seabird populations will have a recovery potential, but if they are impacted by other anthropogenic factors such as hunting (common eiders and thick-billed murres), by-catch (common eiders) or chronic oil spills in their winter quarters (thick-billed murres), recovery can be impaired.

11.5.9 Oil spill impacts on marine mammals

Marine mammals are generally less sensitive to oiling than many other organisms, because individuals (except polar bears) are rather robust to fouling and contact with oil, mainly because adults are not dependent on an intact fur layer for insulation. Seal pups are more sensitive to direct oiling, because they have not developed the insulating blubber layer and are dependent on their natal fur.

There are, however, some especially sensitive populations in the assessment area, and some conditions also increase the risk for marine mammals to be exposed.

Whales apparently do not avoid oil-contaminated waters and they seem not able detect oil (Harvey & Dalheim 1994 and Goodale 1981, cited in Anonymous 2003b).

In ice-covered waters where oil may fill the spaces between the ice floes, marine mammals may be forced to surface in an oil spill, where there is a risk for inhaling oil vapours. This is a potential hazard, and a recent study indicate that the loss of killer whales after the *Exxon Valdez* oil spill in 1989 could be related to inhaling 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).

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 (particularly in the case of the bowhead whale) (Albert

1981, St Aubain *et al.* 1984). Crude oil will adhere to baleens and reduce the filtration efficiency for as long as 30 days, which may impact on nutritional gain for bowhead whales in the assessment area (Braithwaite *et al.* 1983, Werth 2001).

Marine mammals may also be affected through the food chain and particularly exposed are those species which feed on benthic fauna. Especially walrus is sensitive because it feeds in shallow waters where toxic concentrations of oil can reach the seafloor.

Marine mammals species affected by an oil spill during winter and spring could include walrus, bearded seal, bowhead whale, narwhal, white whale and polar bear. Of these, walrus, white whale and narwhal are especially vulnerable because their populations are declining (or have been declining recently) due to unsustainable harvest. The bowhead whale may also be considered as vulnerable because the population is small.

There is a special issue regarding the whale populations occurring in the assessment area in winter/early-spring. Their main food intake takes place when they are in their winter quarters and on migration. The survival of the populations of narwhals, white whales and bowhead whales is dependent on the rich food resources in (and south of) the assessment area, why oil spill effects on these food resources therefore may impact the whale populations (Laidre *et al.* 2008a).

Polar bears are particularly sensitive to oil spills. Contact with oil through grooming of fouled fur, consumption of tainted food or even direct consumption (because polar bears are attracted to fatty substances) can be lethal (Durner & Amstrup 2000). Furthermore, oil in the fur will reduce the insulation properties. Polar bears live in ice-covered waters and the population density is low and probably also declining. Polar bears are already considered as vulnerable (IUCN 2010) due to climate change, which reduce their habitat, the ice-covered Arctic waters.

11.5.10 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 occurred (Table 17). Oil lingered in certain coastal habitats beyond a decade in surprisingly high amounts and in highly toxic forms (and still lingers in these areas (NOAA 2010). The oil is sufficiently bio-available to induce chronic biological exposure and has long-term impacts at the population level. Heavily oiled coarse sediments formed subsurface reservoirs of oil where it was protected from loss and weathering in intertidal habitats. In these habitats several bird populations e.g. harlequin ducks, preying on intertidal benthic invertebrates, showed clear differences between oiled and un-oiled coasts. At oiled coasts they displayed the detoxification enzyme CYP1A nine years after the spill. Harlequin ducks at oiled coasts displayed lower survival, their mortality rate was 22% instead of 16%; their body mass was smaller; and they showed a decline in population density as compared with stable numbers on un-oiled shores (Peterson *et al.* 2003). The oil still lingers in the environment and both the harlequin duck and other populations of coastal birds are still assessed as 'recovering' (NOAA 2010).

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 hit the coasts. The high Arctic conditions in the assessment area may even prolong the impact period compared to Prince William Sound, where effects are still present after more than 20 years.

Another possible long-term effect in Prince Williams Sound was the collapse of the herring stock in 1993, which has been related to sublethal effects of PAH exposure of eggs during the spill in 1989 (Hjermann *et al.* 2007).

Long-term effects were also 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).

11.5.11 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 in the assessment area, where ice in winter, winter darkness and harsh weather conditions prevents effective oil recovery methods.

An important tool in oil spill response planning and implementation is oil spill sensitivity mapping. This focuses on the coastal zone and its resources, but also includes offshore areas. An atlas covering the region between 72° and 75° N was issued in May 2011 (Stjernholm *et al.* 2011), and this constitutes a northward extension of the previous atlas, covering all West Greenland coasts to the south. A further extension to the north, making the combined atlas covering the entire coastline of the Baffin Bay assessment area is under way. See also following section 11.6.

A supplementary way to mitigate the potential impact on animal populations that are sensitive to oil spills, e.g. seabirds, is to manage populations by regulation of other population stressors (such as hunting), in order to increase their ability to compensate for extra mortality due to an oil spill (see Figure 55).

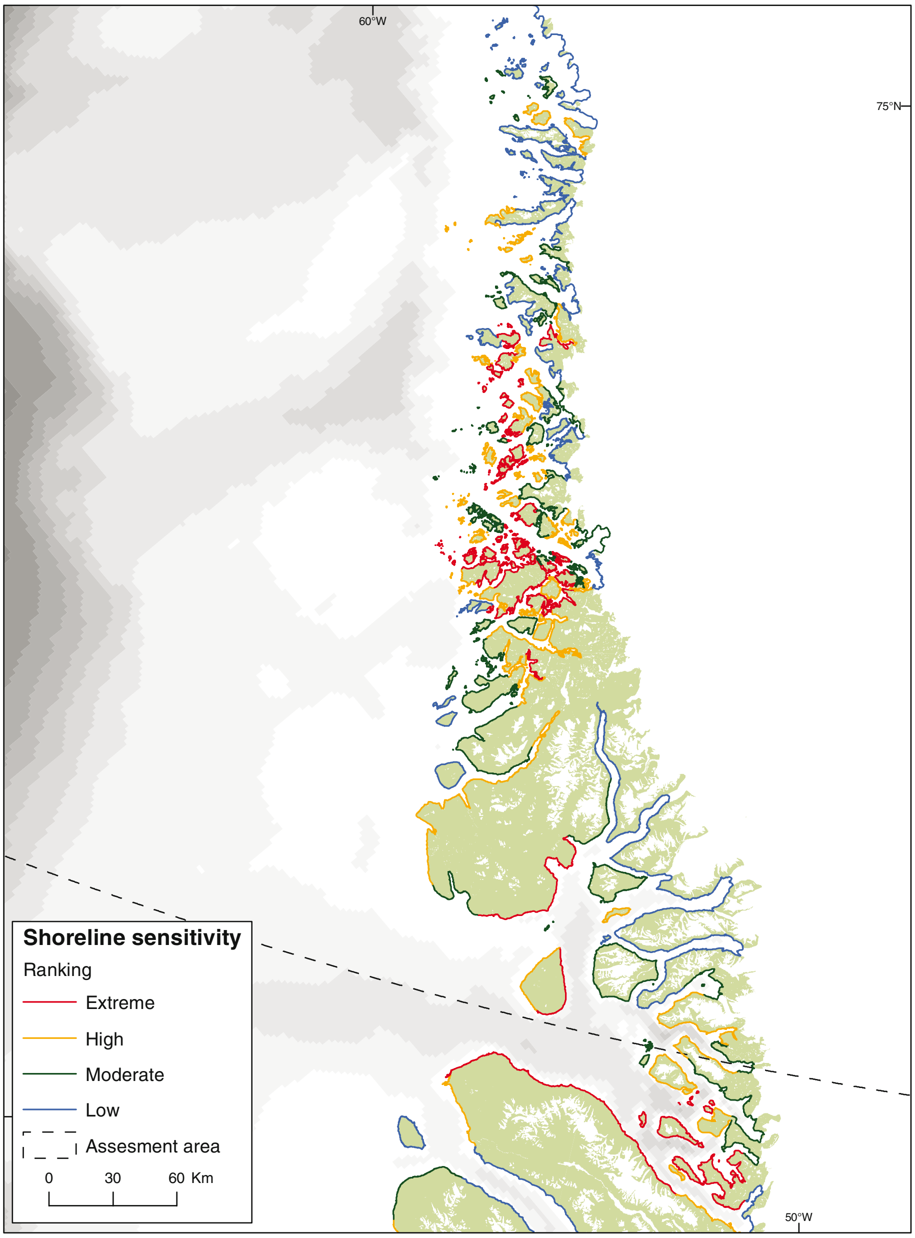
Before activities are initiated, information to the local society both on a regional and local scale is very important. In the context of mitigating impacts, information on activities potentially causing disturbance should be communicated to e.g. local authorities and hunters' organisations, as hunters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

11.6 Oil spill sensitivity mapping

K. Johansen, D. Clausen, D. Boertmann and A. Mosbech

The coast of the southern part of the assessment area has been mapped according to their sensitivity to oil spills (Mosbech *et al.* 2004, Stjernholm *et al.* 2011). The two atlases integrate all available knowledge on coastal morphology, biology, resource use and archaeology; and classify coastal segments of approx. 50 km lengths according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coast types, logistics and proposed oil spill countermeasure methods. Included are also extensive descriptions of ice conditions, climate and oceanography. An overview of the sensitivity classification is shown in Figure 56.

Figure 56. Oil spill sensitivity of coast lines in the southern part of the assessment area according to the oil spill sensitivity atlases issued by NERI (Mosbech *et al.* 2004, Stjernholm *et al.* 2011).



In relation to this assessment the classification of the offshore areas is particularly relevant and this has been updated with the newest available data and extended northwards to cover the entire Greenland part of Baffin Bay (Figures 57A-D). 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 (2 different measurements), temperature at 30 m depth, salinity at surface and at 30 m depth, wind speed, ice coverage, sea depth, slope of seabed and distance to coast (for details see Mosbech *et al.* 2004).

The atlases are available on the following websites http://www2.dmu.dk/1_viden/2_Miljoe-tilstand/3_natur/sensitivity_mapping/68_72/atlas_68_72.pdf and http://www.dmu.dk/Pub/FR828.pdf.

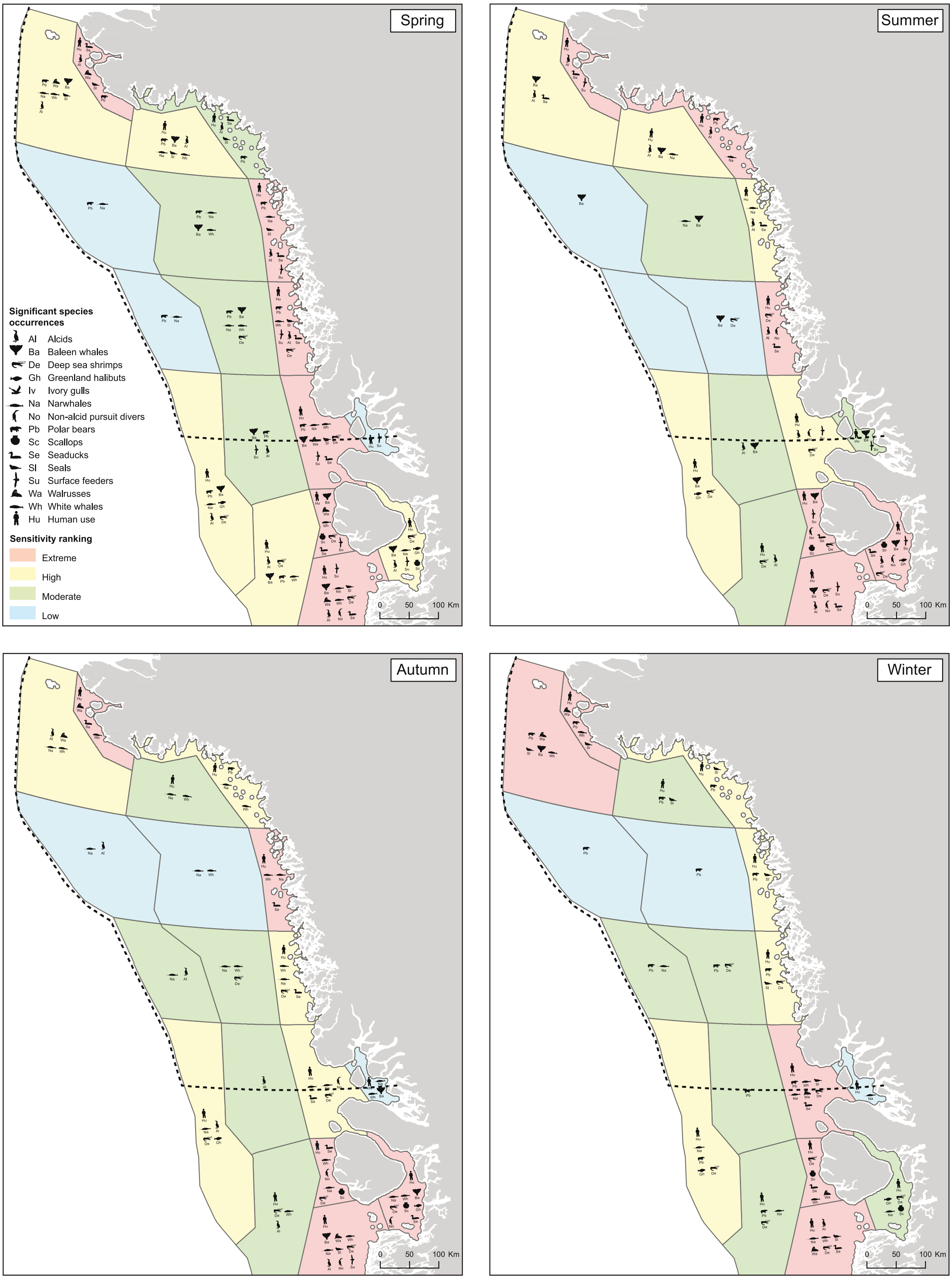


Figure 57. Oil spill sensitivity of offshore areas in the assessment area based on the oil spill sensitivity atlases issued by NERI ((Mosbech *et al.* 2004, Stjernholm *et al.* 2011).

11.6.1 Seasonal summary of offshore oil spill sensitivity

Spring (April/May–June)
The sea ice gradually disintegrates and retreats towards north and west and open-water areas increase, e.g. in polynyas and along fast ice edges. In coastal habitats the shore lead opens and gradually becomes wider. Ice may still be present in the central part of Baffin Bay in late June.

The spring bloom is initiated in these open waters, and many seabirds assemble along the fast-ice edges and other open waters, especially close to the large breeding colonies. Bowhead whales, white whales, narwhals, walrus, ringed seals and bearded seals move northwards in the leads and cracks which opens. As open water becomes available; fin, minke and humpback whales, and harp and hooded seals move in from the south.

At the coasts of the southern part large schools of capelin spawn in the intertidal zone.

Figure 57A shows a classification of the offshore areas according to their sensitivity to oil spills in spring.

Summer July–August
This is the open-water season, when the assessment area usually is ice free except for icebergs. The last ice in the Melville Bay usually is gone by mid-July.

Seabirds occupy the many breeding colonies, often in large concentrations and they feed throughout the offshore part of the assessment area, often in large concentrations. Bowhead whales, white whales, walrus and several narwhal stocks leave the assessment area following the ice towards Smith Sound and Arctic Canada. Other narwhals assemble in the interior parts of Melville Bay and in Inglefield Bredning. Fin, minke and humpback whales feed in the southern and central parts of the assessment area.

Arctic char assemble at the river mouths before moving into the freshwater for spawning and wintering.

Figure 57B shows a classification of the offshore areas according to their sensitivity to oil spills in summer.

Autumn September–November
Seabirds move southwards from the large breeding colonies and may occur in concentrations far offshore. Narwhals and white whales move southwards, the white whales often close to the coast. Minke, fin and humpback whales move south, out of the assessment area.

Figure 57C shows a classification of the offshore areas according to their sensitivity to oil spills in autumn.

Winter (December–April)
Ice move from west into the offshore areas and usually cover most of the assessment area by late December. However open waters are found in polynyas (especially the North Water) and in the shear zone between the drift ice and the fast ice on Greenland coast. Narwhals, white whales, bowhead whales, walrus, ringed seals and bearded seals occur in these open-water areas. Polar bears walk over the sea ice and swim across open water in search of seals. These marine mam-

mals are highly dependent on the open-water areas and sensitive to disturbance and will be highly exposed to oil spills in such open waters.

Almost no birds are present when ice covers all the waters, but they arrive during April and May and are particularly numerous where polynyas reach the coasts and expose the shallow feeding grounds.

Polar cod spawn under the ice in late winter and the eggs accumulate under the ice, where they are particularly exposed to oil spills.

Figure 57D shows a classification of the offshore areas according to their sensitivity to oil spills in winter.

12 Background studies and information needs

D. Boertmann, A. Mosbech, S. Wegeberg, D. Schiedek and F. Ugarte

12.1 Background studies

To support this SEIA a number of background studies were initiated in 2007. These studies should fill some of the knowledge gaps and provide data needed as a baseline and for planning and regulatory purposes. The field parts of these studies are completed now, and included in this assessment.

It is important to stress that the ecology of the assessment area is dependent on several biophysical factors (e. g. hydrography, currents, ice regime) that are manifested on a larger geographical scale than the assessment area itself. Thus a comprehensive assessment of the impact from activities in the area in question will require studies and understanding of processes in adjacent areas as well. Moreover is an ecological baseline dynamic due to climate change, why monitoring studies are required.

Finished projects include:

- Development of a hydrodynamic model and oil spill trajectories (by DMI). Report finished in 2008 (Nielsen *et al.* 2008).
- An evaluation of oil spills in the Baffin Bay ice (by SL Ross, Canada). Report finished in 2008 (SL Ross 2008).
- Thick-billed murre, breeding biology and migration pathways. Preliminary results are presented in Box 1.
- Benthos in ecological key areas in Northwest Greenland. The project was completed in 2010, a cruise report (Blicher *et al.* 2008) and a project report is available (Sejr *et al.* 2010) and results are incorporated in the descriptions above (Box 1).
- White whale migration and habitat use in the assessment area. The plan was to catch ten white whales in West Greenland and tag them with satellite transmitters. Catch was attempted in November 2007, April/May 2008, October-December 2008, October-December 2009 and February 2010 without catching any white whales. However, a number of narwhals were caught and tagged. The project has, nevertheless, resulted in a paper about white whales (Heide-Jørgensen *et al.* 2010a).
- Identification and mapping of bottom fish assemblages in northern Baffin Bay. This study is published (Jørgensen *et al.* 2011).

12.2 Information needs

However there are still research needs and further regional strategic studies as well as project specific studies have to be carried out in order to provide adequate data for future site-specific EIA-reports, to designate sensitive areas, to regulate activities and finally as baseline to use in 'before and after' studies in case of impacts from large accidents. Moreover, climate change is now acting rapidly in the Arctic, altering the ecological conditions, why a baseline is dynamic, requiring ongoing studies to understand and monitor.

Below is an annotated list of current research and information needs related to hydrocarbon activities in the Baffin Bay assessment area. This list is not exhaustive, new gaps may appear, for example when the implications of climate change become more apparent.

Beside the specific research needs listed below, there are a range of needs generic to oil activities in the arctic, cf. the Arctic Council's Oil and Gas Assessment (Skjoldal *et al.* 2007). These should be addressed by cooperative international research, where Greenland participation can secure that specific Greenland perspectives are included. The most important of these are also listed below. The specific Baffin Bay knowledge gaps could be studied and financed locally for example by the environmental forum of Baffin Bay licensees.

12.2.1 Specific research needs for Baffin Bay assessment area

Location of recurrent offshore hot-spots for biological productivity and biodiversity
Relevance: Such 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.

Relevance: Such sites are sensitive to oil spills and possibly release of produced water.

How: By surveys, remote sensing and modelling of oceanographic data.

Shrimp larvae distribution, drift and settling in Baffin Bay
Relevance: Northern shrimp fishery is the single most important industry in Greenland. Shrimp larvae move passively in the upper part of the water column, where they can be exposed to oil spills and produced water.

How: Dedicated field studies and modelling.

Benthic flora and fauna – identification of sensitive areas and establishment of a baseline (diversity, spatial variation, biomass, primary production)
Relevance: Benthic flora and fauna is sensitive to oil spill, to placement of structures and to release of drilling mud especially sedimentation of mud particles and drill cuttings. Sensitive benthic areas are important to consider when sub sea activities shall take place and when drilling locations are identified. For shore habitats (subtidal and intertidal zone) knowledge on benthic flora and fauna is especially important for the identification of the most oil spill sensitive areas, where shoreline protection potentially can be established during an oil spill.

How: Some surveys have been carried out (see Box 1). Dedicated strategic field surveys in combination with the studies carried out by the licensees during site surveys.

Fish – biology, spawning areas, stock relationships of important species (esp. Greenland halibut, polar cod, capelin)
Relevance: Fish, especially egg and larvae, can be sensitive to oil spills and produced water (e.g. tainting) and adult fish can be displaced by noisy activities, why knowledge is important to mitigate impacts on fish stocks and on fisheries.

How: Dedicated surveys.

Seabirds – distribution and abundance of breeding birds, population delineations, migration concentrations and pathways
Relevance: Seabirds are very sensitive to oil spills and knowledge of concentration areas is important to mitigate impacts.

How: Surveys of and ecological studies in breeding colonies including previously un-surveyed areas (Melville Bay), tracking of migrating birds by satellite telemetry and geo-locators and dedicated surveys by ship and aircraft (in combination with the hot-spot studies listed above).

Marine mammals – distribution and abundance (esp. whales), relationship to sea ice (esp. polar bear), stock identity and movements (esp. narwhal, white whale), general biological knowledge of less known species (esp. bearded seal)
Relevance: Marine mammals are sensitive to oil spills and to noisy activities. To mitigate impacts knowledge as specified above is important.

How: Tracking studies by means of satellite transmitters and dedicated surveys (ship, aircraft).

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, and the most important knowledge gaps to address include: Narwhal reactions to seismic noise and cumulative impact on whales from activities in several licence blocks.

How to address gaps: Field studies, passive acoustic monitoring, satellite tracking.

12.2.2 Research needs generic to the arctic

The effects 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 mitigate potential impacts. Assessment criteria and adequate monitoring strategies should be established.

Below some important questions, which should be addressed before production activities are initiated in Greenland. Some of these are of international significance. Many relate to how spills and releases behave and impact organisms under arctic conditions, especially in ice covered waters.

In relation to oil spills some important questions are listed to address include:
- Biological effects and sensitivity of PAHs and other oil components on key species (e.g. polar cod) under Arctic conditions,
- Oil vapours and their effects marine mammals,
- Degredation rates and toxicity of oil and degredation products in water and sediments under Arctic conditions,
- Fate and behavior of oil spills in ice.

In relation to drilling mud and cuttings:
- Degredation rates and toxicity of mud chemicals and their degredation products in water and sediments under Arctic conditions.

In relation to produced water there are similar questions
- Fate, behaviour and toxicity of produced water in ice-covered waters,
- Biological effects, bio-accumulation and sensitivity of the different components of produced water on key species (e.g. polar cod).

Contaminants
- There are research needs concerning the interactions between impacts of oil related pollution and contaminants such as POPs and heavy metals in relevant species living in the assessment area. Integrated studies on these issues are needed.

12.2.3 Ecotoxicological monitoring

To use biological indicators to assess, whether there is an unacceptable impact or not, assessment criteria have to be established. Such criteria are based on ecotoxicological tests that cover the sensitivity range of relevant species at different trophic levels, e.g. OSPAR Environmental Assessment Criteria (EAC). Toxicological tests with relevant species from the Baffin Bay are not available for establishing such criteria. Knowledge concerning species' sensitivity, assessment criteria and an adequate monitoring strategy, have to be available before increased drilling activities. e. g. during oil exploration or production will start in West Greenland.

12.3 New environmental study programme

NERI and GINR have proposed a new strategic environmental study programme to strengthen the knowledge base for planning, mitigation and regulation of oil activities in the Baffin Bay assessment area.

The programme includes:

- Identification and ecology of important areas for seabirds and marine mammals in Baffin Bay.
- Polar bears and sea ice in the Baffin Bay assessment area.
- Distribution and habitat use of ringed seal.
- Winter and spring surveys of the abundance of marine mammals in the Baffin Bay assessment area.
- Acoustic monitoring of the seasonal occurrence of marine mammals in the Baffin Bay assessment area.
- Seabird colony baseline studies along the NW Greenland coast.
- Greenland halibut in Baffin Bay.
- Diversity of benthic macrofauna along the coast and in from 100 to 1000 m depts. in the Baffin Bay assessment area.
- Baseline studies for assessing ecotoxicological effects of oil activities in Baffin Bay.
- Extension of the Greenland coastal zone oil spill sensitivity atlas to 77°N.
- Update of the SEIA.

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