THE WESTERN GREENLAND SEA

A strategic environmental impact assessment of hydrocarbon activities

Scientific Report from Danish Centre for Environment and Energy No. 22 2012

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DCE – DANISH CENTRE FOR ENVIRONMENT AND ENERGY

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Preface

In 2006 the Bureau of Minerals and Petroleum decided to initiate the preparation of licensing rounds for the so-called KANUMAS areas (the waters off Northeast and Northwest Greenland). This was completed in 2008 for the West area, while a licensing round for the East area is scheduled for 2012/13. Preliminary strategic environmental impact assessments (for both areas) were then prepared to be included in the decisions process (Boertmann *et al.* 2009c, d). At the same time several studies were initiated to augment the biological background knowledge (see Section 11) and the results of these studies should be used in updated versions of the SEIAs. The updated SEIA for the KANUMAS West areas (now termed as the Baffin Bay assessment area) was issued in late 2011 (Boertmann & Mosbech 2011). The present report is the updated document covering the KANUMAS East area (Figure 1). However, as the term KANUMAS is not current any more it is substituted with the term Greenland Sea assessment area.

Summary and conclusions

This document is a Strategic Environmental Impact Assessment (SEIA) of activities related to exploration, development and exploitation of hydrocarbons in the sea off Northeast Greenland between 68° and 81° N; the Greenland Sea assessment area (Figure 1).

A preliminary version of this document (Boertmann *et al.* 2009c) was issued in 2009. This is now updated with new information primarily derived from the background study program initiated by Bureau of Minerals and Petroleum. Despite the new information included, the knowledge on the biology is still much more limited than the two license areas in West Greenland – the Disko West and the Baffin Bay.

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

The assessment area is shown in Figure 1, and it is the region which potentially could be impacted by oil exploration and exploitation activities within the licensing area. However, drift modelling indicates that an oil spill 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 early 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 environment of the study area is briefly described with focus on oceanography and ice conditions. Sea ice and icebergs are present throughout the year, with the lowest concentrations in August and September. One of the most important physical features for the biological environment is the polynyas (ice-free or almost ice-free areas surrounded by sea ice). The most important polynyas are found at the entrance to Scoresby Sund, at Wollaston Forland (the Sirius Water Polynya) and at the northeast corner of Greenland (the Northeast Water Polynya), see Figure 5. These polynyas become free of ice very early in spring (April) and also have ice-free parts throughout the winter.

Accounts of some of the physical conditions in the assessment area have been issued by DMI in 2008 and 2011 (Hvidegaard *et al.* 2008, Pedersen *et al.* 2011).

The assessment area is situated within the Arctic region, with all the typical biological properties of this climatic region: low biodiversity, with some species very abundant and a relatively simple food web, having only a few steps from primary producers to top predators and with key species playing important roles in the ecology of the region (Figure 6).

In the marine environment the biologically most significant event is the spring bloom of planktonic algae, the primary producers in the food web (Figure 6). These are grazed upon by zooplankton, including the important copepods of the genus *Calanus*, which is one of the key species groups in the ecosystem. Copepods again form the most important prey for small fish, large crustaceans as well as some seabirds and marine mammals.

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. Very little is known on the benthos communities in the assessment area.

In and on the underside of the sea ice a specialised community exists: the sympagic flora and fauna. Algae live in and on the ice and are grazed upon by crustaceans, which in turn sustain populations of polar cod and Arctic cod. Especially the multi-year ice has a very rich biological community.

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 important: the polar cod is very numerous, both in the water column and associated with sea ice, and it constitutes a major food resource for seals, whales and seabirds. It is another key species. Other fish species in the assessment area include Greenland halibut and Arctic char, and capelin occurs in the southeastern offshore waters.

Seabirds are locally abundant with several species present in the study area in summer and spring. Many species breed in colonies mainly close to the polynyas, where dense aggregations of birds can be found as early as May. Other coastal aggregations of seabirds include moulting ducks in bays and fjords in the summer months. In spring and autumn millions of seabirds migrate through the offshore parts of the area on their passage between Svalbard and Russian breeding sites and Canadian wintering grounds.

The most important seabird species in the assessment area are common eider, thick-billed murre, little auk and ivory gull (Table 5). Almost all the seabirds leave the area for the winter to return in May and June. Thick-billed murre, common eider and black-legged kittiwake are all red-listed in Greenland due to declining populations, although mainly in West Greenland. Other red-listed bird species which occur in the marine part of the assessment area include Sabines gull, Arctic tern and light-bellied brent goose. Also ivory gull is red-listed (both nationally and internationally), mainly because of the expected reductions in its primary habitat, sea ice. The coasts of the Northeast Water are a stronghold for this species.

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 entire population). The most important of these species is the little auk. Other national responsibility species occurring in the marine part of the assessment area are black guillemot and light-bellied brent goose.

Marine mammals are significant components of the 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 that use the assessment area year round are narwhal, bowhead whale, walrus, bearded seal, ringed seal and polar bear (Table 6). They are often associated with ice edges, polynyas or shear zones, where open water is present. In addition, harp and hooded seals assemble in large numbers on the drift ice in March to whelp and later to moult. Several species of whales occur in the assessment area during summer. Of these, blue whales are probably the most important because of their conservation status.

Polar bear, walrus and bowhead whale are red-listed because their populations are small, declining or expected to decline because of climate change (polar

bear). Blue whale is also red-listed, and the assessment area is probably a very important habitat for this species.

Human use of natural resources only occurs in the southern part of the assessment area. Subsistence hunting (marine mammals and seabirds) and fishing is carried out near the town of Ittoqqortoormiit/Scoresbysund and hunters from Tasiilaq occasional venture as far north as the southernmost part of the assessment area.

Commercial fishery is limited to Greenland halibut and this takes place in offshore areas in the southern part of the assessment area. The catches are small compared to other parts of Greenland.

Tourism is a growing industry in Greenland, and this is also the case in Ittoqqortoormiit/Scoresbysund, where activities take place from early spring (April) and throughout the summer. There is a local operator and a few Icelandic operators also have activities in the Ittoqqortoormiit-area. Several cruise ships have visited the National Park and Ittoqqortoormiit annually in recent years.

Knowledge on background levels of contaminants such as hydrocarbons and heavy metals is important 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.

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

Presently, we do not know much about the adaptation capacity of 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 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 economically feasible to exploit, activities will proceed for many years.

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

The most noise sensitive organisms in the assessment area are the marine mammals, particularly the whales. They are sensitive to seismic surveys and may be displaced from extensive areas potentially including critical areas such as feeding grounds. As seismic surveys are temporary, the effects of a single survey are expected to be of short duration (e.g. weeks or a maximum of a few months). However, if several seismic surveys occur simultaneously, the disturbed area becomes much larger and cumulative effects will increase.

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 and bowhead whale during summer and autumn. Walrus and bearded seals may also be displaced from areas where drilling activity takes place.

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

A derived effect of displacement of marine mammals may be reduced availability to hunters from Ittoqqortoormiit.

Noise from a single seismic survey has also 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, mainly depending on fish species. As the commercial fishery is very limited within the assessment area, significant impacts are not expected.

Unless a zero-discharge policy is applied, drilling mud and cuttings will be released on the seabed, with local impacts on the benthos 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 and water based chemicals only (oil based drilling muds are not allowed in Greenland), such as defined by the OSPAR standards. But even non-toxic chemicals may impact benthic organisms. 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 and further testing of degradation and toxicity should be carried out.

Exploration drilling is an energy demanding process emitting large amounts of greenhouse gasses, why even a single drilling will increase the Greenland contribution significantly.

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

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) as well as by application of the Precautionary Principle and international standards (IMO, OSPAR).

Normal operations – development and production

Development and production activities are difficult to evaluate when location and 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). 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. The knowledge on long-term effects of produced water in the marine environment is limited; there is, however, an increasing concern for this issue. In the Arctic for example, polar cod eggs and larvae aggregated under the ice, could be exposed to produced water, because this may accumulate in the same habitat. The most obvious way to mitigate effects of produced water is efficient cleaning before discharge or even better to re-inject it into the wells.

Discharge of ballast water is also 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 related to a producing oil field. This problem may be reduced 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 and production are energy-consuming activities which will contribute significantly to the Greenland emission of greenhouse gases. To illustrate this, 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 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 contribute to reduce impacts.

Placement of structures

Placement of offshore structures and infrastructure may locally impact seabed communities and there is a risk, in shallow areas, of spoiling important feeding grounds, particularly for walrus. If onshore structures are established there will be a risk of river obstruction impacting anadromous Arctic char and also of damage to unique coastal flora and fauna.

Finally, placement of structures and installations onshore will also have an aesthetic impact on the landscapes, an issue especially important to consider when evaluating impacts on tourism.

Commercial fishery will be affected by development and production if installations are placed in the fishing grounds. A safety zone (of typically 500 m) will be applied around the offshore facilities. Commercial fishery is currently limited and takes place only in the southern part of the assessment area, which right now is far outside the areas planned to be included in a licence round.

Illuminated structures and the flame from flaring may attract seabirds in the dark hours, and there will be a risk of mass mortality of 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 contribute to reduce environmental impacts.

Accidents

The environmentally most severe accident from the activities described above is a large oil spill. Oil spills may occur either during drilling (blow-outs) 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 the Greenland Sea with 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, two of the 18 scenarios indicate that under certain conditions, oil may reach shores up to several hundred kilometres from the spill site.

Oil in ice

In general, oil spills occurring in the coastal zone are regarded as much more deleterious than oil spills in the open sea. This may, however, not apply in an area such as Greenland Sea, which is dominated by sea ice for the major part of the year. Ice will initially contain the oil between the floes and on the rough underside. However, as the ice moves around with currents 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 the sea surface

The impact of a surface oil spill in the assessment area on primary production, plankton and fish/shrimp larvae in open waters will probably 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. The same may be the case for localised concentrations of plankton and fish larvae if they occur in the uppermost part of the water column. However, on a wide scale only slight effects on these ecosystem components are expected. More vulnerable are seabird concentrations (see below).

Sub sea oil spills

The lessons learned form the *Macondo*-oilspill was that a subsea spill in very deep waters (1500 m) could give rise to huge subsea plumes of dispersed oil. This situation is less likely to occur in the licensing area, which is situated on the shelf with max. water depth of 530 m, although the same apparently also happened after the *Ixtoc*-spill in only 50 meters water depth.

Oil spills in the coastal zone

The coastal zone is especially sensitive to oil spills because of the high biodiversity. The 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 and even impact the seabed. Furthermore, local hunters use the coastal zone in the southern part of the assessment area.

Long-term impacts may occur in the coastal zone if oil is buried in sediments, among boulders, in mussel beds or is embedded in crevices in rocks. From such sites oil may seep and cause chronic pollution which may persist for decades. In Prince William Sound in Alaska such preserved oil has caused long-term effects on birds utilising the polluted coasts, and several populations have still not recovered.

Oil spill 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 hydrocar-

bons 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. But a subsea spill have the potential to impact the seabed communities in deeper waters too.

Oil spill 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).

A subsea spill may however, have the potential to impact demersal fish directly or through the food.

Oil spill impacts on seabirds

Bird populations particularly at risk of being impacted by an oil spill in the Greenland Sea area include the large breeding colonies of little auk and the two thick-billed murre colonies, all on the coasts of the Scoresby Sund Polynya. Furthermore, the large assemblages of pre-breeding eiders in the polynyas will be very exposed. Some red-listed seabird species (e.g. thick-billed murre, ivory gull) occur in the assessment area and the populations of these will be exposed to increased mortality in case of a large oil spill. The huge numbers of seabirds on migration through the assessment area in spring and autumn will also be at risk.

Oil spill impacts on marine mammals

Polar bears are especially vulnerable to oil spills because oiling of the fur may kill the bears. The other marine mammals are less sensitive to direct oiling, but for example, baleen whales may be vulnerable to oiling of their baleen. Bowhead whales, which occur in very low numbers (and are red-listed), belong to a stock which now is recovering from heavy exploitation. This recovery may be halted by even a slight increase in mortality. Walrus and bearded seal feeding on benthos may be exposed to oil through their food if oil sinks and accumulates on the seafloor.

Recent studies indicate that whales and seals are very sensitive to inhaling oil vapours, and particularly narwhals 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.

The seals whelping on the drift ice will be very sensitive to an oil spill in the area and many adults and pups may be fouled. Adult seals are rather robust to oiling, but pups are more likely to succumb. Walruses are also sensitive because the population is concentrated at relatively few sites, and oil on one individual may be transferred to many other due to the walruses behaviour of resting in close contact with each other.

Even though seals may tolerate some oil on their fur, such oiling may impact local hunters, as fouled skins are of no use and commercially worthless.

Oil spill impacts on fisheries

Oil spill effects on commercial fisheries are mainly linked to the closure of fishing grounds (Greenland halibut) for longer periods (weeks to months) due to the risks associated with marketing polluted or tainted fish. Effects on subsistence hunting

and fishing will include closure of polluted coasts and probably also temporary changes in the distribution and habits of quarry species.

Oil spill impacts on tourism

The tourist industry in the assessment area is also expected to be negatively impacted by a large oil spill.

Long term impacts

Long term effect of residual oil caught in the beach sediments must be expected if oil hits the coasts. This was the case in the Prince Williams Sund, where oil from the *Exxon Valdez* spill in 1989 still is present in such habitats and still impacts the environment.

Areas sensitive to oil spills

In Figure 50 a number of areas especially sensitive to oils spills are shown. These are based on the available knowledge, and may be changed when new and improved information on seabirds, marine mammals and other sensitive components of the ecosystem have been provided.

Further studies

Compared to West Greenland the lack of information on the biological environment is much more pronounced for the assessment area covered by this SEIA. There is a general lack of knowledge on many of the ecological components, processes and interactions in time and space. To fill some of these information needs, BMP, GINR and DCE initiated and carried out a number of background studies in 2008, 2009 and 2010. The results from these studies have been incorporated in this revised and updated SEIA. See Section 11.1 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 the preparation of site-specific EIAs. A list of the most important studies identified so far is given in Section 11.2. Some of these research needs are generic to the Arctic and have also been identified by the Arctic Council Oil and Gas Assessment (Skjoldal *et al.* 2007). An international effort should address these needs.

Dansk resumé

Strategisk miljøvurdering af olieaktiviteter i den grønlandske del af Grønlandshavet

Denne rapport er en strategisk miljøvurdering af aktiviteter forbundet med olieefterforskning og -udvinding i den grønlandske del af Grønlandshavet. Nærmere bestemt farvandet mellem 68° og 70° 30' N (Figur 1). Dette område betegnes som vurderingsområdet i Grønlandshavet (Greenland Sea assessment area). I dette område forventes gennemført en udbudsrunde af licensområder i 2012/13, og der er udpeget et kommende udbudsområde beliggende på kontinentalsoklen mellem 75° og 80° N.

I 2009 udgav 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. På trods af denne nye viden, er den generelle biologiske vidensbasis fra Grønlandshavet stadig meget ringere end den er for de to udbudsområder i Vestgrønland: Baffin Bugt og Disko Vest.

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

Rapporten behandler et område, som er større end det forventede udbudsområde (se Figur 1). Det skyldes, at der skal tages højde for, at oliespild kan drive meget langt og dermed også ud af det område som vil blive udbudt. Det vurderede område kaldes i rapporten "the assessment area" = det vurderede område.

Området er beliggende i den højarktiske zone og har de for denne zone karakteristiske biologiske træk: Forholdsvis lav biodiversitet (undtaget de bundlevende dyr), 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. Dvs. at de højere trofiske niveauer er afhængige af disse nøglearters forekomst i tid og rum.

Det vurderede område er lokalt meget rigt i biologisk/økologisk forstand, men der er også områder med sparsomt liv. Primærproduktionen om foråret er visse steder høj, der er rige dyresamfund på havbunden ligesom der er store og meget vigtige forekomster af både fugle og havpattedyr.

Blandt fuglene forekommer der vigtige (både nationalt og internationalt) og rødlistede arter som polarlomvie (nationalt rødlistet) og ismåge (internationalt og nationalt rødlistet) og på kysterne af polyniet ved Scoresby Sund yngler flere millioner par søkonger (national ansvarsart). Ikke alene lokale ynglefugle forekommer; men store mængder af havfugle trækker igennem vurderingsområdet forår og efterår mellem ynglepladser på Svalbard og Barentshavets kyster og vinterkvarterer ved Newfoundland eller Sydvestgrønland. De talrigeste arter er søkonge og polarlomvie, og en meget stor del af den samlede bestand af den fåtallige og rødlistede ismåge foretager dette træk.

Blandt havpattedyrene er der vigtige og rødlistede (både nationalt og internationalt) arter som isbjørn, hvalros, narhval og grønlandshval.

Særligt vigtige biologiske områder i det marine miljø er polynierne, som er mere eller mindre åbent vand på ellers isdækket hav. De tre store polynier er Nordøstvandet ud for Nordostrundingen, Siriuspolyniet ud for Wollaston Forland og mundingen af Scoresby Sund. Der er tillige flere mindre polynier fordelt langs kysten. Polynierne har åbent vand om vinteren og deres udbredelse udvides om foråret (april/maj). Det medfører, at primær-produktionen kan indledes meget tidligere end i de omkringliggende isdækkede områder. Det betyder også, at havpattedyr kan overvintrer her, og at trækfugle, der er afhængige af åbent vand, kan raste her meget tidligere på året end andre steder langs kysterne. Den tidlige produktion tiltrækker desuden koncentrationer af havpattedyr og fugle, og det er ikke tilfældigt, at byen Ittoqqortoormiit/Scoresbysund blev etableret ved et af de store polynier. Vurderingsområdets store ynglekolonier af havfugle ligger alle ved polynierne og det er her mange af indlandets vandfugle samles inden isen forsvinder fra søer og kær. Områdets hvalrosser overvintrer i polynierne og i denne sammenhæng er Nordøstvandet meget vigtigt.

Hellefisk udnyttes kommercielt i den sydligste del af vurderingsområdet, og fangst og fiskeri til lokalt brug er vigtige aktiviteter for beboerne i Ittoqqortoormiit og for de fangere fra Tasiilaq, der tager på fangst mod nord til vurderingsområdet.

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 Sund i Alaska i 1989, den norske miljøvurdering af olieaktiviteter i Barentshavet (2003) og på Arktisk Råds "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.

Vurderingsgrundlag

Vurderingerne i denne rapport bygger på de eksisterende klimatiske forhold. Klimaændringer forventes at påvirke miljøet i vurderingsområdet i de kommende årtier, og især isens forekomst forventes at ændre sig. Det betyder ændrede leveforhold, som vil medføre at nogle arter reduceres i forekomst og udbredelse, mens andre vil 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, formentlig i perioden juli til oktober. Et selskab gennemførte dog seismiske undersøgelser på isdækket hav i 2010 og 2011 ved hjælp af en isbryder.

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 udvik-

ling 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, boring og helikopterflyvning). Der forventes kun relativt svage, midlertidige og lokalt forekommende påvirkninger, idet mere omfattende 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 påvirkninger, som i yderste konsekvens kan påvirke særligt sårbare bestande – inden for vurderingsområdet særligt narhval, grønlandshval og måske også blåhval. Flere aktiviteter i samme område vil desuden kunne give anledning til kumulative påvirkninger, et forhold der bør tages højde for i planlægningen af for eksempel seismiske undersøgelser.

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

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 fra en enkelt seismisk undersøgelse vil være midlertidig (varighed uger til måneder), fordi aktiviteten ophører. Men kumulative påvirkninger fra flere aktiviteter kan forstærke påvirkningerne.

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 kan derfor konkluderes, at seismiske undersøgelser ikke giver anledning til risiko for væsentlige påvirkninger af fiskebestandene i den grønlandske del af Grønlandshavet.

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. Støjen kan påvirke havpattedyr på store afstande, sådan at de søger væk fra lydkilden, og særligt hvaler er følsomme. Der er derfor risiko for at narhvaler, grønlandshvaler og hvalros kan blive fortrængt fra vigtige opholdsområder. Der er også risiko for midlertidig fortrængning af blå-, fin-, våge og pukkelhval i sommermånederne.

Fangst på havpattedyr vil kunne påvirkes, hvis byttedyr bortjages fra traditionelle fangstpladser.

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 6.000 tons boremudder og 2261 m^3 borespåner. Der må tillige kun bruges de mere miljøvenlige 'grønne' og 'gule' tilsætningskemikalier (jvf. OSPARs klassifikation). 'Røde' og 'sorte' er ikke tilladte. Dog kan der gives tilladelse til 'røde' (som er svært nedbrydelige), hvis det kan godtgøres at brugen bidrager til på anden vis at gøre en boring mere miljøvenlig. Dette svarer til reglerne for brug af borekemikalier i Norge. 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 har vanskelige boreforhold 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 tilladelsen betinger, at selskaberne skal arbejde aktivt for at afskaffe brugen af dette 'røde' kemikalie. Udledningen af 'grønne' og 'gule' tilsætningsstoffer skal tillige fremover vurderes konkret med henblik på giftighed og nedbrydning under arktiske forhold, fordi disse forhold ikke er undersøgt.

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 Grønlandshavet, 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 %.

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.

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 re-

duceret 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 ('re-injection').

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 deponere begge dele i land eller 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 anlægget af et stort oliefelt i Grønlandshavet 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 fortrænges permanent fra vigtige fourageringsområder eller således at de ændrer trækruter. I Grønlandshavet er det især narhval, 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 potentiale 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.

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 lokale havmiljø. Problemet har hidtil ikke været særligt stort i Arktis, men formodes at blive større som følge af klimaændringerne. Risikoen kan formindskes ved særlige regler for udpumpning og behandling af ballastvandet, som forventes at blive international rutine når de nye IMO-foreskrifter ratificeres.

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 blevet sjældne, 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 Grønlandshavet med udgangspunkt i tre spildsteder forholdsvis langt fra kysten (Figur 47). I to ud af de 18 simuleringer når olien kysten op til flere 100 km fra spildstedet.

Oliespild i kystnære farvande regnes generelt som meget mere ødelæggende end oliespild på åbent hav. Men i et område som Grønlandshavet 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 isen kan også medvirke til at 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. 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 eller i strande med rullesten, hvorfra olie langsomt kan frigives til det omgivende miljø med risiko for langtidsvirkninger f.eks. på fuglebestande som udnytter kysterne. Endelig udnyttes de kystnære fravande i den sydlige del af det vurderede område af lokale indbyggere til fangst og fiskeri.

På åbent hav er fortyndingseffekten med til at mindske miljøeffekterne af et oliespild. I og nær vurderingsområdet i Grønlandshavet 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 ('marginal ice zone'), 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 vil dog næppe påvirke bestanden af hellefisk, den eneste fiskeart der udnyttes kommercielt i vurderingsområdet.

Fugle er særligt sårbare overfor oliespild på havoverfladen, og i Grønlandshavet er der lokalt mange sårbare fugleforekomster. For eksempel de store ynglekolonier af polarlomvie og søkonge, forårsforekomster af ederfugl og den fåtallige og rødlistede ismåge. Der er også steder med fældende ederfugle og flokke af fældende kongeederfugle er kendt fra en enkelt fjord. De store mængder af trækfugle vil også være udsatte.

Havpattedyr kan påvirkes af oliespild på havoverfladen. I vurderingsområdet vil hvalros være særligt udsat, fordi hvalrosserne forekommer meget koncentreret omkring nogle få vigtige fødesøgnings områder. Der er tillige helt nye undersø-

gelser der tyder på, at spækhuggere (og dermed formentlig også andre hvaler) er sårbare overfor indånding af oliedampe over et spild, et forhold som kan blive aktuelt ved oliespild i is (se nedenfor).

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. Grønlandshvalerne, der forekommer i området, tilhører en meget lille bestand, som blev næsten udryddet i begyndelsen af 1900-tallet. Bestanden er så reduceret, at selv en lille ekstra dødelighed kan tænkes at påvirke bestandens bedring.

Et oliespild i havområder med is vil formentlig samles i åbne revner og under isflager, hvor den kan påvirke de fugle og havpattedyr, der er afhængige af åbent vand, men 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 blot 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. 1.500 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. Udbudsområdet i den grønlandske del af Grønlandshavet ligger inde på shelfen, med vanddybder op til 530 m, hvorfor det er mindre sandsynligt at olie der strømmer ud fra havbunden her, vil opføre sig på denne måde. Men det kan ikke udelukkes at sådanne skyer af olie dannes her, da det formentlig også skete på kun 50 m vand under det store *Ixtoc*-spild i 1979.

Områder følsomme overfor oliespild

På kortene på Figur 50 er der udpeget en række områder, som er særligt følsomme overfor oliespild. Disse er baseret på den nuværende forholdsvis sparsomme viden, og må forventes ændret, når ny viden bliver tilgængelig.

Baggrundsviden

Da arbejdet med denne miljøvurdering blev indledt, var det klart, at der manglede væsentlig viden til at foretage vurderinger af olieaktiviteter i Grønlandshavet. Flere studier blev gennemført, og resultaterne er indarbejdet her (Box 1-8).

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 i Vestgrønland.

Imaqarniliaq kalaallisooq

Grønlandshavip kalaallinut atasortaani uuliasiornikkut ingerlatat avatangiisinut sunniutigisinnaasaannik siumut naliliineq

Nalunaarusiaq una Grønlandshavip kalaallinut atasortaani uuliasiorluni qalluillunilu ingerlatat avatangiisinut sunniutigisinnaasaannik siumut naliliineruvoq. Erseqqinnerusumik oqaatigalugu immamik allorniusat 68° aamma 70° 30' N (Figur 1) akornanniittumik. Tamanna Grønlandshavimi nalilersuiffimmik taagorneqarpoq (Greenland Sea assessment area). Tamaanga tunngatillugu akuersissuteqarfinnik neqerooruteqarnissaq 2012/13-imi ingerlanneqarumaartoq ilimagineqarpoq.

2009-mi DMU utaqqiisaagallartumik tamaani uuliasiornikkut ingerlatat avatangiisinut sunniutigisinnaasaannik naliliinikuuvoq (Boertmann *et al.* 2009). Unalu nalunaarut tassaavoq utaqqiisaagallartumik nalunaarusiap tunuliaqutaasunik misissuinerit Aatsitassamut Pisortaqarfiup 2008-mi aallartissimasaasa angusai tunngavigalugit nutarterneqarnera. Naak ilisimasat tamakkua pigineqalersimagaluartut biologiskimik Kitaani neqerooruteqarfinnut marlunnut: Baffin Bugtimut aamma Disko Vestimut, tunngatillugu ilisimasanit annikinnerujussuupput.

Nalunaarusiaq una suliarineqarpoq DCE – Nationalt Center for miljø og Energi aamma Pinngortitaleriffimmit (GN) Aatsitassamut Pisortaqarfik suleqatigalugu

Imartaq nalunaarummi sammineqartoq neqeroorteqarfiusussatut ilimagineqartumit annertuneruvoq (tak. Figur 1). Taamaanneranut pissutaavoq uuliaarluerneq avungarsuaq siaruarsinnaasarmat taamaattumillu neqerooruteqarfiup avataanut pisinnaammat. Imartaq nalilersuiffigineqartoq nalunaarusiami taagorneqarpoq "the assessment area" = nalilersuiffigineqartoq.

Pineqartoq issittorsuup zonianiippoq zonillu taamaattup uumasoqarnikkut ilisarnaataanik peqarluni: Uumasut assigiinngisitaat amerlasoorsuunngillat, nerisareqatigiinnerit naatsuupput, uumasuararpassuaqarfeqartiterporlu. Uumasut assigiinngitsut amerlanginnerat uumasuisa amerlasoorujussuakkuutaarnerannit illuatungilerneqarpoq, tamakkualu ilaat nerisareqatigiinnernut pingaaruteqarluinnartuupput. Imaappoq nerisareqatigiinnermi annertussutsinut tamakkua qaqugukkut sumilu takkusimaartarnerat apeqqutaalluinnartarluni.

Nalilersuiffigineqartoq sumiiffinni biologiskimit/økologiskimit isigalugu pisoorsuuvoq, aammali uumasoqarfiorpianngitsunik ilaqartiterluni. Tamatuma ilaani upernaakkutpinngorarnerujussuaqartarpoq, immap naqqani uumasorpassuaqarluni soorlulu aamma timmissanik miluumasunillu pingaarutilinnik pilerujussuulluni.

Timmissanut tamakkununnga pingaarutillit ilaapput (Kalaallit Nunaannut nunanullu allanut) aammalu navianartorsiortutut nalunaarsorsimasut soorlu appat siggukkaat (Kalaallit Nunaanni navianartorsiortutut nalunaarsugaq) naajavaarsuk (Kalaallit Nunaanni navianartorsiortutut nalunaarsugaq) sinerissamilu Scoresby Sundip paani aakkarnersuarmi appaliarsuit aappariikkuutaat millionit arlalissuit piaqqiortuupput. Timmissat tamaani piaqqisartut kisimik naapitassaanngillat, timmissalli imarmiorpassuit Svalbardimi Barentshavellu sineriaanni erniorfimminnukartut Newfoundlandimi Kalaallit Nunaatalu kujataani kitaani ukiisarfimminnukaallutik nalilersuiffigineqartukkoorlutik upernaakkut ukiakkullu aqqusaartarput. Amerlanerpaalli tassaapput appaliarsuit appallu siggukitsut, aammalu naajavaarsuit amerlanngeqisut aarlerinartorsiortutullu nalunaarsorsimasut ilarparujussui tamaana ingerlaartarput.

Miluumasunut imarmiunut ilaapput pingaarutillit aarlerinartorsiortutullu nalunaarsorsimasut (Kalaallit Nunaanni nunanilu allani) soorlu nanoq, aaveq, qilalugaq qernertaq arfivillu.

Immami uumasoqarnermut immikkut pingarutilinnut ilaapput aakkarnersuaqarfiit sikuugaluartilluguluunniit ammaannartartut. Tunup avannaani aakkarneqarfissuit pingasuupput, Nordostrungingip sioraaniittoq, Siriuspolyniet Wollaston Forlandip sioraaniittoq aammalu Scoresby Sundip paavaniittoq. Sinerissamullu siassimasunik minnerusunik aakkarneqartiterpoq. Aakkarnersuit ukiuugaluartilluguunniit ammajuaannangajattuusarput upernassaliinnartorlu (april/maj) imarujussuanngortarlutik. Tamatuma kingunerisarpaa pinngoralerneq aakkanerup avataani sikuusumiit piaarnerujussuarmik aallartissinnaalersarmat. Aammalumi miluumasut imarmiut tamaani ukiisarput, timmissat aallartartut immamik ammasumik pisariaqartitsisut sinerissap ilaanit allanit piaarnerusumik tamaani qasuersersinnaasarput. Tamakkualu saniatigut piaarnerusumik pinngoralersarneq miluumasumik imarmiunik timmissanillu eqitserutitsilersarpoq, taamaattumik illoqarfiup Ittoqqortoormiit/Scoresbysundip tamaanga aakkarnersuit ilaata sanianut inissinneqarsimanera nalaatsornerinnaanngilaq. Nalilersuiffigineqartumi timmissat imarmiut erniorfissui aakkarnersuit eqqaanniipput, nunami tiffasinneruumiittartut naloraarusillit tatsinik taseqqanillu sikuersiillutik aamma tamaaniittarput. Tamatuma aavii aakkarnersuarni ukiisarput taamaattumik Tunup avannaarsuata imartaa pingaarutilerujussuuvoq.

Nalilersuiffiup kujasinnerusortaani qaleralinnik aalisarneq inuussutissarsiutaavoq, aammalu nammineq atugassanik piniarneq aalisarnerlu tamaani najugaqartunut, ittoqqortoormiinut, Tasiilamilu piniartunut avannarparterlutik nalilersuiffimmut piniariartartunut ingerlataapput pingaaruteqarluinnartut.

Uuliasiorfimmi tamakkiisumik ingerlatsineq sapinngisamik ingerlatanut pisartunullu avatangiisinut sunniuteqarnerusartunut tunngatillugu nalilersuiffigineqarpoq. Kalaallit Nunaannili uuliamik qalluinermut tunngatillugu misilittagaqanngimmat, tassunga tunngatillugu ingerlatanik nalilersuineqtamaani pisartunik tunngaveqarnani tammani pissutsinut assingusunik atugaqarfiusuni misilittakkanik tunngaveqartinneqarput. Pingaartumik Alaskami Prince William Sund-imi 1989-imi uuliaarluernerujussuarmut tunngatillugu naqitarpassuit, norskit Barentshavemi uuliasiornermut tunngatillugu avatangiisinik nalilersuineri (2003) aammalu Arktisk Rådip saqqummersitaa "Arctic Oil and Gas Assessment", suli massakkumut ilaanakuusumik internettimi (Link) pissarsiarineqarsinnaasoq,tunngavigineqarput. Mexicanske Golf-imi aprilimi 2010 puaasartoorujussuarnerup avatangiisinut sunniutai suli nalilersorneqaratillu nalunaarusiorneqanngillat, taamaattumik annikitsuinnarmik nalunaarummi uani eqqartuiffigineqarput.

Nalilersuinermi tunngaviusoq

Nalunaarummi uani nalilersuinermi klimami pissutsit massakkut atuuttut toqqammavigineqarput. Ilimagineqarpoq klimap allanngorneri ukiuni qulikkuutaartuni aggersuni nalilersuiffiusumut sunniuteqalerumaartut, pingaartumik sikoqartarnera allannguuteqarumaartoq ilimagineqarluni. Tamatuma inuunniarnikkut pissutsit allanngornerat kingunerissavaa, uumasut ilaasa ikilillutik annikinnerusumillu takkusimaartalernerat, aammali uumasut allat takunnissaannut tamaaniiginnalernissaannulluperiarfissiissallutik.

Nalilersuinerit biologitut ilisimasanik pigineqartunik, pissutsinut arlalinnut tunngatillugu suli naammanngeqisunik, tunngaveqarput. Misissuinerit arlallit 2008-mi aallartinneqarput ilisimasat tunngaviusinnaasut pissarsiarineqarsinnaasut pitsaanngorsarniarlugit, nalunaarummilu uani ilisimasat tunngaviusinnaasut pitsanngorsarniarlugit misissueqqinneqarnerunissaainassutigineqarpoq.

Ujarlerneq

Ujarlerluni ingerlatat utaqqiisaannaasarput, ukiualunnik sivisussuseqarajupput amerlanertigullu akuersissutaateqarfiusumi sumi tamaani ingerlanneqartarlutik. Aammalu tamakkua sikuunnginnerinnaani, tassalu aasaanerani ukiakkullu, ingerlaneqartarput, qularnanngitsumik julimiit oktoberimut.

Ujarlerneq qallorlugu imminut akilersinnaasumik uuliaqarneranik immaqaluunniit gasseqarneranik malussarfiunngippat ingerlatat unitsinneqartarput atortullu tamarmik peerneqartarlutik. Akerlianilli uuliamik nassaartoqarpat piffissap "appraisal"-periodemik taasap ingerlareerneratigut iluaqutigineqarsinnaasutut paasineqartumi ingerlatat uuliasiorfimmik pilersitsiartorninngortarput peqarfiup killeqarfii ujarlugit qillerininngorlutik atortussaqarfinnillu sanaartorninngortarlutik uuliamik nassaarineqartumik piiaavinngortarlutik (ataaniittoq takuuk).

Ujarlernikkut ingerlatat sunniutiginerusaat tassaajumaarput ingerlatat pisorpaluttut akornusersuineri (assersuutigalugu sajuppillatsitsisarluni misissuinerit, qillerinerit helikoptererpalunnerlu). Ilimagineqarpoq tamakkua annertunngitsumik, qaangiukkumaartumik sumiiffinnullu aalajangersimasuinnarnut sunniuteqarumaartut, tassami sunniutaasinnaasut annertunerusut isumannaallisaanikkut iliuutsitigut pinngitsoortinneqarsinnaammata, assersuutigalugu sumiiffit ukiulluunniit qanoq ilineri misikkarinnerusut atornaveersaarnerisigut. Sumiiffinnili annertunnginnerusuni misissuinerit, 3D-seismiske undersøgelser taaneqartut, malunnartumik sunniuteqarsinnaapput, ajornerpaassagunik uumasoqatigiinnik ajoquseruminarnerusunut sunniuteqarsinnaasunik – nalilersuiffiusumi tassaasut qilalukkat qernertat, arfiviit immaqalu aamma tunnullissuit. Sumiiffimmi ataatsimi ingerlatat arlaqarpata tamanna ataatsimoortumik sunniuteqarsinnaavoq, assersuutigalugu tamanna sajuppillatitsisarluni misissuinissat pilersaarusiorneranni naatsorsuutigereerneqartariaqassaaq.

Sajuppillatitsisarluni annertuumik misissuinerit qalerallit tamaanngaannit qimagukkallarnerannik kinguneqarsinnaassagunarpoq, tamannalu aalisarfiusuni pingaarutilinni pissappat aalisarnermut ajortumik kinguneqarsinnaavoq. Misissuinerni paasinarpoq aalisakkanulli allanut tunngatillugu sunniut taamaattoq sivikitsuinnaajumaartoq. Suffisarfiit sajuppillatitsisarluni misissuinernut misikkarinnerusutut isigineqartarput, qalerallilli nalilersuiffigineqartumi suffineq ajorput, taamaattumik tamaani taanna ajornartorsiutaanngilaq.

Sajuppillatitsisarluni misissuinerit akornusersuinerat pissutigalugu miluumasut imarmiut neriniarfimminnit ingerlaartarfimminnillu pingaarutilinnit nujutsinneqarnissaat aarlerigineqarsinnaavoq. Ilimagineqarporli sajuppillatitsisarluni misissuinerup ataasiinnaap sunniutiginnaasai sivikitsuinnaajumaartut (sap.ak. qaammataalunniluunniit sivisussusillit), ingerlatarmi unittussaammat. Ataatsikkulli ingerlatat ataatsimut sunniutaasa akornusiinerit annertunerulersissinnaavaat.

Naqitsinerupsajuppillatitsisarluni misissuinerni atorneqartartunit qamutilinnit silaannarmik ingerlasunit pisup aalisakkat suaat piaraallu tukerlaat annerpaamik 5 m ungasitsigisumiittut toqussinnaavai. I Norgip aarleqqutigaa annertuumik aalisagaararpassualimmi sajuppillatitsisarluni misissuinerit aalisagaaqqanik ima toqoraatigisinnaasut allaat aalisakkat inersimasut nutaanik ilaartornerat ajoquserneqarsinnaalluni. Taamatorsuaq aalisagaaqqanik ataatsimoortoqartarnera kalaallit imartaanni ilisimaneqanngilaq, eqiterunnerilli amerlanerpaasarnerat pisarpoq upernaakkut sajuppillatitsisarluni misissuinerit nalinginnaasumik aallartittarnerat sioqqullugu. Taamaattumik inerniliineqarpoq sajuppillatitsisarluni misissuinerit aalisagaqatigiinnik malunnartumik sunniisinnaanera Grønlandshavip kalaallinut atasortaani aarleqqutissaanngitsoq.

Ujarlerluni qillerisarnerit nipiliornermittaaq pilersitsisarput. Maskiinarpaluk, angallatit qilleriviit puttaasut nikinnaveersaartillugit atorneqartut sarpii (tamaanimi imaq qilleriviit immap naqqanut tunngasut atornissaannut itivallaarpoq)sakkortuumik nipiliorput. Pisorpaluup taamaattup miluumasut imarmiut ungasissorsuarmiikkaluartut sunnersinnaavai nipiliorfimmit nujuttillugit, pingaartumimmi arferit nipimut misikkarissuupput. Taamaattumik qilalukkat qernertat, arfiviit aarrillu najortakkaminnit pingaarutilinnit nujuttinneqarnissaat aarlerinarsinnaavoq. Tunnulissuit, tikaagulliusaat qipoqqaallu aasaanerani tamaannga qimagusimagallartinneqarsinnaanerat aarleqqutissaavortaaq.

Miluumasunik imarmiunik piniarneq sunnerneqarsinnaavoq ileqquusumik piniarfiusartut piniagassai nujutsinneqarpata.

Misiliilluni qillerinermi maralluk boremudder qillerummut pujassaatigalugu, qillikkami naqitsinermut nakkutilliissutitut atortartoq aammalu qillernerlukut (sequnnerit) qallornerannut atorneqartarpoq. Maralluk taamaattoq imermik akuliusimappat amerlanertigut qillerereernikkut immamut aniatiinnarneqartarpoq, maralluilli uuliamik akullit avatangiisinut ajoqusiinerusartut ullumikkut nunaliaanneqarajupput passunneqassallutik imaluunniit nakkutigisamik toqqortorneqassallutik.

Kalaallit Nunaanni boremudder imermik akulik taamaallaat atoqqusaavoq. Qeqertarsuup avataani 2010-mi qillerinerni pingasuni boremudder 6000 tons qillernerlukullu 2261 m3 aniatinneqarput. Kemikalialli akuliunneqarajuttartut ilaat OSPARs systemimi "aappaluttutut" (navianarsinnaasutut) nalunaaqutsigaapput. Norskit imartaanni tamakkua atorneerutivissimapput taammalu avatangiisinut ajoqusiinnginnerussartut "qorsuit" aamma "sungaartut" kisimik kemikaliatut atorneqalerlutik. Ilanngulluguli oqaatigisariaqarpoq Norgemi aamma boremudder uuliartalik atorneqarmat, kisiannili taanna nunamukaaneqartasasoq taamalu immamut aniatinneqassanngitsoq piumasarineqarluni.

Kalaallit Nunaanni akuutissat kemikaliat "aappaluttut" atorunnaarsinneqarnissaat anguniagaavoq.Qillerinikkulli atukkat ajornakusoortuunerat pissutigalugu maannamut (2010-mi 2011-milu) akuutissap kemikaliaasup ataatsip "aappaluttup", arriitsumik arroriartortarnera pissutigalugu taamatut nalunaaqutsigaasup, atorneqarnissaa akuerisaagallarpoq. Akussalli "qorsuit" "sungaartullu" siunissami atorneqarnissaat nalilersorneqartariaqarpoq toqunartoqarnerat issittumilu arroriartortarnerat pissutigalugu.

Boremudderip imermik akoqartup aniatinneqartarnera qillernerlukullu aniatitsiviusup eqqaani immap naqqani uumasunut sunniuteqarnerlussinnaanerat aarlerinartoqarpoq atortussat qaleriiaarneqarlutillu imaq isortunngortittarmassuk.

Grønlandshavemi boremudderip qillernerlulukku aniatinneqarnerat nalileruminaatsuuvoq tamaani immap naqqani uumasuusunut tunngatillugu ilisimasat killeqaqimmata. Ilimagineqarporli ujarlerluni qillerinerup ataasiinnaap aniatitai annikitsuinnarmik sunniuteqarumaartut, boremudderit avatangiisinut uloqianaateqannginnerusut atorneqarpata. Boremudderimiit qillernerlukuniillu sunniutit ajoqutaasut pinngitsoorneqarsinnaapput tamakkuninnga aniatitsinnginnikkut, taarsiulluguli qillerinerup naammassinerani tamakkua nunamukaallugilluunniit qillikkamut immiuteqqinneqarpata. Kisiannili taamaaliorneq aamma avatangiisinut sunniuteqartussaammat aniatitsiinnarnermut sanilliussuullugu oqimaaqatigiissitsivigisariaqarpoq.

Kiisalu misiliilluni qillerineq nukimmik annertoorujussuarmik piumasaqarpoq, tamatumalu illup naatsitsiviup gassiinik annertoorujussuarmik aniatitsineq king-

unerisarpaa. Qeqertarsuup avataani 2010-mi qillerinerit pingasut kalaallit aniatitsinerata 15 % imik annertusissutigaa.

Ujarlerluni qillerinermi ajutoornikkut puaasartoornissaq ("blow-out") avatangiisit ajortumik sunnerneqarnissaannut aarlerinartut annersaraat, taamma pisoqaraangat uuliamik aniasoorujussuarnermik pisoqartarmat. Uuliamik aniasoornerup kingunerisinnaasai matuma ataani eqqartorneqarput.

Ineriartortitsineq tunisassiornerlu

Uuliaqarfimmik ineriatortitsinerup uuliamillu tunisassiornerup ujarlernerup nalaaniit allaassutigaa sivisoorujussuusarami (ukiut qulikuutaat arlaliusinnaasut), ingerlatallu ilarpassui avatangiisinik annertuumik ajoqusiisinnaasuusarput. Tamakkua sunniutigisinnaasaat peqqissaartumik pilersaarusiornikkut pitsaalineqarsinnaalluarput, periaatsit akuerineqartut "Health, Safety and Environment" (HSE)-p periaasii "Best Available Technique" (BAT) aamma "Best Environmental Practice" (BEP) atoraanni. Aniatitalli, (assersuutigalugu erngup tunisassiornermi atorneqartup aniatinneqarnerata) ataatsimoorlutillu sunniutaannut tunngatillugu ilisimasat amigaataapput, tamannami pisarmat qulaani taaneqartut atorneqaraluaraangataluunniit.

Imeq tunisassiornermi atorneqartoq (uuliamut ilanngullugu qallorneqartartoq) immami avatangiisinut aniatitat annerpaartaraat. Uuliasiorfiup ullormut 30.000 m3 eqqarlugu aniatissinnaavaa, ukiumullu norskit sineriaata avataani aniatinneqartarpoq 174 millioner m3. Ukiuni kingullerni erngup tunisassiornermi atorneqartup eqqarneqarnera isumakuluutigineqaleriartorpoq, naak passunneqartaraluartoq nunallu assigiinngitsut avatangiisinut tunngatillugu piumasaqaataat malinneqaraluartut. Erngup tunisassiornermi atorneqartup eqqarneqarnera immami sikuusumi immikkut ajornartorsiutitaqarpoq immammi qaavanut akuliussuunnera sikuutillugu annikillisinneqartarmat. Erngup tunisassiornermi atorneqartup avatangiisinut ajornartorsiutitai pinngitsoorneqarsinnaagaluarput akugititanut tunngatillugu piumasaqaatit sakkortusineqarpata imaluunniit imeq tamanna uuliamik qalluiviup sulluanut utertillugu immiussuunneqarpat, norskimmi Barentshavemi uuliasiornermut tunngatillugu politikkianni tamanna piumasaavoq.

Aniatinneqartoq annertooq alla tassaavoq boremudder qillernerlukullu, tunisassiornerummi ineriartortinneqarnerani annertoorujussuarmik qillerineqartarmat. Ujarlerluni ataasiinnarmik qillerinerup avatangiisinut sunniutigisartagai qulaani eqqartorneqarput. Ineriartortitsinerup tunisassiornerullu nalaani aniatitat annertunerulluartussaapput taammalu immap naqqa annertunerusoq sunnersimassallugu. Boremudderip qillernerlukullu avatangiisinut sunniutaat pitsaanerpaamik pinngitsoorniarneqarsinnaapput taakkua taaneqartut nunamut katersornerisigut imaluunniit killeriffikunut immiussuunnerisigut. Boremudderip imermik akullip avatangiisinut ajoqutaanngitsunik akullip atorneqarneratigut aniatitsineq avatangiisit tungaannit isigalugu akuersorneqarsinaasuusinnaavoq.

Ineriartortitsinermi tunisassiornermilu nukik atorneqartoq annertoorujussuusarpoq, Grønlandshavemilu angisoorsuarmik uuliasiorfiliortoqarpat tamanna Kalaallit Nunaata tamakkiisumik illup naatitsiviup gassiinik aniatitsinerata tamarmiusup malunnartumik annertusissutigissavaa. Assersuutigalugu taaneqarsinnaavoq norskit uuliasiorfissuisa ilaat ataaseq kisimiilluni CO2-mik Kalaallit Nunaata aniatitaata tamarmiusup marloriaataanik aniatitsimmat.

Atortulersuutit sumut inissinneqarnerata taakuninngaanniillu akornusersuutit miluumasut imarmiut sunnersinnaavaat, neriniarfitoqqaminnut utertussaajunnaarlutik nujutsillugit imaluunniit ingerlaartarfimminnik allanngortitsisillugit. Grønlandshave-

mi pingaartumik qilalukkat qernertat, arfiviit aarrillu tamatumunnga atatillugu taasariaqarput. Tamatumalumi aamma uumasunik taakkuninnga piniagaasunik piniarneq ajornarnerulersissinnaavaa.

Tamatumunnga atatillugu taasariaqarportaaq uuliasiorfiup atuunnera tamaat sajuppillatitsisarluni misissuinerit ingerlanneqartuartarmata, tamannalu misissuinerup eqqartorneqarnerani oqaatigineqareersut aamma piiaanerup nalaani ingerlanneqartarput sunniutinullu tamarmiusunut sakkortusaaqataasinnaallutik.

Atortulersuutit nunamut inissinneqarsimappata nunamut sunniutaasussat nalilersorneqartariaqarput sapinngisamillu annikitsuutinniartariaqarlutik, tamakkuami nunap tamatuma takornariarfissatut naleqassusianik annikillisitsisarmata.

Annertuumik helikopteri atorlugu timmisartortoqarnera aamma timmissanik miluumasunillu imarmiunik najortagaanniit pingaarutilinniit nujutitsisinnaavoq. Tamanna illuatungilerneqarsinnaavoq aqqutit portussutsillu aalajangersut atorlugit timmisartut ingerlatittarnerisigut.

Ineriartortitsiviullutillu tunisassiorfiliorfiusut aalisarfiunerat immap naqqatigut atortulersuutitigut (puilasuliat ruujorillu) aammalu qilleriveqarfiit assigiinngitsumik sannaqarnerisigut annikillisinneqarumaarpoq. Nalinginnaasumik atortulersuutit taammaattut 500 m ungasitsigalugu isumannaallisaanikkut/assersuinikkut killilineqartarpoq.

Uulia tunisassiarineqartoq umiarsuartigut aallarussorneqartussaavoq, umiarsuarnik uuliamik usilersulersinnatik immermik ballasterisimasaminnik tamaanga imaarsisartussanit. Tamatumunnga atatillugu uumasut allarujussuarmeersut maanimiunngorsinnaasut (imaappoq amerliartorlutik matuma uumasorpiaanik inangiiartulersussat) eqqussorneqarsinnaanerat aarleqqutissaasinnaavoq.Issittumi tamanna imatorsuaq manna tikillugu ajornartorsiutaasimanngilaq ksiannili klimap allanngorneratigut annertunerulissangatinneqarpoq. Aarlerinartua annikillisinneqarsinnaavoq imermik ballastiusumik saliillunilu imaarsisarneq immikkut peqqussusioraanni, tamannalu nunarsuarmi ileqquulersussatut ilimagineqarpoq IMO-p peqqussutai nutaat atortuulersinneqarpata.

Erseqqissarneqassaaq ineriartortitsisinnaanerup tunisassiulersinnaanerullu kingunerannik sunniutaasinnaasunik nalilersuissalluni ajornartorujussuummat, tassami sumiinnissaat, qanoq annertutiginissaat, qanoq sivitigisumik atuunnissaat ingerlatallu sorpiaanissaat aammalu tamakkununnga teknikikkut aaqqiissutaasinnaasut suli ilisimaneqanngimmata.

Uuliaarluerneq

Uuliasiornermut atatillugu avatangiisnik ajornerpaamik sunniisinnaasut tassaapput uuliamik aniasoorujussuarnerit. Tamakkua puaasartoornikkut ("blow-outs") pisinnaapput, taamaaligaangat qilligaq aqunneqarsinnaajunnaartarpoq, imaluunniit uuliap katersorneqarfiani assartorneqarneraniluunniit ajutoornikkut, assersuutigalugu umiarsuup uuliamik assartuutip ajunaarneratigut.

Ullutsinni annertoorsuarmik uuliamik aniasoortarnerit qaqutigoortorujussuupput, teknikikkummi isumannaallisaanikkullu pissutsit nutarterneqartuarlutillu pitsanngoriartortinneqartuarmata. Aarlerinartuali suli taannaajuarpoq, pingaartumik "frontier"-områdeni, tassa kalaallit imartaanni pissutsitut ittuni pingaartumik ilulissat aarlerinartorsiortitsivianni, tamannami pissutaalluni ajutoornissap ajunaarnissallu aarlerinartua annertunerulersarmat. AMAP (Skjoldal *et al.* 2007)-plssittumi uuliaarluernissamik aarlerinartoq anneq uuliap angallanneqarneraniittutut nalilerpaa.

DMI-p Grønlandshavemi avasiartorsuarmiittuni assigiinngitsuni pingasuni uuliaarluernermut missiliuusiuullugu, uuliaarluernerup tissukarnissaa missingersuusiorsimavaa (Figur 48). Pisuusaartitsinerit 18-iusut ilaat marluk mingutitsiviusumiit kilometerinik unteritilikkuutaannik arlalinnik ungasitsigisumut uuliaarluerneq sinerissamut annguppoq.

Sinerissap qanittuani uuliaarluerneq imaannarmi uuliaarluernermiit aseruinerujussuusartutut naatsorsuunneqartarpoq. Sumiiffimmili Grønlandshavetut ittumi taamatut ataatsimut oqaatiginninneq allanngortittariaqarpoq. Tamatumunnga pissutaavoq sikoqarnera, sikup imatorsuaq uulia arrunngitsoq sumorsuaq angallassisinnaavaa. Sikulli aamma pissutaallutik aniasoortup siaruarnissaa immani sikoqanngitsuninngarnit killilersimaarneqarnerusinnaavoq. Uuliaarluernerup sikulimmi qanoq pisarneranut tunngatillugu ilisimasat pissarsiarineqarsinnaasut amerlanngeqaat.

Sinerissap qanittuaniittut uuliaarluernermit aseruiffiunerusinnaanerannut pissutaavoq uuliap assigiinngitsorpassuit amerlasoorsuillu uumaffiat, soorlu ikkanneriit immap naqqani aarrit neriniagaannik uumasoqarfiit timmiarpassuillu najugaat eqqorneqarsinnaammata. Uulia iterlanni kangerlunnilu unissinnaavoq, taammalu toqunartut annertuut uuliap akuineersut immami itissuseq immallu naqqa tamakkerlugu uninngaannalersinnaallutik. Aarleqqutissaavoq uulia immap naqqani sananeqaatigut sissamulluunniit tuapalimmut unissinnaammat taammalu arriitsumik avatangiisinut anialersinnaalluni sivisuumik sunniusimalluni, assersuutigalugu timmiaqatigiinnut sissamik atuisunut. Aammami nalilersukkap kujasinnerusortaani sinerissap qanittua tamaanimiut piniarfigalugulu aalisarfigaat.

Imaannarmi uuliaarluernerup avatangiisinut sunniutai arrorsarneqarneratigut annikinnerulersarput. Grønlandshavemi nalilersuiffimmi tamatumalu qanittuani sinerissamiit ungasissumiikkaluartut uuliaarluernermit ajoquseruminartorujussuusinnaanerat isiginngitsuusaarneqarsinnaanngilaq. Ilisimasalli pigineqartut naammanngimmata tamakkua sumiinnerat toqqarlugu oqaatigineqarsinnaanngilaq. Tamakkua tassaasinnaapput frontzoninik taaneqartartut, pikialaarfiit "up-welling"-områdit aammalu sikut tissukaattut avammut sinaavi ("marginal ice zone"), tamaanimi pingaartumik upernaakkut pinngorartoqarnera annertoorujussuusarpoq, algit planktoniusut uumasuaqqallu planktoniusut amerlasoorujussuullutik immap qaavani tamatumalu atinnguani katersuussimasarmata.

Uuliaarluernerli qaleraleqarneranik ajoqusiissasimanngilaq, tamaanimi nalilersuiffiusumi aalisagaq taanna kisimi iluanaarniutigalugu aalisarneqartuummat.

Timmissat uuliaarluernerup immap qaavaniittup assut navianartorsiortittarpai, Grønlandshavemilu ajoquseruminartunik sumi tamaani timmiarpassuaqarpoq. Assersuutigalugu appat appaliarsuillu erniortorpassuit, upernaakkut mitit takkusimaartartut aammalu aappalaartumik nalunaarsorsimasut naajavaarsuit amerlanngereeqisut. Tamatumalu ilaani mitit isasarput aammalu mitit siorakitsut ilisimaneqartumik kangerluk ataaseq isaffigisarpaat. Timmiarpassuittaaq ingerlaarlutik tamaanaqquttartut aamma ulorianartorsiortitaassapput.

Miluumasut imarmiut uuliaarluernermit immap qaavaniittumitamma sunnerneqarsinnaapput. Nalilersuiffiusumi aarrit ulorianartorsiornerussapput, aarrimmi aalajangersimalluinnartuniitartuummata neriniarfimmik amerlanngeqisut pingaaruteqaqisulli eqaanniittarlutik.Misissuinerittaaq nutaat takutippaat aarluit (taamaattumillu aamma immaqa arferit allat) uuliap aalaanik uuliaarluernermeersumik najuussuinikkut ajoquseruminartuusut, tamannalu sikulimmi uuliaarluerneqarpat pisinnaalluarpoq (ataaniittoq takuuk).

Nannut pingaartumik ajoquseruminartuupput, meqqutimmi uuliaarluersimasut aluttorlugit salinniartaramikkit uuliamit iijorakkaminnit toqunartoqalersinneqartaramik.Arfiviit tamaaniittartut arfeqatigiimininnguanut 1900-ikkut aallartinneranni nungutaangajalluinnarsimasunut ilaapput. Taakkua ima ikilisimatigaat allaat toqusarnerup annikitsuinaagaluartumilluunniit annertusinera amerliartornerannut sunniuteqarsinnaammat.

Sikulimmi uuliaarluerneq qularnanngitsumik quppani sikutallu ataanni katersuukkumaarpoq taamalu timmissat miluumasullu imarmiut immamik ammaannartumik pisariaqartitsisut sunnersinnaallugit, aammali eqalugaasat piaraat sikup ataani katersuuttartut sunnerneqarumaarput. Miluumasut imarmiut tamaani immami sikoqanngitsumi annertugisassaanngitsumi uuliaarluernikkut puiarsinnaapput taammalu uuliap aalarneranik najuussuisinnaallutik.

Aalisarneq piniarnerlu akornuserneqarsinnaapput uuliaarluerfiusunimi taakkuninnga ingerlatsinissaq mattunneqartarmat. Taamatut matusisoqartarpoq aalisakkat piniakkallu uuliaarluernermiissimasut imaluunniit uuliasunnilersinnaasutut ilimagineqarsinnaasut nioqqutaanissaat (assersuutigalugu uuliasunnitsut) pinngitsoortinniarlugu. Uuliaarluerfiusumi aalisarnerup qaammaterpassuarni matoqqatinneqartarneranut assersuutissaqarpoq.Ilimagineqarsinnaavortaaq piniakkat uuliaarluerneqartillugu akuttunerulersarnissaat, aammalu puisit amii uuliaarluersimasut tunineq ajornarsisarput.

Mexicanske Golf-imi *Macondo*-brøndimi uuliaarluernerujussuaq itisoorsuarmeerpoq (1500 m missiliorlugu ititigisumiit). Tamatuma uulia aniasoq itissutsini assigiinngitsuni pujuusarsuanngorluni tissukartilerpaa. Uulia itissutsini tamakkunaniiginnalerpoq sumorsuarlu tissukarluni. Grønlandshavemi uuliamik aniasoornikkut pujuusarsuit pilersinneqassagaluarpata itissutsini assigiinngitsuni uumasut ajoquseruminartut (pinngorarneq, planktonit, aalisakkat kinguppaallu piaraat) aammalu uumasut immap natermiut (kinguppaat natermiullu allat) sunnerneqarumaarput, pingaartumik pujuusarsuit taamaatuut ikkannersuit aqqusaarpatigit.

Ilisimasat tunuliaqutaasut

Avatangiisinik nalilersuineq aallartinneqarmat Grønlandshavemi uuliasiornikkut ingerlatanik nalilersuinissamut ilisimsasat pingaarutillit amigaatigineqartut erseqqilluinnarpoq.Ilisimatuutut misissuinerit arlallit ingerlallugillu naammassineqarsimapput, tamakkualu inerneri nalunaarummut uunga ilanngussuunneqarput (Box 1, 2, 3, 4 aamma 5).

Misissuinerit ingerlatarpiamut tunnganerusut, avatangiisinik nalilersuinermut nakkutiliinermullu atatillugu ingerlatsiviit nammineerlutikingerlataminnut atatillugu ingerlataasa saniatigut pisariaqarpoq sumiiffinnut aalajangersunut tunngatillugu misissuinerit siumut sammisitat ingerlanneqarnissaat suli pisariaqarpoq. Misissuinerit tamaattut sumiffinnut aalajangersunut tunngatillugu misissuinerusut Disko West-imut, Kitaaniittumut, tunngatillugu aallartinneqareerput.

1 Introduction

This document comprises a strategic environmental impact assessment (SEIA) of expected hydrocarbon activities in the Greenland part of the Greenland Sea. It was initiated and funded by the Bureau of Minerals and Petroleum (BMP), and prepared by the 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 many respects is comparable to 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 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 environmental 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 extent possible, as they have not yet been published in a scientific context. Two marine mammal species – walrus and polar bear – are given especially detailed accounts because they have been extensively studied and because much information is still unpublished.

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

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 under reduction in both space and time, and this again will impact the ecology and particularly wildlife dependent on the ice, such as polar bears and ivory gulls. 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 conditions described in this report.

1.1 Coverage of the SEIA

The offshore and coastal waters between 68° N to 82° N (from Kangerlussuaq Fjord northwards to Nordostrundingen) are the focus of this report, as it is the region which potentially can be affected by hydrocarbon activities, particularly from accidental oil spills originating from oil activities in the future licence areas (Figure 1). This area will be referred to as 'the assessment area'. However, the oil spill trajectory models developed by DMI and SINTEF indicate that oil may drift further, out-

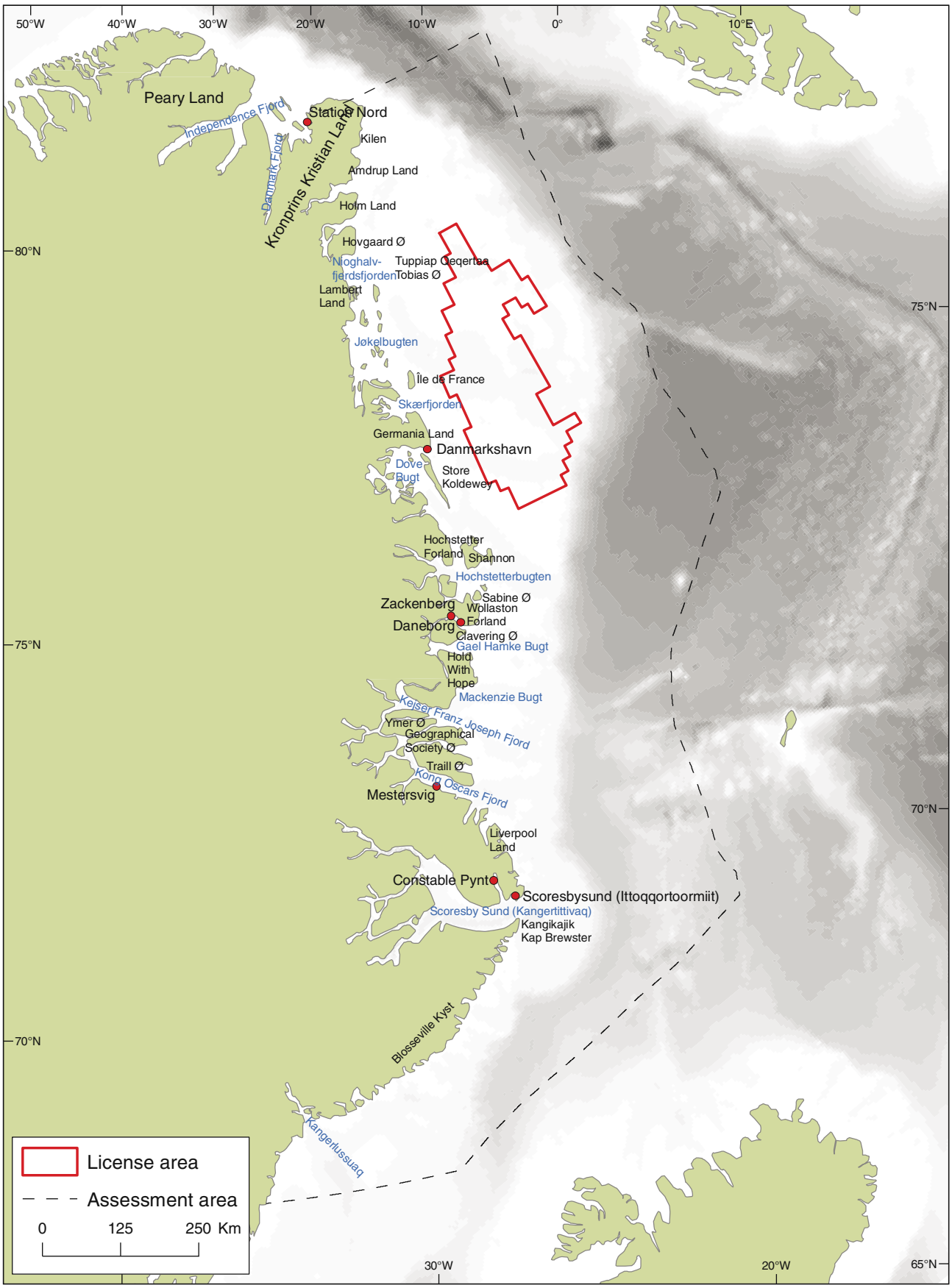


Figure 1. The assessment area with the most important places names shown. Red dots indicate inhabited sites: Towns (only one: Ittoqqortoormiit/Scoresbysund), military outposts, weather and research stations etc. See also text. The licence area opened in December 2012 is framed with red.

side the boundaries of this area, for example into Norwegian and Icelandic EEZs (Nielsen *et al.* 2008, Johansen 2008).

The assessment area extends over waters of the former municipality of Ittoqqortoormiit /Scoresbysund and the National Park of North and Northeast Greenland. There is only one town in the area: Ittoqqortoormiit/Scoresbysund with an airport (Nerleriit Inat/Constable Pynt) and few villages/settlements nearby (these are more or less abandoned today). The total number of people living here is approx. 500. The National Park is an unspoilt high arctic environment, almost without anthropogenic impacts. There are a few permanently manned sites: the weather station Danmarkshavn and the military outposts Daneborg and Station Nord. Moreover, is the old airport at Mestersvig guarded by military personnel and there is a research station at Zackenberg which currently is manned from May to September.

To the south, the assessment area borders the former municipality of Tasiilaq. The inhabited sites here are far from the assessment area, but hunters may occasionally travel as far as the southern part of the Blosseville Kyst. The two East Greenland municipalities are now part of a large municipality covering both the east and the west coast of Greenland: Kommuneqarfik Sermersoq.

1.2 Abbreviations and akronyms

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
BIOS = Baffin Island Oil Spill study
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
JNCC = Joint Nature Conservation Committee (UK)
LRTAP = Convention on Long-Range Transboundary Air Pollution
MARPOL = International Convention for the Prevention of Pollution from Ships
MIZ = Marginal Ice Zone
NAFO = Northwest Atlantic Fisheries Organssation
NAO = North Atlantic Oscillation
NERI = National Environmental Research Institute, Denmark.
NEW = Northeast Water Polynya
NOW = North Water Polynya
NGO = Non-Governmental Organisation
NMDA = N-methyl-D-aspartate
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
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
VME = Valuable Marine Ecosystems
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 Physical environment

This section only gives a short account of some of the most important physical characteristics of the assessment area. A more detailed description is given in a report by the Danish Meteorological Institute (Pedersen *et al.* 2011).

The assessment area is situated mainly within the High Arctic climate zone, which means that the average July temperature does not exceed 5° C. It is also far north of the Polar Circle, so 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 the year (Section 2.3), and permafrost is widespread in the inland areas.

The offshore part of the assessment area is the western part of the Greenland Sea. The bathymetry is generally poorly known, illustrated by the fact that as late as in 1993 a new island was discovered 80 km off the Greenland coast (Bennike *et al.* 2006). The shelf (waters less than 200 m depth) has a width of more than 300 km in the northern and central part of the assessment area, while in the southern part it becomes much narrower – down to approx. 80 km. Waters outside the shelf are very deep, reaching more than 3,000 m.

2.1 Oceanography

2.1.1 Currents

The Greenland Sea is important in the global thermohaline circulation as a region where the ocean looses heat to the atmosphere. This cause a change in the buoyancy of the surface water, and it sinks. The less dense portion of these water masses can flow south and across the Greenland-Scotland Ridge (overflow water) into the North Atlantic, where it contributes considerably to the North Atlantic Deep Water. The importance of this process for the global thermohaline circulation ('the cold heart of the oceans') has drawn a great deal of attention to the Greenland Sea and to the water masses and the mechanisms that create the overflow water (Olsen *et al.* 2008b and references therein).

The East Greenland Current (EGC) is the main source of the waters of the Arctic Ocean to the North Atlantic (Figure 2). In the surface layers it transports cold and low salinity Polar Surface Water and sea ice during spring and summer (Rudels *et al.* 2002). A branch of the North Atlantic Current, known as the Irminger Current (IC), turns westward along the west coast of Iceland (Figure 2). Part of the Irminger Current turns southward towards Greenland, flowing parallel to the East Greenland Current down to Cape Farewell, where it joins the East Greenland Current (Figure 2), and flows up along the west coast. In the central part of the Greenland Sea the currents move counter-clockwise in the large Greenland Sea Gyre. A summary of the currents is given by Buch (2007).

2.1.2 Hydrodynamic discontinuities

Hydrodynamic discontinuities are areas where different water masses meet with sharp boundaries creating steep gradients (temperature, salinity etc.) between them (Figure 3). Examples are upwelling events where nutrient-rich water is forced upwards to the upper layers, fronts between different water masses or ice edges

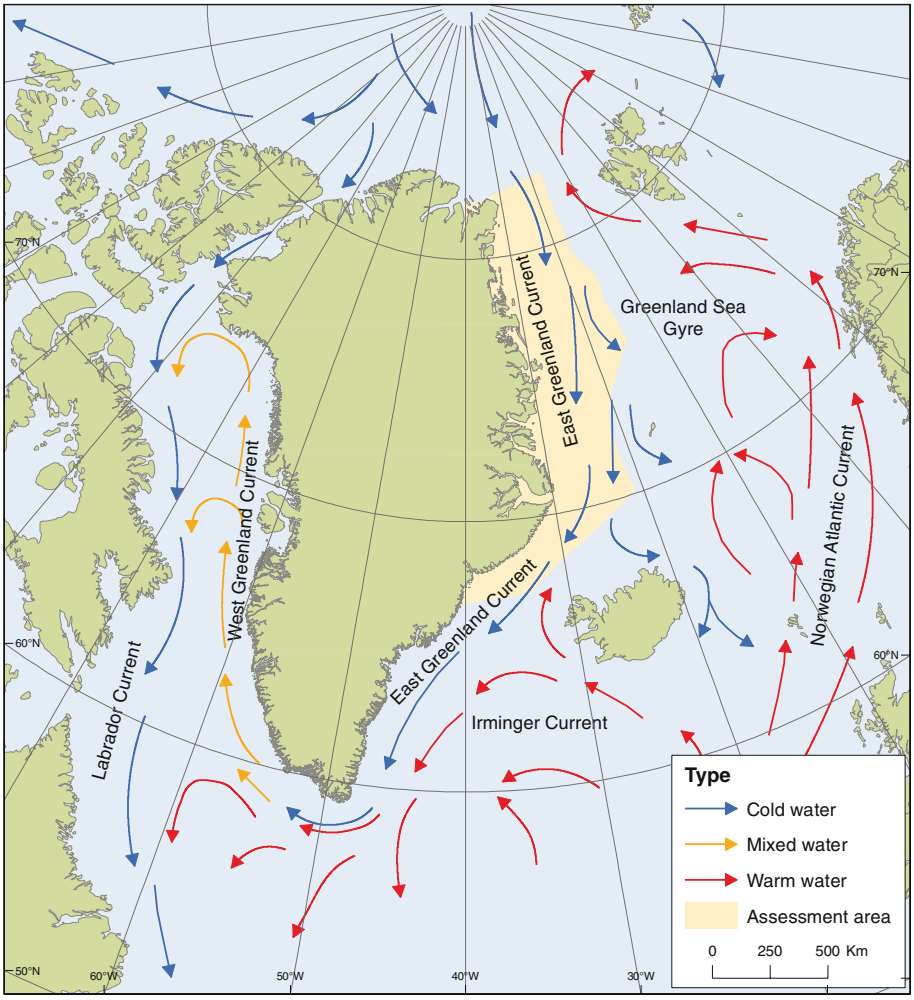


Figure 2. Major sea surface currents in the northern Atlantic (partly after Buch 2007).

(inclusive marginal ice zones). Upwelling occurs often along the steep sides of the banks driven by the tidal current, with upwelling thereby usually alternating with downwelling. Hydrodynamic simulations performed as part of the Disko West assessment programme revealed some significant upwelling areas. It is not known whether such upwelling events occur off East Greenland, but it is likely.

2.2 The coasts

The coasts of the assessment area are very diverse. Rocky shores made up from bedrock, basalts or sedimentary rocks are frequent, but also low shores of loose sediments are widespread. Large glaciers, more or less active (calving icebergs to the sea), reach the coast at many sites.

There are many fjords penetrating far into the mainland, particularly in the central part. The Scoresby Sund is one of the largest fjord complexes in the world.

2.3 Ice conditions

Two types of sea ice occur in the assessment area: fast ice, which is stable and anchored to the coast, and drift or pack ice, which is very dynamic and consists of floes of varying size and density. In addition to sea ice, icebergs originating from calving glaciers are very frequent in some areas. As part of the preparations for oil activities in the assessment area, BMP has initiated a study by DMI which will include descriptions of sea ice distribution, thickness and movements of the drift ice (Hvidegaard *et al.* 2008, Pedersen *et al.* 2011). See also Buch (2007) for a summary of the ice conditions in the Greenland Sea.

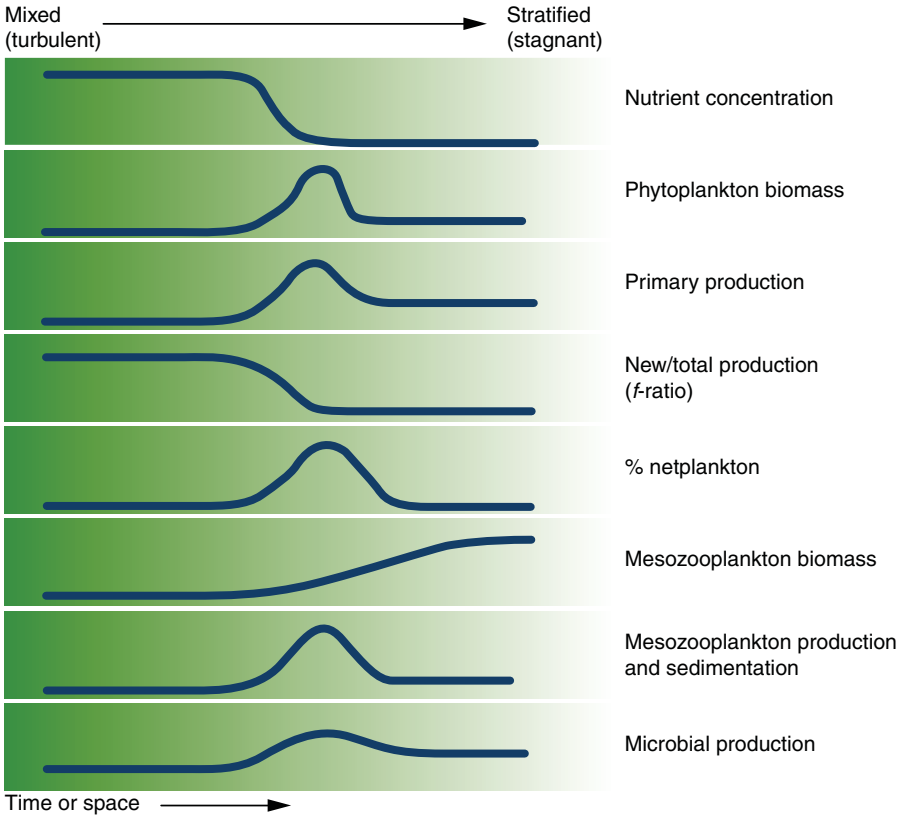


Figure 3. Hydrographical discontinuities are often sites of enhanced biological activity. Such can be defined in time, e.g. the shift from mixed water in the winter to stratified water in the spring or in space when two water masses meet or at the marginal ice zone where the frontal zone will provide better growth conditions for plankton and the succeeding links in the food web (Kiørboe 1992).

2.3.1 The drift ice

The drift ice is transported by the East Greenland Current along the coast. It is usually very dense and difficult to navigate, except for the summer months August and September. Some of the recent summers although have had very light ice conditions, e.g. 2008 (Figure 4) while 2011 was almost a normal ice year. The drift ice consists of several types of ice of varying age (first year (or annual), second year, multi year).

2.3.2 The fast ice

The fast ice covers the fjords and a shelf along the outer coast. The fjord ice disappears usually during June and July, and also the ice shelves along the outer coasts melt. However in some areas a stationary or semi-permanent shelf made up from fast ice and consolidated drift ice is present throughout the summer. The most prominent is found between Germania Land and Hovgaard Ø and was in July 2008 100 km wide (Figure 4). In 2010 it almost disintegrated during August. The coastal waters and the fjord to the west of this shelf usually become ice free in summer. A few fjords are usually also covered with permanent ice throughout the summer, e.g. Carlsberg Fjord.

2.3.3 Polynyas, shear zone and MIZ

Polynyas are more or less ice free areas in otherwise ice-covered waters. They are predictable in time and are of a high ecological significance. The most significant polynyas of the assessment area are the North East Water (NEW) off Kronprins Christian Land, the waters off Wollaston Forland (now termed the Sirius Water Polynya (Pedersen *et al.* 2010)) and the mouth of the Scoresby Sund (Figure 5). There are also some much smaller and less frequent open polynyas along the coast.

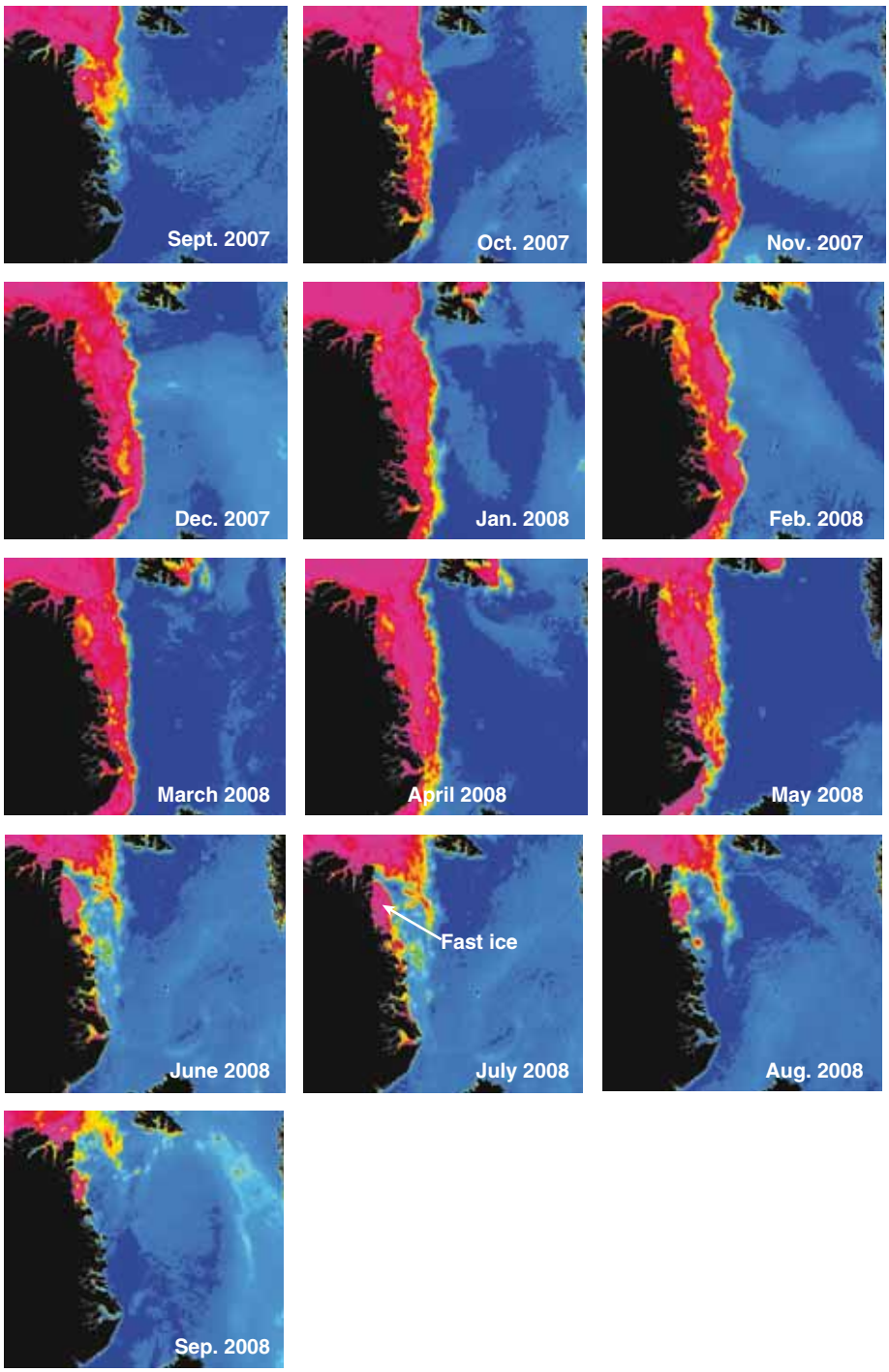


Figure 4. Distribution of seaice in the Greenland Sea September. 2007 to September 2008. Images based on Multichannel Microwave Radiometer (AMSR and SMMR; (Source DMI). Red and magenta indicate the very dense ice (8-10/10); while yellow indicate somewhat looser ice. The loosest ice (1-3/10) is not recorded. Note the differences between September 2007 and September 2008.

Moreover, a shear zone may occur (with open cracks and leads) between the land-fast ice and the drift ice.

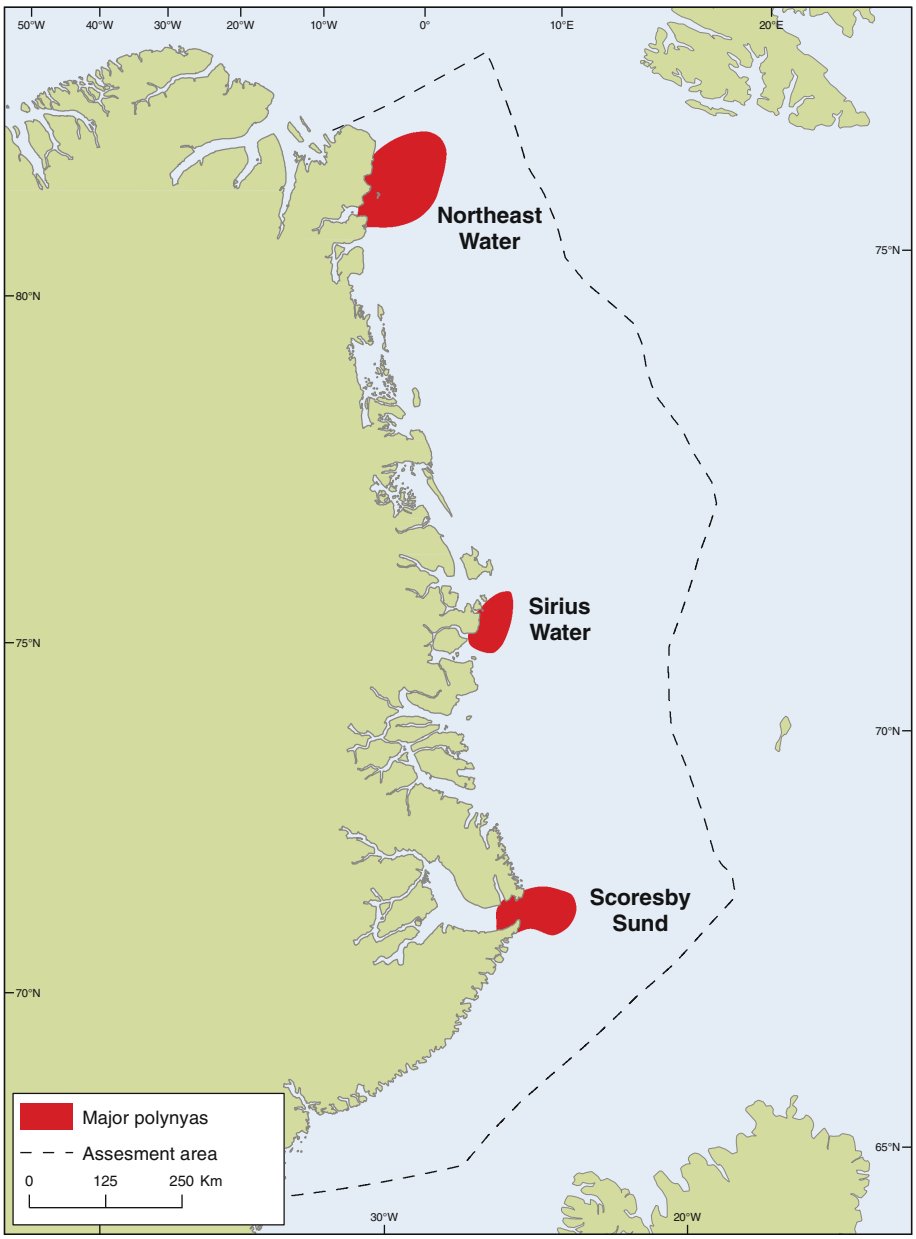
The zone between the dense drift ice and the open ocean is the Marginal Ice Zone (MIZ). The extension of this varies with wind and wave conditions, and is supposed to be very important in a biological sense.

2.3.4 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

Figure 5. The most prominent polynyas in the assessment area.



Icebergs from the Northeast Greenland outlet glaciers between 78°00' N and 79°30' N differ from bergs from other parts of Greenland being much larger and formed as the tabular bergs seen in the Antarctic area. Due to the presence of a semi-permanent or stationary sea-ice cover in the shore region such bergs can be trapped for decades in Jøkelbugten. However, through the summers of 2002 and 2003 the East Greenland sea ice retreated dramatically. The semi-permanent sea-ice cover broke up and many of the trapped bergs began drifting; numerous of them several kilometres wide and 50 m high.

Icebergs from other glaciers in the assessment area are generally smaller than the icebergs from glaciers in Northeast Greenland.

The general movement of icebergs from the Northeast Greenland glaciers is southwards along the coast, where they are transported by the East Greenland Current.

3 Biological environment

3.1 Primary productivity

M. Frederiksen and K. Johansen

3.1.1 General context

From an Arctic perspective, the shelves off Northeast 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 North 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 Northeast Greenland is generally 2–3 months, but in polynyas may be > 6 months. Large areas off Northeast Greenland are dominated by heavy drift ice throughout most summers. 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 Sund 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. Large parts of the area is dominated by heavy drift ice throughout most summers, leading to low productivity and causing great logistical challenges for scientific studies. Existing studies have thus concentrated on three areas where the open-water season is longer and productivity is higher: the North East Water Polynya in the north of the assessment area, the extensive fjord systems along the Greenland coast, and the marginal ice zone in the Greenland Sea, close to the eastern edge of the assessment area. 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.

3.1.2 The North East Water Polynya (NEW)

This large (~45 000 km^2) and important polynya is very remote and access is difficult, and as a consequence the only major study of physical and biological processes remains the extensive summer cruises in 1992 and 1993 (Hirche & Deming 1997). It is likely that conditions have changed substantially in the last 15 years, due to e.g. decreasing summer ice cover in the Greenland Sea and Fram Strait, but the description here is necessarily based mainly on the 1992/3 studies. The most open part of the polynya, with high primary production dominated by diatoms, was generally located around the northern limit of the assessment area, whereas the southern part was characterised by higher ice cover, no surface stratification, lower primary production and dominance by flagellates, all typical of a non-bloom situation (Pesant *et al.* 1996). Stable isotope analyses indicated that benthic-pelagic coupling in NEW was strong, i.e. that a large fraction of primary production was exported to the benthic community rather than being consumed by pelagic organisms (Hobson *et al.* 1995). However, detailed studies of production and grazing of both large and small phytoplankton indicated that a large part of late-season production was advected out of the polynya sensu stricto to neighbouring ice-covered areas, where it subsidised local heterotrophic planktonic and benthic communities (Pesant *et al.* 1998, Pesant *et al.* 2000). Food web dynamics in NEW seem largely to be regulated by advective processes, and horizontal exchanges are important relative to vertical and internal flows. The microbial components form an almost closed loop, recycling dissolved organic matter with little connection to the rest of the food web and weak seasonal variations (Berreville *et al.* 2008). In this regard NEW differs from the North Water Polynya (NOW) off Northwest Greenland, probably due to differences in their seasonal longevity, i.e. the longer-lived NOW Polynya having more time to develop complex trophic interactions.

3.1.3 Fjord ecosystems in Northeast Greenland

The coastline of the assessment area is highly indented with many large fjord systems. Only one of these has been subject to extensive scientific studies, namely Young Sund (~74° N). Rysgaard & Nielsen (2006) summarise results of detailed studies of most ecosystem components since 1994, and a long-term monitoring programme (MarineBasis) was initiated in 2003 (Rysgaard *et al.* 2007). Primary production in the shallow part of Young Sund was dominated by macrophytes, but also included substantial contributions from benthic microalgae and phytoplankton, whereas production by ice algae was unimportant. Phytoplankton biomass and productivity was similar to other Arctic areas. However, in both shallow and deeper parts of the fjord, total community respiration was substantially higher than local primary production, implying that the heterotrophic community was subsidised by terrestrial runoff as well as advection from the Greenland Sea (Rysgaard & Nielsen 2006).

3.1.4 The Greenland Sea and the marginal ice zone

A large part of the assessment area is covered by dense drift ice during most summers, and for logistical reasons very few studies have been conducted here. In contrast the marginal ice zone (MIZ), which is often located close to the eastern edge of the assessment area, is relatively well studied. Gradinger & Baumann (1991) found that phytoplankton biomass was very low and dominated by flagellates in the drift ice, but much higher and dominated by diatoms and the prymnesiophyte *Phaeocystis pouchetii* in the MIZ (cf. Hirche *et al.* 1991). Based on several cruises in the open Greenland Sea, Richardson *et al.* (2005) found that primary production peaked in May and was dominated by diatoms, and that flagellates including *Phaeocystis* were more important later in summer. Production was highest, with

evidence for recurring blooms throughout the summer, along the ice edge, where diatom dominance was also most pronounced. A subsurface peak in phytoplankton biomass was found at most stations. Estimated overall mean production was 81 g C m^{-2} yr^{-1}.

3.1.5 Satellite-derived maps of estimated surface chlorophyll concentration

In Figure 7 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, for example, sea-ice areas with too little incident light to give 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 instance, irregular white areas north of Iceland in August-September are more likely to represent extremely high cloud concentration.

Despite the high annual and seasonal variation in ice cover, some spatiotemporal patterns were recurrent between years. For example, surface chlorophyll concentrations tended to be very high in June (in some years including May and/or July) along the ice edge in the eastern part of the assessment area, although actual values varied strongly between years. These high and variable concentrations may represent widespread *Phaeocystis* blooms. Less intensive surface blooms were seen in some years in the fjords, as ice cover breaks up in July-August. In contrast, satellite data consistently showed relatively low levels of surface chlorophyll in the North East Water Polynya.

3.1.6 Important and critical habitats

The information on primary productivity is generally too sparse to identify localised important and/or critical areas, except for the polynyas.

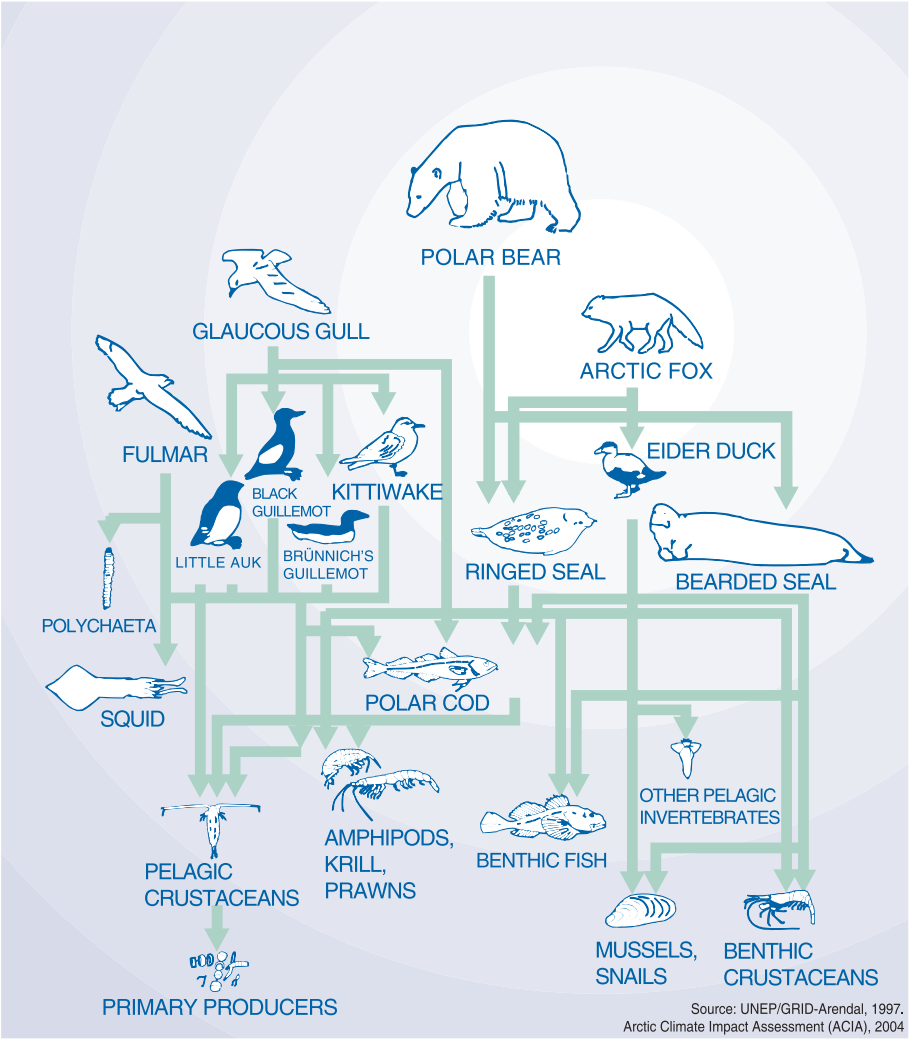
3.2 Zooplankton

M. Dünweber and D. Schiedek

3.2.1 General considerations

Zooplankton has an important role within marine food webs (Figure 6) 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 feeders on the large copepods of the genus *Calanus* (Karnovsky *et al.* 2003, Heide-Jørgensen *et al.* in review). Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipids that are ac-

Figure 6. An overview of the interactions in the marine Arctic environment. From UNEP/GRID-Arendal Maps and Graphics Library 2008. Available at: http://www.grida.no/graphicslib/detail/coastal-arctic-food-web-drift-ice_a0af.



cumulated 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). Mainly, the *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 the almost continual presence of light for four months per year have a strong influence on food availability and on the life cycle of Arctic organisms. 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 cycle, since these depots not only provide energy during starvation in winter but also the materials for egg production and naupliar 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

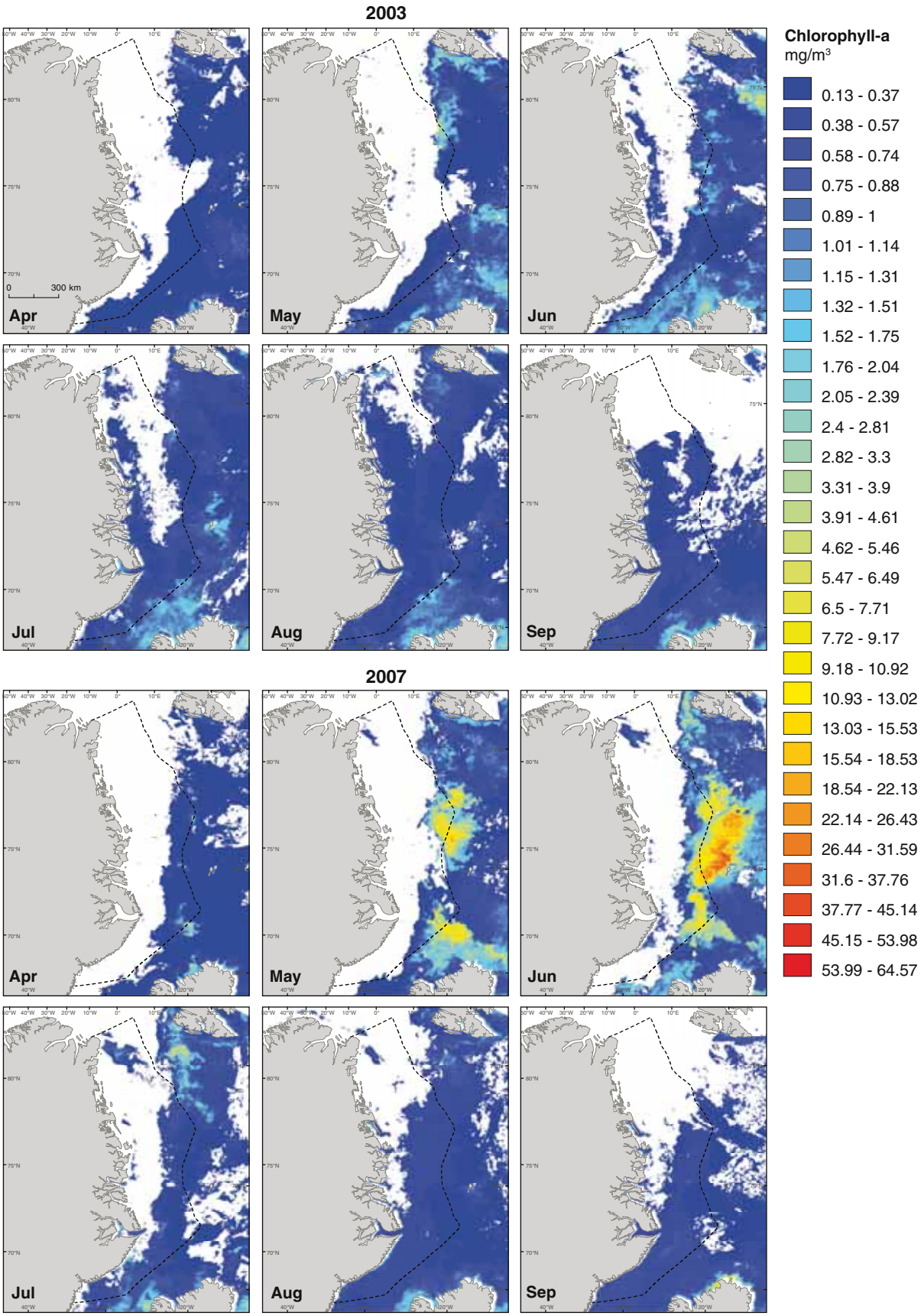


Figure 7. Estimated monthly mean surface chlorophyll concentration in the period April-September 2003 (upper two rows) and April-September 2007 (lower two rows) in the western Greenland Sea. The maps are based on level 3 data from the MODIS Aqua satellite sensor and downloaded from OceanColorWeb (http://oceancolor.gsfc.nasa.gov). 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* scale-dreading)$^{-2}$). 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.

prominent role of the large copepod, *Calanus*. The species of this genus feed on algae and protozoa in the surface layers and accumulate surplus energy in the form of lipids which are used for over-wintering at depth and to fuel reproduction the following spring. Their life cycles have been estimated to be of 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 3-4 years life cycle, reproducing at depth early in the year (November–March) (Hirche 1997). 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 11 larvae stages and one adult stage. The young larvae exploit the spring phytoplankton bloom and develop into older larvae. The largest larvae stages and the adults also ascend to feed during spring after overwintering in the deeper parts. 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 over-wintering both species utilize lipid reserves stored in the productive summer (Kosobokova & Hirche 2001, Ashjian *et al.* 2003). The other main copepod species, *C. finmarchicus*, was first characterised as a boreal species, but now is 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 Arctic Ocean and the Greenland Sea assessment area by the main inflow of Atlantic water, and its distribution in the Arctic Ocean is associated with the circulation of Atlantic waters. The last major copepod species, *Metridia longa*, has been classified by several authors as an Arctic deep-water species that overwinters as stage large larvae and adults (Ashjian *et al.* 2003).

Other smaller species, such as *Oithona similis*, *Pseudo Calanus* spp. and *Micro-Calanus 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 (Lischka & Hagen 2005, Møller *et al.* 2006).

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 pelagic amphipods. Thus, hyperiid amphipods also play a key

role in the Arctic pelagic food web (Figure 6) as a major link from mesozooplankton secondary production to higher trophic levels such as seabirds and marine mammals (Auel *et al.* 2002). Also euphausiids (krill) can be very numerous and constitute important food for seals, whales and seabirds (Figure 6).

In general, life cycles of Arctic zooplankton species are prolonged compared with populations of closely related species at lower latitudes, and often exceed 1 year (Hirche 1991). 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*. In larvae of the Greenland halibut (*Reinhardtius hippoglossoides*) and sandeel (*Ammodytes* spp.) from the West Greenland shelf, copepods were the main prey 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 large variations in physical forcing such as extent of sea-ice cover, light and stratification in the Arctic makes general predictions of the time when *Calanus* spp. ascent to the surface waters in spring difficult. A long period of ice cover, i.e. a short open water period, seems to result in a dominance of *Calanus* (Rysgaard *et al.* 1999) as this genus is able to control plankton biomass throughout the short productive season. In contrast, in Disko Bugt in western Greenland (Levinsen & Nielsen 2002), where there is a longer open water period, the smaller species and juvenile stages of copepods dominate the copepod biomass during the late summer. This is possible because *Calanus* leave the surface waters as early as midsummer to start their winter hibernation. Therefore predications and extrapolations from one Arctic region to another is very uncertain (Wassmann *et al.* 2004) due variable succession criteria of the species within the different regions.

Mumm *et al.* (1998) showed latitudinal changes of plankton variability from the high Arctic down to the Greenland Sea and suggested its relationship to the hydrographical characteristics. The Arctic Sea was not only restricted by a lower total biomass, but was also dominated by species of polar origin where the Greenland Sea had species of a more temperate origin. The distribution of the species dominating in the Greenland Sea is caused by the Atlantic water, which enters the Arctic Ocean north of Spitsbergen transporting nutrient rich water east towards the continental rise where it contributes to the food supply of the zooplankton community. Other studies from the Greenland Sea have shown that the onset of the phytoplankton bloom in spring and the appearance of the *Calanus* species in the surface waters results in a short and intense biological productivity in the surface waters (Hirche *et al.* 1994, Møller *et al.* 2006). This indicates a close linkage of the hydrography with the plankton distribution in the area and the productive cycle is highly pulse-like in nature, which is characteristic for Arctic marine ecosystems.

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

Anthropogenic impacts, e.g. oil pollution, might also have an impact. In recent 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 when the pelagic food web has high activity (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 is assumed to be less severe (Söderkvist *et al.* 2006).

In the assessment area, plankton vulnerability to anthropogenic impacts is also likely to depend on season and on biological activity. However, environmental conditions (e.g. currents, temperature and ice occurrence) are different from those in better studies areas, why the diversity and activity of the pelagic food web, including zooplankton, presumably also differs.

3.2.2 Zooplankton in the assessment area

In some coastal areas and fjords, zooplankton structure and distribution has been studied already in the 1930s by Ussing (1938). Later, quantitative measurements of phytoplankton and zooplankton were made at Scoresby Sund, mostly at Rosenvinge Bugt (70° N, 22°03' E), one or two miles offshore the town of Ittoqqortoormiit (Digby 1953, 1954). Copepods were numerically the most dominant group. In a more recent study, a very similar copepod community in terms of species composition and biomass was found in Young Sund. In the standing stock, biomass was dominated by the three *Calanus* species, *C. glacialis*, *C. hyperboreus* and *C. finmarchicus* (Rysgaard & Glud 2007). Their functional role was revealed by comparing data from studies prior to sea-ice breakup with those taken during different open water periods in the summer and in the winter. During sea ice cover the water column in the outer Young Sund was strongly heterotrophic and was sustained by organic material originating from the open sea. During open-water periods, the grazing community was completely dominated by copepods (Rysgaard & Glud 2007).

3.2.3 The eastern part of the Greenland Sea

The main outflow from the Arctic Ocean into the North Atlantic occurs through the Fram Strait and the Greenland Sea. The Greenland Sea consists of different water masses (see also Section 2.1), with consequences for the plankton community.

The distribution of zooplankton was investigated during summer 1983 in the marginal ice zone of the East Greenland Sea. Nutrient levels, especially inorganic nitrogen, were extremely low, and probably limited the growth of phytoplankton during this period. Generally, zooplankton biomass was similar to other polar regions and species distributions indicate the origin of the two major water masses in this area (Smith *et al.* 1985). Other studies have indicated that the zooplankton community on the East Greenland shelf and slope is composed of Arctic species transported south by the East Greenland Current (EGC) and a variety of Atlantic species injected into the area via the Return Atlantic Current (Hirche *et al.* 1994). Furthermore, it was shown that zooplankton distribution was influenced by the Greenland Sea Gyre (the large gyre in central Greenland Sea), which also contributes to the existence of the Northeast Water Polynya (NEW).

The temporal and spatial distribution of the main zooplankton communities was analysed showing that *Calanus* spp. dominated the copepod community in all water masses during early summer (Møller *et al.* 2006). Later in the summer, when the majority of the *Calanus* spp. population descended, smaller species such as *Pseudo Calanus* spp. took over and kept the copepod biomass high. This trend was particularly pronounced in the Arctic Surface Water. In the same study, the role of the non-*Calanus* components of the zooplankton community was documented. They were responsible for 70–99% of the total zooplankton grazing on phytoplankton during summer and were crucial to the recycling and respiration of primary production (Møller *et al.* 2006). *Calanus* spp. may, however, also contribute to the vertical export of carbon through their vertical migration and the production of large-sized faecal pellets. With the inclusion of small copepods and protozooplankton, grazing impact on the primary production was clearly higher than for *Calanus* spp. alone (Møller *et al.* 2006 and references therein).

3.2.4 Northeast Water Polynya (NEW)

During 1991 and 1993 the Northeast Water Polynya (NEW) on the northeast Greenland continental shelf and the surrounding ice-covered areas were studied intensively.

Zooplankton biomass in the ice-covered region off Northeast Greenland was dominated by copepods with 84% biomass of all taxa, followed by chaetognaths (Hirche & Kwasniewski 1997). The large *Calanus* species, i.e. *Calanus glacialis*, *C. hyperboreus* and *C. finmarchicus* made up to 91% of the biomass, which was in accordance with earlier investigations in the area (Hirche *et al.* 1994, Hirche & Kwasniewski 1997). These species are commonly associated with Polar Water on Arctic shelves (*C. glacialis*), Arctic Water in the Greenland Sea (*C. hyperboreus*) and Atlantic Water in the North Atlantic Current (*C. finmarchicus*). In the NEW, *C. glacialis* inhabited areas of low current speeds on Belgica and Ob Bank, *C. hyperboreus* dominated shelf slopes and trough stations, while *C. finmarchicus* was most abundant in the Return Atlantic Current along the shelf slope and also at the eastern Belgica Trough (Hirche & Kwasniewski 1997).

However, biomass was low and only 10% of the phytoplankton carbon was grazed, which was in agreement with earlier studies (Hirche *et al.* 1994). The meso- and macroplankton appeared to be only minor contributors to the overall carbon flow within the NEW Polynya system. It was suggested that a large portion of the organic matter is not utilised in the water column, but is exported to the benthos where it supports a rich community. High sedimentation rates in the NEW Polynya were reported from Belgica Bank (Piepenburg 1988) and benthic distribution patterns in the NEW usually reflected pelagic regimes (Piepenburg *et al.* 1997). Further evidence for a high benthic biomass is given by the large stocks of benthos-feeding marine mammals and seabirds, such as walruses and eider ducks (Hirche *et al.* 1994). Other studies confirmed the low standing stock of mesozooplankton in the NEW and it was suggested that this might be a typical feature for this region (Ashjian *et al.* 1997).

The production of copepod eggs and nauplii and the occurrence of polar cod (*Boreogadus saida*) larvae have been seen as an adaptation to match the hatching and first feeding of cod larvae with their main prey. Polar cod spawn under the ice in winter and the buoyant eggs rise to the ice–water interface (Bouchard & Fortier 2008). Consistent with this hypothesis, hatching occurs from mid-May to mid-July in the Northeast Water Polynya, coinciding with the opening of the polynya and the short season of intense biological production (Fortier *et al.* 2006). In spring, first-feeding larvae (<8 mm long) prey on eggs of large calanoid copepods (16%) such as *C.*

hyperboreus, *C. glacialis* and *Metridia longa*, and on nauplii (80%), primarily *Oithona similis*, *Pseudo Calanus* spp. and *Micro Calanus pusillus* (Michaud *et al.* 1996).

Matching the first feeding of larvae with the brief maximum production of copepod eggs and nauplii in early summer has been identified as a dominant force constraining the reproduction strategy of polar cod (Bouchard & Fortier 2008). The larger the young polar cod are at the end of the summer, the less vulnerable they appear to be to avian predation in early fall and cannibalism over the winter. In the Northeast Water in 1993, a spring cohort (14 May to 15 June) of larvae was hatched under the ice at sub-zero temperatures and survived poorly (Fortier *et al.* 2006). A summer cohort (21 June to 21 July) was hatched at above-zero temperatures and survived well.

The different studies performed in the Northeast Water and the Greenland Sea clearly indicates the central role of zooplankton in the assessment area.

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 flux variability affects the pelagic ecosystem. Plankton are in general found to be 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).

3.2.5 Important and critical areas

Existing knowledge on zooplankton is not sufficient to designate any important or critical areas within the assessment area, except for the NEW Polynya as such.

3.3 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.

Investigation of the marine benthic flora in the assessment area is scarce and has mainly been conducted as floristic studies by Lund (1959a, b) in the region between the Ittoqqortoormiit District and Kejser Franz Josephs Fjord. Even earlier, however, marine macroalgae were collected at different expeditions to Greenland during the 19th century, and were identified and described by Rosenvinge (1893, 1898, 1910 & 1933). A check-list and distribution of the marine algae of Greenland for the east and west coast separately was compiled by Pedersen (1976). Only few, more recent, studies of the macroalgal flora have been conducted at the northeast coast of Greenland. A study at Mestersvig (Birklund *et al.* 2006), which included collections and identifications of macroalgae, supplements the floristic overview, and studies of marine macroalgal biomass and production in Young Sund has been performed by Borum *et al.* (2002), Roberts *et al.* (2002) and Krause-Jensen *et al.* (2007).

3.3.1 General context

The marine macroalgae are found along shorelines with hard and stable substratum, such as stones, boulders and rocky coast. The vegetation is distinctly divided in zones, which are most pronounced in areas with high tidal amplitudes. Some species even grow above the high-water mark, in the supralittoral zone, where sea water reaches them as spray or by wave action. In the littoral zone the vegetation is alternately immersed and emersed, and characterized by fucoid (of the genus *Fucus*) species. The majority of the macroalgal species grows, however, below the low water mark. The submerged vegetation is restricted to depths with sufficient light. In the Arctic, the length of the ice-free period is an important controller of the light reaching the sea floor, and the depth range of the kelp belt increases from north towards south along Greenland's coast in parallel to the increase in the ice free period (Krause-Jensen *et al.* 2011). In North Greenland, a relatively rich macroalgal flora can be found down to water depths of about 15-20 m depth (Krause-Jensen *et al.* 2011), while they occur as deep as 50 m in South Greenland (Wegeberg *et al.* 2005).

The marked seasonally changing light regime consolidated by cover of sea ice during 9-10 months of a year in, e.g. Young Sund (74° N) and the low temperatures call for efficient adaptive strategies (Bertness *et al.* 1999, Borum *et al.* 2002, fig. 1). The seasonal, physiological performance of Arctic macroalgae is strongly linked to life-strategies of individual species or ecotypes as observed for *Laminaria solidungula* and *Saccharina latissima*, respectively, in the assessment area. Particularly *L. solidungula*, and to a lesser extent *S. latissima* can possess up to several blade (lamina) generations (Lund 1959a,b , Borum *et al.* 2002), whereas in temperate regions the lamina of *S. latissima* from the proceeding year's growth is lost successively due to erosion along with development of the new lamina. 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, implying that the old tissue is still photosynthetically active and thus contributing to a positive carbon balance of the individual. They found that the photosynthetic capacity of the lamina from the proceeding year was similar to that of the current year in June 1999 of *Saccharina latissima* in Young Sund. The ability to support a photosynthetic performance, comparable to that of macroalgae in temperate regions, might be explained by low light compensation points facilitated by 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. It also ensures optimal harvest of light when available (Becker *et al.* 2009, Krause-Jensen *et al.* 2007)

The sea ice is a high physical impact factor on the macroalgal vegetation. 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 species of the filamentous green algae *Ulothrix* and *Urospora*, develop quickly during the summer months due to the available substratum and life history microstages not detached by ice. This scenario is described by Lund (1959b) for the Scoresby Sund and Kejser Franz Joseph Fjord districts in the assessment area.

Perennial species from the littoral zone do tolerate freezing, and will survive being froze in into an ice foot, provided the ice foot melts without being disrupted. The macroalgal vegetation then remains intact as observed in more sheltered localities by Lund (1959b). *Fucus distichus* from Spitsbergen was able to halt the photosynthetic activities at subzero temperatures and resume almost completely when unfrozen again (Becker *et al.* 2009).

Fresh water or water of low salinity may influence the macroalgal vegetation 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 bleaching (strong loss of pigments) or increased mortality, which suggests that hyposalinity also impacts 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. Lund (1959b) observed species (*Desmarestia aculeata, Fucus distichus, F. evanescens* and species of red and green algae) in localities with a soft, muddy bottom, attached to shells, small stones or loose-lying in the assessment area. 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 re-suspended particles in melt water. The light conditions are impacted due to reduced water transparency as well as to the sedimentation of re-suspended particles on the macroalgal tissue resulting in shading.

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

Isotope ($\delta^{13}C$) analyses used to trace kelp-derived carbon in Norway, suggest that kelp may serve as carbon source for marine animals at several trophic levels (e.g. bivalves, gastropods, 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 reduc-

tion 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. However, lowered salinity and increasing water turbidity, as a result of and an increase in freshwater runoff, could also impoverish growth conditions in some areas (Borum *et al.* 2002, Rysgaard *et al.* 2007). A northward range expansion of species is another likely scenario with oceanic warming (Müller *et al.* 2009).

There are different reports on the impact of oil contamination on macroalgal vegetation and communities. The macroalgal cover lost in connection with the *Exxon Valdez* oil spill in 1989 in Prince William Sund, as observed for *Fucus gardneri*, has taken years to fully re-establish. This has been a result of the changed interactions between grazers and macroalgae as well as of intrinsic changes in plant growth and survival (Driskell *et al.* 2001). The algal cover is still considered under recovery in many areas (NOAA 2010). In contrast, no major effects of oil on shallow sublittoral macroalgae were observed in a study carried out on Baffin Island 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).

3.3.2 The macroalgal vegetation in the assessment area

A checklist and distribution of the marine macroalgal species in the assessment area are presented in Table 1, respectively. Caution should be taken in interpreting the species distribution as the species list is a positive list, which means that the species was listed if it was collected and identified, but systematic and exhaustive sampling of macroalgae were probably only performed at Mestersvig (Birklund *et al.* 2006).

In total, 183 macroalgal species (excl. the bluegreen algae, Cyanophyta) have been recorded from Greenland according to the most recent checklist (Pedersen 1976). Due to taxonomic and nomenclatural changes the number presently equals 137 species; 37 red algal species, 66 brown and 37 green. Within the assessment area 34 red algae, 57 brown, 26 green have been recorded and only few species are registered for the highest latitudes (higher than 77° N), 5, 13 and 2, respectively.

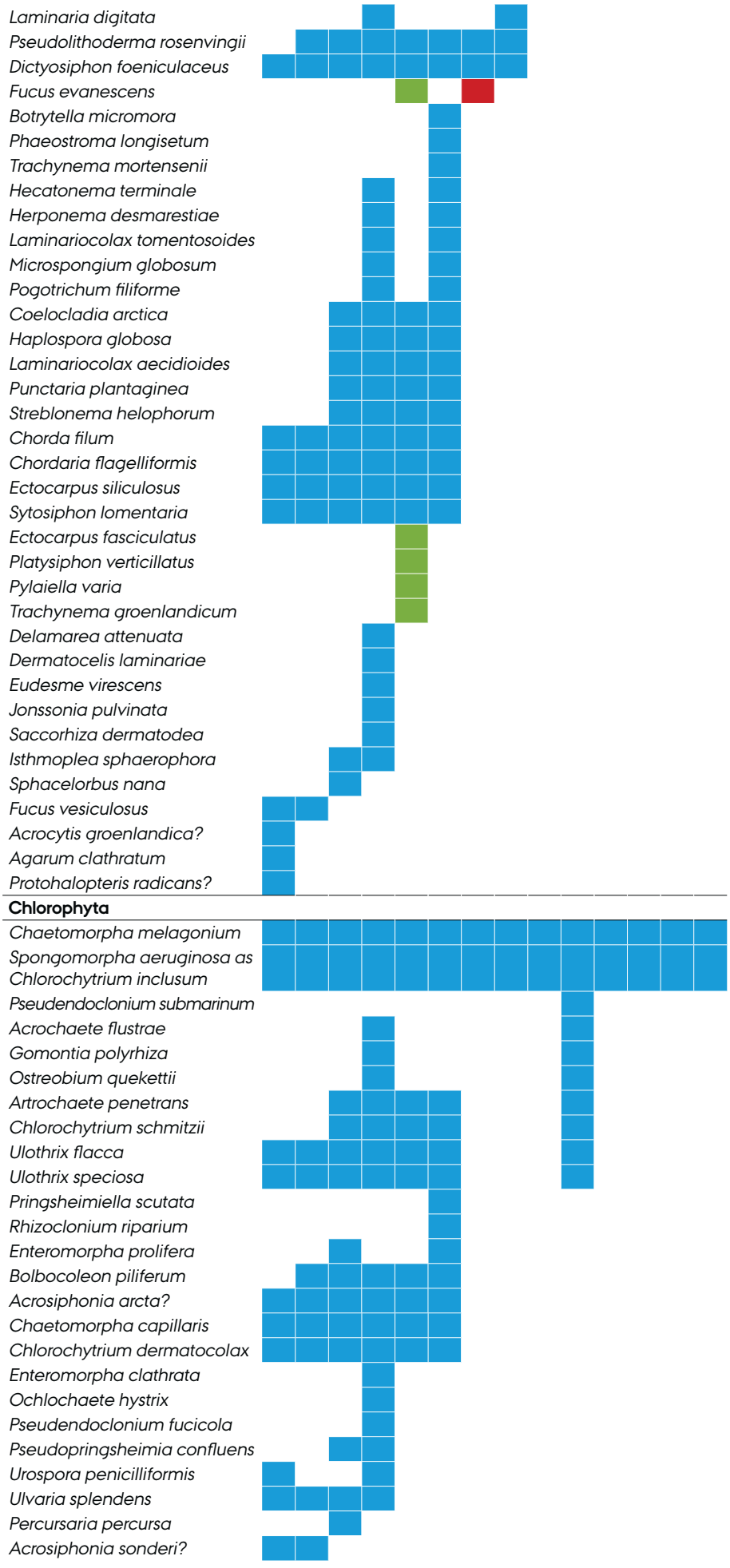
The brown algae *Laminaria solidungula, Punctaria glacialis, Platysiphon vertillatus* and the red algae *Haemescharia polygyna, Neodilsea integra, Devaleraea ramentacea, Turnerella pennyi* and *Pantoneura fabriciana* are considered as Arctic endemics (Wulff *et al.* 2009) and are all present in the assessment area.

Lund (1959b) described the macroalgal vegetation of the littoral and sublittoral zones at localities within the assessment area. In a single locality (Ella Ø, 72,51° N) he was able to apprehend a supralittoral zone occupied by the red algal species *Rhodochorton purpureum*.

The vertical extension of the littoral zone is described as being relatively small in accordance with the tide amplitude in the Scoresby Sund area (<1 m, Farvandsvæsenet 2011). The *Fucus* vegetation, known to occupy the littoral zone in the North Atlantic and on more southern coasts of East and West Greenland (Lund 1959b, Wegeberg *et al.* 2005), was poor and feebly developed, and occurred exclusively in sheltered localities in the Scoresby Sund area (Lund 1959b). Instead

Table 1. Distribution of the macroalgae species in the assessment area in relation to latitude. Blue markings are based on Pedersen (1976), lilac markings on Borum *et al.* (2002) and green markings on Birklund *et al.* (2006). Scientific names follow Pedersen (2011).

Latitude (°N)	68	69	70	71	72	73	74	75	76	77	78	79	80	81
Cyanophyta														
Calothrix scopulorum				■										
Rhodophyta														
Coccotylus hartzii	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Coccotylus truncatus	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Grania efflorescens	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Polysiphonia arctica	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Rhodomela lycopodioides	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Callocolax neglectus										■				
Rhodophysemopsis hyperborea			■	■	■	■	■	■	■	■				
Lithothmanion glaciale			■	■	■	■	■	■	■	■				
Lithothamnion tophiforme			■	■	■	■	■	■	■	■				
Rhodophysema elegans	■	■	■	■	■	■	■	■	■	■				
Clathromorphum compactum	■	■	■	■	■	■	■	■	■	■				
Devaleraea ramentacea	■	■	■	■	■	■	■	■	■	■				
Haemescharia polygyna	■	■	■	■	■	■	■	■	■	■				
Meiodiscus spetsbergensis	■	■	■	■	■	■	■	■	■	■				
Phycodrys rubens	■	■	■	■	■	■	■	■	■	■				
Phymatolithon foecundum	■	■	■	■	■	■	■	■	■	■				
Phymatolithon tenue	■	■	■	■	■	■	■	■	■	■				
Rhodocorton purpureum	■	■	■	■	■	■	■	■	■	■				
Scagelothamnion pusilla	■	■	■	■	■	■	■	■	■	■				
Turnerella pennyi	■	■	■	■	■	■	■	■	■	■				
Pantoneura fabriciana	■	■	■	■	■	■	■	■						
Ptilota serrata	■	■	■	■	■	■	■	■						
Dilsea integra			■	■	■	■	■							
Harveyella mirabilis			■	■	■	■	■							
Peyssonellia rosenvingii			■	■	■	■								
Rubrointrusa membranacea	■	■	■	■	■	■								
Acrochaetium microscopicum				■										
Ahnfeltia plicata				■										
Colaconema hallandicum				■										
Hildenbrandia rubra			■	■										
Euthora cristata	■	■	■	■										
Rhodophysema kjellmanii			■											
Fimbrifolium dichotomum	■													
Polysiphonia stricta	■													
Phaeophyceae														
Punctaria glacialis			■	■	■	■	■	■	■	■	■	■	■	■
Battersia arctica	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Chaetopteris plumosa	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Desmarestia aculeata	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Desmarestia viridis	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Elachista fusicola	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Halosiphon tomentosus	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Hincksia ovata	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Leptonematella fasciculata	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Pylaiella littoralis	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Saccharina latissima	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Stictyosiphon tortilis	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Pleurocladia lacustris										■				
Phycocelis foecunda						■				■				
Pseudolithoderma extensum			■	■	■	■				■				
Symphyocarpus strangulans			■	■	■	■				■				
Omphalophyllum ulvaceum			■	■	■	■	■	■	■	■				
Alaria pylaiei	■	■	■	■	■	■	■	■	■	■				
Fucus distichus	■	■	■	■	■	■	■	■	■	■				
Laminaria solidungula	■	■	■	■	■	■	■	■	■	■				
Sorapion kjellmanii	■	■	■	■	■	■	■	■	■	■				


Laminaria digitata
Pseudolithoderma rosenvingii
Dictyosiphon foeniculaceus
Fucus evanescens
Botrytella micromora
Phaeostroma longisetum
Trachynema mortensenii
Hecatonema terminale
Herponema desmarestiae
Laminariocolax tomentosoides
Microspongium globosum
Pogotrichum filiforme
Coelocladia arctica
Haplospora globosa
Laminariocolax aecidioides
Punctaria plantaginea
Streblonema helophorum
Chorda filum
Chordaria flagelliformis
Ectocarpus siliculosus
Sytosiphon lomentaria
Ectocarpus fasciculatus
Platysiphon verticillatus
Pylaiella varia
Trachynema groenlandicum
Delamarea attenuata
Dermatocelis laminariae
Eudesme virescens
Jonssonia pulvinata
Saccorhiza dermatodea
Isthmoplea sphaerophora
Sphacelorbus nana
Fucus vesiculosus
Acrocytis groenlandica?
Agarum clathratum
Protohalopteris radicans?
Chlorophyta
Chaetomorpha melagonium
Spongomorpha aeruginosa as Chlorochytrium inclusum
Pseudendoclonium submarinum
Acrochaete flustrae
Gomontia polyrhiza
Ostreobium quekettii
Artrochaete penetrans
Chlorochytrium schmitzii
Ulothrix flacca
Ulothrix speciosa
Pringsheimiella scutata
Rhizoclonium riparium
Enteromorpha prolifera
Bolbocoleon piliferum
Acrosiphonia arcta?
Chaetomorpha capillaris
Chlorochytrium dermatocolax
Enteromorpha clathrata
Ochlochaete hystrix
Pseudendoclonium fucicola
Pseudopringsheimia confluens
Urospora penicilliformis
Ulvaria splendens
Percursaria percursa
Acrosiphonia sonderi?

the littoral zone often was dominated by the filamentous cyanobacteria *Calothrix scopulorum*, or species of Chlorophyta; *Ulothrix flacca* and *Urospora penicilliformis* accompanied by filamentous cyanobacteria and the brown algae *Pylaiella* spp. At the islands, Fame Øer (70,82° N), *Ulva clathrata* was observed in the littoral zone (Lund 1959b).

In the upper part of the sublittoral zone, Lund (1959b) described a rich *Fucus* community consisting of *Fucus distichus* and *F. evanescens*. This observation is in accordance with the records of Birklund *et al.* (2006) at Mestersvig where *F. distichus* and *F. evanescens* were abundant and present at 81 % and 63 % of the sampling stations (n = 16), respectively. Lund (1959b) recognized a distinct *Fucus* community at 6-9 m's depth at some localities, but recorded the genus down to a depth of 35-38 m at Hurry Inlet (70,65°). Lund (1959b) furthermore observed *Fucus* spp. on soft bottom apparently loose-lying at Danmarks Ø (70,27° N) and Ella Ø, which also was observed at Mestersvig (Birklund *et al.* 2006).

The kelp community was described by Lund (1959b) as being widely distributed and found at depth from 10 to 30 m. *Saccharina latissima* and *Laminaria solidungula* were the dominant species, the latter in greater depths and at greater degrees of exposure. Also *Alaria esculenta* was considered of some importance in the kelp community, especially at Uunarteq (Kap Tobin, 70,25° N), which is an exposed locality.

Moreover, Lund (1959b) described communities of *Desmarestia aculeata*; 1) in sheltered localities on soft bottom up the fjords as attached to small stones or shells, or as loose-lying, the species appeared well-developed but less sturdy than the typical morphology; 2) on hard substratum at depths of 14-26 m and of 40 m at Ella Ø with a typical and vigorous appearance of the species. Analogously, this type of macroalgal community is well-known from Antarctica, where endemic species of *Desmarestia* occupy the ecological niche comparable to the kelp forests in temperate and Arctic regions, as this order of kelp species (Laminariales) is completely absent in the Antarctic macroalgal flora (Zacher *et al.* 2009).

The red algal species occurred in an almost unmixed community, i.e. with no presence of brown or green algae species, or in the kelp forest at greater depths down to 40 m. The dominating red algal species were *Phycodrys rubens*, *Coccotylus truncatus, Turnerella pennyi* and *Euthora cristata*, but also *Polysiphonia arctica, Rhodomela lycopodioides* and *Dilsea integra* were mentioned. In addition, encrusting coralline red algae (*Leptophytum foecundum* and *L. leave*) were abundant, covering open rock surface in the sublittoral zone. Of other encrusting, but uncalcified, algae, the brown crust *Lithoderma fatiscens* and especially the encrusting tetrasporophytic stage of *Turnerella pennyi* (as *Cruoria arctica*) was considered as important members of the macroalgal communities in the lowest sublittoral (Lund 1959b).

Measurements of biomass and primary production of macroalgal species and communities in the assessment area have been performed by Borum *et al.* (2002) on a kelp species, *Saccharina latissma*, Roberts *et al.* (2002) on the deep water coralline red algae community and Krause-Jensen *et al.* (2007) on the foliose macroalgal community, which included species as *Desmarestia viridis, D. aculeata, Fucus evanescens* and *S. lattissima*. All the studies were performed in Young Sund.

In the littoral, the biomass was dominated by *Fucus evanescens*, which reached a maximum of c. 290 g dw m^{-2} (Krause-Jensen *et al.* 2007, fig. 9.4) (Table 2) corresponding to c. 0.5 kg ww m^{-2} (presuming a dry matter content of app. 1/6 (Wege-

Table 2. Biomass and production of some macroalgal species studied in the assessment area. ww = wet weight, dw = dry weight. *From Krause-Jensen *et al.* (2007, fig. 9.4).

Authors	Species	Depth	Biomass (max-min)	Production (min-max)
Borum *et al.* (2002)	*Saccharina latissima* (kelp)	2.5 m		0.1 g C m^{-2} yr^{-1}
		10 m	49 (±13) g ww m^{-2}	1.6 g C m^{-2} yr^{-1}
		15 m	2.3 (±2.7) g ww m^{-2}	
Roberts *et al.* (2002)	Coralline red algae	17 m		2.6 g C m^{-2} yr^{-1}
Krause-Jensen *et al.* (2007)	Foliose macroalgae	2.5 m	< 290 g dw m^{-2}*	
		5 m	< 100 g dw m^{-2}	
		10 m	≈ 30 g dw m^{-2}	
		15 m	≈ 10 g dw m^{-2}	

berg *et al.* 2005)). For comparison the same species reached a mean biomass of 1.5 kg ww m^{-2} in Payne Bugt, Arctic Canada, 60° N (Sharp *et al.* 2008).

The biomass of *Saccharina latissima* in Young Sund is considered as being relatively low (2.3-49 g ww m^{-2}) (Table 2) due to strong influence of scouring ice floes to about 5 m's depth. In greater depths foraging of walruses disturbing the sea floor was considered of most importance in relation to low biomass level (Borum *et al.* 2002). For comparison biomasses of *S. latissima* averaged 0.9 kg ww m^{-2} in the district of Qaqortoq, Southwest Greenland, 60° N (Wegeberg 2007).

The present knowledge on benthic primary production in Young Sund is presented by Krause-Jensen *et al.* (2007): down to 20 m depth the benthic net production was estimated to exceed the pelagic primary production in Young Sund (Glud *et al.* 2002); at shallower depths the kelp species were the most important contributors to the benthic primary production; at intermediate depths (5-20 m) the main contribution to the primary production was performed by benthic microalgae (diatoms), which was studied by Glud *et al.* (2002); below 30 m only coralline red algae contributed to the benthic primary production (Table 2).

The existing knowledge of macroalgal diversity is limited and species composition, biomass, production and spatial variation are largely 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 shoreline intervals cannot be identified on the available information. In addition, at present no research has been conducted on macroalgal community interactions; neither biodiversity/abundance of macroalgal associated fauna or mapping of macroalgal /-faunal interactions including grazing.

3.4 Benthic fauna

D. Schiedek

Benthic macrofauna is 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. This is also the case in the Arctic, where approximately 20% of the world's shelf areas are located (Menard & Smith 1966), and where a high standing stock of benthic macrofauna is found even though input of food is low and highly seasonal. This is possible because large parts of the Arctic consist of relatively shallow shelf areas with tight pelago-benthic coupling.

Furthermore, the low temperature reduces the energy requirements of benthic species, allowing a relatively high biomass to exist despite the low primary production (Sejr & Christensen 2007). In areas with low temperatures and a stable physical environment, benthic species with long life span are favoured, allowing accumulation of a large biomass over decades in spite of low annual production. Food availability is one of the major driving forces influencing biomass and composition of benthic assemblages in the Arctic.

A fundamental conclusion from findings of various benthic surveys conducted in the recent past 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, additional factors such as sediment heterogeneity, disturbance, food availability, geographical setting, sea-ice cover, particle load from land and hydrographical regime also influence benthic diversity and species composition.

Compared with plankton, which show high spatial and temporal variability in biomass, the macrobenthos are a stable food source for higher trophic levels such as walrus (Born *et al.* 2003), bearded seal (Hobson *et al.* 2002) and eider (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 several years and if the community is disturbed it may take decades for the system to recover.

In areas with low temperatures and a stable physical environment, benthic species with long life span are favoured, allowing accumulation of a large biomass over decades in spite of low annual production. Food availability is one of the major driving forces influencing biomass and composition of benthic assemblages in the Arctic.

3.4.1 Benthic fauna and its role in the Greenland Sea assessment area

The Greenland Sea assessment area covers a wide range of physical habitats extending from the tidal zone to almost 3 000 m depth. It ranges from the innermost parts of the large fjord systems strongly influenced by glacial run-off to the open ocean.

Primary production in the Greenland Sea assessment area is generally controlled by sea ice that limits light availability. As a consequence annual primary production is low and confined to a short period in summer. Food is an important constraint on benthic growth and reproduction, and patterns of macrobenthic biomass often reflect the variations in primary production in the overlaying water column. For example, benthic biomass is higher underneath polynyas (Piepenburg *et al.* 1997). Another example how food availability governs benthic biomass is the depth zonation found in Young Sund where a high biomass of bivalves is found at a depth of 20 m to 40 m, which corresponds with the depth of the chlorophyll maximum in summer (Sejr & Christensen 2007). In addition to food supply, level of disturbance is also an important factor influencing benthic biomass and distribution. Typical sources of disturbance are sedimentation of inorganic particles either from rivers or glaciers or grounding sea ice. Hence benthic biomass is likely to be lower in the inner parts of the fjords or on shallow banks where larger ice floes ground. Thorson

(1933, 1934) reported a benthic biomass in the range 200–500 g per wet weight m^{-2} from East Greenland fjords.

So far, investigations concerning benthic communities, their distribution and functions, have been focused on the Northeast Water Polynya at the northern limit of the assessment area, where multidisciplinary studies including the macrobenthos have been conducted (Piepenburg & Schmid 1996; Weslawski *et al.* 1997). Benthic life has also been studied along the East Greenland continental margin at two downslope transects at 75° N (200-2700 m depth) and at 79° N (200-2 000 m depth) during 1994/1995 (Schnack 1998), and in the western Fram Strait (78°-80° N;4°30'-14° W) in summer 1985 (Piepenburg 1988) (Figure 8A). In these studies seabed imaging has been applied to describe benthic communities living on the sediment surface (epibenthos; Piepenburg *et al.* 1997). A few studies have also used Agassiz trawls to estimate benthic diversity (Mayer & Piepenburg 1996) and up to 80 species were found (Figure 8B). These were mainly crustaceans, echinoderms, molluscs and polychaetes and their presence was sediment and depth dependent (Figure 8C). Multivariate analyses of megabenthic species distribution revealed a distinct depth zonation (Piepenburg *et al.* 1997). Shallow shelf banks (> 150 m), characterised by coarse sediments, numerous stones and boulders as well as by negative bottom-water temperatures, housed a rich epifauna (30 to 340 individuals per m^2, Figure 8B). It was strongly dominated (80 % to 98 % by number) by the brittle stars, *Ophiocten sericeum* and *Ophiura robusta* (Piepenburg *et al.* 1997).

On the East Greenland continental slope at 75° N, a total of 91 different epibenthic species were identified, and up to 50 species at single locations (Figure 8D). Using classification and ordination analyses, three faunal zones were distinguished which correspond to different depth regions of the continental margin: shelf break (190 to 370 m), upper slope (760 to 800 m) and lower slope (1 400 to 2 800 m), which differed clearly in species composition (Figure 8E).

The Young Sund in the central part of the assessment area is another region where macrobenthic fauna and other aspects of this ecosystem have been investigated in past years (Rysgaard & Glud 2007). In addition, a long-term marine monitoring program was initiated in Young Sund in 2003. Based on the findings from these studies our current knowledge regarding macrobenthos distribution and role in the ecosystem is summarised below:

In the shallow coastal zone bivalves are a dominant component of the benthos. At depths between 5 and 20 m the genus Astarte is often found at abundances of 100–300 individuals per m^2. In the tidal zone sea ice often destroys flora and fauna, and the effect of ice can extend down to 5 m. Also in fjords with a large input of freshwater a low-saline surface layer can also influence the benthos of the upper 0–5 m. At depths from 10 to 50 m, large species such as *Mya truncata*, *Hiatella arctica* and *Serripes groenlandicus* can be found at abundances of 50-100 individuals per m^2 (Figure 9). Below 50 m depth total biomass drops significantly and the bivalves are replaced by polychaetes (Sejr *et al.* 2000). As in many other Arctic regions, brittle stars are the most dominant group with a biomass in the range of 400–600 mg C m^{-2} (Piepenburg 2000, Piepenburg & Schmid 1996). Generally, the benthic fauna consists of boreal/Arctic species as well as of those which have been described as being confined to the Arctic proper (Piepenburg & Schmid 1996).

From an ecosystem point of view the benthos is of importance because it harbours a significant fraction of the biodiversity. It is not unusual that up to 200 different macrofauna species are found per m^2. Moreover, benthos plays an important role in the food web. It is well established that especially bivalves are an important

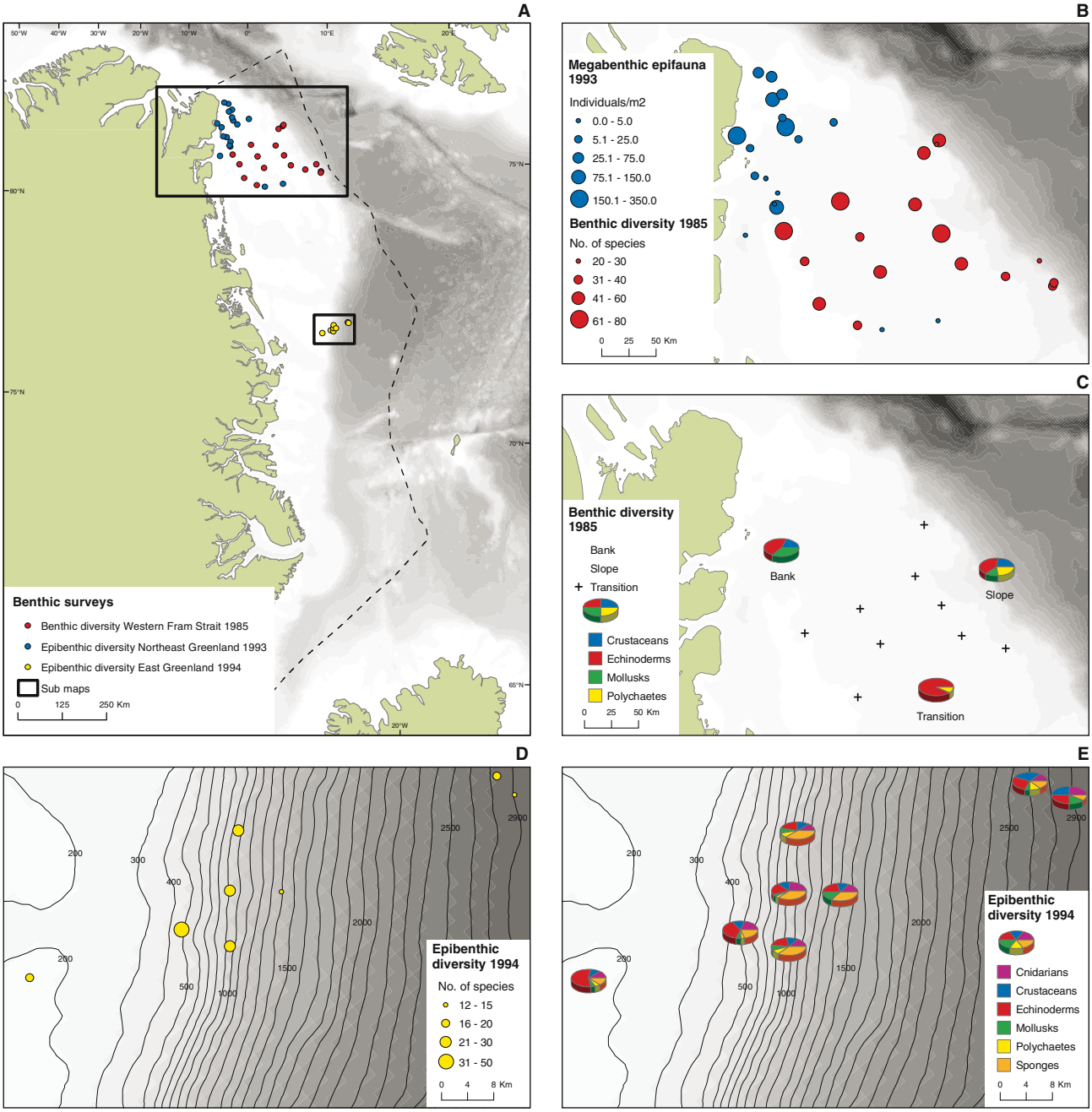


Figure 8. Benthic fauna studies in two areas of the assessment area (Piepenburg 1988, Schnack 1998). A) Sampling stations. B) Densities and species richness in northern area. C) Diversity of different taxonomical groups in different habitats in northern area. D) Species richness in the in the southern area. E) Diversity of different taxonomical groups in southern area. See also text.

food source for walruses (Born *et al.* 2003) and eiders (Lovvorn *et al.* 2004). Undoubtedly, the benthos is equally important for bottom-living fish and shrimp but this effect has not yet been thoroughly quantified for the Greenland Sea assessment area.

In this respect the coastal region at depths from 0 to approximately 75 m is of particular importance, since this is the region where the benthos can be expected to play a significant role as a source of food for fish, seabirds and mammals. Furthermore, this depth range is most likely to be influenced by potential oil spills. Besides the coastal areas it is also essential to improve the knowledge of benthic life and its dynamics in the deeper areas in relation to release of drill cuttings and mud and to placement of structures.

Figure 9. Photo of the seafloor in Young Sound showing the diverse infaunal and epifaunal community (at approximately 30 m depth). Photo: Mikael Sejr.

3.4.2 Important and critical areas

The existing knowledge on distribution, diversity and abundance of the benthos in the assessment area is still too sparse to identify especially important and or critical habitats.

3.5 Ice flora and fauna

S. Wegeberg and D. Boertmann

When 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, witnessing that there is a whole 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. These ecosystems are found both in drift ice and in fast ice, and one of the most important structural parameters for the community is the age of 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 (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 Sund within the assessment area, that the patchiness of algal activity was strongly linked to the corresponding patchiness in the light regimes below the ice.

Algae contribute to the biomass of the sea-ice communities with 43%, bacteria with 31%, heterotrophic flagellates with 20% and meiofauna with 4% in the Greenland Sea (Gradinger *et al.* 1999). Diatoms are the main primary producers, and contribute with up to 60% of total algal biomass. *Melosira arctica*, together with the pennate diatom, *Nitzshia frigida*, tend to be the dominant diatom species off Northeast Greenland/Barents Sea (Gutt 1995, Gosselin *et al.* 1997, Quillfeldt *et al.* 2009), and when the ice melts it is supposed that the diatom sinks to the bot-

tom and thereby may constitute a relatively large input of organic material to the pelagic grazers and benthic communities (Gutt 1995, Michel *et al.* 2002).

However, flagellated algal cells were also found to be of significance (Gradinger *et al.* 1999), and they were primarily cryptophytes and dinoflagellates (Ikävalko & Gradinger 1997), the latter were almost all heterotrophic in the North Water Polynya in northern Baffin Bugt (Michel *et al.* 2002).

It seems, though, that the dominant organism in the ice algae community may depend on age of ice. In Baffin Bugt, Irwin (1990) found dominance of a centric diatom, *Cosinodiscus* sp., which accounted for 63 % of the total number of cells in ice floes at the Labrador Shelf, while Michel *et al.* (2002) found completely dominance of pennate diatoms (85 % in first-year ice) in the North Water Polynya. However, somewhat conflicting results have been reported for the colonial, centric diatom species, *Melosira arctica* (Table 3). This diatom, which has a significant and dominant biomass in the Barents and Greenland Seas, is not reported from the Beaufort Sea, Baffin Bugt and in Kobbefjorden, in West Greenland (Horner & Schrader 1982, Irwin 1990, Michel *et al.* 2002, Mikkelsen *et al.* 2008). It has been noted by Gutt (1995), that this species may be absent in localities in the Arctic and either is very dominant or rare/absent.

The measured 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), but <1 g C m^{-2} $year^{-1}$ has been reported from costal fast-ice environments in Young Sund in the assessment area (Rysgaard *et al.* 2001).

The ice algal production in the northern part of the Barents Sea is reported to be 5 g C m^{-2} $year^{-1}$, which corresponds to 16-22 % of the total annual primary production (Quillfeldt *et al.* 2009), and in the Arctic Ocean the ice algae were found to contribute on average 57 % of the entire primary production (15 g C m^{-2} $year^{-1}$) (Gosselin *et al.* 1997). Rysgaard *et al.* (2001) found that the ice algae only accounted for <1 % of the pelagic primary production in Young Sund over their measuring period.

The annual productions of the ice algae communities in the Northeast Arctic seas are presented in Table 4.

Mikkelsen *et al.* (2008) tested if the ice algae acted as primers initiating 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

Table 3. Observations of *Melosira arctica* connected to either first-year or multiyear ice.

Source	Area	First-year ice	Multiyear ice
Gosselin *et al.* 1997	Arctic Ocean	X	
Gutt 1995	NE Greenland	X	
Quillfeldt *et al.* 2009	Barents Sea		X

Table 4. Ice algal annual production (g C m^{-2} $year^{-1}$) in different areas of the Arctic.
*Calculated from an ice algal contribution averaging 57 % of the entire primary production (15 g C m^{-2} $year^{-1}$).

Source	Arctic Ocean	Young Sund	Barents Sea (multi-year ice)
Gosselin *et al.* (1997)	8,55*		
Rysgaard *et al.* (2001)		< 1	
Quillfeldt *et al.* (2009)	6,5		90 (average)/ 5 (northern part)

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 in Davis Strait.

The ice fauna was found to be dominated by ciliates, nematodes, flatworms and crustaceans in the Greenland and Barents Seas (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 Sund did not seem to be caused by high grazing pressure, since the biomass of grazers was not exceptionally high in the location. 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.

Ice-associated fauna does differ according to age and origin of the ice in the Barents Sea (Arndt *et al.* 2009), perhaps reflecting the abundance of available suitable prey items as algal community seemingly change with age of ice.

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 considered the contribution as important as it preceded the phytoplankton spring bloom and constituted the only algal biomass under heavy pack ice, which is 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 therefore be of great importance to the marine ecosystem at times of the year where 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 and Arctic cod.

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.

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).

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

3.6 Fish

K. Sünksen, O. Jørgensen and D. Schiedek

The occurrence and abundance of non-commercial fish species in this part of the Arctic has not been studied very much. From the data available so far, it appears that fish diversity on the East Greenland shelf is lower than in sub-Arctic or boreal regions. According to Muus (1990) about 26 species can be found on the Northeast Greenland shelf. Most of them belong to the Cottidae, Zoarcidae and Liparidae, which predominantly are benthic living species (Dunbar 1985). They are of minor commercial value, but play an important role in the Arctic ecosystem (Atkinson & Percy 1992), being an important food source for many Arctic seabirds and seals (Dorrien 1993 and references therein).

During a cruise of RV *Polarstern* in summer 1990 (ARK 7/2), the distribution of fish at the continental margins of Northeast Greenland was studied (Figure 10). The region

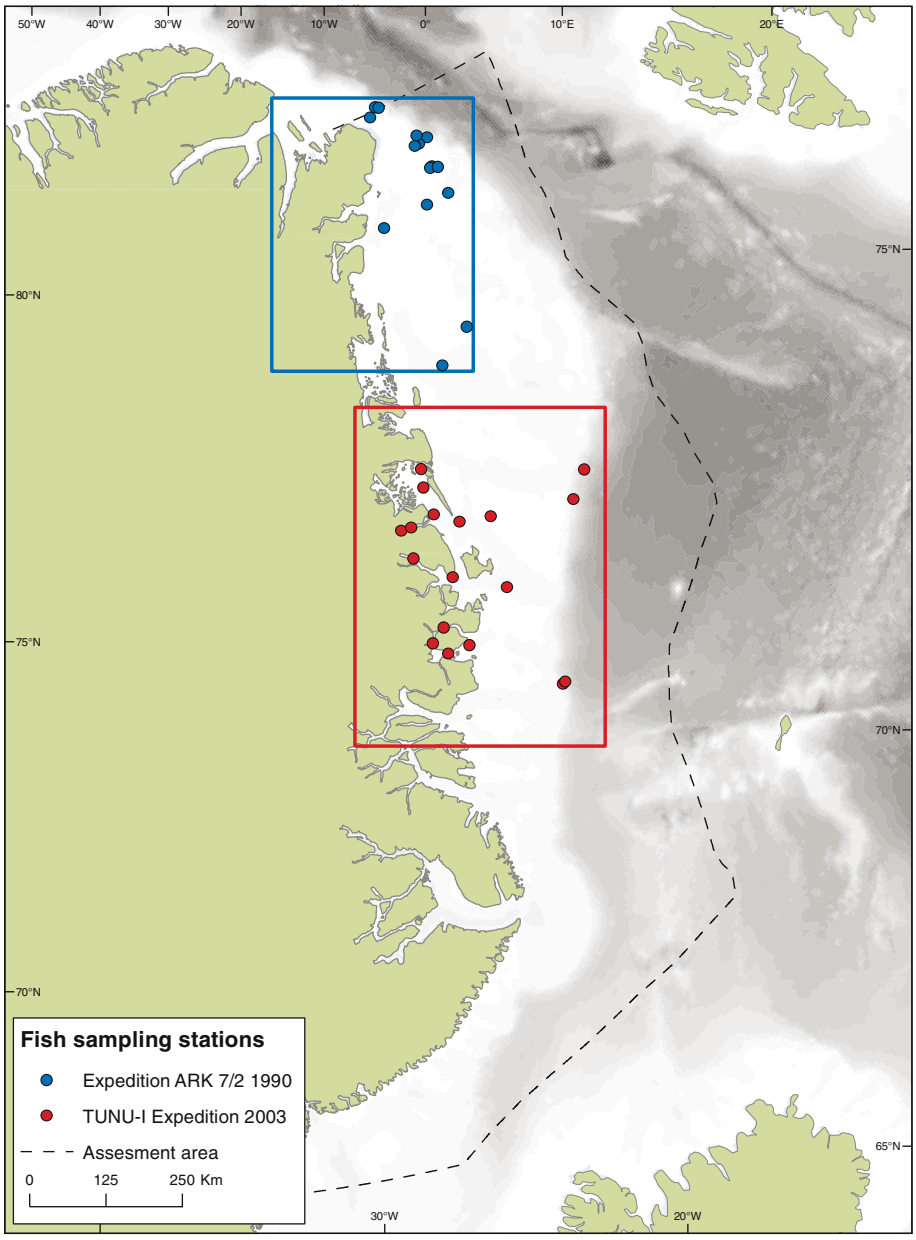


Figure 10. Sampling stations during the Polarstern cruise ARK 7/2 in 1990 and during the TUNU-1 cruise in 2003 (Dorrien *et al.* 1991, Christiansen 2003).

is characterised by the cold East Greenland Current coming from the Arctic Ocean and flowing southerly along the east coast of Greenland. The investigations were focused on the North East Water Polynya, which opens regularly each spring. Using an Agassiz trawl, a large bottom trawl and an underwater camera, 21 stations off Northeast Greenland (75° to 82° N) were sampled (Dorrien *et al.* 1991).

In total, 23 fish species were found (Figure 11). At most of the sampling sites the following five species showed the highest numbers: Arctic cod *(Arctogadus glacialis*) (up to 5 000 indiv./km^2), *Artediellus atlanticus* (up to 4 500 indiv./km^2), *Icelus bicornis* (up to 4 000 indiv./km^2), *Triglops nybelini* (up to 2 000) and *Liparis fabricii* (up to 4 000 indiv./km^2). The abundance of the other species was usually lower (Dorrien 1993).

Both the Arctic cod or ice cod (*Arctogadus glacialis*) and its near relative the polar cod (*Boreogadus saida*), were present in the polynya (Figure 11). A. glacialis was the most abundant fish species in the trawl catches in the northernmost part of the study area, where it probably replaces *B. saida* (Dorrien *et al.* 1991).

In a more recent multidisciplinary study in 2003 (TUNU-MAFIG) diversity of marine fishes in the fjords and coastal waters of Northeast Greenland between Danmarkshavn (77° N) and Eskimonæs (74°) was studied (Figure 10). At each station, species composition and abundance was estimated (Figure 12). In total, 33 species belonging to 13 families were recorded (Christiansen 2003). The most species rich families were the Zoarcidae (8 species), Liparidae (6 species) and Cottidae (5 species), whereas the most frequent species were *Liparis fabricii*, polar cod and Arctic cod.

About 70% of the fish species analysed were 'Arctic' or 'mainly Arctic', according to common zoogeographical classification (Karamushko *et al.* 2003). The total number varied between 36 and 10 780 specimens for a standardised one-hour trawl haul (Figure 12). On most stations (excluding those in deeper water), polar cod and Arctic cod were the absolute dominant species (up to 95% by number and biomass).

There was a clear latitudinal cline with the Arctic cod being most abundant at higher latitudes compared with polar cod. Generally the two cod species formed the most important part of the Northeast Greenland marine ecosystem (Karamushko *et al.* 2003). These cod species are generally considered as ecological key species due to their abundance and importance as food for seabirds and marine mammals.

Current climatic changes – higher temperatures, less sea ice and increased freshwater discharges into the fjords – may have adverse effects on the physiological performance and thermal behaviour and potentially the distribution range of some of the fish species (Christiansen *et al.* 1997, Clarke 2003), but may favour others.

Only two species of fish have been exploited commercially in the assessment area, and only in the southernmost part.

3.6.1 Important fish species

Greenland halibut *Reinhardtius hippoglossoides*

The Greenland halibut is a sub-Arctic or Arctic species. Although a flatfish, spending most of its life on the bottom, it makes frequent migrations into the water column to feed, and it occurs typically in deep water along continental slopes. It is often found

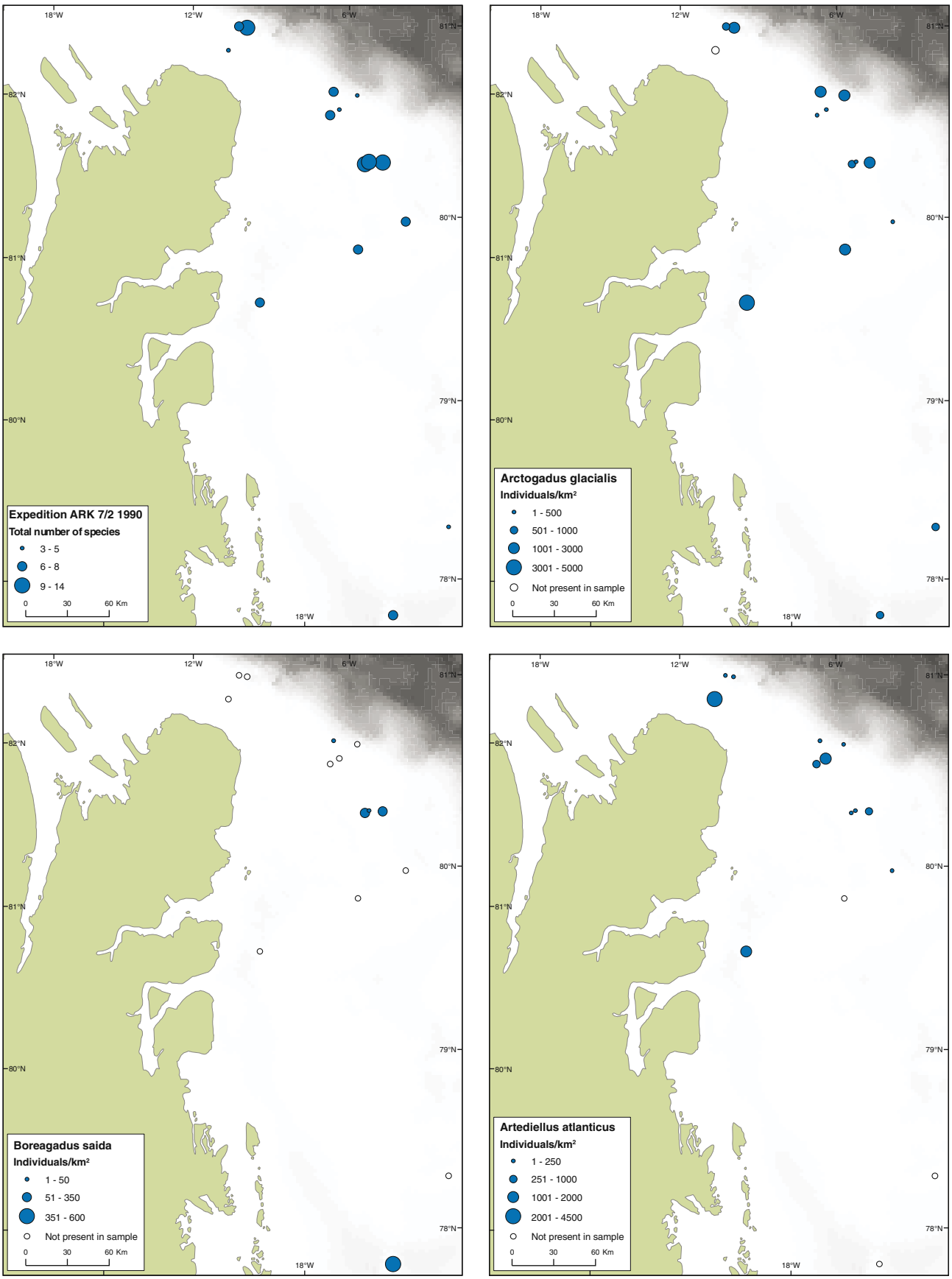
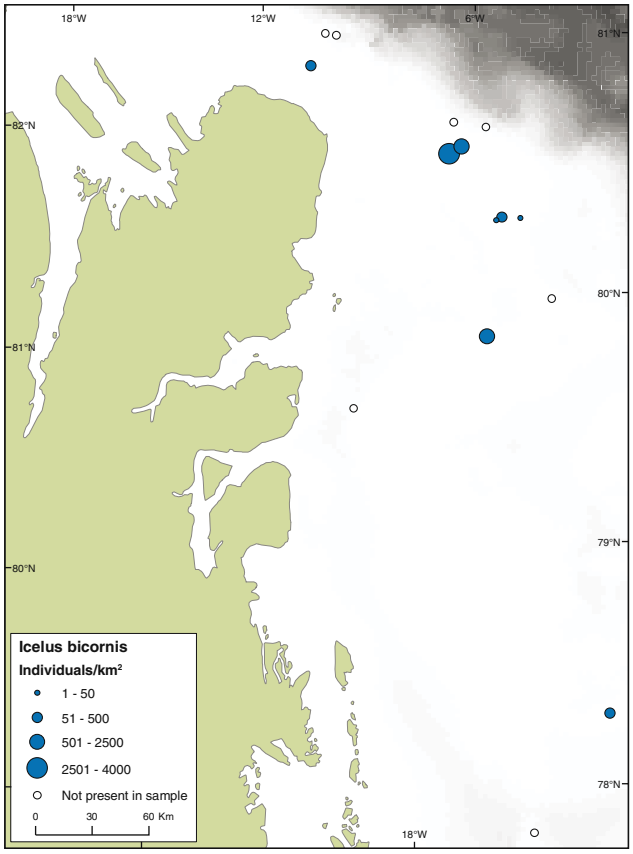
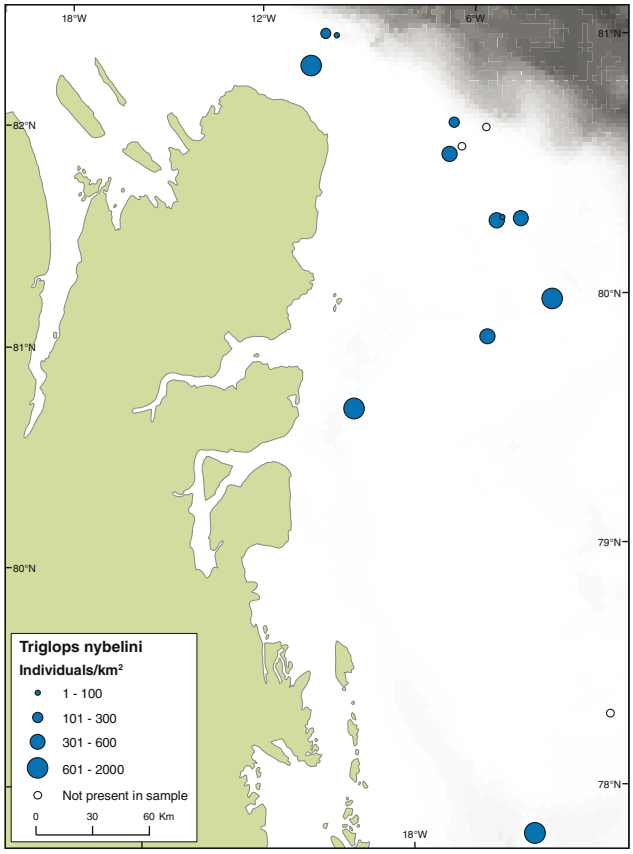


Figure 11. Text on page 65.

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 they and the larvae when they hatch drift with the currents to nursery areas.





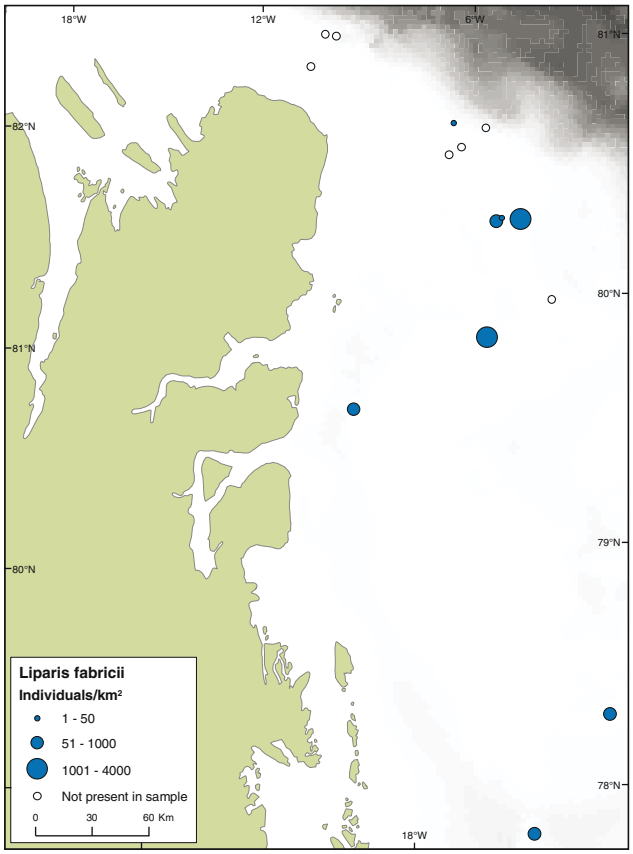


Figure 11. Occurrence of some abundant fish species in the northern part of the assessment area in 1990 (Dorrien 1993). Dots represent sampling stations.

Greenland halibut occurs in the assessment area (see Section 4.1 on commercial fisheries), but the biology of these fish is unknown. They probably belong to the Iceland/Greenland stock also found further south in the Denmark Strait. Small (less than 20 cm long) Greenland halibut are very rarely found in the assessment area. The nearest known nursery ground is found east of Svalbard and since much of the area

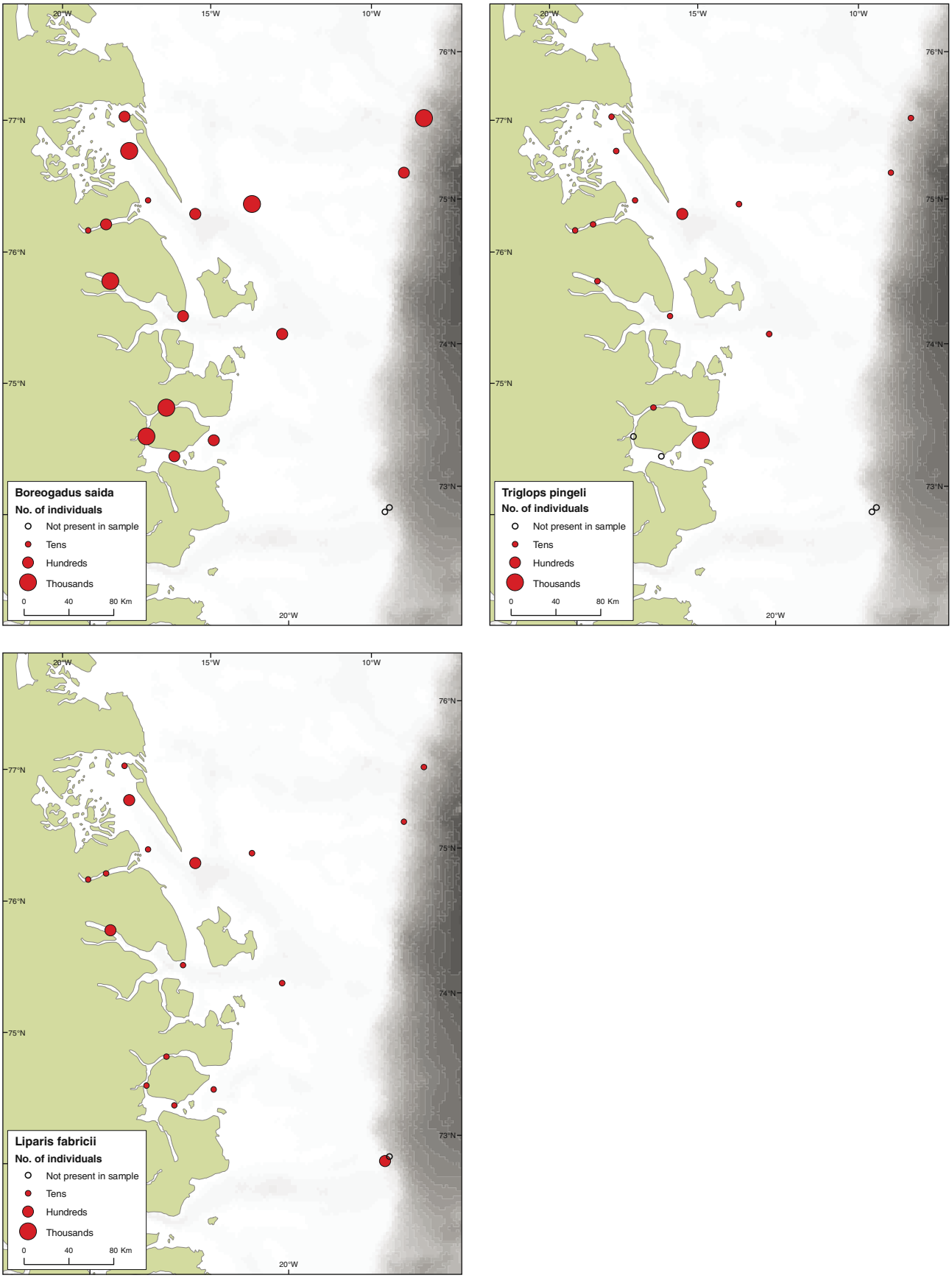


Figure 12. Text on page 67.

between Svalbard and the Denmark Strait is covered by ice most of the year it is not known to what extend juvenile Greenland halibut from this stock complex is distributed into Greenlandic waters. Due to the prevailing current system it is however plausible that there is a net transportation of juvenile pelagic Greenland halibut from the Norwegian nursery areas into the area being assessed in this report.

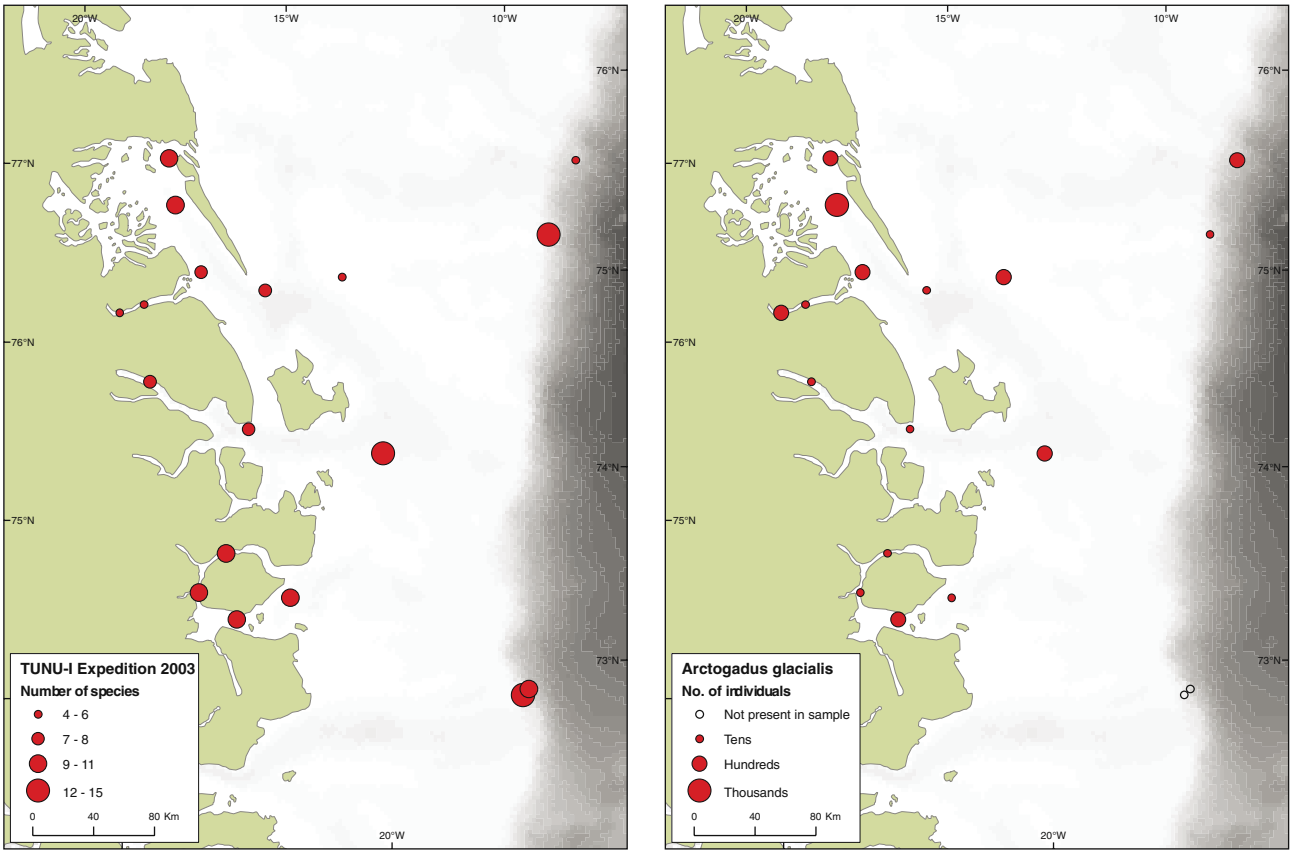


Figure 12. Occurrence of the most abundant fish species during the TUNU-I Expedition 2003 (Christiansen 2003). Dots represent sampling stations.

In 2006, a bottom trawl survey covered the offshore area from 67° to 72° N and the outer part of Scoresby Sund fjord at depths down to 1500 m (Jørgensen *et al.* 2007). Greenland halibut was caught in the entire area. Apart from the sampling that took place in the same areas where commercial fishing is ongoing, catches were generally low. The species was almost absent in areas with bottom temperatures below zero, mainly found in the south eastern part of the survey area. In 1988 in the same offshore area a joint Japan/Greenland survey also caught Greenland halibut in most of the area. The catches were generally small except a few large catches in the southern part of the area (Jørgensen & Akimoto 1990). In the southern part of the assessment area (68° to 72°) these surveys proved the presence of several species of potential economic interest e.g. capelin (*Mallotus villosus*), roughhead grenadier (*Macrourus berglax*), Atlantic cod (*Gadus morhua*) and polar cod. Only Greenland halibut were however found in high concentrations (Jørgensen *et al.* 2007).

Results from other recent biological surveys indicate that no other species than Greenland halibut are of commercial interest. However, predicted climatic changes with higher temperature, less sea ice and an increase in freshwater discharges into the fjords will probably lead to a change in the ecosystem favouring species of more commercial interest such as Atlantic mackerel (*Scomber scombrus*) and Atlantic herring (*Clupea harengus*). In 2010 a research quota were given for an exploratory fishing on these species in East Greenland waters. Although Atlantic mackerel not have been verified here (Møller *et al.* 2010) it has been found in great numbers recently in adjacent waters. The exploratory fishery however had no luck finding Atlantic mackerel. Instead 1200 tonnes of Atlantic herring was caught during a week's fishery east of Jan Mayen (Jens Bisgaard, pers. comm.).

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 also 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. 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 web and constitute an important prey for many marine mammals and seabird species, notably ringed seal, harp seal, thick-billed murre, northern fulmar, black-legged kittiwake and ivory and Ross's gulls.

Capelin *Mallotus villosus*

The capelin is a small pelagic schooling fish. It is a cold-water species that occurs widely in the northern hemisphere. The capelin in the Iceland-East Greenland-Jan Mayen area is considered to be a separate stock. Unlike other commercial stocks, adult capelin undertakes extensive feeding migrations north into the cold waters of the Denmark Strait and Iceland Sea during summer. Total annual catch from this stock has decreased in recent years from 1 600 000 tonnes in 1996/1997 to 200 000 tonnes in 2007/2008 followed by only 15 000 tonnes in 2009 and 150 000 tonnes in 2010. Capelin is a very important forage species for several commercial fish, as well as whale and seabird species where they occur.

Around the mid-1990s a rise in both temperature and salinity was observed in the Atlantic water south and west of Iceland. In the same period capelin shifted both their larval drift and nursing areas far to the west to the colder waters off East Greenland, the arrival of adults on the wintering grounds on the outer shelf off North Iceland was delayed, and migration routes to the spawning grounds off south and west Iceland became located farther offshore from North and East Iceland and do not reach as far west along the south coast as was the rule in most earlier years (Figure 13).

Capelin has in recent years been observed in coastal waters at Ittoqqortoormiit.

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 occur 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 human population of Greenland (Riget & Böcher 1998).

Life history characteristics of anadromous populations such as growth rate, age of first seaward migration, age of maturity, and time of year for seaward and up-

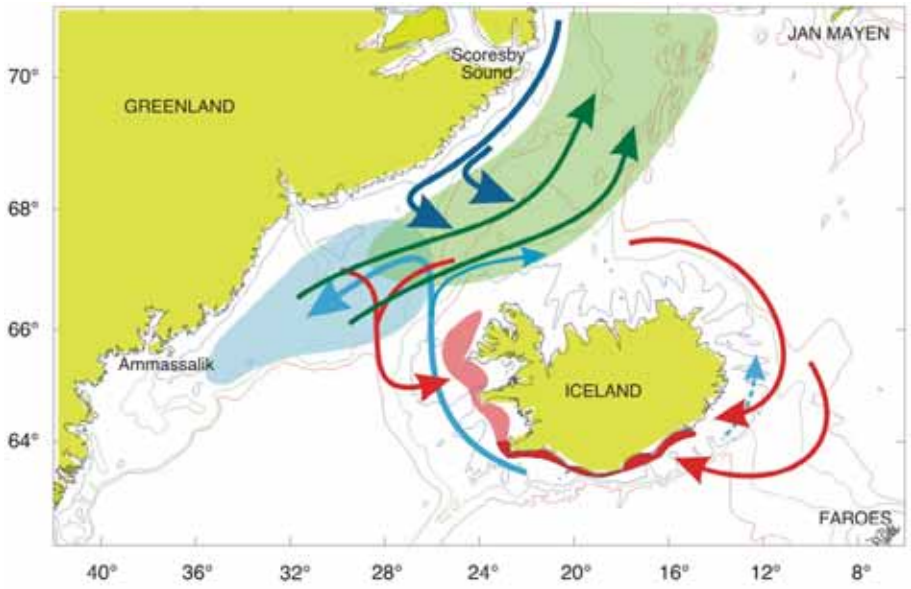


Figure 13. Likely changes of distribution and migration routes of capelin in the Iceland/Greenland/Jan Mayen area in the years 2005-2008. Green: Feeding area; Light blue: Area for juveniles; Red area: Main spawning grounds; Lighter red colour: Lesser important of W-Iceland spawning areas; Light blue arrows: Larval drift; Dark green arrows: Feeding migrations; Dark blue arrows: Return migrations; Red arrows: Spawning migrations. Depth contours are 200, 500 and 1 000 m (ICES 2008).

stream migration vary considerably due to the extensive distribution of this population. In general, it must be expected that higher latitudes with a shorter growing season, lower temperatures and variability in food resources will result in 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 freshwater 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 (approximately 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 tagged fish movements 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 Sund, 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 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).

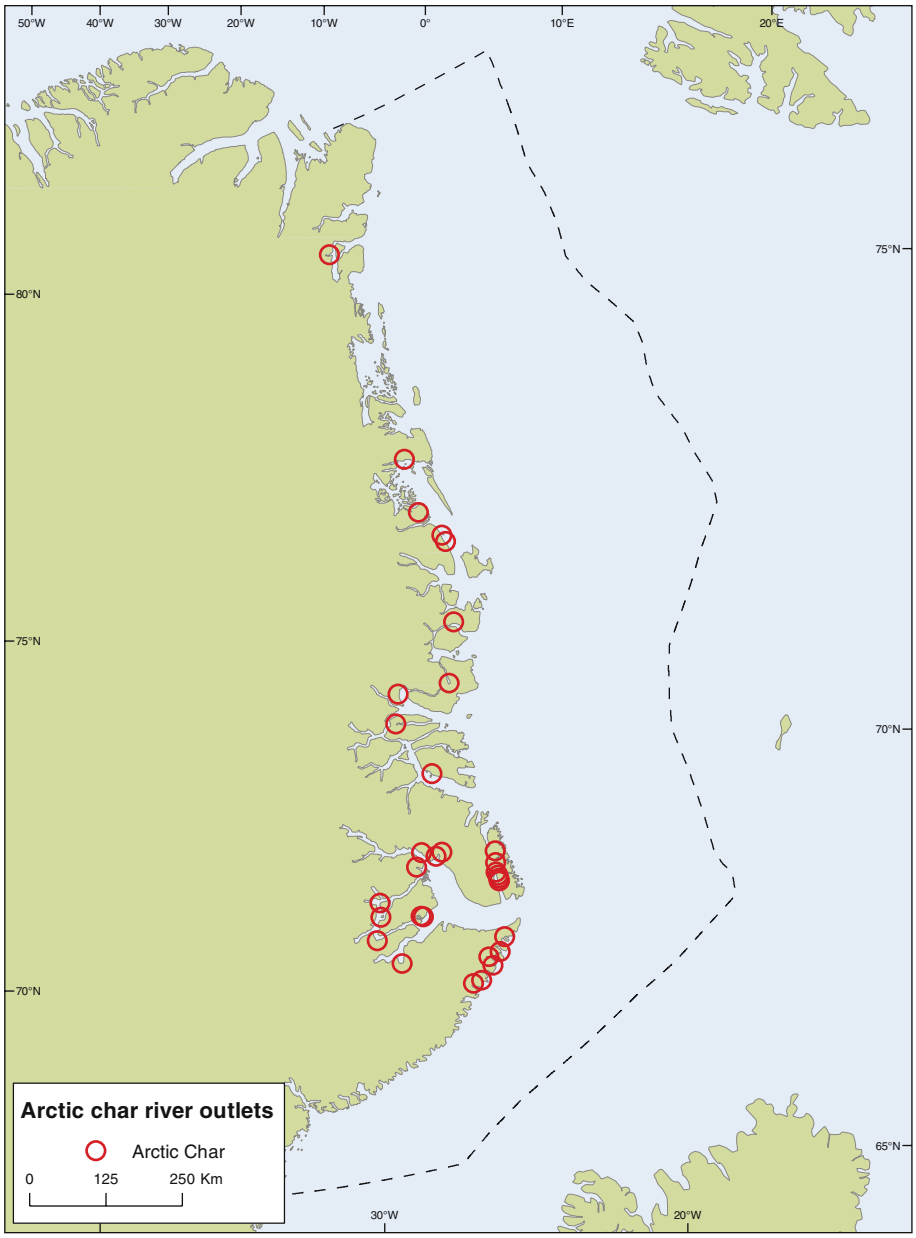


Figure 14. Outlets of rivers where anadromous Arctic char spawn and winter (red circles). There are probably many more rivers with Arctic char in the assessment area, but no comprehensive reviews have been published. (Sources: Grønlands Fiskeri- og Miljøundersøgelser 1986, Sandell & Sandell 1991, Petersen 1993, Mikkelsen 2008, Rysgaard *et al.* 1998, Aastrup *et al.* 2005, DCE unpubl.).

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 rives 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.

3.6.2 Critical 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 on these sites in the assessment area is fragmented, and there is no doubt many more sites than shown on the map (Figure 14).

3.7 Seabirds

D. Boertmann

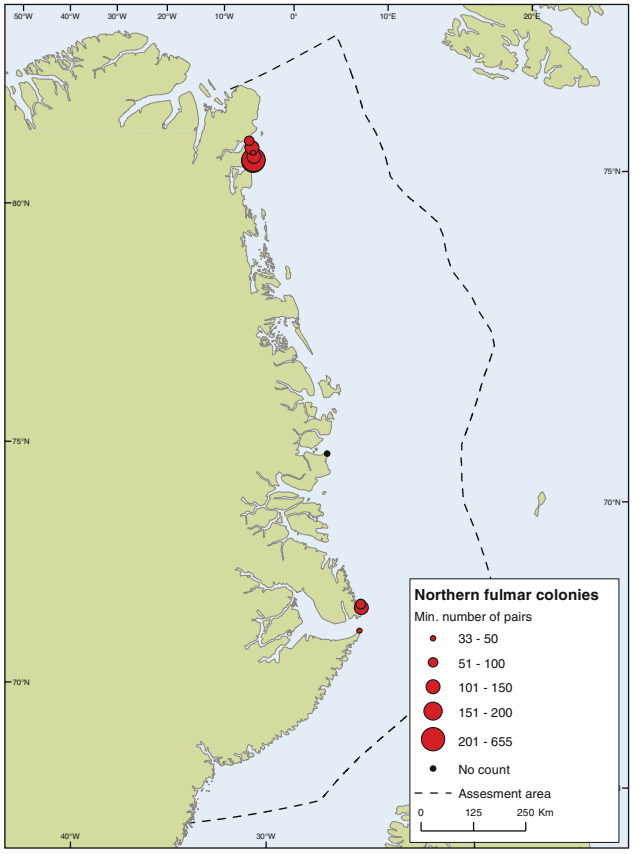
Seabirds can locally be very numerous in the assessment area and they constitute an important link between the productive marine ecosystem and the relatively low productive terrestrial ecosystem, as they transport nutrients from the sea to the breeding colonies in land. About 13 species breed within the assessment area. Some of these species are very numerous and occur in very high concentrations while others are rare and threatened. The occurrence of the seabirds is governed by the presence of sea ice, which is why they can be scarce in large regions in summer and almost absent in winter but, on the other hand, very numerous in areas with predictable open waters in spring and summer.

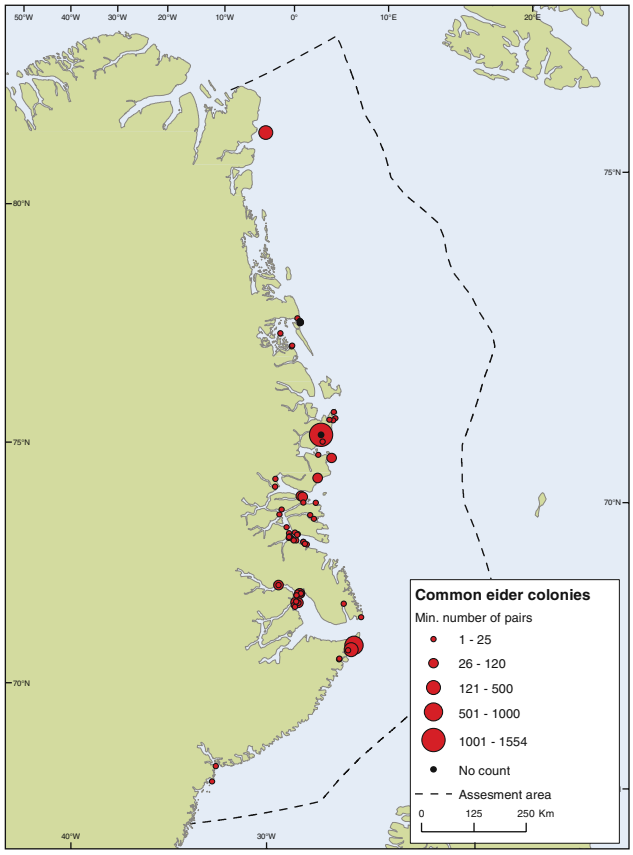
Knowledge on birds associated with the marine environment varies between regions. Some coastal areas are well known from the reports of natural history expeditions since the late 19th century (Bay 1894, Manniche 1910, Degerbøl & Møhl-Hansen 1935, Pedersen 1926, 1930, 1934, 1942, Meltofte *et al.* 1981a, Hjort 1976, Hjort *et al.* 1983, Elander & Blomqvist 1986, Gilg 2005) and from work carried out by local residents (Meltofte 1975, 1976, Forchhammer 1990, Forchhammer & Maagaard 1990), while other areas, e.g. the Blosseville Kyst, are almost unknown from an ornithological point of view. The offshore areas are even less well known than the coastal areas. Norwegians have studied the waters between Svalbard and Greenland (Mehlum 1989) in summer, and in the early 1990s extensive studies were carried out in the Northeast Water Polynya, including bird studies (Falk & Møller 1995, 1997, Falk *et al.* 1997a, Joiris *et al.* 1997). However, reports from the migration periods and the winter are very few (e.g. Hjort 1976, Brown 1986, Petersen 1995, Byrkjedal & Madsen 2008). Relatively few birds have been ringed in East Greenland compared to West Greenland, and the recoveries were reported by Lyngs (2003).

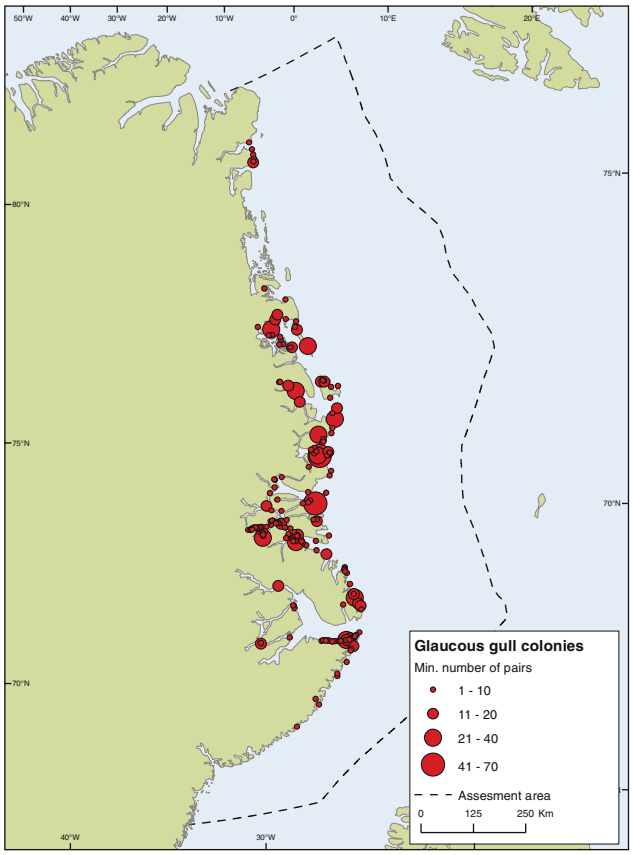
To supplement these published data NERI and GINR conducted aerial surveys along the coasts and in offshore areas in spring and summer 2008, again in summer 2009. Finally unpublished observations from seismic data acquisition surveys and some fish research surveys in 1994, 1995, 2006, 2007, 2009 and 2010 have been included (Figure 20A).

Most of the breeding seabirds are colonial breeders and these constitute 12 species in the assessment area. The largest concentrations of breeding colonial seabirds are found on the coasts of the Scoresby Sund Polynya, where an estimated 3.5 million little auks breed in a large number of colonies on the Liverpool Land coast and the Volquart Boon Kyst (Figure 15). This area also holds the only breeding sites for thick-billed murre (Figure 15). The second most important polynya, in a seabird context, the Northeast Water (NEW) in the northern part of the assessment area also holds significant seabird breeding colonies, mainly northern fulmars and common eiders, and the rare species ivory gull has a key area here with numerous colonies on the and near the coasts. A third important polynya is the waters east of Wollaston Forland, the Sirius Water Polynya, where large numbers particularly of eiders occur.

Besides the true seabirds, a number of species utilise the marine environment during critical phases of their annual life cycle. These are species utilising freshwater habitats during breeding time; divers and ducks. They depend on coastal habitats with early ice break-up, for example coastal polynyas, river outlets and narrow straits with strong tidal currents. Such sites are presumed to hold concentrations of both migrant seabirds and inland waterbirds (red-throated diver *Gavia stellata*, king eider *Somateria spectabilis*, long-tailed duck *Clangula hyemalis* and







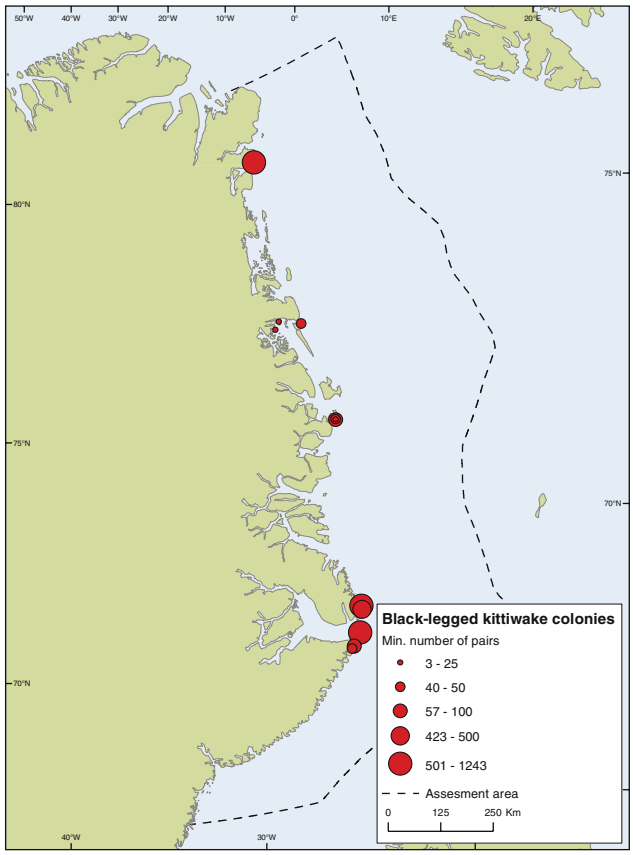
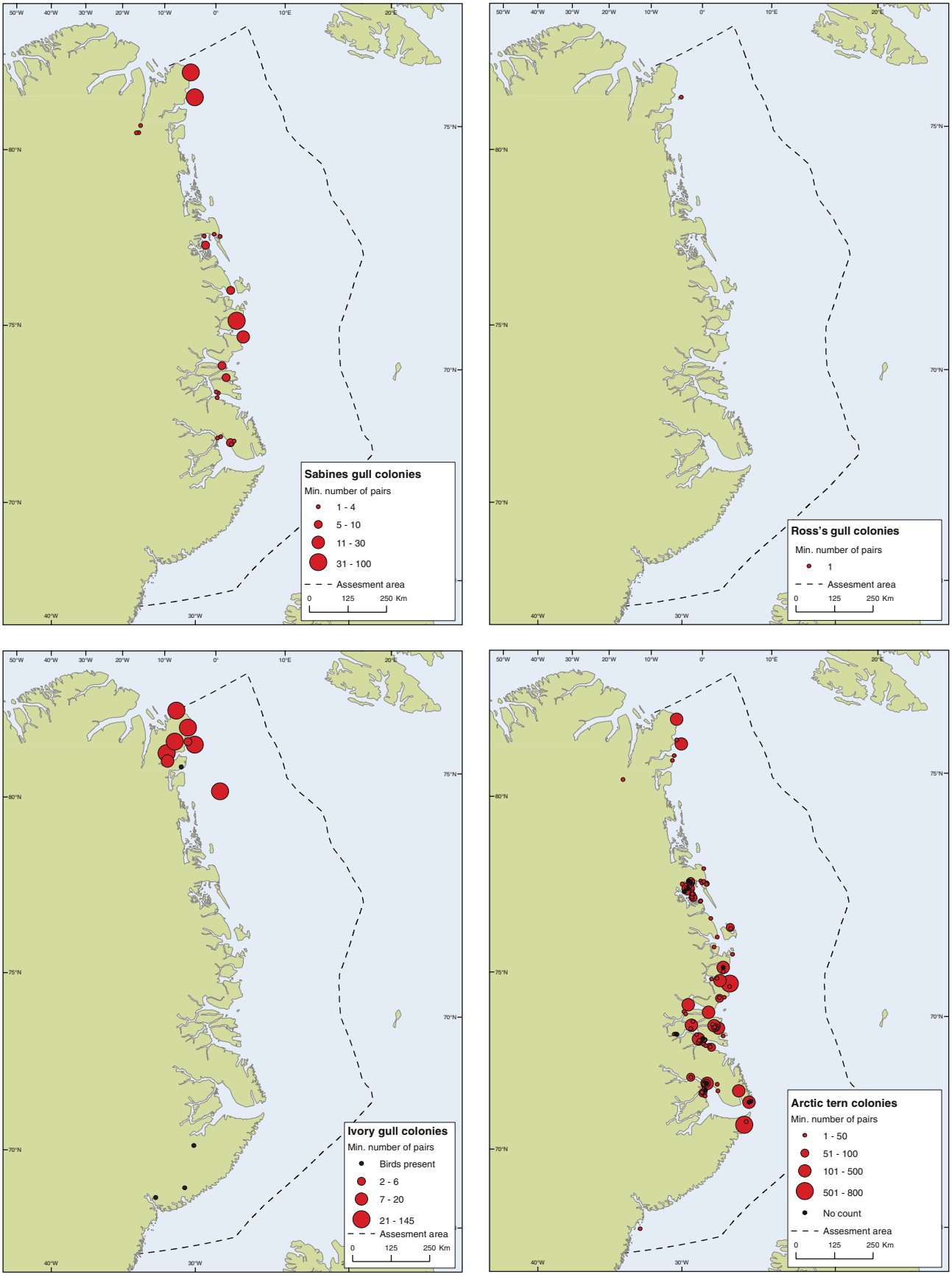


Figure 15. See text on page 74.



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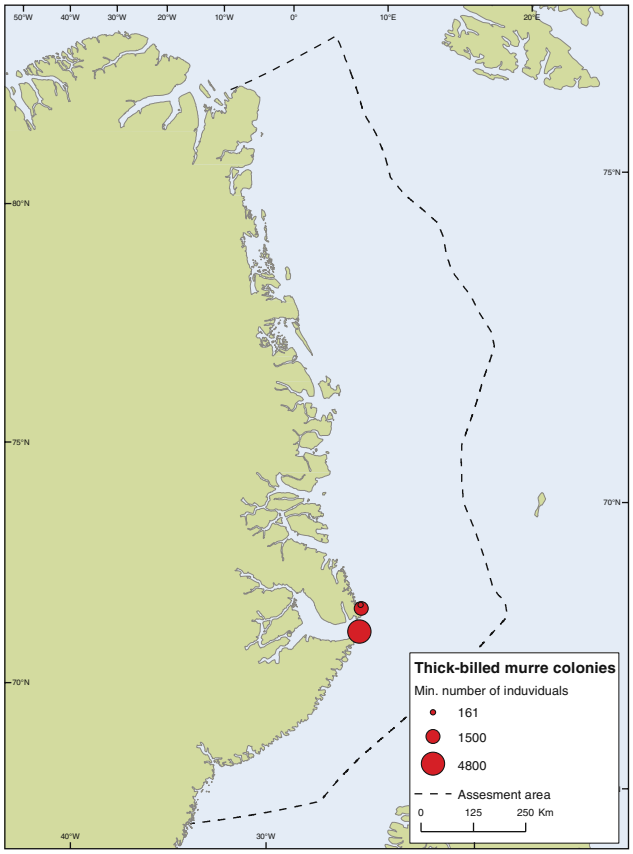
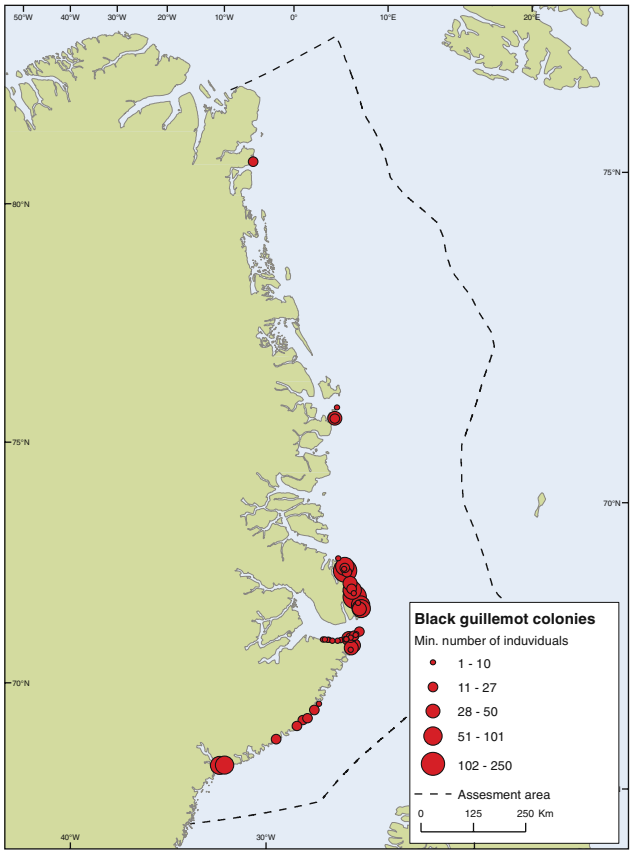




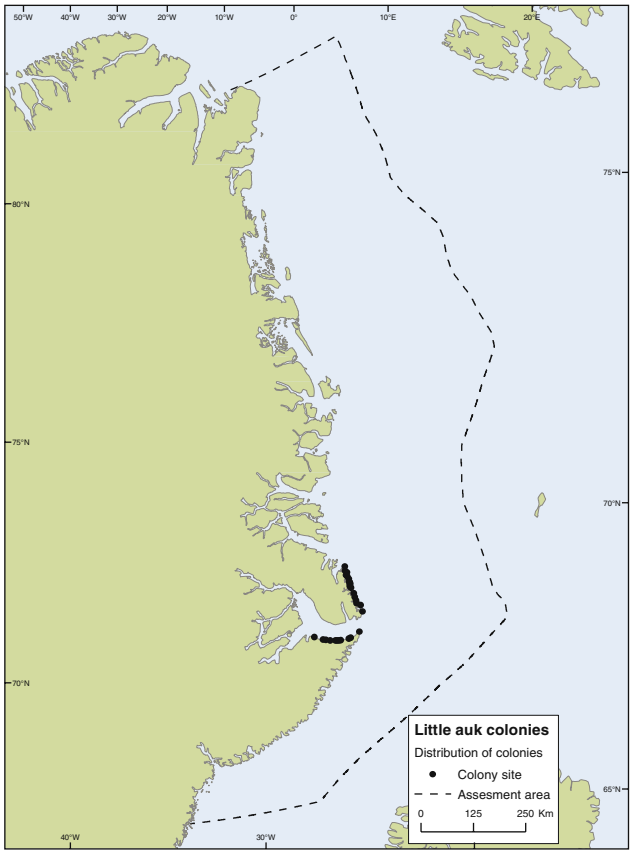


Figure 15. Distribution and size of breeding colonies for seabirds in the assessment area. Large areas are not surveyed properly, and many of the known colonies have not been counted precisely. This is for example the case for all the little auk colonies in and near the entrance to Scoresby Sound. These colonies account for at least 3.5 million pairs in total.

perhaps grey phalaropes *Phalaropus fulicarius*) waiting for lakes and freshwater habitats to become accessible after the winter.

Other inland birds like geese and shorebirds also utilise habitats which could be exposed to marine oil spills. These habitats are mainly salt marshes and tidal mud flats, where many birds occasionally aggregate.

In autumn, large numbers of seabirds from Svalbard and arctic Russia pass through the offshore regions of the assessment area (Figure 19). The most numerous are likely to be thick-billed murres and little auks. The threatened ivory gull also use this migration pathway, but within the drift ice (Hjort 1976b, Bensch & Hjort 1990, Byrkjedal & Madsen 2008). It was recently documented by satellite telemetry that birds from all the northeast Atlantic populations (Greenland, Svalbard, Russia) use this pathway (Gilg *et al.* 2010). High numbers of black guillemots may also use this flyway (Bensch & Hjort 1990, Byrkjedal & Madsen 2008).

In winter, seabirds are almost absent from the area, although common eiders, king eiders, long-tailed ducks and black guillemots have been reported in the very restricted areas with open waters (Boertmann 1994).

An overview of the seabird species occurring in the assessment area is given in Table 5.

Besides the published accounts, unpublished data from the many seismic surveys which in recent years have taken place in the waters off Northeast Greenland are included. The Marine Mammal and Bird Observers (MMSO) shall supply their data to a database with offshore observations of seabirds and marine mammals kept at Aarhus University, and so far data from 1995, 2006, 2007, 2009 and 2010 are included (Figure 20).

Table 5. 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		Habitat	Red-list status in Greenland	Importance of study area to population	VEC
Fulmar	b/s/w	Year round	c & o	Least Concern (LC)	Low	+
Common eider	b/m	Summer	c	Least Concern (LC)	High	+
King eider	b/m	Summer	c (in spring)	Least Concern (LC)	Medium	+
Long-tailed duck	b/m	Summer	c (in spring)	Least Concern (LC)	Medium	+
Grey phalarope	b/mi	Summer	c (in spring)	Least Concern (LC)	Low	
Arctic skua	b	Summer	c	Least Concern (LC)	Low	
Black-legged kittiwake	b/s/mi	Summer	c & o	Vulnerable (VU)	Low	+
Glaucous gull	b/s/mi	Summer	c	Least Concern (LC)	Low	
Sabine's gull	b	Summer	c	Near Threatened (NT)	Low	+
Ross's gull	b/s	Summer	c & o	Vulnerable (VU)	Low	+
Ivory gull	b/s/w	Year round	c & o	Vulnerable (VU)	High	+
Arctic tern	b	Summer	c	Near Threatened (NT)	Low	+
Thick-billed murre	b/s/mi	Summer	c & o	Vulnerable (VU)	High	+
Black guillemot	b/s/w	Year round	c & o	Least Concern (LC)	Low	
Atlantic puffin	b	Summer	c & o	Near Threatened (NT)	Low	
Little auk	b/mi	Summer	c & o	Least Concern (LC)	High	+

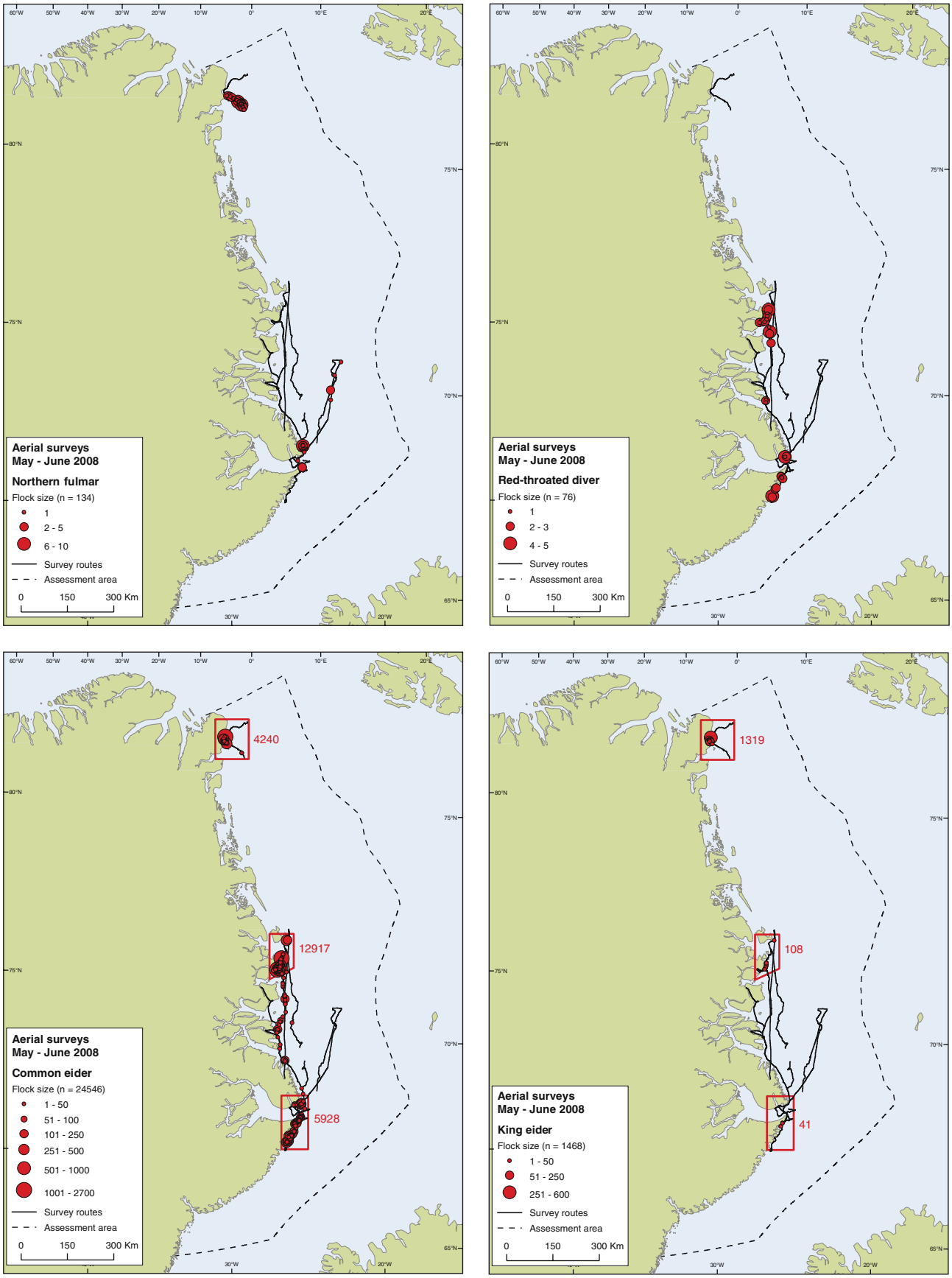
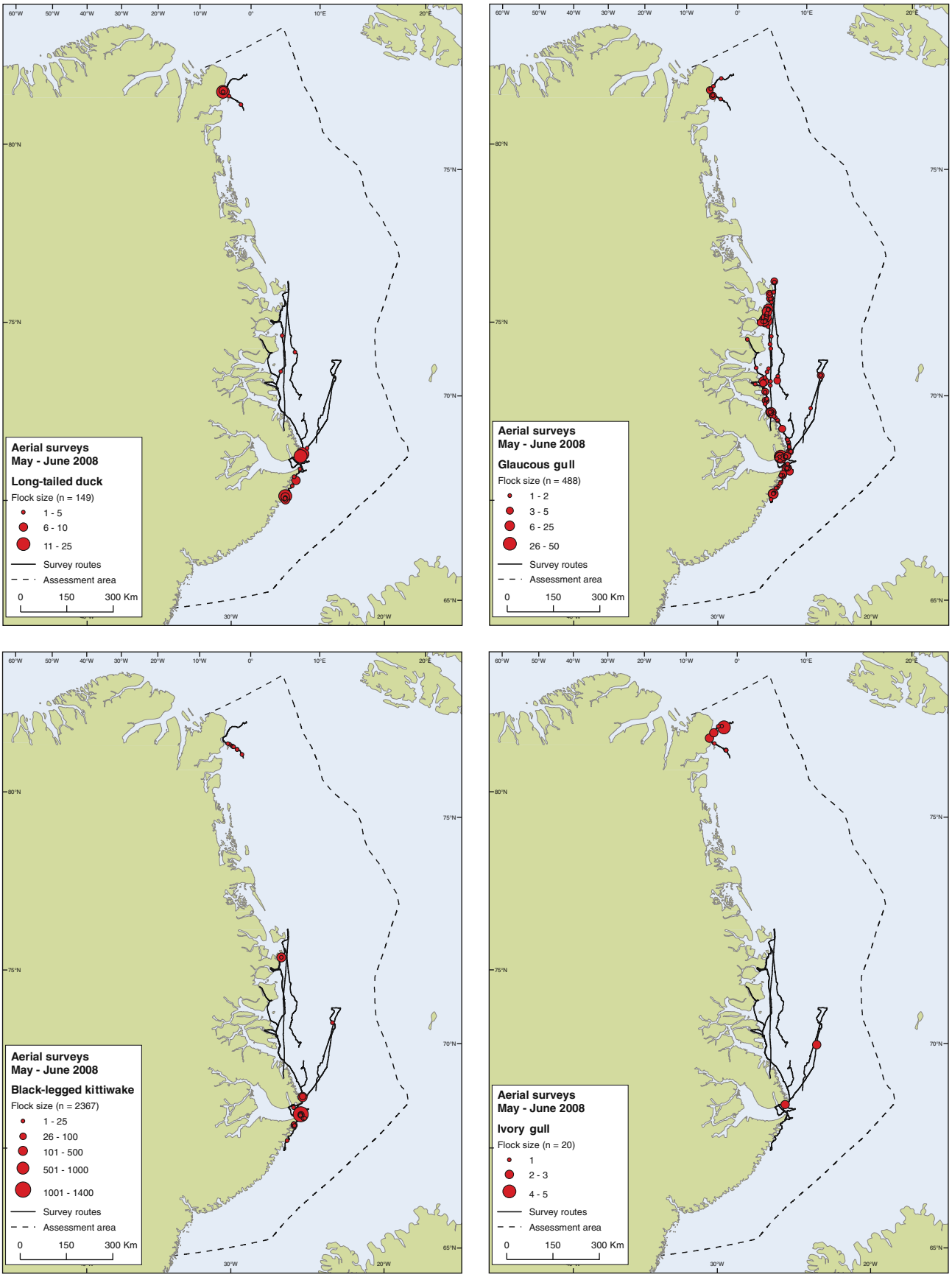


Figure 16. See text on page 78.



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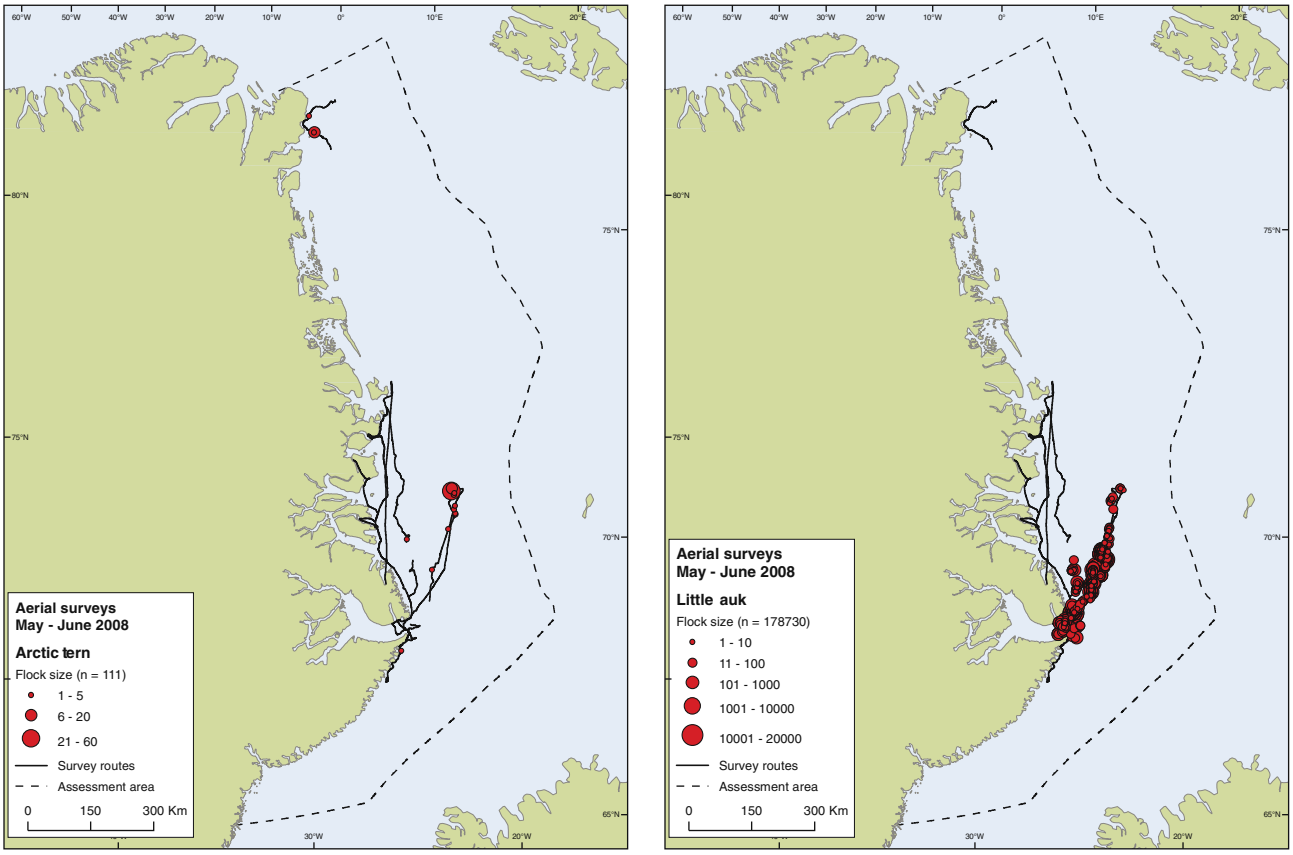


Figure 16. Maps showing the distribution and numbers of selected seabird species observed during the NERI 2008 aerial survey in May and June. n = the total number of individuals counted during the surveys. For common eider the numbers of birds are given inside the framed areas.

Several seabird studies were initiated as a part of the SEIA process in order to collect new background knowledge:

- Two aerial surveys carried out along coasts and ice edges in the spring and summer of 2008. The summer survey was repeated in 2009. These surveys were specifically designed for collecting data of seabird distribution and abundance in relation to impact assessment of future oil activities (Figure 16, 17, Boertmann *et al.* 2009a, 2010).
- Satellite tracking of seaducks (common eider, king eider and long-tailed duck) for identification of important habitats and migration routes (Box 1, 5 & 6).
- Satellite tracking of thick-billed murre for identification of important habitats and migration routes (Box 3).
- Satellite tracking of red-throated diver for identification of important habitats and migration routes (Box 7).
- Geolocator deployment on little auks in order to identify migration routes and winter quarters (Box 4, Mosbech *et al.* 2012).
- Geolocator deployment on Arctic terns and Sabines gulls in order to identify migration routes and winter quarters (Box 2, Egevang *et al.* 2010).

3.7.1 Important bird species occurring in the assessment area

This section gives an account of important birds in the assessment area. Species designated as VECs (Valued Ecosystem Components) are listed in Table 5.

Northern fulmar *Fulmarus glacialis*

Breeding distribution: Small breeding colonies are located in and near the mouth of Scoresby Sund. Compared with colonies in other part of the north Atlantic, these are small and hold up to a few hundred pairs (Meltofte 1976). A few colonies have

been claimed to be have been present further north along the coast, at Hvalros Ø (Stemmerik 1990) and Home Foreland (Bay & Boertmann 1989), but these have not been confirmed at later visits (Gilg 2005, Boertmann *et al.* 2009a). However, much larger concentrations of breeding fulmars occur at the North East Water shores where more than 2,500 pairs were counted in six colonies on the coasts of Holm Land and Amdrup Land (Falk *et al.* 1997a). Breeding birds are present on the cliffs from April and the fledglings leave the nesting ledges in early October (Falk & Møller 1997).

Offshore distribution: Fulmars occur everywhere but in relatively low concentrations in the open-water areas in summer from April at least until October (Meltofte 1975, Bensch & Hjort 1990, Byrkjedal & Madsen 2008). During the ship based surveys in 1994, 1995, 2006, 2007, 2009 and 2010 they were generally recorded widespread but in low densities. Almost the same picture was apparent during the aerial surveys in 2008, where the highest concentrations were found along the southern ice edge of the Northeast Water Polynya. The results of Norwegian surveys indicate that densities of fulmars are low in the western Greenland Sea compared to the eastern part off Svalbard and the Barents sea, and that the highest concentrations in the western part was located in the Northeast Water (Mehlum 1989, 1997). In early spring (February-April) and possibly also in winter, fulmars occur in the open waters east of the drift ice belt (Brown 1986).

Conservation status: The fulmar population in the assessment area has a favourable conservation status and is not considered as threatened, neither nationally nor internationally (categorised as of 'Least Concern' (LC) on the Greenland Red List).

Biology: Fulmars are surface feeders, feeding on fish, crustaceans, etc. and in areas with fishery discards. They feed when swimming on the surface and are also able to perform short dives.

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. No offshore concentrations were located during the NERI 2008 surveys in May/June and July/August (Boertmann *et al.* 2009a)

Geese *Anser* and *Branta* spp.

Geese usually utilise inland habitats, but may stage, moult and feed in coastal habitats of which salt marsh is the most important. There are several species of geese in the assessment area: Snow geese (*Anser caerulescens*), brent geese (*Branta bernicla*), barnacle geese (*Branta leucopsis*), pink-footed geese (*Anser brachyrhynchus*) and Canada geese (*Branta canadensis*). The most important and numerous are pink-footed geese and barnacle geese. Both occur as breeders and in large, non-breeding flocks which spend the summer moulting. Besides the risk of being exposed to oil spills in the marine habitats, geese are especially sensitive to disturbance during moulting (Mosbech & Glahder 1991). In the northernmost part of the assessment area, brent geese utilise coastal habitats both for moulting and for rearing chicks. These brent geese belong to a small and 'Near Threatened' (NT) population (unfavourable conservation status) breeding only in Northeast Greenland, Svalbard and Franz Josef Land.

Common Eider *Somateria mollissima*

Breeding distribution: Breeding common eiders occur along most of the coasts close to the Greenland Sea. Many breed dispersed, but there are also several breeding colonies, some holding thousands of pairs (Figure 15). Most colonies are found on small islands and skerries, while solitary breeders also occur on mainland

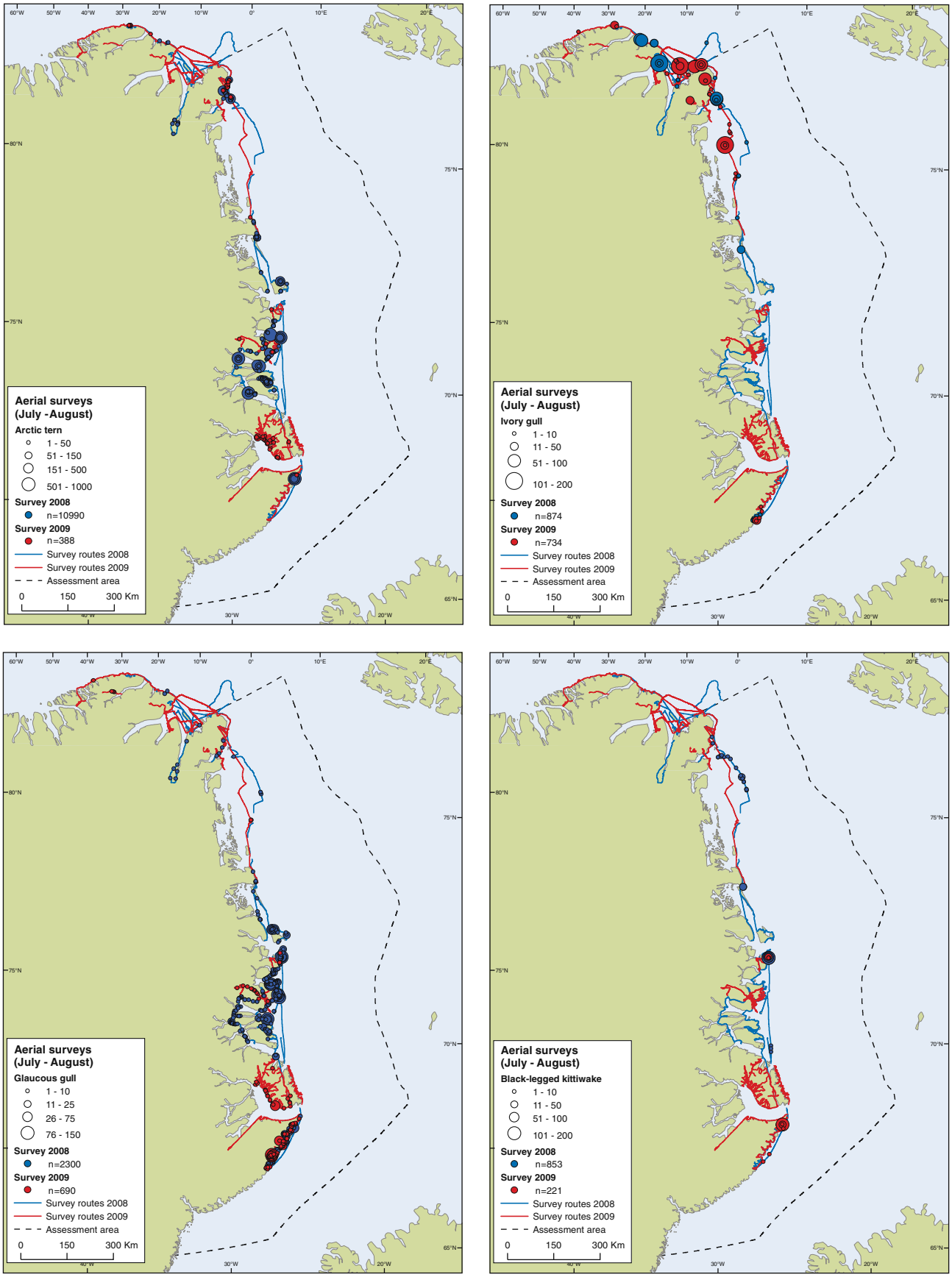
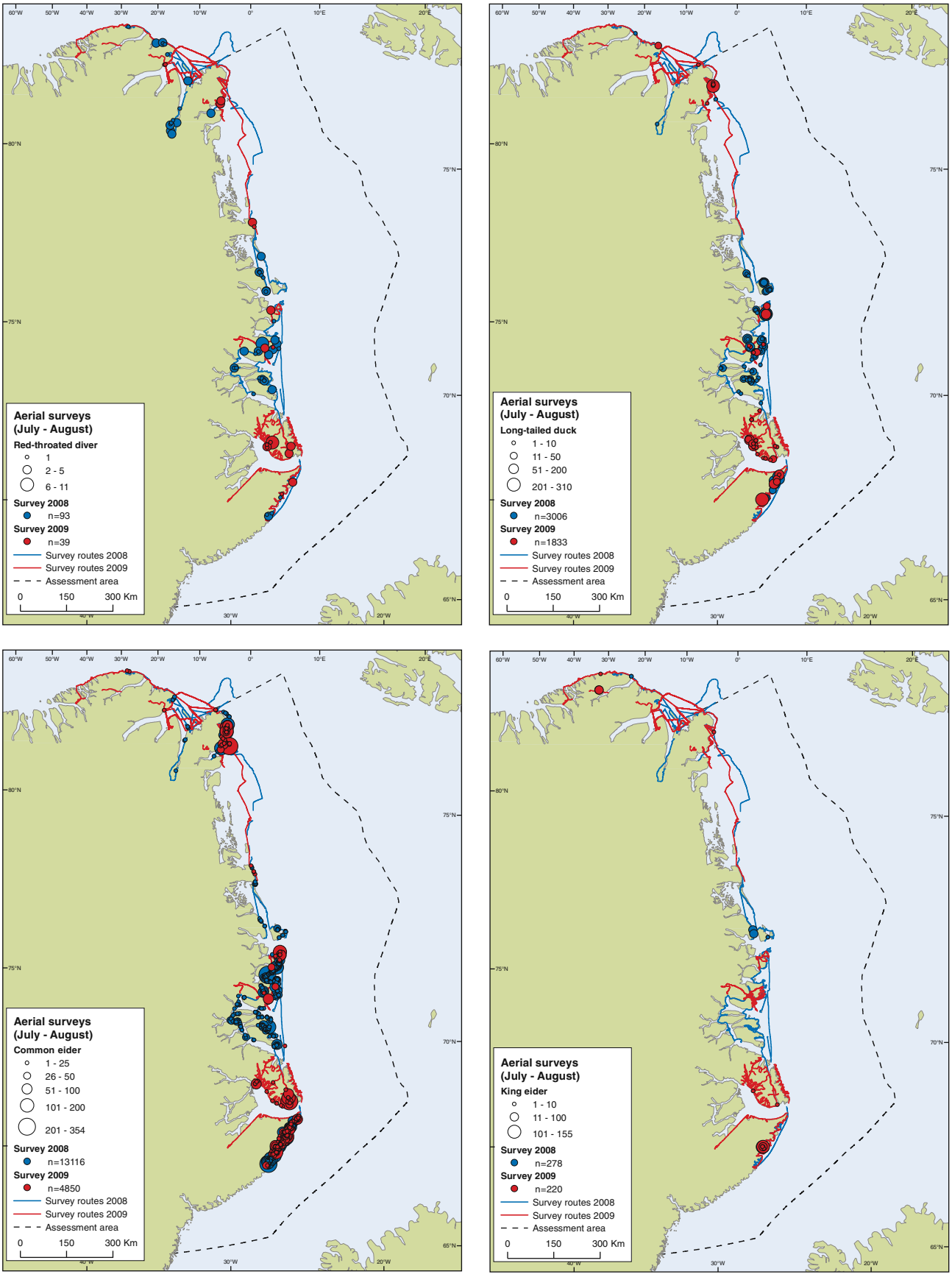


Figure 17. See text on page 82.



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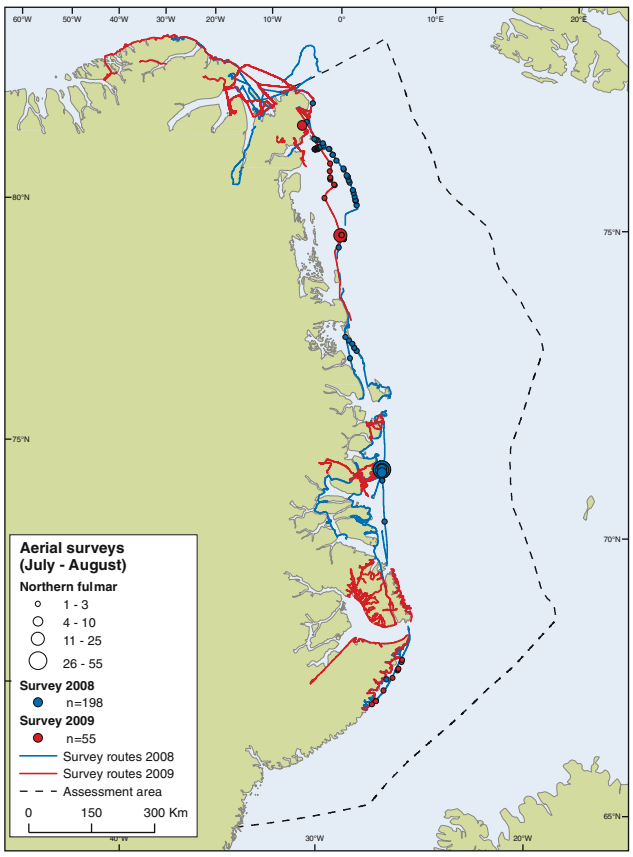


Figure 17. Maps showing the distribution and numbers of selected seabird species observed during the NERI aerial surveys in July and August in 2008 and 2009. n = the total number of individuals counted during the surveys). For common eider the total numbers of birds (males, females and chicks) are given inside the framed areas.

coasts. The total breeding population is roughly estimated at around 10 000 pairs. This order of magnitude seems to be confirmed by the aerial survey in 2008.

The largest colony known in the area is found at the military outpost Daneborg (up to 3 000 nests depending on the timing of snowmelt), where they seek shelter from fox predation among the tethered sledge dogs (Meltofte 1978).

Non-breeding occurrence: Common eiders arrive in April and May to the open-water areas of the assessment area (even in the north), and from here they disperse to the coasts as soon as these become ice free, for example, in early June at Zackenberg and Danmarkshavn (Meltofte 1975, 1976, Hansen *et al.* 2007). At first,

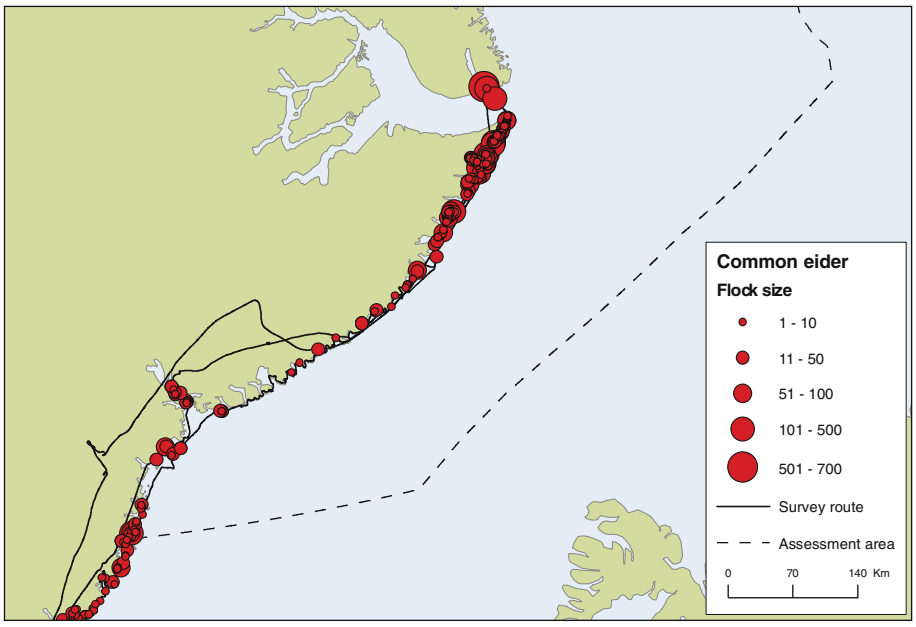
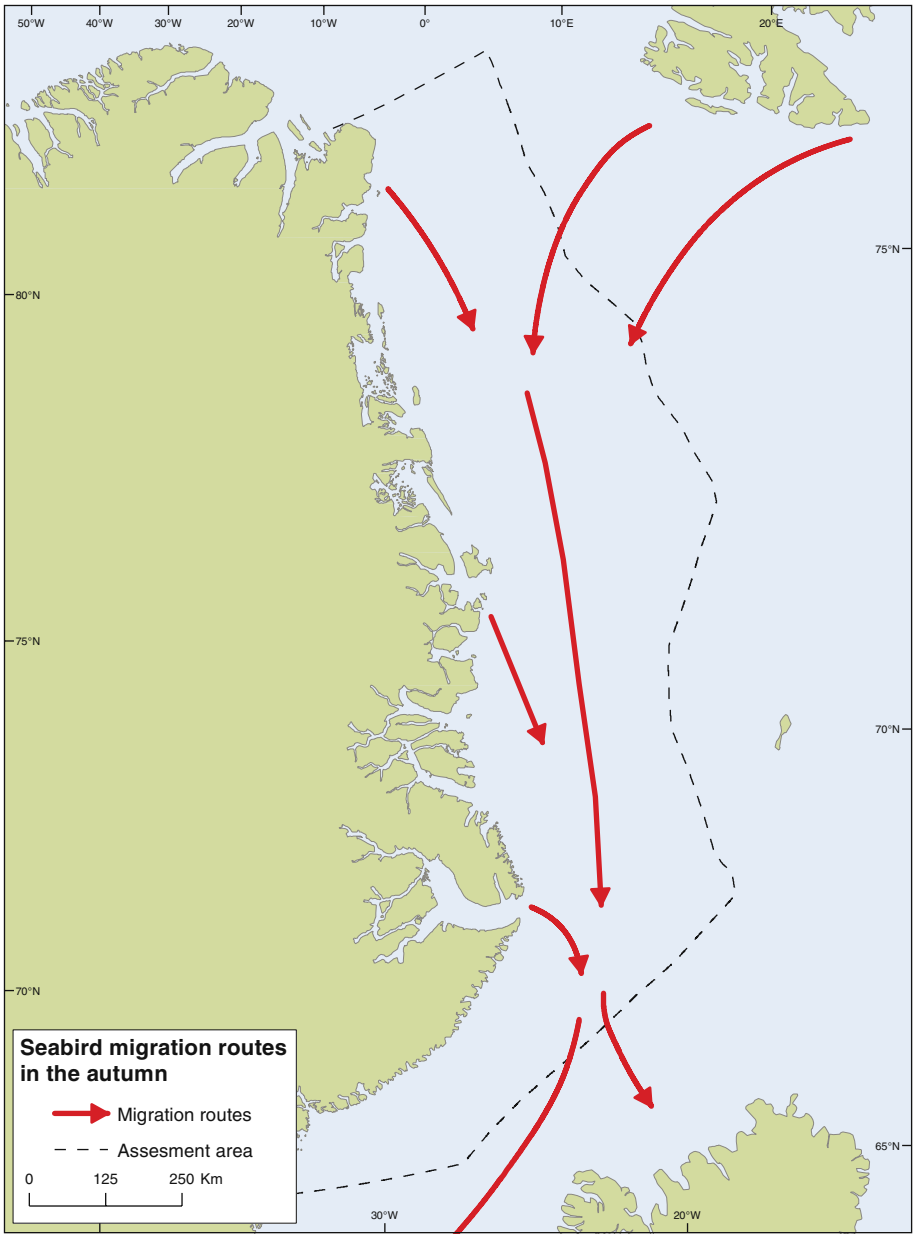


Figure 18. Distribution and abundance of common eider observed during the aerial GINR survey along the Blosseville Kyst 20 July 2008. Black line is the flying route (Merkel *et al.* 2010).

Figure 19. Expected autumn migration routes for seabirds in the assessment area. At least 2 million little auks, 2 million thick-billed murres, an unknown number of black guillemots and probably thousands of ivory gulls migrate through the assessment area each year. All these bred in Svalbard, but also birds from Arctic Russia may follow these flyways through the assessment area. In addition to these extralimital breeding birds, birds breeding within the assessment area move out for the winter – to Iceland (common eider), the waters off SW Greenland and Labrador/Newfoundland and further away (see boxes 1-7).



the common eiders assemble in pre-breeding congregations before they move to the breeding sites. At least 2 500 common eiders were counted in such pre-breeding flocks off Kilen in Kronprins Christian Land in 1993 (Falk *et al.* 1997a). During the NERI survey in spring 2008 about 2 600 were recorded in this area and more than 10 000 were counted in the Sirius Water Polynya off Wollaston Forland.

Common eiders assemble in moulting flocks during the summer (July). The flocks consist of males and non-breeding females. Meltofte (1976) describes the occurrence of moulting common eiders in the Scoresby Sund area, where the flocks occur from early July. However, knowledge on the distribution and abundance of these moulting birds is very sparse for other parts of the assessment area. The NERI surveys in July/August 2008 and 2009 indicate that moulting common eiders occur in small flocks distributed along the coasts with the highest recorded concentrations in the fjords of the Blosseville Kyst (south of 70°) (Figure 17). During a survey in mid-June GINR (Merkel *et al.* 2010) also recorded common eiders along the Blosseville Kyst, indicating that they occur in very high numbers throughout the entire coast (Figure 18). Satellite tracking of common eiders has confirmed the winter quarters in Iceland and documented the migration routes during more than a year (see Box 1).

Box 1

Satellite tracking of common eider

A. Mosbech, K. Johansen, M. Bjerrum and C. Sonne

This study was initiated to study the migration pathways, the phenology and the habitat use by East Greenland common eiders.

Between 2007 and 2011, 14 common eiders from the assessment area were tracked by means of implanted satellite transmitters. In June 2007, six females and four males were instrumented at the eider colony in Daneborg, and in 2009 further 3 females and 1 male were captured in vicinity of the eider colony in Myggbukta. The eider colony in Daneborg is by far the largest in East Greenland totalling about 2 000 pairs, whereas the colony in Myggbukta is significantly smaller (minimum 120 pairs). Several of the eiders were tracked through more than 2 seasons.

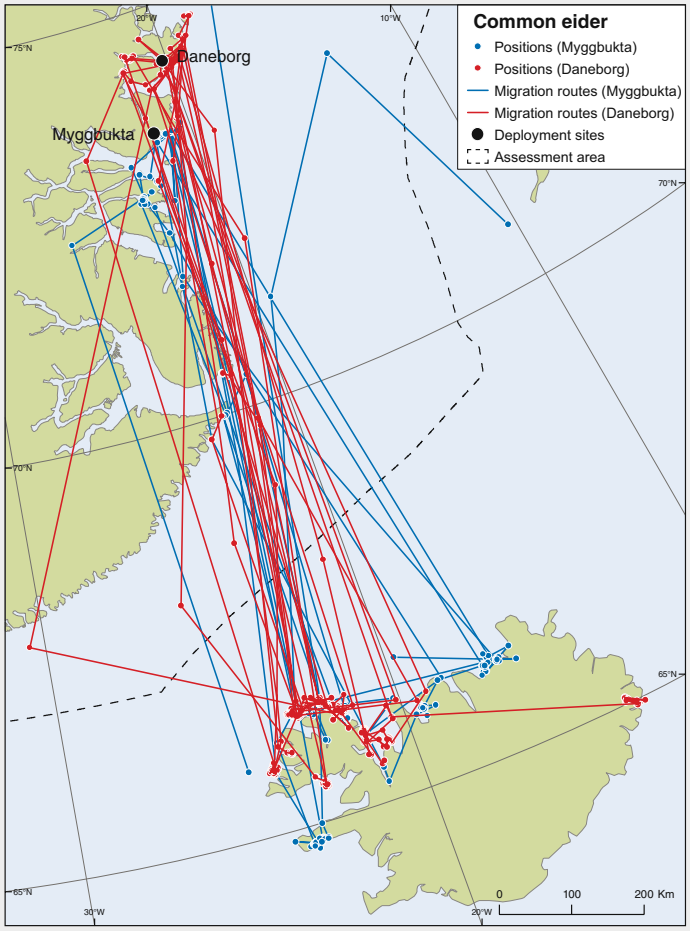


Figure 1. Locations and track lines for 14 common eiders tracked from the Daneborg colony (2007-2009) and from Myggbukta (2009-2011).

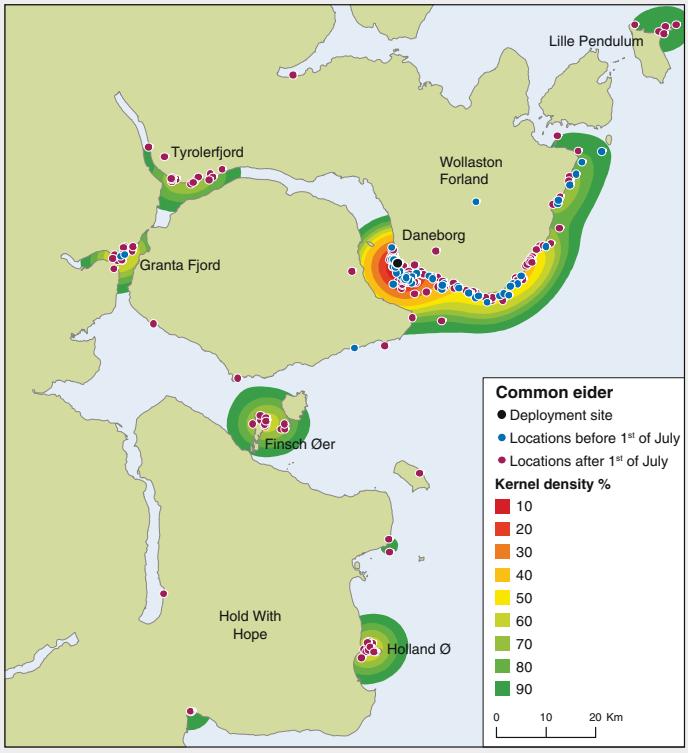


Figure 2. Kernel home range for the common eiders tracked from the Daneborg colony. Locations before 1 July including pre-breeding locations are shown by blue dots, and locations after 1 July including post-breeding locations are shown by purple dots. Locations from the whole tracking period within the area shown on the map are included in the kernel analysis (summers 2007-2009). The kernel home range contours represent an estimation the areas in which a certain percentage of the locations will be found. Thus 95 % of the locations are found within the 95 % probability contour.

All eiders from both colonies wintered on the north coast of Iceland (Figure 1). Males left Greenland territory about three weeks earlier than females (median day of departure 4 August and 27 August, respectively) and on the autumn migration neither males nor females staged for any length of time outside a 100 km radius of the respective colony sites. The eiders from Daneborg primarily staged scattered along the south and southeast coast of Wollaston Forland including Sandøen, but also at Tyrolerfjord, Grantafjord, Finsch Øer, around Lille Pendulum and off Hold With Hope near Holland Ø (Figure 2). The eiders from Myggbukta staged scattered along the south coast of Hold With Hope, but also further to the south by Scott Keltie Øer and around Kap Mackenzie (Figure 3).

The eiders arrived back in Greenland in the second half of May, the males a little earlier than the females (median day of arrival 13 May and 24 May, respectively). As was the case with the autumn migration, the eiders did not stage underway and flew more or less directly from Iceland to the area in vicinity of the colony sites. The eiders from Daneborg arrived on the south and east coast of Wollaston Forland and at Sandøen, whereas the eiders from Myggbukta primarily arrived on the south coast of Hold With Hope (Figure 2, 3).

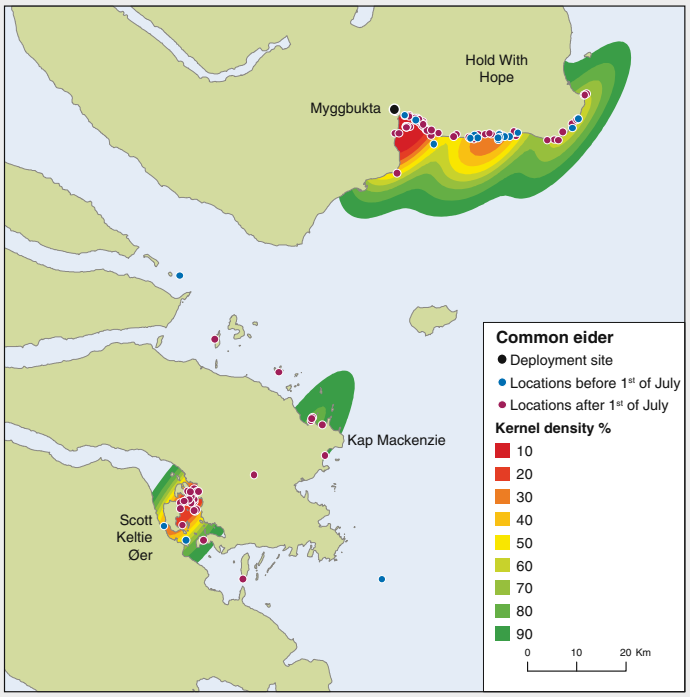


Figure 3. Kernel home range for the common eiders tracked from the Myggbukta colony. Locations before 1 July including pre-breeding locations are shown by blue dots, and locations after 1 July including post-breeding locations are shown by purple dots. Locations from the whole tracking period within the area shown on the map are included in the kernel analysis (summers 2009-2011).

Sensitivity and critical areas: The most sensitive common eider habitats will be the large breeding colonies, pre-breeding congregation areas and moulting areas where many birds potentially can be exposed to oil spills. Particularly moulting birds are sensitive because they cannot escape oiled areas. Besides oil spills both colonies and moulting sites are sensitive to disturbance.

Conservation Status: The common eider population of East Greenland has a favourable conservation status; it is not considered as threatened and is listed as of 'Least Concern' (LC) on the Greenland Red List.

Biology: Eiders are diving ducks feeding on the seabed down to about 30 m depth and mainly on molluscs, crustaceans and echinoderms. They are therefore confined to coastal waters. After pairing males assemble in flocks and, due to moult, they become flightless for a three-week period.

Kittiwake *Rissa tridactyla*

Breeding distribution: Breeding colonies are found at a few sites along the coast of the assessment area. Most (n = 5) are found on the coasts of the Scoresby Sund Polynya with Kap Brewster as the largest numbering about 700 nests in 2010 (Meltofte 1976, Falk *et al.* 1997b, Gilg 2005, Labansen *et al.* 2010b). Further north three small colonies were found on Hvalros Ø in 1999 (Gilg 2005, confirmed by the NERI 2008 and 2009 surveys (Boertmann *et al.* 2009a, Boertmann & Nielsen 2010a). In Dove Bugt a few colonies have been noted, although only one seems to be stable over the years. At the Northeast Water Polynya there are two colonies: one with 873 nests in 1993 and another with 200 birds in 2009 (Boertmann 1994, Falk & Møller 1995, Falk *et al.* 1997b, Gilg 2005, Boertmann *et al.* 2009a, Boertmann & Nielsen 2010a).

Offshore distribution: Offshore, non-breeders occur in flocks here and there and occasionally in large concentrations May-September; for example, in the Scoresby Sund Polynya (Meltofte 1976, Gilg 2005). The Norwegian surveys 1980–1984 found only few kittiwakes in the western part of the Greenland Sea and mainly in the Northeast Water (Mehlum 1989), and during the NERI surveys in July/August only few were recorded in offshore areas. Low densities were also recorded by the ship based surveys with some higher densities off the mouth of Scoresby Sund. Kittiwakes are usually absent from the assessment area in winter, but may occur in small numbers during unusual weather conditions (Brown 1986, Forchhammer 1990).

Biology: Kittiwakes are surface feeders living from small fish such as polar cod and crustaceans (Mehlum 1989), which they take when swimming on the surface or from short dives. They are considered as pelagic seabirds, only associated with the coast when breeding.

Conservation status: Nationally, the kittiwake is considered threatened and categorised as 'Vulnerable' (VU) due to its decline in West Greenland. However, the small East Greenland population seems to be increasing (Labansen *et al.* 2010b). Internationally it is not considered threatened and is categorised as being of 'Least Concern' (LC). However a general decline in most of the North Atlantic range gives reason for concern.

Sensitivity and critical areas: The breeding colonies are the most sensitive kittiwake habitats in the assessment area. Many birds assemble on the surface below the breeding cliff and are here potentially exposed to oil spills. Disturbance is another potential impact on these breeding sites. Offshore concentrations probably also occur, but have not been described in detail and their occurrence will probably not be predictable.

Sabines gull *Larus sabini*

Breeding distribution: This gull breeds in small colonies mainly on low islands in company with Arctic terns. At least 14 colonies were known before 2008 from the assessment area (Figure 15) (Boertmann 1994, Gilg *et al.* 2003, 2005, Hansen *et al.* 2007). The NERI 2008and 2009 surveys in July/August confirmed the presence of most of these and located a few more (Boertmann *et al.* 2009a, Boertmann & Nielsen 2010a). The best-known colony within the assessment area is Sandøen in Young Sund. The highest number of birds recorded here were 300 in 1999 (Levermann & Tøttrup 2007, Egevang & Stenhouse 2007).

Sabine's gulls arrive in the breeding colonies in June when open waters prevent foxes from accessing the breeding islands. However the gulls arrive somewhat earlier (late May) in the open-water areas, e.g. the Northeast Water, where more than 200 were recorded during the NERI 2008 survey on 3 June (Boertmann *et al.* 2009a). They leave again when the chicks are fledged in August.

Offshore distribution and concentrations: Very little information is available on offshore distribution, but the very few observations from the ship based surveys and the tracking study on Sandøen in 2007/08 indicate that the birds move through the assessment area rapidly both during autumn and spring migration (Box 2, Egevang *et al.* 2010).

Conservation status: Sabine's Gull is included on the Greenland Red List as 'Near Threatened' (NT), due to the small national population size. It is however of favourable conservation status and its numbers seem to be increasing. Internationally it is not red-listed and is considered as of 'Least Concern' (LC).

Biology: Sabine's gulls are surface feeders living from small fish and invertebrates which they take in flight or during shallow dives, and they feed mainly close to the breeding colony and are confined to the coastal habitats during breeding. When migrating they are true pelagic seabirds.

Sensitivity and critical areas: Sabine's gulls are most sensitive at the breeding colonies, and disturbance is the most severe threat.

Glaucous gull *Larus hyperboreus*

Breeding occurrence: This is the most widespread and common breeding seabird within the coastal part of the assessment area (Figure 15). Small breeding colonies (usually below 50 pairs) and solitary pairs usually occur at steep cliffs facing the sea or on low islands. Breeding concentrations are often found in areas with high numbers of other breeding seabirds; for example, in the little auk colonies in the Scoresby Sund area.

The glaucous gulls arrive at the breeding sites in Aril and May, and leave again when the waters freeze over in the autumn (Meltofte 1975, 1976).

Offshore distribution: Glaucous gulls were relatively rare in the western Greenland Sea compared with Svalbard waters during the Norwegian summer surveys in 1980-1984 (Mehlum 1989) and were only recorded in the Northeast Water. During the ship based surveys glaucous gulls were found widespread in the survey areas (Figure 20).

Conservation status: The glaucous gull population in the assessment area is of a favourable conservation status and the species is not considered as threatened, either nationally or internationally.

Box 2

Arctic tern and Sabines gull migration study

Carsten Egevang

The Arctic tern and the Sabines gull are both ground nesting seabirds breeding in colonies along the coasts of Northeast Greenland. Both species are trans-equatorial migrating birds wintering in high productive seas of the southern hemisphere.

In order to map the migration and utilization of marine areas outside the breeding season, Arctic terns and Sabines gulls were equipped with geolocators – small devices recording light intensity which subsequent can be transformed into geographical positions. Geolocators were deployed on 50 Arctic terns and 30 Sabines gulls at Sandøen, Young Sund (74°43'N, 20°27'W) in July 2007. In July the following year, ten and eleven loggers were retrieved respectively from the two species. The study revealed novel knowledge on some of the longest annual migrations performed within the animal kingdom (Egevang *et al.* 2010, Stenhouse *et al.* 2011). Here are the tracking results inside and near the assessment area described.

As the geolocator derived positions depend on the time of sunset and sunrise, positions from the Arctic summer with midnight sun (late May to August) are limited.

Arctic tern: The post-breeding departure of the terns from the Young Sund area takes place immediately after fledging of the young. The study revealed that the Arctic terns left the Sandøen colony primo to mid-August and migrated south through the Denmark Strait region – likely without the use of significant stop-over sites along the way (Figure 1). The birds didn't pause the migration until around 50° N (far south of Greenland waters) where they spend an average of 25 days at-sea, before continuing the migration into and across tropical regions. The winter was spent in the

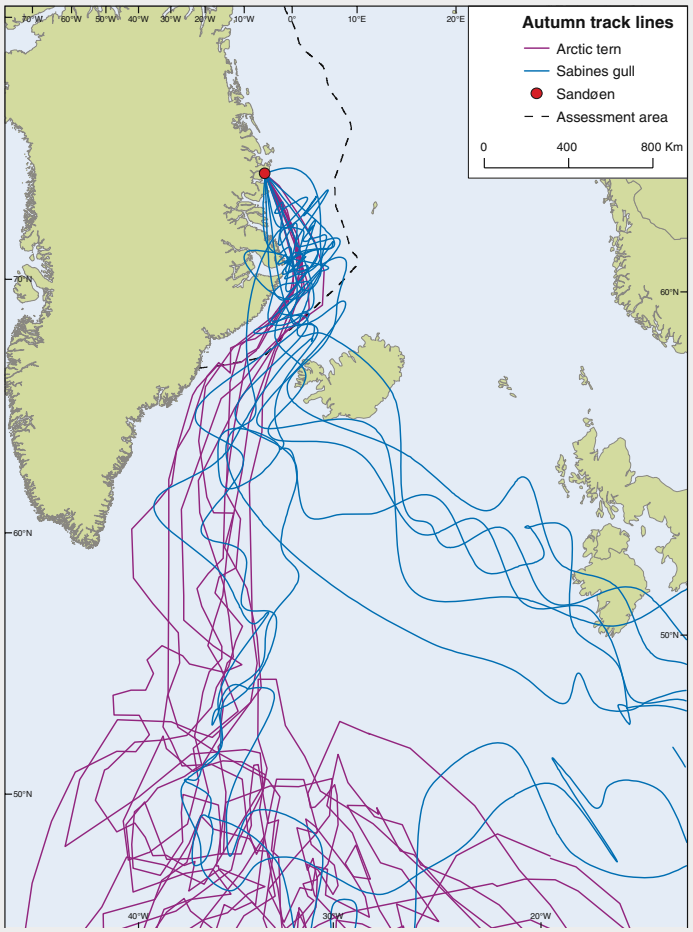
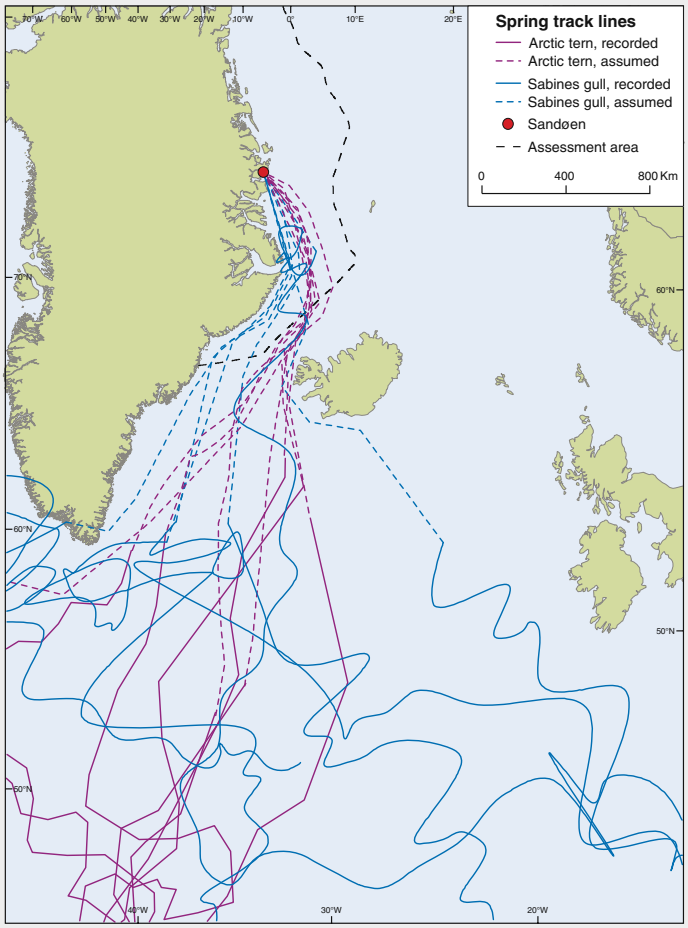


Figure 1. Autumn track lines of Arctic terns and Sabines gulls equipped with geolocators on Sandøen in Young Sund, East Greenland. The Arctic terns move quickly out of the assessment area towards staging areas in the central Atlantic, while the Sabines gulls seems to move more around and spend some time within the assessment area before moving southwards



Wendell Sea off Antarctica, and the north-bound migration was initiated mid-April. The Arctic terns of Sandøen entered southern Greenland waters late May. But at this time day-night light difference were too low to produce accurate geographical positions (Figure 2). However, primo June the Young Sund is still covered by sea ice and it is likely that the terns utilize the open water marine areas east of Young Sund, until egg laying is initiated in ultimo June/primo July (Egevang & Stenhouse 2007, Egevang *et al.* 2008).

Sabines gull: The post-breeding migration of the Sabines gulls differed from the Arctic terns by a more eastward migration from the Young Sund area. The Sabines gulls left Sandøen medio August and moved into the marine areas east and southeast off the coast. Here, in the southern part of the assessment area the birds spend between 10 and 14 days before continuing their southbound migration (Figure 1). The winter quarters were identified to the marine areas off southern Africa (Benguela Upwelling System), with distinct stop-over sites in autumn (in the Bay of Biscay) and in spring off the west African coast (Morocco, Mauritania, Senegal) (Stenhouse *et al.* 2011). By the time the Sabines gulls of Sandøen returned to East Greenland late May/earlyJune day-night light difference were too low to produce accurate geographical positions and movements within the assessment area cannot be elucidated (Figure 2).

Figure 2. Spring track lines of Arctic terns and Sabines gulls equipped with geolocators on Sandøen in Young Sund, East Greenland. Due to the midnight sun conditions most of the track lines within the assessment area are assumed.

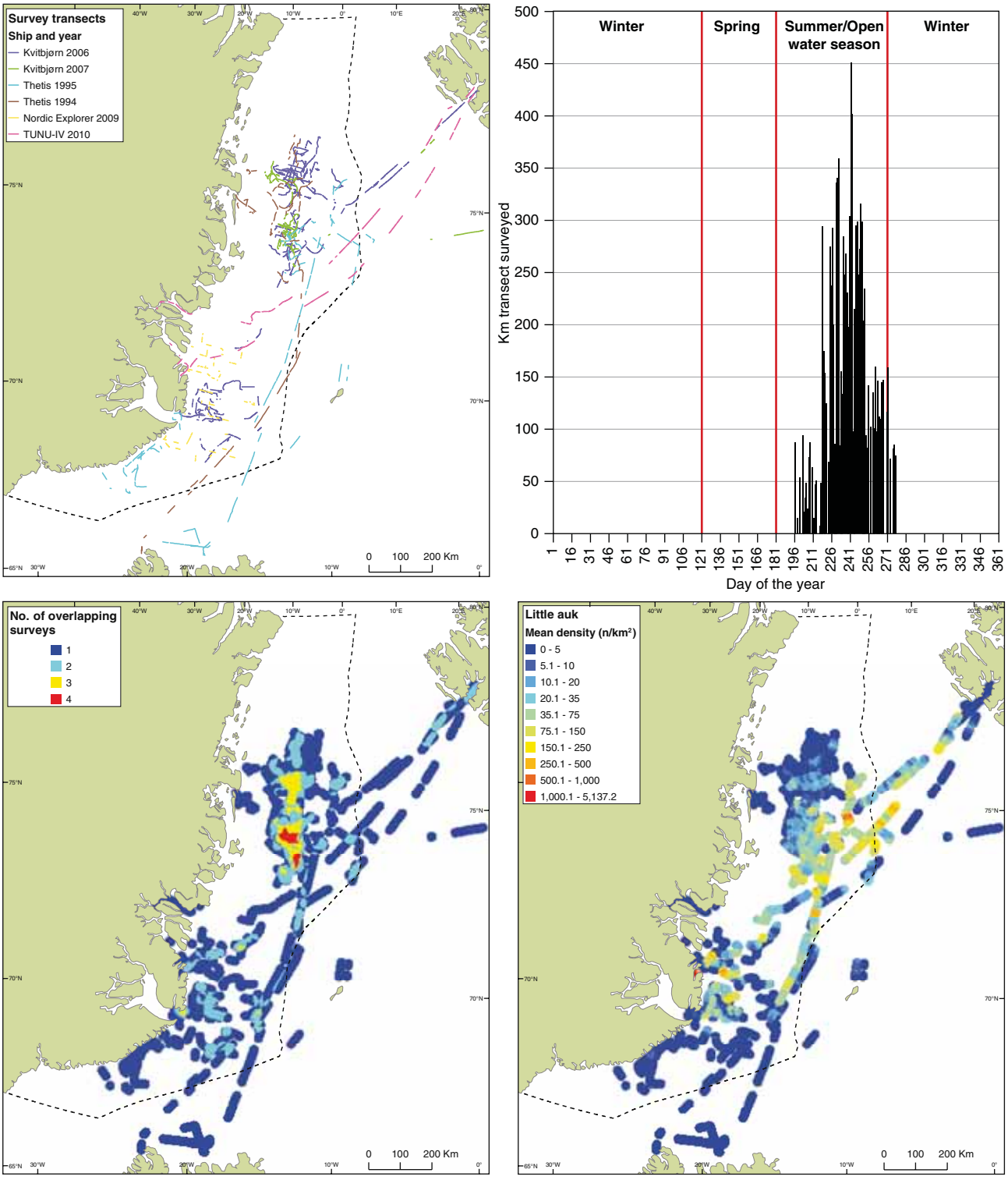


Figure 20A. Seabird observations during seismic surveys in 1994, 1995, 2005, 2006 2009 and 2010. A shows the spatial and temporal coverage of the surveys routes and the calculated densities for little auk.

Biology: Glaucous gulls are omnivorous and act as top predators in the Arctic ecosystem by taking seabird eggs, chicks and even adult little auks and kittiwakes. They often feed when swimming on the surface. Glaucous gulls are attracted to human activities where discards can be an important food source. They are usually confined to the coastal environment, but may occur far offshore.

Sensitivity and critical areas: Glaucous gulls are less sensitive to oil spills than many other seabirds staying for longer periods on the water surface. The population is

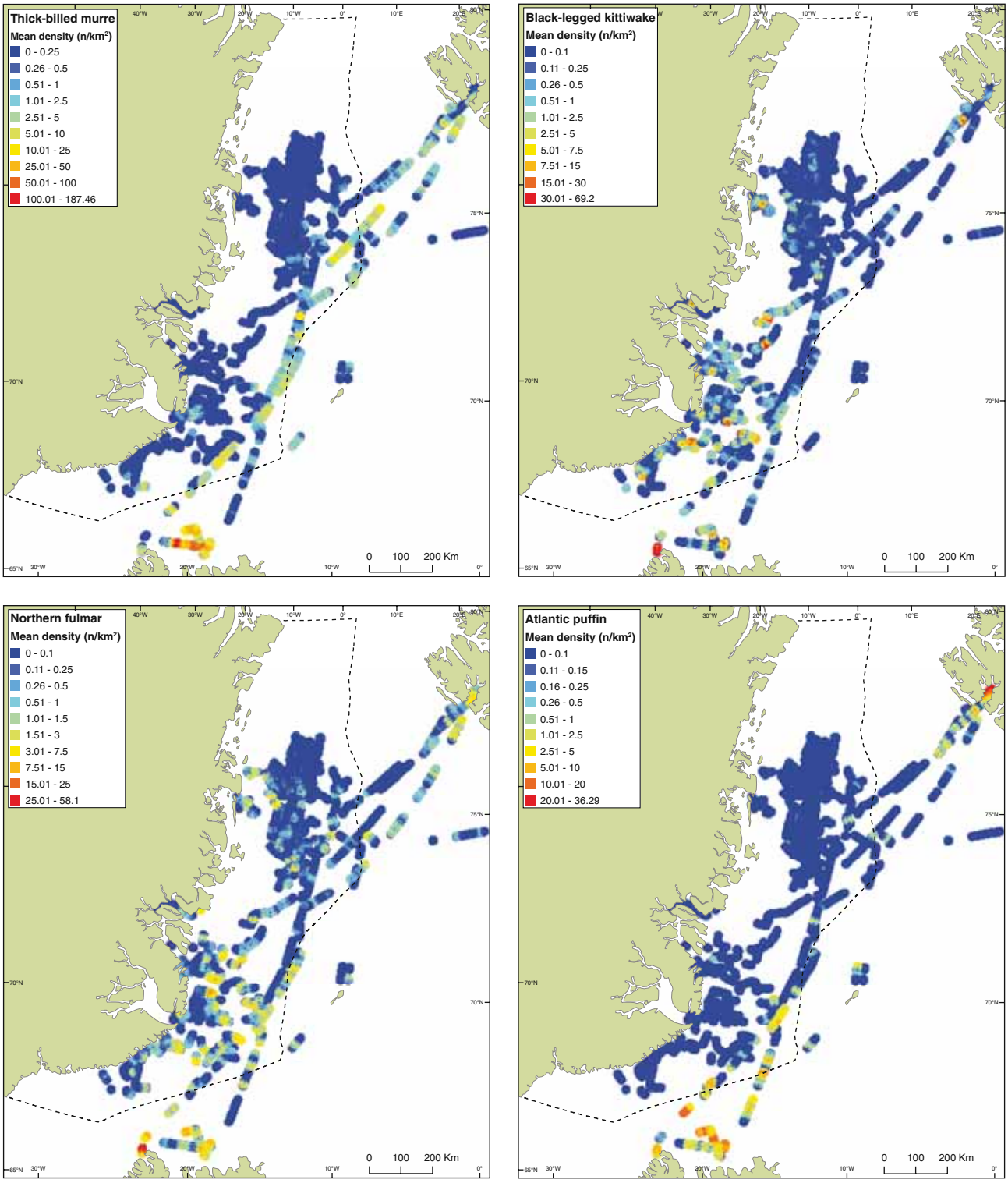


Figure 20B. Calculated densities for thick-billed murre, black-legged kittiwake, northern fulmar and Atlantic puffin based on the surveys shown on map in Figure 22A.

dispersed (many small colonies; Figure 15); why even a large oil spill most likely only will affect relatively few individuals.

Ross's gull *Rhodosthetia rosea*

Breeding occurrence: This gull is a very rare species, breeding regularly in Greenland only at two sites. One of these sites is located within the assessment area: Henrik Krøyer Holme in the Northeast Water Polynya (Egevang & Boertmann

2008). Here a few pairs have been recorded among the ivory gulls and Arctic terns during recent visits to the islands (Figure 15).

Biology: Very little is known about the phenology and biology of this species in Greenland. Breeding birds are probably confined to the coastal environment, while non-breeders and migrating birds occur in the marginal ice zones of polynyas and in the drift ice.

Offshore occurrence: Non-breeders occur in relatively high numbers in the Northeast Water during summer (Falk *et al.* 1997a, Meltofte *et al.* 1981b), and small flocks were also seen during the ship based surveys (Figure 20).

Conservation status: The Ross's gull is considered as threatened in Greenland and categorised as 'Vulnerable' (VU) on the national Red List. Internationally it is not red-listed ('Least Concern' (LC)).

Sensitivity and critical areas: The breeding site on Henrik Krøyer Holme is particularly sensitive to disturbance.

Ivory Gull *Pagophila eburnea*

This gull is the most Arctic of all the seabirds. It is associated with ice-covered waters always near predictable open water areas, such as polynyas, ice edges and shore leads.

Breeding concentrations: Breeding colonies are placed on steep cliffs, often on remote nunataks, on low gravel islands, low beaches, coastal plains or even on debris covered ice floes (Boertmann & Nielsen 2010a, Boertmann *et al.* 2010). The most important breeding site in the assessment area is Henrik Krøyer Holme in the Northeast Water, where up to 300 (2003) pairs breed (Figure 15). Several new breeding colonies were found during the NERI 2008 and 2009 surveys in July and August in and north of the assessment area (Figure 17). The entire Greenland breeding population is assessed at 1000-2000 pairs, with the majority concentrated at the Northeast Water Polynya (Gilg *et al.* 2009, Boertmann & Nielsen 2010a).

Biology: Very little is known on the biology of the Greenland ivory gulls, but recently (2007) individuals have been equipped with satellite transmitters to track their migration, and some results from this study have recently been published (Gilg *et al.* 2010, see below). Ivory gulls are surface feeders, living from small fish and crustaceans taken in leads and pools in the ice. They also feed on remains from polar bear kills and are attracted to human activities that create open waters in the ice and to garbage and discards for example at military outposts.

Offshore distribution: Post-breeding migration takes place from late August and birds move south in the drift ice belt off the East Greenland shore in small flocks. Substantial numbers have been recorded, e.g. in early September 1975 when hundreds were observed migrating south (Hjort 1976b) and likewise hundreds were observed in mid-October in the marginal ice zone at about 74° N (Byrkjedal & Madsen 2008). Bench & Hjort (1990) also reported ivory gulls from the drift ice in October. During the ship based surveys ivory gull was among the most frequently seen species (Figure 20). These autumn records include birds from all the Northeast Atlantic breeding areas (Greenland, Svalbard, Arctic Russia) documented by tracking of birds from all these areas (Gilg *et al.* 2010). The winter grounds are found in the ice margin in the Labrador Sea, but some also winter on the ice off Southeast Greenland (Orr & Parsons 1982, Gilg *et al.* 2010), and they are also present in the Greenland Sea in February–April (Brown 1986). In mid- and late-May 2002 many hundreds were observed migrating north in the East Greenland Current between

65° and 75° N (Kylin 2006), indicating spring migration. Nevertheless, a few birds arrive to the breeding colony at Station Nord as early as April (Sirius Sledge Patrol pers. comm.). During the Norwegian summer surveys 1980–1984, ivory gull was the most abundant seabird species in the waters off Northeast Greenland and always in close association with the drift ice (Mehlum 1989).

Conservation status: The global ivory gull population has an unfavourable conservation status (Gilchrist *et al.* 2008)), as the global population is small (estimated at 14,000 pairs) and regional declines are evident. Moreover, the birds in Russia and Svalbard display high contaminant loads (Gilchrist *et al.* 2008) and a general population decline is expected due to climate change. A significant decrease in the Canadian breeding population has recently been reported (COSEWIC 2006). Ivory gull was therefore recently red-listed as 'Near Threatened' (NT) (BirdLife International 2006). In Greenland, the ivory gull is considered as threatened and categorised as 'Vulnerable' (VU) on the national Red List.

Sensitivity and critical habitats: Ivory gulls spend only little time on the water surface and are therefore not as sensitive to oil spills as many other marine birds. But as the species is relatively rare and populations seem to be decreasing (at least in Canada) even mortality of a relatively small number of birds may have population effects. However, the breeding colonies are sensitive to disturbance, particularly low level helicopter flights. But on the other hand under certain circumstances ivory gulls are able to habituate to disturbance (e.g. the colony at Station Nord is very close to the air strip situated there).

Arctic tern *Sterna paradisaea*

Breeding distribution: Many breeding colonies are located along the shores of the assessment area (Figure 15). Most are small, but a few hold more than 500 pairs. Moreover, there are many Arctic terns breeding at inland sites at lakes. The breeding colonies are concentrated at polynyas and areas with early ice break-up, such as the outer parts of sounds and fjords: e.g. Vega Sund, Young Sund, Dove Bugt and Henrik Krøyer Holme.

Offshore distribution: Arctic terns arrive to the coastal waters in early to mid-June, and leave soon after the chicks have fledged in late August to early September. During the NERI 2008 survey flocks arrived in the outer parts of the offshore drift ice on 2 June (Boertmann *et al.* 2009a). During the breeding season terns mainly stay close to the breeding sites and very few were observed during the Norwegian offshore surveys in 1980–1984 (Mehlum 1989). Both during spring and autumn migration, Arctic terns move through the offshore areas, but this is brief and rapid (Box 2, Egevang *et al.* 2010), and for example very few were seen during the aerial NERI survey May/June 2008 (Figure 16), which took place during the peak spring migration period.

Biology: Arctic terns are surface feeders, catching fish and crustaceans by plunge diving from the air. In the breeding season Arctic terns are confined to coastal waters, but during migration they also occur far offshore.

Conservation status: The Greenland population is considered as 'Near Threatened' (NT) on the national Red List due to a considerable population decline in West Greenland. However in East Greenland including the assessment area Arctic tern has a favourable conservation status. Internationally it is categorised as of 'Least Concern' (LC).

Sensitivity and critical areas: Terns rarely rest on the water, and are therefore less vulnerable to oil spill than many swimming seabird species. The breeding colonies however are particularly sensitive to disturbance.

Thick-billed murre *Uria lomvia*

Breeding distribution: There are only two breeding colonies of this alcid within the assessment area (Figure 15). All are situated at the Scoresby Sund Polynya (Meltofte 1976, Falk *et al.* 1997b). The colonies have been surveyed a number of times in recent decades, and the large colony on Kap Brewster have shown a significant decrease: in 2005, it numbered 9 500 birds and in 2010 4 800 birds. The other colony on the island Raffles Ø, is smaller and held about 2 200 birds in 2004 and 1 500 in 2010. A third colony on the island, Steward Ø is abandoned as no birds were seen during the recent surveys in 2005 and 2008 (Gilg 2005, Boertmann *et al.* 2009a). A few birds have been tracked on their autumn migration from Kap Brewster (Box 3).

Offshore distribution: Murres are numerous in and near the Scoresby Sund Polynya in summer, but further north in the assessment area only few occur, and in the Northeast Water they occurred sparsely in 1991–1994 (Mehlum 1989, Falk *et al.* 1997a). In September numbers increase in the offshore areas (Figure 20) and high densities of thick-billed murres have been recorded in polar waters between Iceland and Greenland with up to 30 birds/km^2 (Petersen 1995). This influx of birds consists mainly of breeders from Svalbard (approx. 850 000 pairs in 1975 Anker-Nilssen *et al.* 2000) on autumn migration to winter quarters off Southwest Greenland and Newfoundland. Probably all the breeding birds from Svalbard pass through the assessment area, both on spring and autumn migration. Winter observations are very few, but at least in late winter 1982 few were observed in the eastern parts of the assessment area (Brown 1986).

Biology: Thick-billed murres occur both in coastal and offshore waters. They are diving birds feeding on fish (capelin, polar cod) and large zooplankton, and they spend much time on the surface swimming. Chicks leave the nesting ledges when three weeks old and not yet fully grown, and together with the male bird (which becomes flightless due to flight feather moult) they perform a swimming migration more or less passively with the currents. This migration probably takes a considerable number of Svalbard birds into the assessment area.

Conservation status: The thick-billed murre population breeding in the assessment area has an unfavourable conservation status due to decline. In West Greenland many populations are also in decline, so the species is red-listed as 'Vulnerable' (VU) in Greenland. Internationally it is considered as of 'Least Concern' (LC).

Sensitivity and critical areas: Murres are particularly sensitive to oil spills, because they spend most of their time on the water surface. They are moreover sensitive at the population level, because the population is decreasing, reducing the potential for post-spill recovery. The most sensitive occurrences in the assessment area are the breeding colonies in the Scoresby Sund Polynya. These colonies are declining, and the birds also are exposed to oil spills in their winter quarter (Wiese & Ryan 2003), why the population is particularly sensitive to oil spills in its breeding range. Significant concentrations most likely occur offshore during the migration periods, for example in the marginal ice zone, but information is limited.

Black guillemot *Cepphus grylle*

Breeding distribution: The black guillemot is a rather common breeder on coasts near the Scoresby Sund Polynya (Meltofte 1976, Gilg 2005). Further north, colonies are scarce and associated with areas with early ice break-up or polynyas, e.g. at

Box 3

Satellite tracking of thick-billed murres from Kap Brewster

A. Mosbech, K. Johansen, M. Bjerrum and C. Sonne

This study was initiatad to study the migration pathways, the habitat use and the phenology of the thick-billed murres breeding on the colony at Kap Brewster.

In late July 2009 three male and two female thick-billed murres from the colony at Kap Brewster were caught on the ledge with noose pole and equipped with implanted satellite transmitters. With an estimated maximum of 4,800 birds, the colony at Kap Brewster is the larger of only two murre colonies in the assessment area, both related to the Scoresby Sound Polynya.

Two birds remained in or near the colony after the transmitters had been implanted and did not embark on the autumn migration until approximately 6 August. One of these, a female, continued chick rearing and made several round-trips to a primary foraging area 20 km east of the colony and a secondary foraging area 120 km southeast of the colony (Figure 1). Due to the low precision of many of the coordinates the existence of foraging areas closer to the colony cannot be excluded.

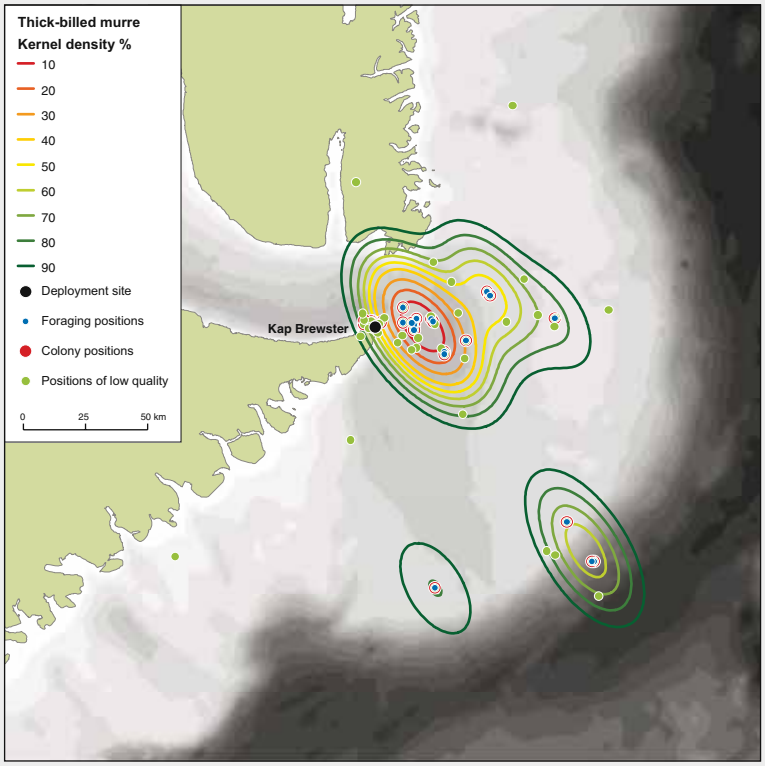


Figure 1. Foraging areas of a female thick-billed murre (ptt ID 36372) tracked with satellite transmitter while commuting between the colony at Kap Brewster and foraging areas. The foraging areas are estimated as kernel home range contours, only including high accuracy positions away from the colony. The bathymetry backdrop is 100 m contours extracted from the GEBCO model.

Three murres were tracked for a considerable distance of their autumn migration (Figure 2). One male (ptt ID 6934) left the colony 6 August, rounded Cape Farewell 24 August and transmitted its last signal 8 September off the coast of Southwest Greenland. A female (ptt ID 36371) left the colony right after transmitter implant 22 July and staged for about a week within a restricted area off the Blosseville Kyst 130 km south of the colony. Thereafter it continued south along the coast and transmitted its last signal just before Kap Farvel on 13 September. Another male (ptt ID 6938), which seemingly also left the colony right after instrumentation (on 26 July), rounded Cape Farewell on 10 August. It crossed Davis Strait in the course of September and October, continued south off the Labrador and Newfoundland coast in October and November, and reached its presumed wintering area on Grand Banks in late November.

The tracks of the three murres revealed no significant staging areas within Greenland territory. Judging by the speed of movement, the migration down the east coast of Greenland was a combination of swimming/drifting and short legs of flight. Moulting of flying feathers during the tracking period was only suggested by the male that was tracked all the way to Grand Banks (ptt ID 6938). During the crossing of Davis Strait it had a continuous period of 2 months with speeds consistently below 1.6 km/h.

Figure 2. Locations and migrations routes for 5 thick-billed murres tracked from the Kap Brewster colony in 2009.

Hvalros Ø and at Holm Land (Falk *et al.* 1997a, Gilg 2005), and they are somewhat unstable in their occurrence, probably governed by the annual variation in ice distribution (Figure 15). A new breeding site was located on Jackson Ø during the NERI 2008 survey in July (Boertmann *et al.* 2009a).

Offshore distribution: Very few black guillemots were reported by the Norwegian summer surveys in 1980-1984 in the northern part of the assessment area (Mehlum 1989). During the ship based surveys black guillemots were rather numerous in the drift ice, and also Byrkjedal & Madsen (2008) reports black guillemots in autumn. The number of birds recorded during these autumn surveys exceeds by far the numbers breeding in Northeast Greenland, indicating that birds move in from Svalbard. In winter Brown (1986) observed very few black guillemots and mainly in the marginal ice zone.

Biology: Black guillemots are diving birds, which stay for long periods on the surface. They feed on fish and invertebrates mainly in the extensive kelp beds along the shore, but offshore they feed on the fauna associated with ice floes and icebergs. They breed in small colonies in steep cliffs along the shores. The migration pattern of East Greenland birds is unknown.

Conservation status: Black guillemots are not threatened and are categorised as of 'Least Concern' (LC), both nationally and internationally. Although the breeding population is small in the assessment area, it most likely has a favourable conservation status, and further colonies may be established when the ice in summer become more reduced.

Sensitivity and critical habitats: As swimming birds, spending long periods of time on the surface, black guillemots are vulnerable to oil spills, and the most sensitive occurrences are the breeding colonies along the coasts of the assessment area. However, there are few other human-induced threats to the population, making them less vulnerable at the population level than thick-billed murres.

Little auk *Alle alle*

Breeding distribution: This species is by far the most numerous seabird breeding in the assessment area. The breeding distribution is however limited to the coasts near the Scoresby Sund Polynya (Figure 15), where the population has been estimated at approx. 3.5 million pairs (Kampp *et al.* 1987). Breeding outside this region has been suggested at Hvalros Ø (74°30' N) – not confirmed in 1999, 2005 and 2008 – and at Kap Dalton (69°30' N) – not confirmed in 2008 (Stemmerik 1990, Gilg 2005).

Offshore distribution: In summer, breeding birds undertake foraging flights up to approx. 100 km from the colonies (e.g. Gilg *et al.* 2005), and within this range little auks can occur in very dense concentrations. However, further offshore little auks are much scarcer in summer, as shown by the Norwegian surveys in 1980-1984 (Mehlum 1989). Little auks probably move to Southwest Greenland and Newfoundland waters for the winter, but Brown's survey (1984) indicates that little auks are present also in winter (March), and then mainly in the marginal ice zone. One of the studies initiated to provide data for this assessment concerned tracking the migration of little auks. This resulted in the discovery of a post-breeding staging area in the Greenland Sea (Mosbech *et al.* 2012) (see Box 4).

Birds from the very large breeding population in Svalbard (at least 1 million pairs; Anker-Nilssen *et al.* 2000), migrate through the assessment area from late August and return again in April (Brown 1986, Gilg 2005). Concentrations were recorded by the ship based surveys (Figure 20) performed in September. In mid-August

2010, very high densities were observed in open sea between the drift ice edge and Svalbard. In October, only few little auks have been observed (Bensch & Hjort 1990, Byrkjedal & Madsen 2008), suggesting that the autumn migration through the assessment area peak earlier.

Biology: Little auks are diving birds feeding on large pelagic crustaceans – mainly *Calanus*-copepods (Falk *et al.* 2000, Pedersen & Falk 2001). Little auks breed in very dense colonies in the talus rocks below steep cliffs. Off the breeding season little auks occur usually far offshore.

Conservation status: The little auk population breeding in the assessment area is most likely of favourable conservation status, and the species is listed as 'Least Concern' (LC) on both the national and the global Red Lists.

Sensitivity and critical habitats: Little auks are very vulnerable to oil spills, and the most sensitive occurrences are the breeding colonies along the coasts of the assessment area. Large offshore aggregations will also be very sensitive, but their occurrence is not known and will probably depend on distribution of food.

Other species

Four species of skua (*Stercorarius*) occur frequently in the assessment area in the summer period. Breeding birds are confined to terrestrial and coastal habitats, but non-breeders and failed breeders move to offshore areas, and are usually common and widespread (Figure 20). They are all migrants and leave the assessment area for the winter period.

Several species of waterbirds breeding at the freshwater habitats of Northeast Greenland are dependent on the marine environment for spring staging in a vulnerable period of their life cycle. Before the freshwater habitats become free of ice and available, many waterbirds assemble together with true marine birds, in coastal areas were polynyas reach the coast or where the sea ice has melted, e.g. in river outlets or in straits with strong tidal currents. Species include red-throated diver (*Gavia stellata*), great northern diver (*Gavia immer*), long-tailed duck (*Clangula hyemalis*), red-breasted merganser (*Mergus serrator*), king eider (*Somateria spectabilis*), red-necked phalarope (*Phalaropus lobatus*) and grey phalarope (*Phalaropus fulicarius*). Some of these birds also forage in the marine environment during breeding. Later in the summer postbreeding and moulting birds also assemble in the marine environment of the assessment area.

The most numerous of these species are the king eider and the long-tailed duck. During the spring 2008 survey about 2,000 king eiders were observed in the Northeast Water Polynya, 100 at the Wollaston Forland Polynya and 40 at the Scoresby Sund Polynya (Figure 16). Long-tailed ducks were most abundant in the Scoresby Sund Polynya with about 100 birds followed by the Northeast Water with 40 birds (Figure 16). Red-throated divers were recorded in small numbers and very dispersed (Figure 16).

Long-tailed ducks, king eiders and red-throated divers were in 2008 and 2009 captured in the central part of the assessment area and equipped with satellite transmitters. The subsequent tracking of these birds is described in Box 5, 6 and 7.

Another period when such birds may use the marine environment is during the summer, when they moult. The most numerous species are again long-tailed ducks and king eiders. During the NERI 2008 and 2009 surveys in July and August moulting long-tailed ducks were located at many sites. Flocks were usually small with less than 100 birds, but at a few sites, e.g. the coast of Wollaston Forland, more than

Box 4

Little auk migration and feeding ecology

A. Mosbech, J. Fort and K. Johansen

Little auk is the most numerous seabird in the north Atlantic, and Greenland is estimated to hold 80% of the world breeding population making it a species of national responsibility. In the assessment area 3.5 mill little auks were estimated to breed very concentrated at the coasts around the Scoresby Sund Polynya (Kampp *et al.* 1987).

Little has been known on ecology and key marine habitats for this little auk population. However, recently French researchers (CEFE, Montpellier) and NERI/GINR initiated studies at Kap Höegh, Liverpool Land, to investigate the ecology of this high arctic species. Main objectives are responses to a changing climate and location of important at-sea areas during the seasonal cycle.

Migration and staging areas

In the breeding season of 2007 and 2008, little auks were caught at nests and fitted with small geolocators on tarsus bands. Five geolocators were retrieved the following breeding season and recorded light regime data from the previous year were downloaded. The accuracy of the calculated positions is quite coarse, typically within approximately ± 150 km for individual locations. However, a model-based smoothing was applied to the position data, and coordinates predicted daily for each bird were connected in chronological sequence to reconstruct paths of movement during the non-breeding season (Figure 1). The daily predictions of longitude and latitude were also used for identifying staging areas.

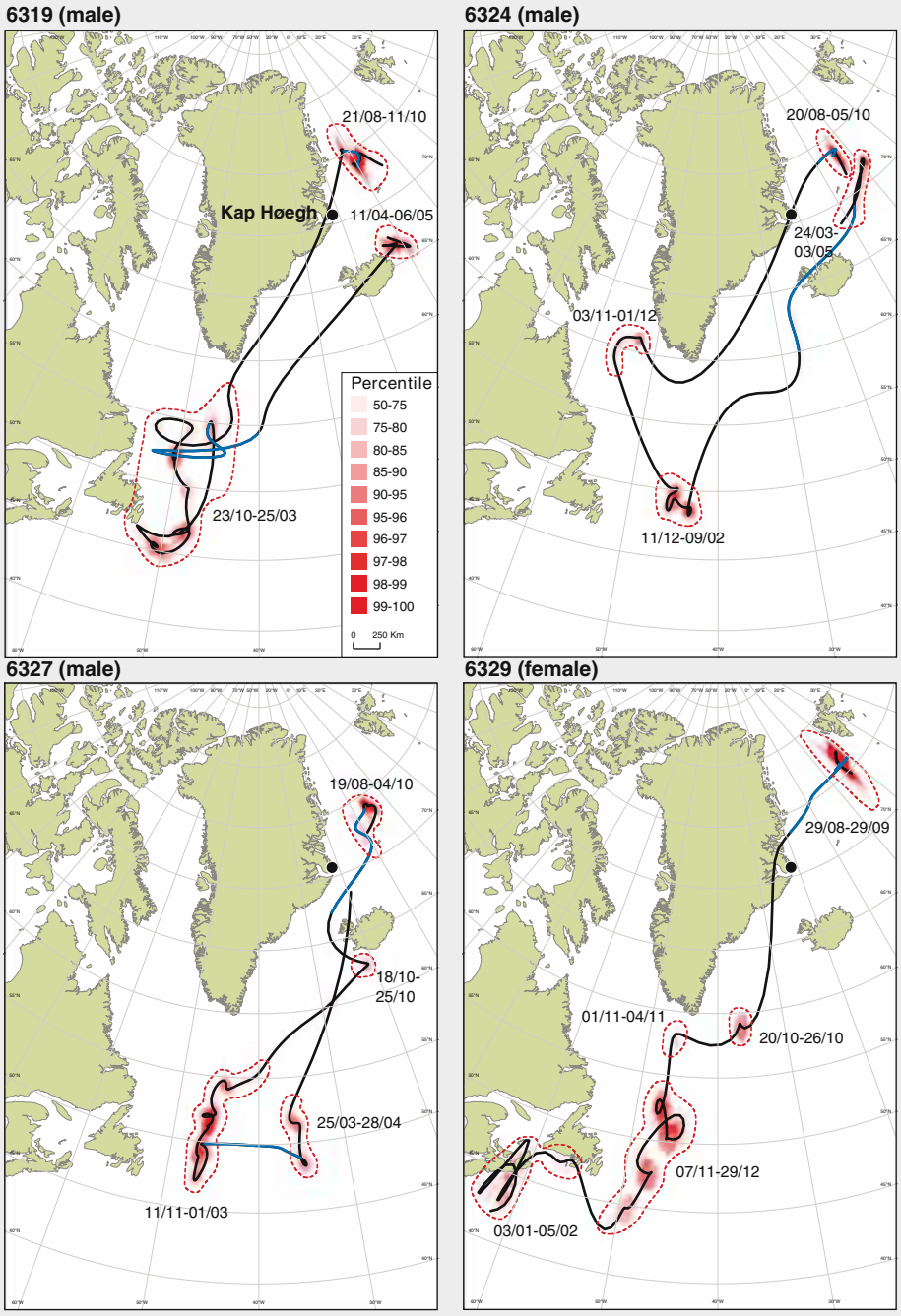


Figure 1. Path of movement of 5 little auks (3 males and 2 females) equipped with a geolocator at the breeding colony Kap Höegh near Scoresby Sund in 2007 (4) and 2008 (1, ID 8379). All birds were recaptured a year after deployment. The maps show the most likely track for each bird based on modelling of a daily location. Blue sections of the path highlight equinox periods where latitude data are unreliable. The red areas indicate staging areas estimated as a relative measure of duration of stay taking into account the uncertainty of the locations. A very remarkable result is that after breeding, all birds moved towards northeast and staged between Jan Mayen and Svalbard from the end of August to the beginning of October

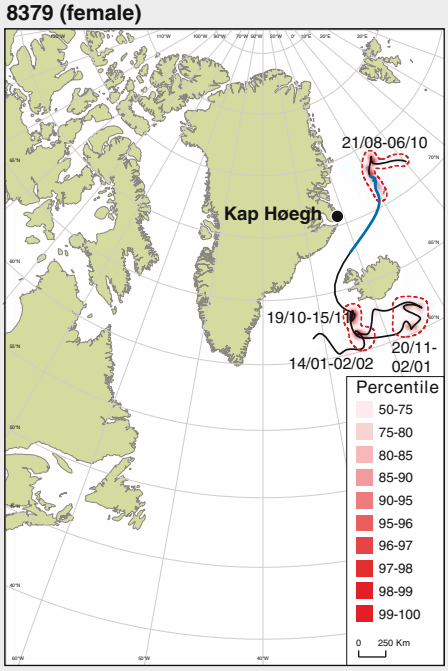
For the five recaptured birds the median post breeding departure time from the colony was 8 August (range 25 July-13 August) while arrival the following year could be determined for three birds arriving from beginning of May to mid-June. A very remarkable result is that after breeding all birds moved towards northeast and staged in the Greenland Sea in an area between Jan Mayen and Svalbard between end of August and beginning of October. This is probably a moulting area and an important feeding area for little auks. During winter the little auks were mostly staging far offshore Newfoundland, but one bird staged most of November offshore Southwest Greenland and one bird was south of Iceland until February when the geolocator stopped recording prematurely. This study is described in a recent paper by Mosbech *et al.* (2012).

Foraging ecology during the breeding season

The chick meals at Kap Höegh are dominated by Calanus copepods (95 %), and in total it has been estimated that chick-rearing little auks needed to catch about 59 800 copepods per day, which is equivalent to about six copepods caught per second spent underwater (Harding *et al.* 2009). These astonishing results underline the importance of areas with dense patches of large, energy-rich copepods to little auks. The quality of little auk foraging areas is to some extent determined by ocean temperature because the distribution and abundance of the large lipid-rich Calanus copepod species are associated with cold water (Falk-Petersen *et al.* 2007, Loeng & Drinkwater 2007).

Welcker *et al.* (2009) did a comparative study of foraging ecology during chick rearing in the colony at Kap Höegh, and at three colonies at Svalbard (Hornsund, Isfjorden and Kongsfjorden). They found that at Kap Höegh compared to the three colonies at Svalbard, sea surface temperature was lower (0.34° C at Kap Höegh and between 1.96° C and 5.64° C at the Svalbard colonies), little auks spent less time foraging (80 % compared to 87-93 % at the Svalbard colonies) and their 'long' foraging trips where shorter (69 ± 11 km compared to between 129 ± 16 km and 219 ± 17 km at Svalbard). These results document the good conditions at Kap Höegh for this high arctic seabird.

8379 (female)



Foraging Ecology during the non-breeding season

New research indicates that the winter may be the real bottleneck for the little auk populations. Fort *et al.* (2010b) has shown that the winter foraging effort is twice the one measured in the breeding season (Harding *et al.* 2009) during which birds have to forage for themselves and as well as for their chicks. During winter (December-January), birds perform impressively, with hundreds of dives conducted daily (min = 234, max = 718). The mean dive duration is 45 sec (max = 73.4 sec) and mean dive depth is 12 m (max = 50.2 m). During this season, birds spent 24 % of their time diving. These results highlight the importance of resource availability for wintering little auks. They devote a high proportion of their time to capture prey and might be unable to increase their foraging effort in response to a degradation of their environment for example a change in food availability/quality.

The year-round trophic status of little auks breeding at Kap Höegh has been determined using stable isotope analyses. Little auks perform two distinct moults per year: one complete moult in autumn (September-October) that involves the replacement of the complete body plumage, and a partial moult in winter (March) when only feathers from the neck and head are replaced. Analysing blood, 'head feather' and 'body feather' samples collected on breeding birds, makes it possible to establish the trophic status and isotopic niche of little auks during summer, autumn and winter (Fort *et al.* 2010a). Briefly, birds showed a strong inter-seasonal variation in trophic status, suggesting an important dietary shift between summer and autumn, and between autumn and winter. These changes are most likely due to a modification of food availability in the upper layer of the water column. Soon after summer, copepods (including *Calanus* spp. species), which are the favourite prey of little auks, are known to perform a vertical migration to depths of several hundred meters to undergo diapause, thereby becoming inaccessible to the birds, which can only dive to 50 m (Fort *et al.* 2010b, see below). During autumn, little auks are thus expected to feed on alternate prey. For instance, larger, energy-richer amphipods feeding at higher trophic levels might be consumed by little auks in early autumn (Stempniewicz 2001). In winter (March), the birds displayed a second dietary shift and fed at low trophic levels similar to those of summer (similar $\delta^{15}N$). Measured winter $\delta^{15}N$ values are in agreement with birds preying upon copepods (Sato *et al.* 2002, Karnovsky *et al.* 2008) which migrate back to surface waters following the phytoplankton bloom. This bloom occurs from February off Newfoundland (Henson *et al.* 2009), and copepods might therefore be available to diving little auks during their winter moult in this region. Such information notably highlights the ability of little auks to modulate their feeding ecology depending on the temporal availability of their prey and also to exploit a wide range of prey, ranging from calanoid copepods to fish larvae. The information is also essential to understand how this species responds to a constraining and changing environment, notably in the context of climate change already leading to a modification of prey/zooplankton availability/quality in North Atlantic waters (Beaugrand *et al.* 2010).

Box 5

Satellite tracking of long-tailed ducks from Myggbukta

A. Mosbech, K. Johansen, M. Bjerrum and C. Sonne

This study was initiated to study the migration pathways, the habitat use and the phenology of long-tailed ducks breeding in Northeast Greenland.

Myggbukta is a pond-rich wetland area on the south coast of Hold With Hope with a high density of breeding long-tailed ducks (Elander & Blomquist 1986). In mid-June 2007 three presumed pairs caught in mist nets during courtship flight were equipped with implanted satellite transmitters. In late July 2009 the area was revisited and another four females and one male caught in mist nets at a coastal foraging area were instrumented.

The long-tailed ducks stayed in the Myggbukta area (60 km radius) until the onset of the autumn migration in September (Figure 1). The males left Myggbukta about two and a half weeks earlier than the females (median day of departure 10 and 26 September, respectively) and neither males nor females staged for any significant length of time along the East Greenland coast.

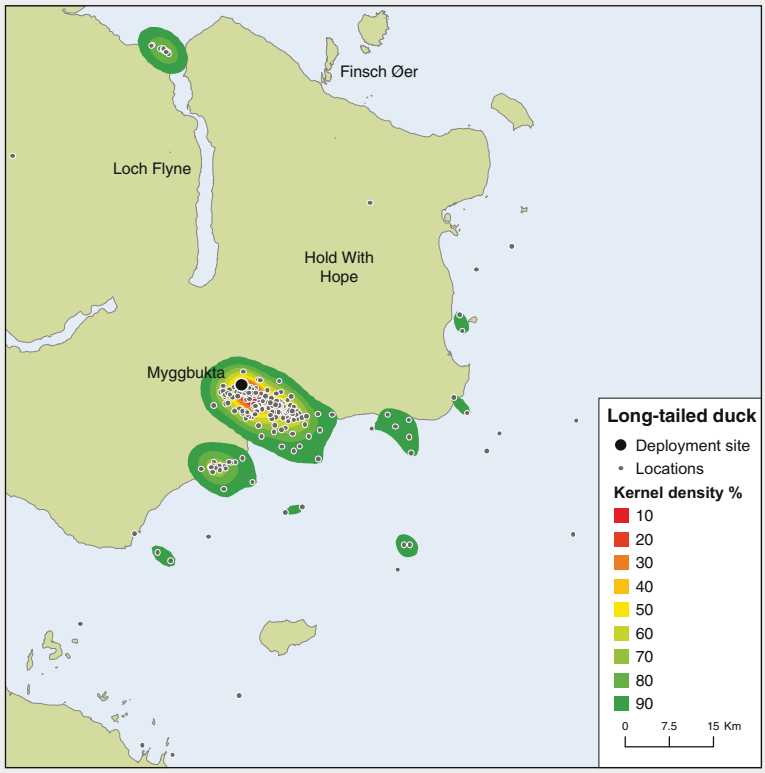
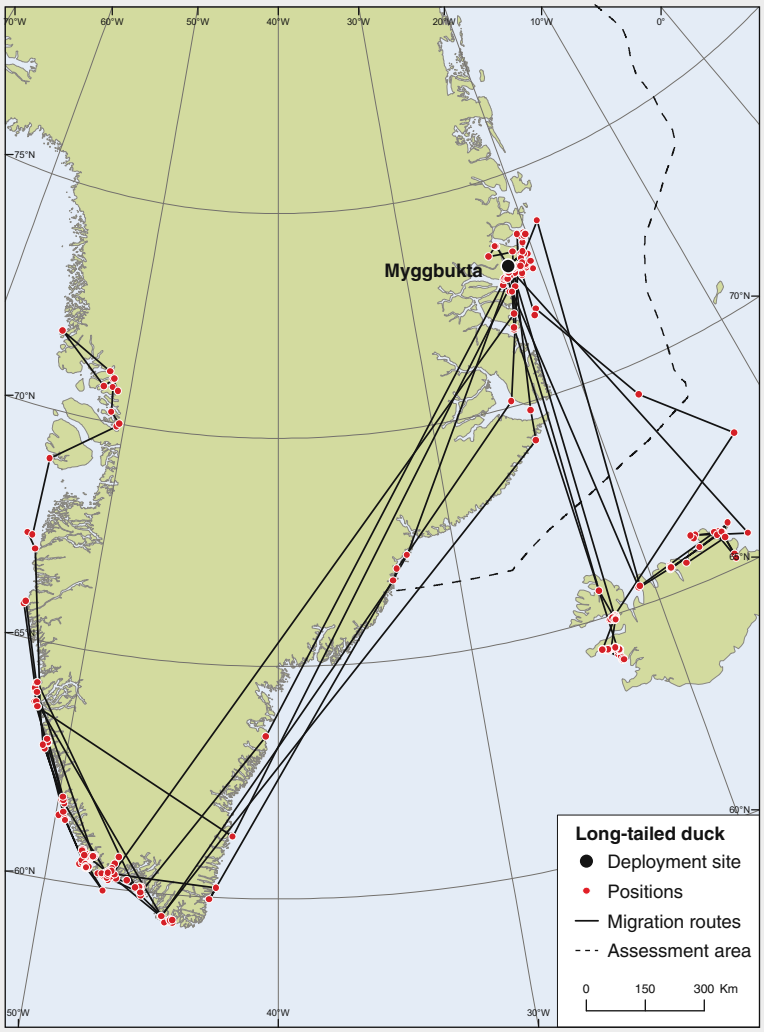


Figure 1. Kernel home range for the 11 long-tailed ducks from the Myggbukta breeding area deployed with satellite transmitters in 2007 and 2009. Locations from the whole tracking period within the area shown on the map are included in the kernel analysis (summers 2007, 2009 and 2010). The kernel home range contours represent an estimation the areas in which a certain percentage of the locations will be found. Thus 95 % of the locations are found within the 95 % probability contour.



Five of the long-tailed ducks wintered in northern Iceland and five went to Julianehåb Bugt in South Greenland (Figure 2). Some of the latter presumably stayed in Julianehåb Bugt throughout the winter, others made return trips from Julianehåb Bugt to the coast of Southwest Greenland, and some only staged in Julianehåb Bugt on their way to Southwest Greenland. One female went directly from Myggbukta to the wintering area in Southwest Greenland.

Of the three pairs instrumented in 2007, one pair migrated to Iceland, one pair migrated to Julianehåb Bugt and one pair split between Iceland and Julianehåb Bugt during the winter. None of the pairs stayed together during migration.

Only three long-tailed ducks were tracked throughout a whole season. One female, which wintered in Southwest Greenland, went up the west coast of Greenland to Uummannaq Fjord where it spent the summer as a non-breeder. Of two females, which wintered in Iceland, one stayed in Iceland the following summer whereas the other returned to the Myggbukta on 4 June.

Figure 2. Locations and track lines for the 11 long-tailed ducks tracked from the breeding area in Myggbukta to wintering areas in Iceland and Southwest Greenland.

Box 6

Satellite tracking of king eiders from Myggbukta

A. Mosbech, K. Johansen, M. Bjerrum and C. Sonne

This study was initiated to study the migration pathways, the habitat use and the phenology of king eiders breeding in Northeast Greenland.

In late July 2009 two female king eiders were caught in mist nets at a coastal foraging area in Myggbukta and equipped with implanted satellite transmitters. Both individuals were tracked for approximately two complete seasons between 2009 and 2011.

The king eiders remained in the Myggbukta area until the onset of the autumn migration in the beginning of August (median day of departure 9 August, range 2 August-15 August). During all tracked seasons, one of the birds made a very short stop on the south coast of Shannon Ø (1 location each 3 seasons). Otherwise both individuals went directly to the southwest coast of Spitsbergen without any staging in Greenland territory (Figure 1).

The king eiders spent the autumn period from approximately 12 August-13 November along the southwest coast of Spitsbergen, whereas during the winter (median dates 13 November-6 April) they moved to the shallow offshore Spitsbergen Bank and the coast of Bjørnøya. In the spring, the king eiders returned to the southwest coast of Spitsbergen (median arrival 6 April) and stayed there for some time before they embarked on the spring migration to Greenland.

During the spring migration one of the king eiders left Spitsbergen early and staged on the way to Myggbukta, whereas the other left much later and seemingly flew directly from Spitsbergen to Myggbukta without significant staging underway. The former arrived at the polynya off the southeast coast of Wollaston Forland in the beginning of May (3 May 2010, 6 May 2011), staged there for about a month, and was first recorded back in Myggbukta on 15 June both years (Figure 2). The latter arrived in Myggbukta on 3 June 2010 but seemingly gave up breeding this summer and returned to Spitsbergen after spending a month at mouth of Loch Fyne. In 2011, transmission from this bird unfortunately terminated shortly after arrival in Greenland at coast of Lille Pendulum on 6 June.

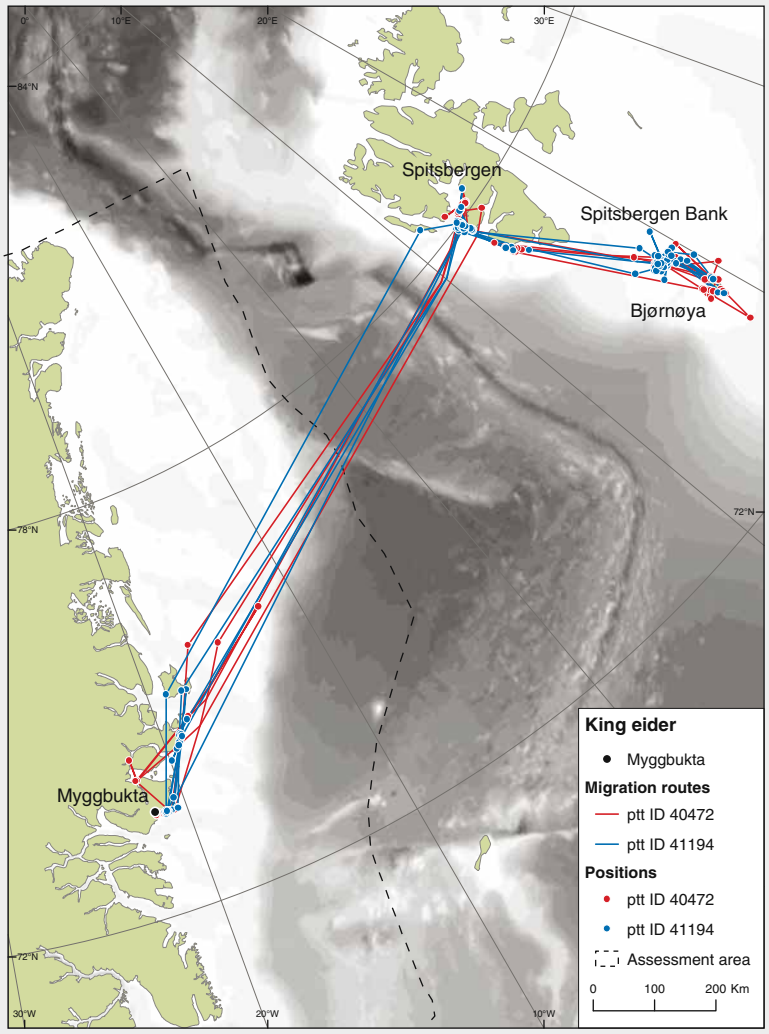


Figure 1. Locations and track lines for the two female king eider tracked from Myggbukta between 2009 and 2011.

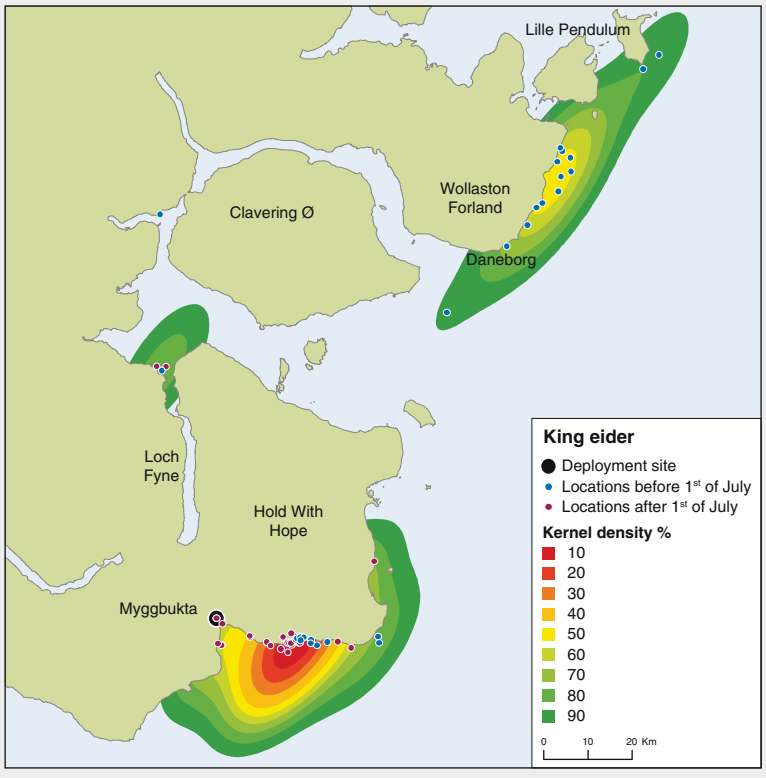


Figure 2. Kernel home range for the two king eiders tracked from Myggbukta. Locations before 1 July including pre-breeding locations are shown by blue dots, and locations after 1 July including post-breeding locations are shown by purple dots. Locations from the whole tracking period within the area shown on the map are included in the kernel analysis (summers 2009-2011). The kernel home range contours represent an estimation the areas in which a certain percentage of the locations will be found. Thus 95% of the locations are found within the 95% probability contour.

1 000 birds were recorded in 2008 and 460 in 2009 off a river outlet (Figure 17). Moulting king eiders were only found on the Blosseville Kyst, where a moulting site were located in Knighton Fjord, with 150 birds in 2008 and 245 in 2009 (Figure 17).

Some coastal habitats, such as sedimentary beaches, deltas and lagoons, also attract birds from terrestrial and freshwater habitats during the summer and migration periods, primarily shorebirds and geese.

3.7.2 Important and critical marine habitats for birds

Besides the breeding colonies described in the sections above, many other areas are important to seabirds within the assessment area.

Polynyas (Figure 5) are particularly important as staging and feeding areas in the spring when the sea elsewhere is covered with ice. Large numbers of seabirds assemble in such areas, mainly the mouth of Scoresby Sund, the Sirius Water Polynya and the Northeast Water (Meltofte 1976, Falk *et al.* 1997a, Boertmann *et al.* 2009a). These sites are of regional importance, holding birds from a large region for a short period.

In spring, open waters (besides the polynyas) at river outlets, straits with strong currents, etc. also provide feeding and staging possibilities to waterbirds before the inland breeding habitats become accessible. Such sites may be important on a local scale. No such sites were observed during the 2008 spring survey.

Moulting ducks often assemble in undisturbed areas, and concentrations are known from the Scoresby Sund area (see above, common eider), but other moulting areas may be found within the assessment area. Such sites are particularly sensitive to disturbance, from e.g. low-level helicopter flights. During the 2008 and 2009-surveys, moulting common eiders were found dispersed along many coasts, but not in large concentrations. Most were found in the fjords of the Blosseville Kyst, where the only concentration of moulting king eiders was also found. Moulting long-tailed ducks were seen at many sites, mainly in shallow bays and at river outlets. The highest numbers was approx. 1,000 at the coast of Wollaston Forland (Figure 17).

As mentioned above the marginal ice zone in the Greenland Sea may be a very important habitat for migrating seabirds in spring. The major part of these birds has their breeding grounds in Svalbard and wintering grounds in Southwest Greenland and Newfoundland waters. In the Barents Sea the marginal ice zone is designated as a particularly important area, e.g. due to concentrations of feeding seabirds in spring, and the marginal ice zone of the Greenland Sea may have a similar significance. As the drift ice in the Greenland Sea is less dynamic, at least in overall distribution (multi-year ice), than in the Barents Sea, a marginal ice zone may also occur (at least locally) in autumn and be similarly important. However, the climate change scenarios indicate that the multi-year ice will be replaced by first-year ice in large areas, and for example in autumn 2008, there was very little drift ice in the assessment area and no ice edges were apparent (Figure 4).

3.8 Marine mammals

3.8.1 Marine mammals, species treated in detail

Polar bear and walrus are the best studied marine mammal species in the Greenland Sea assessment area, and much information is still unpublished. To include this information, they are therefore treated in more detail here. Table 6 gives an overview of the most important marine mammals occurring in the assessment area.

Box 7

Satellite tracking of a red-throated diver from Myggbukta

A. Mosbech, K. Johansen, M. Bjerrum and C. Sonne

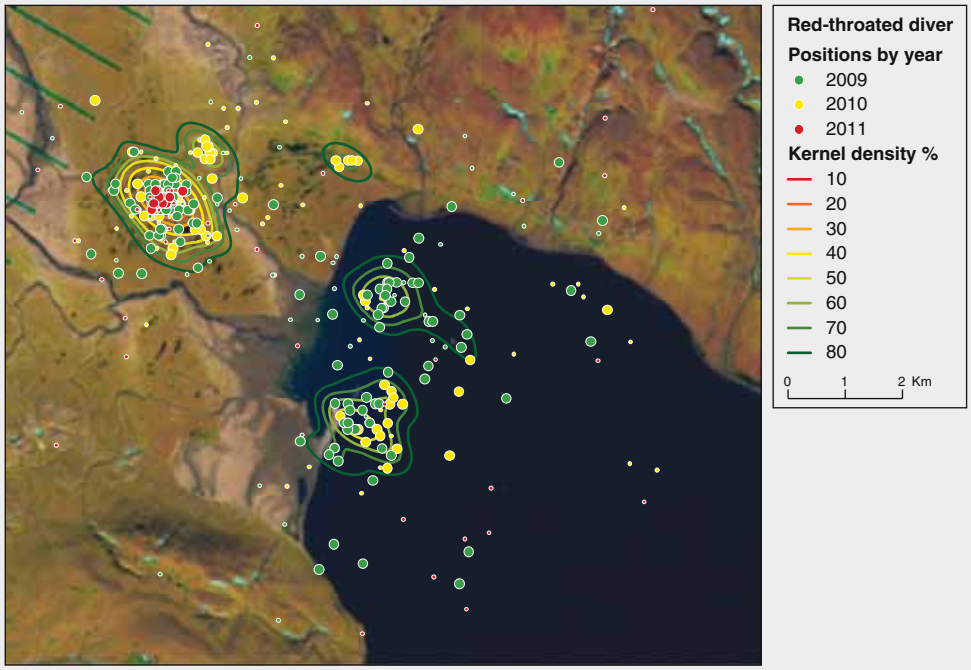


Figure 1. Kernel home range for the red-throated diver tracked from the breeding area in Myggbukta. The dots represent Argos positions differentiated by year (color) and accuracy (small = low, large = high). High accuracy positions from the whole tracking period within the area shown on the map are included in the kernel analysis. The kernel home range contours represent an estimation the areas in which a certain percentage of the locations will be found. Thus 50 % of the locations are found within the 50 % probability contour. The kernel analysis highlights the nesting site on the pond, two other ponds used for resting in 2010, and coastal two foraging areas used in 2009 and 2010. The backdrop is a Landsat image from 9 August 2008.

This study was initiated to study the migration pathways, the habitat use and the phenology of red-throated divers breeding in Northeast Greenland.

The pond-rich wetland area of Myggbukta on the south coast of Hold With Hope is a well known breeding area of red-throated divers (Elander & Blomquist 1986). In late July 2009 a red-throated diver breeding on one of the ponds was caught with a nest trap and equipped with an implanted satellite transmitter. It was tracked for two complete seasons between 2009 and 2011.

During the breeding season the diver undertook regular forging trips from the nesting site to coastal foraging areas (Figure 1). The positions indicate use of the same pond for nesting all three summers. The two coastal foraging areas located 4 and 5 km from the nesting site were used in 2009 and 2010, whereas the foraging positions from 2011 were much more scattered, although still concentrated in the inner part of Myggbukta Bugt 4-15 km from the nesting site.

The diver remained in Myggbukta until the onset of the autumn migration in the beginning of September (day of departure 6 September 2009 and 14 September 2010). It staged on the southwest coast of Iceland for 12-30 days (9-21 September 2009, 20 September-19 October 2010) before it embarked on the last leg of the trip to the wintering area along the coast of southeast England. Here it arrived 23 September in 2009 and 19 October in 2010 and remained until spring.

The spring migration started 21 April 2010 and 3 April 2011. Both years the diver initially took a detour east along the southern coast of the North Sea before it set off for the northwest coast of Iceland. In spring 2010 there was only one position from Iceland (23 May), indicating a very short stopover, whereas in 2011 it probably staged for about two weeks from 21 May-4 June. From Iceland the diver went more or less directly to Myggbukta where it arrived on May 31 2010 and June 4 2011.

Figure 2. Locations and migration routes for a red-throated diver from Myggbukta tracked between 2009 and 2011.

Table 6. Overview of marine mammals occurring in the assessment area. Red List status from Boertmann (2008). 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. *No or limited data available for the assessment area, but species is abundant in neighbouring Norwegian and/or Icelandic waters.

Species	Period of occurrence	Main habitat	Distribution and occurrence in assessment area	Protection/ exploitation	Greenland Red List status	Importance of assessment area to population	VEC
Polar bear	Whole year	Mainly ice-covered waters	Widespread	Hunting regulated	Vulnerable (VU)	High	+
Walrus	Whole year	Coastal waters	Low numbers, very localised	Hunting regulated	Near Threatened (NT)	High	+
Hooded seal	March-October	Whelp on drift ice	Numerous	Hunting unregulated	Least Concern (LC)	High	+
Harp seal	March-October	Whelp on drift ice	Numerous	Hunting unregulated	Least Concern (LC)	High	+
Bearded seal	Whole year	Both in coastal and offshore waters	Widespread in low numbers	Hunting unregulated	Data Deficient (DD)	High	+
Ringed seal	Whole year	Whole area, usually in ice	Common and widespread	Hunting unregulated	Least Concern (LC)	High	+
Bowhead whale	Whole year	MIZ	Widespread, very few	Protected (since 1932)	Critically Endangered (CR)	High	+
Minke whale	June-October	Ice-free waters	Unknown*	Hunting regulated	Least Concern (LC)	Pot. medium	
Sei whale	June-October	Ice-free waters	Unknown*	Protected	Data Deficient (DD)	Pot. medium	
Blue whale	July-October	Ice-free waters	Unknown*	Protected (1966)	Data Deficient (DD)	Pot. high	+
Fin whale	June-October	Ice-free waters	Unknown*	Hunting regulated	Least Concern (LC)	Pot. medium	
Humpback whale	June-October	Ice-free waters	Unknown*	Protected (1986)	Least Concern (LC)	Pot. medium	
Pilot whale	June-October	Outside the ice-covered areas	Unknown*	Hunting unregulated	Least Concern (LC)	Probably low	
White-beaked dolphin	June-October	Outside ice-covered areas	Unknown*	Hunting unregulated	Not Applicable (NA)	Probably low	
Killer whale	June-August	Mainly ice-free waters, whole area	Unknown*	Hunting unregulated	Not Applicable (NA)	Unknown	
White whale	Summer	Fjords and shallow waters	Very rare	Hunting unregulated	Critically Endangered (CR)	Low	
Narwhal	Whole year	Fjords, ice edges	Common	Hunting unregulated	Data deficient (DD)	High	+
Sperm whale	May-November	Deep waters, southern part	Unknown	Protected (1985)	Not Applicable (NA)	Probably low	
Northern bottlenose whale	May-November	Deep waters only, mainly southern part	Probably rare	Unregulated	Not applicable (NA)	Probably low	

Polar bear *Ursus maritimus*

E.W. Born, K. Laidre, R. Dietz, Ø. Wiig, J. Aars & M. Andersen

Background

The distribution of polar bears in East Greenland was summarised by Pedersen (1945), Born (1983), Dietz *et al.* (1985), Born & Rosing-Asvid (1989), Born (1995) and Sandell *et al.* (2001) based on observations made by sealers, various expeditions

and subsistence hunters living in the area and catch statistics. Furthermore, studies involving satellite telemetry during spring 1979 (Larsen *et al.* 1983) and 1993-1998 (Born *et al.* 1997, Wiig *et al.* 2003) provided detailed information on movement of individual polar bears and habitat selection (Durner *et al.* 2007, 2009).

Distribution

Polar bears occur throughout the assessment area along the coasts and in the drift ice areas (Figure 26, 27, Box 8).

Demographic identity of the East Greenland polar bear population

The polar bears in East Greenland are thought to constitute a single population with only limited exchange with other populations (Born 1995, Wiig 1995). Hence, polar bears in East Greenland constitute one management unit (PBSG 2010). Polar bears that are brought by the East Greenland pack ice to Southwest Greenland south of Paamiut (where they are also harvested) belong to the East Greenland population (Born 1995, PBSG 2010).

The movements and habitat use by polar bears in Southeast Greenland south of Tasiilaq (ca. 65° N) have never been studied. However, the existence of two separate subpopulations in Northeast Greenland and Southeast Greenland has been suggested by the finding of significant differences in various cranial traits in polar bears in these two areas (Henrichsen & Sjøvold 1986, Henrichsen 1988). Long-term site tenacity to regions in East Greenland was also indicated in a study of heavy metals. Polar bears that were shot in the coastal areas north of 72° N (1983–1990) had significantly different loads of mercury and cadmium than polar bear shot further south (Dietz *et al.* 2000).

Polar bears typically show fidelity to den and spring feeding areas (Ramsay & Stirling 1990, Wiig 1995). Two adult females that were tracked during 1994–1998 (Wiig *et al.* 2003) showed an affinity during the open-water period to the coastal areas where they had been instrumented (72° and 73° N). However, these bears spent most of their time roaming the offshore pack ice. Therefore, it is likely that the females studied in spring 1973–1975 (Vibe 1976a, b, Born and Rosing-Asvid 1989) also had large home ranges but returned annually to the same denning and spring feeding areas. Indications of the existence of 'local groups' in East Greenland are therefore not unequivocal. A tendency of seasonal site tenacity was also found during satellite tracking of bears between 78° and 81° N in East Greenland (Born *et al.* 1997).

The tendency that some polar bears can be found in the same area during the same season in consecutive years while exploiting much larger areas during their annual cycle has also been reported from other parts of the Arctic where polar bears inhabit areas with dynamic pack ice (Wiig 1995, Amstrup *et al.* 2000, Mauritzen *et al.* 2002).

A genetic study revealed significant differences between polar bears from East and West Greenland (Paetkau *et al.* 1999). Limited exchange between the polar bear subpopulations in these two regions was also indicated by differences in concentrations of mercury in hair and internal organs (Born *et al.* 1991, Dietz *et al.* 2000, 2006).

However, there was only minimal genetic difference between East Greenland and the neighbouring Barents Sea (i.e. Svalbard-Franz Josef Land) subpopulation to the east (Paetkau *et al.* 1999). Interestingly, in the study by Paetkau *et al.,* polar bears

from East Greenland were grouped with the Chukchi Sea, the Southern and Northern Beaufort Sea and the Barents Sea populations indicating that the East Greenland population is not genetically isolated from these other populations (Paetkau *et al.* 1999). Recovery in East Greenland of a few individual polar bears that were tagged in the Northern Beaufort Sea and the Barents Sea populations support the notion that the East Greenland polar bear population is not entirely closed.

Size of the East Greenland population

The habitat used by polar bears basically encompasses all fast ice and offshore pack ice along the entire East Greenland coast. There have been no population inventories covering this vast area and therefore the number of bears in the East Greenland population is not known (e.g. Aars *et al.* 2006).

A mark-recapture study conducted in the fjords and along the coast between Kong Oscars Fjord and Dove Bugt in 1973–1975 (Vibe 1976a, b) resulted in an estimate of approx. 180 polar bears in the coastal areas between approx. 72° and approx. 77° N (Born & Rosing-Asvid 1989).

Given the estimates of the proportion of adult females found in a sample of the catch in the Scoresby Sund area and a catch of approx. 70/year during 1993–2005 (i.e. after introduction of a new catch recording system and before the introduction of quotas in 2006) in East and Southwest Greenland combined, a minimum population of approx. 2000 individuals would have been needed to have sustained this take.

Due to the lack of information on total population size in East Greenland (PBSG 2010) it is not possible to calculate the fraction of the entire population that may be influenced by oil activities in the assessment area.

Recent studies of movement and habitat use of polar bears in the assessment area is described in Box 8.

Maternity denning sites

Female polar bears move to coastal areas in autumn where they dig a burrow in a snowdrift (a maternity den) in which they give birth to their cubs around 1 January.

During the study period (2007-2010) seven maternal denning sites used by five female bears were identified along the coast (Box 8, Figure 3). All these dens were on land. Five of the dens were clustered between 78°44' N and 81°24' N (i.e. along the shores of the Northeast Water Polynya) while two were on the coast north of Scoresby Sund between 71° and 72° N on Liverpool Land and Traill Ø, respectively. Two female bears denned twice during the study period and in both cases the dens were situated on the shore of the Northeast Water Polynya.

Entry into the maternity dens occurred between September 14 and October 17, however most of the entry dates were in the first week of October. Emergence from the dens occurred the following year between March 18 and April 8.

Miscellaneous observations of maternity dens and family groups with 0-year-old cubs indicate that maternity dens may occur along the entire East Greenland coast with an apparent tendency of higher densities north of approx. 68° N (Pedersen 1945, Born 1983, Dietz *et al.* 1985, Born & Rosing-Asvid 1989, Glahder 1995, Born *et al.* 1997, Sandell *et al.* 2001, Wiig *et al.* 2003), where ice and weather conditions are generally more stable than further south (Vibe 1967). Previous information indicates

Box 8

The 2007-2010 study on polar bear habitat use in East Greenland

E.W. Born, K. Laidre, R. Dietz, Ø. Wiig, J. Aars and M. Andersen

A study initiated in March 2007 involving the use of satellite transmitters was aimed to provide supplementary and updated information on distribution, movement and habitat use of polar bears in the assessment area. During this study a total of 36 polar bears were immobilized and tagged in late winter 2007 and 2008 on the fast ice and the pack ice in the East Greenland region between 72°09' N and 81°05' N and between 25°17' W (western Kong Oscars Fjord, E Greenland) and 13°13' E (NW Spitsbergen, Svalbard), Table 1. Twenty-five of these bears were fitted with a satellite radio and results were used to describe habitat use by polar bears in the Greenland Sea assessment area between 2007 and 2010 (Table 2).

Table 1. Information on number, date and location for polar bears that were immobilized and tagged during late winter 2007 and 2008 in East Greenland and Northwest Spitsbergen (Svalbard) with information on sex, individual age, satellite transmitter type and their ID number.

No	ID	No.	Satellite ID no.	Sex	Tooth[1] age (yrs)	Date			Tagging location				Transmitter type Telonics A-3610 collar WC: SPOT5 matchbox
						Day	Month	Year	Min N	Deg	Deg	Min	W/E	
1	D	7360	74762	F	7	16	3	2007	72	10	20	24	W	Telonics A-3610
2	D	7361	–	F	1	16	3	2007	72	10	20	24	W	–
3	D	7362	74777	M	15	17	3	2007	72	13	19	24	W	WC: SPOT5
4	D	7363	74763	F	4	17	3	2007	72	32	20	47	W	A-3610
5	D	7364	74764	F	9	22	3	2007	73	7	19	7	W	A-3610
6	D	7365	–	F	2	22	3	2007	73	7	19	7	W	–
7	D	7366	–	M	2	22	3	2007	73	7	19	7	W	–
8	D	7367	74778	M	18	24	3	2007	73	23	20	40	W	SPOT5
9	D	7368	74779	M	11	24	3	2007	73	19	17	3	W	SPOT5
10	D	7369	74780	F	4	24	3	2007	73	33	19	6	W	SPOT5
11	D	7250	74765	F	14	28	3	2007	72	42	17	18	W	A-3610
12	D	7251	74766	F	14	29	3	2007	73	12	17	11	W	A-3610
13	D	7252	–	M	1	29	3	2007	73	12	17	11	W	–
14	D	7253	74781	M	5	29	3	2007	73	39	17	24	W	SPOT5
15	D	7254	74767	F	8	30	3	2007	73	7	17	1	W	A-3610
16	D	7255	74782	M	2	30	3	2007	73	7	17	1	W	SPOT5
17	N	23879	–	M	12	22	3	2007	76	59	11	31	W	–
18	D	7256	74768	F	6	22	7	2007	72	9	16	9	W	A-3610
19	D	7257	–	F	0	22	7	2007	72	9	16	9	W	–
20	D	7258	–	F	0	22	7	2007	72	9	16	9	W	–
21	D	7259	74777	M	13	12	3	2008	81	5	5	37	E	SPOT5
22	D	7260	74769	F	13	22	3	2008	73	56	16	50	W	A-3610
23	D	7261	68011	M	2	22	3	2008	73	57	16	49	W	SPOT5
24	D	7262	68012	M	16	22	3	2008	73	56	16	50	W	SPOT5
25	D	7263	68013	M	3	25	3	2008	72	54	25	17	W	SPOT5
26	D	7264	74770	F	13	25	3	2008	72	20	22	18	W	A-3610
27	D	7265	–	M	0	25	3	2008	72	20	22	18	W	–
28	D	7266	–	M	0	25	3	2008	72	20	22	18	W	–
29	D	7267	68014	F	5	26	3	2008	72	42	22	43	W	SPOT5
30	D	7268	74771	F	10	26	3	2008	72	23	24	22	W	A-3610
31	D	7269	–	M	0	26	3	2008	72	23	24	22	W	–
32	D	7270	–	M	0	26	3	2008	72	23	24	22	W	–
33	D	7271	74779	M	13	30	3	2008	77	29	5	23	W	SPOT5
34	N	23882	74772	F	7	14	4	2008	79	27	13	13	E	A-3610
35	N	23824	74773	F	10	14	4	2008	79	44	12	13	E	A-3610
36	N	23942	74774	F	8	16	4	2008	79	45	12	6	E	A-3610

[1]Age estimated from reading growth layers groups in tooth cementum except for N23879, N23882, N23824 and N23942 where expert estimates of field age is given.

Results

Home ranges and focal areas

Tracking of polar bears between March 2007 and March 2010 confirmed previous information that polar bears in East Greenland are widely distributed over a large and consistent portion of the Northeast Greenland coast and offshore pack ice in Fram Strait, the Greenland Sea and Denmark Strait at all times of the year. The area used by polar bears extended offshore between 200-500 km and ranged over ca. 16 degrees of latitude from ca. 66° N (the Tasiilaq area) to ca. 82°N (north of Nordostrundingen in Greenland). This covers the offshore pack ice areas between ca. 38° W at Tasiilaq to ca. 11°E at ca. 81° N north of Spitsbergen in the Svalbard archipelago. As sea ice recedes during spring and summer the range of the polar bears shifts north (Figure 1a, b, c).

Total 95 % kernel seasonal home range sizes for the entire population were 553 471 km^2 in winter, 453 767 km^2 in spring and 549 132 km^2 in summer (Figure 1a, b, c, Figure 2).

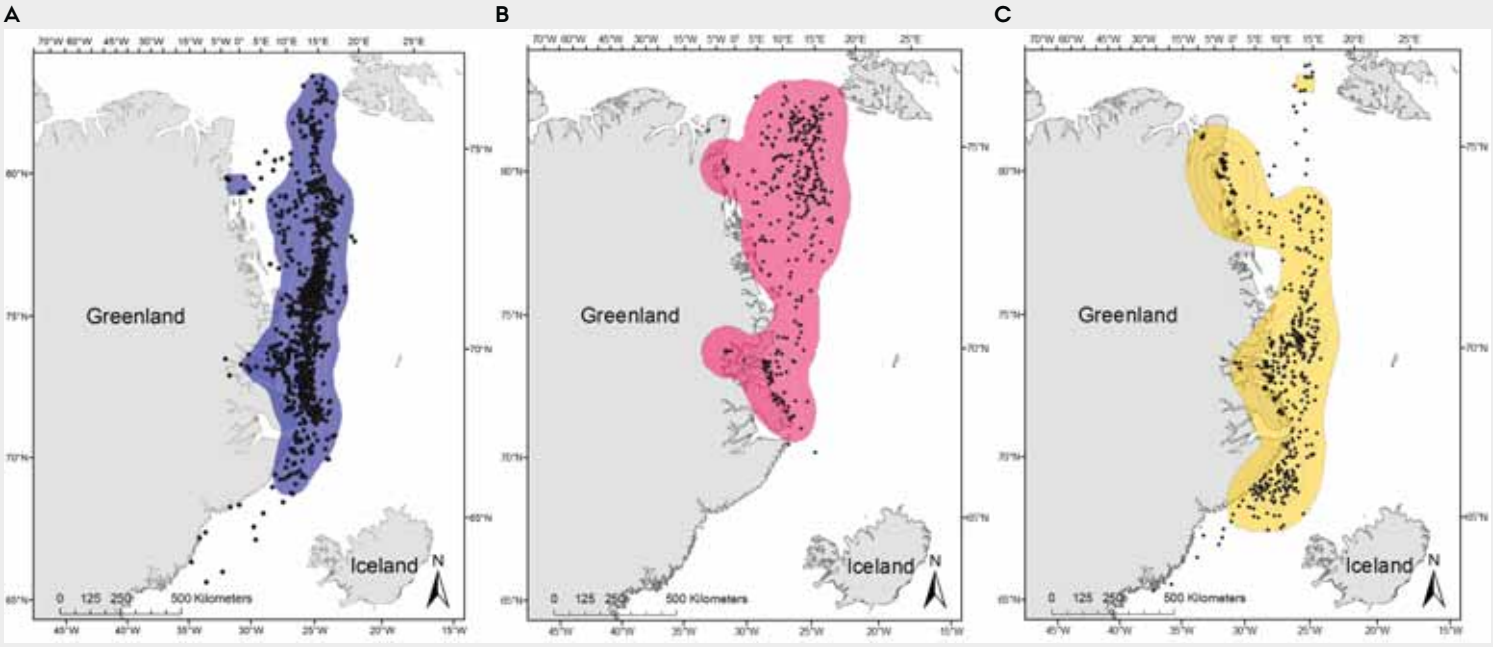


Figure 1. A) Winter 95 % kernel home range, March 2007-March 2010 based on one location per day for18 polar bears that were instrumented with satellite transmitters in East Greenland in 2007 and 2008. The bears showed a clear affinity to the eastern edge of the pack ice in the Fram Strait-Greenland Sea area. B) Summer 95 % kernel home range, March 2007- March 2010 based on one location per day for 10 polar bears that were instrumented with satellite transmitters in East Greenland in 2007 and 2008. Home range shifts north in summer with receding sea ice. C) Spring 95 % kernel home range, March 2007-March 2010 based on one location per day for 18 polar bears that were instrumented with satellite transmitters in East Greenland in 2007 and 2008.

General movement patterns were contrasted between male and female polar bears during the on-ice period in spring and early summer (see section below), however multi-annual analyses were limited to adult females only given the duration of tracking with satellite radio collars (i.e. not including ear satellite radio tags). Adult females tracked in this study for up to 3 years (in total n = 7) ranged widely over the entire coastline of northeast Greenland and covered over 2 000 km in a single year. Of the 7 adult female bears, 5 moved south of Scoresby Sound into Denmark Strait (Figure 3). This movement occurred during winter and spring months on the sea ice.

In spring, the population uses a very clearly defined linear home range region (blue in Figure 4) along the sea ice edge from nearshore at ca. 70° N to offshore at 79-80° N. The area of this home range is approximately 179 000 km^2. In summer or the 'open water season', bear focal areas include one of two regions, a northern region on the receding annual ice and multi-year pack ice offshore between ca. 77° N and ca. 80° N between NE Greenland and Svalbard or an area closer to the coast north of Scoresby Sound between 71° N and ca. 73°30' N (red in Figure 4). The summer 75 % focal area is in total approximately 189 000 km^2. In winter, bear focal areas are closer to the coast and shift south with the forming annual pack ice (yellow in Figure 4). This includes three general regions – one in NE Greenland between ca. 78° N and 81° N, one north of Scoresby Sound between ca. 70° and ca. 74°30' N, and one south of Scoresby Sound along the Blosseville Coast in northern Denmark Strait. The total winter 75 % kernel range is approximately 204 000 km^2.

The three adult females that were instrumented in April 2008 on the fast ice of NW Spitsbergen (Svalbard) only showed relatively local movement in more and less the same area where they were tagged (data not shown).

Table 2. Polar bears tagged in 2007 and 2008 used in the analysis. Table shows year of tagging, PTT (Platform terminal transmitter) ID number, animal ID, start and stop of transmission, durations of tracking, individual age (years) obtained from reading growth layers in pm1 tooth cementum, age category, standard body length (cm), satellite transmitter type and fraction of total received locations that were on land. Four bears (74767, 74781, 74782 and 74771) were not included in analyses because their transmitters stopped prematurely either because of transmitter failure or because the bear died. Individual ages for bears 74772, 74773 and 74774 tagged in NW Spitsbergen are expert estimates of age in the field. The fraction on land is not given for these 3 bears because they were not included in the analyses of use of sea ice habitat in East Greenland.

Year	PTT	animal ID-PTT	Start date	Stop date	# days	Tooth age	Age Cat	SL	Type	Fraction on land
2007	74762	D7360-74762	3/17/07	8/29/09	896	7	AF	212	collar	0.12
2007	74763	D7363-74763	3/17/07	11/25/09	984	4	SF	205	collar	0.19
2007	74764	D7364-74764	3/22/07	12/20/08	639	9	AF	212	collar	0.27
2007	74765	D7250-74765	3/28/07	3/29/10	1097	14	AF	216	collar	0.03
2007	74766	D7251-74766	3/29/07	3/29/10	1096	14	AF	212	collar	0.12
2007	74767	D7254-74767				8		218	collar	
2007	74777	D7362-74777	3/17/07	6/9/07	84	15	AM	263	spot	0.00
2007	74778	D7367-74778	3/24/07	7/5/07	103	18	AM	232	spot	0.01
2007	74779	D7368-74779	3/24/07	8/29/07	158	11	AM	244	spot	0.13
2007	74780	D7369-74780	3/24/07	4/23/07	30	4	SF	183	spot	0
2007	74781	D7253-74781	3/29/07	4/9/07	11	5	AM	221	spot	0
2007	74782	D7255-74782				2		176	spot	
2008	68011	D7261-68011	3/22/08	5/26/08	65	2	SM	203	spot	0
2008	68012	D7262-68012	3/22/08	6/11/08	81	16	AM	238	spot	0
2008	68013	D7263-68013	3/25/08	5/2/08	38	3	SM	214	spot	0.67
2008	68014	D7267-68014	3/26/08	5/18/08	53	5	AF	215	spot	0.06
2008	74769	D7260-74769	3/22/08	3/29/10	737	13	AF	213	collar	0.52
2008	74770	D7264-74770	3/25/08	3/29/10	734	13	AF	223	collar	0.22
2008	74771	D7268-74771				10		200	collar	
2008	74777	D7259-74777	3/12/08	7/19/08	129	13	AM	238	spot	0
2008	74779	D7271-74779	3/30/08	6/27/08	89	13	AM	257	spot	0
2008	74772	N3882-4772	4/14/08	3/17/10	702	7	AF	207	collar	NA
2008	74773	N3824-4773	4/14/08	8/21/09	494	10	AF	215	collar	NA
2008	74774	N3942-4774	4/14/08	12/20/08	250	8	AF	205	collar	NA

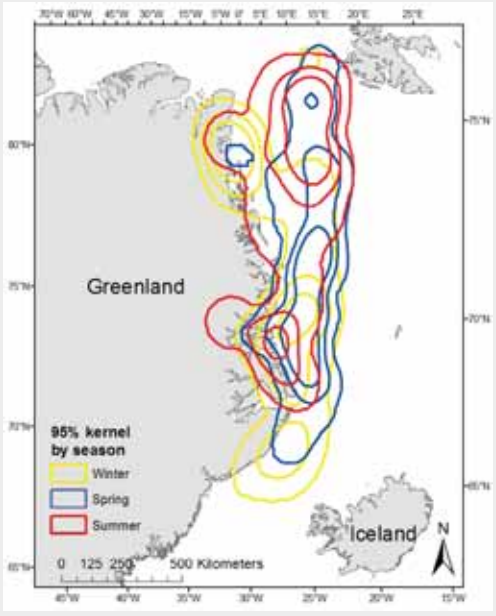


Figure 2. All seasons combined for 95 % kernel home range, 2007-2010, based on one location per day per bear. Note the large extent of overlap for the home ranges in each season.

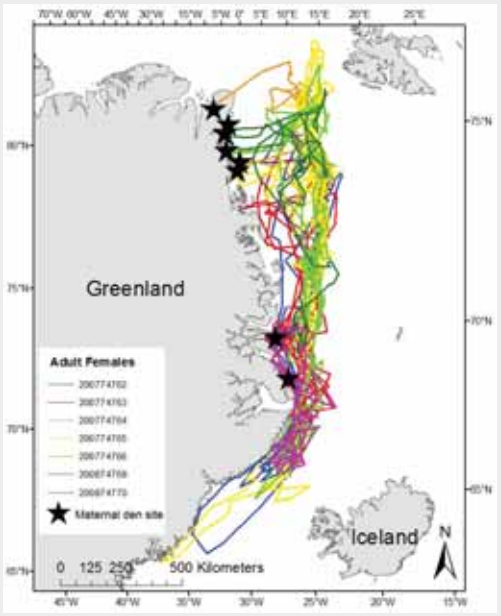


Figure 3. Movements of adult female polar bears (n = 7) during March 2007-March 2010, and maternal den sites (stars) during the winters 2007/08, 2008/09 and 2009/10.

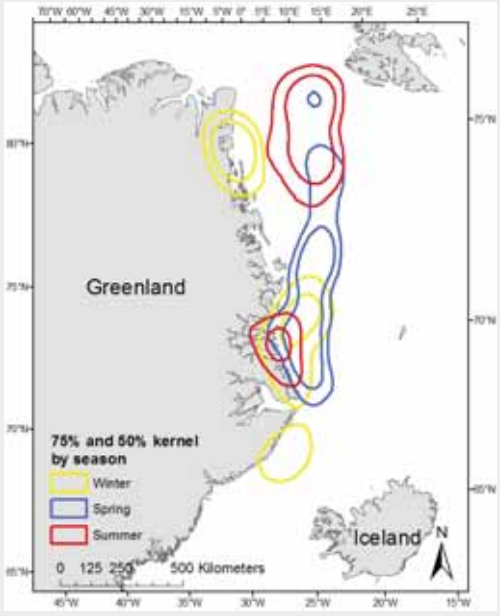


Figure 4. Focal areas or "hot spots" used by polar bears in winter, spring and summer as defined by 75 and 50 % kernel contours based on one location per day per bear.

Comparison between adult female and adult male movement metrics

Adult females and males demonstrated no difference in 4-day displacements either when all months were combined or when spring and summer were analyzed separately. They moved the same total number kilometers over a 4-day period, however, there were highly significant differences between the tortuosity of movements of adult females and males. Female movement was significantly more linear while male movement was more tortuous and less directed. This difference was present when all months were pooled (April to August) and also when the mating season (April and May) was examined independently.

Sea ice habitat analysis

Sea ice in East Greenland undergoes a large annual cycle which has a great influence on the movements of polar bears. Monthly maps of the sea ice concentration and location of bears on a given day demonstrates the extent over which the sea ice changes and how the bears respond (Figure 5).

In general polar bears in Northeast Greenland had a remarkable affinity for using sea ice in all months of the year. Overall bears spent little time on land in any given month outside of time spent on land for denning. On average across the population, only 16 % of all bear locations were in land.

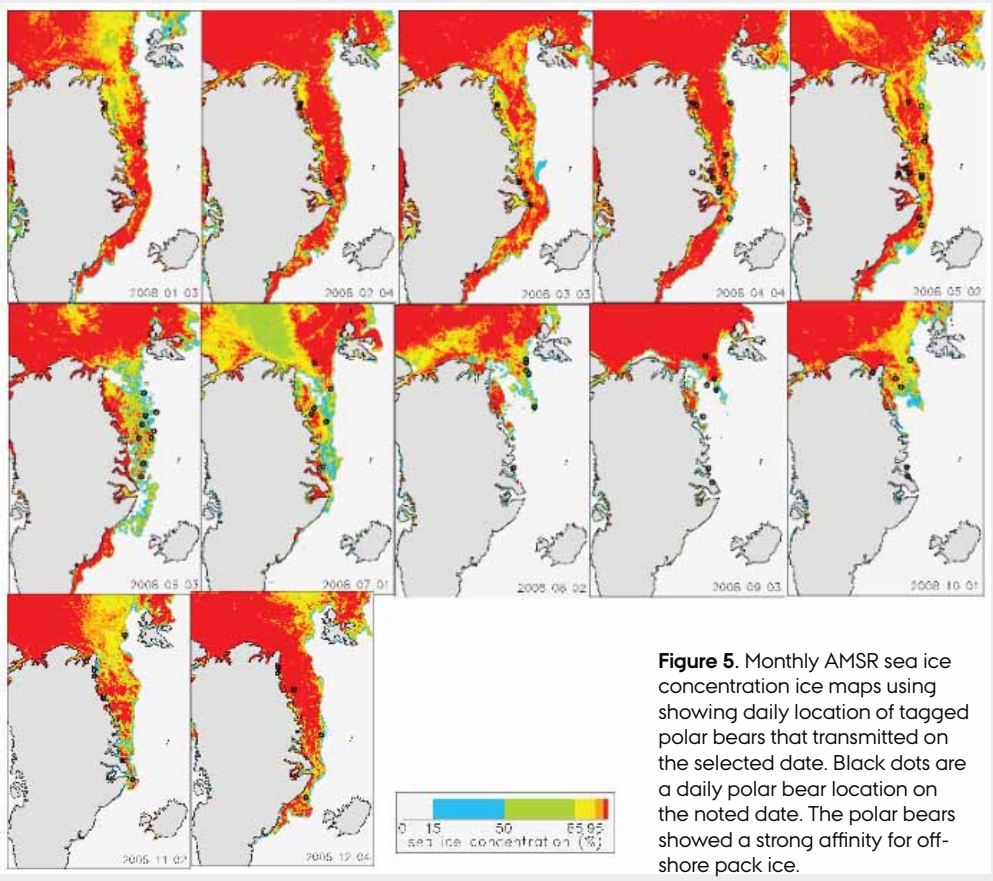


Figure 5. Monthly AMSR sea ice concentration ice maps using showing daily location of tagged polar bears that transmitted on the selected date. Black dots are a daily polar bear location on the noted date. The polar bears showed a strong affinity for offshore pack ice.

Preliminary results of the polar bear sea ice preferences showed several intriguing patterns

Adult females were located on significantly higher sea ice concentration in all seasons when compared to available habitat. This suggests the tactic for adult females is to follow the ice north into the multi-annual pack ice in summer and select for dense sea ice year-round unless they are in a maternity den.

Adult females also had a strong preference for being located approximately 35-55 km from the sea ice edge (when defined as 15 % sea ice concentration) or 20-40 km from the sea ice edge (when it was defined as 50 % sea ice concentration). Females adjusted their locations relative to the location of the ice edge so that they could be present in preferred sea ice habitat. In winter months when the average distance to the sea ice edge was larger due to wide spread sea ice cover, females actively selected to be present in areas that were significantly closer to the ice edge than what was present across the null sets of available habitat. The reverse was true in summer months and for both sea ice edge thresholds (15 % or 50 %).

Adult males demonstrated a similar pattern as adult females, strongly selecting for dense sea ice concentrations in spring and summer. Adult males showed a similar pattern to adult females for selection of the sea ice edge in spring. However, the time series for adult males was much shorter because ear tags fell off or stopped transmitting due to battery exhaustion, so it was not possible to evaluate their selection over the entire year or even beyond the summer season.

The sample sizes for sub-adult females was n = 1. Sample sizes for sub-adult males were also small with very short tracking durations. Therefore, results for these two categories should be interpreted with caution.

Table 3. Age/sex category (adult males vs. adult females), period, sample sizes (n = number of bears), means and SDs summarized for the comparison between spring/summer displacement of polar bears in East Greenland. S.median = median 4 day displacement (km) and Kappa = mean cosine of the turning angles (unitless). Kappa was significant for an interaction between sex and season ($p < 0.05$) while there were no significant differences between sex and season for displacement.

Sex	Seasons	n	Kappa. mean	Kappa.sd	S.median. mean	S.median.sd
AF	Mating	11	0.290	0.439	53	25
AF	Summer	10	0.211	0.140	55	20
AM	Mating	5	0.059	0.212	57	18
AM	Summer	2	0.335	0.407	61	4

Discussion and conclusion - Home ranges, focal areas, female and male movement and sea ice analysis

Generally, polar bears inhabiting active and highly fluctuating offshore ice make use of considerable areas of sea-ice covered habitat during the year. They have larger home ranges than bears inhabiting land-fast ice (Ferguson *et al.* 1999, Amstrup *et al.* 2000, Mauritzen *et al.* 2002).

The 2007-2010 study showed that polar bears exploit vast areas of the offshore pack ice in Fram Strait, the Greenland Sea and Denmark Sea and the East Greenland coast in these areas. The seasonal 75 % kernel home-range of the bears ranged between 180 000 and 205 000 km^2. The home ranges of these bears were for the most part concentrated in Northeast Greenland and although some bears ranged into Southeast Greenland it was not a concentration area.

Previous satellite-telemetry studies in East Greenland (1993–1998) indicated that the home range of polar bears exploiting the offshore pack ice for most of the year are on average approximately five times larger than those of polar bears that prefer coastal habitat (mean: approx. 50 000 km^2) (Born *et al.* 1997, Wiig *et al.* 2003).

Although the polar bears roamed vast areas of comparable size during all seasons there was some seasonal variation in focal areas. The spring distribution likely reflected an affinity to the whelping patches of harp and hooded seals and the ice edge where there presumably is access to various seals including immature ringed seals and narwhals. The distribution during summer reflected the fact that the polar bears show strong affinity to dense sea ice as shown in this study and therefore follow the northward retreat of the pack ice where food (seals) is available during summer. In winter the bears seemed to prefer to stay in vicinity of denning areas and closer to the coast, or they move south into Denmark Strait.

According to observations made by hunters living in coastal East Greenland there is a general 'passive' transport of polar bears south with the drifting ice and an 'active' movement north along the coast (Dietz *et al.* 1985, Sandell *et al.* 2001). However, this and other studies involving the use of satellite telemetry (Larsen *et al.* 1983, Born *et al.* 1997, Wiig *et al.* 2003, this study) have shown that polar bears are able to move south and north in the pack ice irrespective of the general southward movement of the ice floes in the East Greenland Current. Wiig *et al.* (2003) suggested that the distribution of polar bears in the East Greenland pack ice likely reflects behavioural rather than physical processes, similar to the case of the polar bears in the Barents Sea (Mauritzen *et al.* 2003). The highest rates of movement occurred from April to September. A higher rate of movement in summer than in winter potentially relates to the slower southward ice drift of the East Greenland Current in summer than in winter or it may reflect increased feeding activity during the summer (Born *et al.* 1997, Wiig *et al.* 2003).

The 2007-2010 study demonstrated a clear preference for areas with dense sea ice. This is accordance with Wiig *et al.* (2003), who found that polar bears in East Greenland showed a preference for areas with ≥70 % ice cover at all seasons.

In conclusion: Polar bears exploit vast coastal and offshore areas in East Greenland throughout the year. Tracking of polar bears equipped with satellite radios during 2007-2010 showed that the bears make extensive use of the assessment area at all seasons. In particular the eastern edge of the pack ice between the entrance to Scoresby Sound (East Greenland) and NW Spitsbergen (Svalbard) seems to be important polar bear habitat.

Table 4. Median values for sea ice habitat parameters at daily polar bear locations by age class and season. 25 % and 75 % interquartile range are shown in parentheses. Values that are significantly different from the random expectation of available habitat at $p < 0.05$ are bold. Values for the bear locations that were higher than expected are denoted by a *. Legend: For definition of season see Introduction. Age category: AF = adult female, AM = adult male, SF = subadult female and SM = subadult male.

Season	Age Cat	N	Ice at pixel	Ice within 45 km	Ice within 85 km	Distance to land	Distance to 15 % ice	Distance to 50 % ice	Bathy
Spring	AF	3808	96 (86,100)*	85 (70,93)*	75 (61,88)*	141 (100,215)	39 (22,69)*	23 (11,43)*	610 (1752, 274)
Spring	AM	1874	95 (86,99)*	85 (73,93)*	76 (64,85)*	129 (92,162)	39 (23,61)*	23 (12,42)*	613 (1674, 308)
Spring	SF	971	93 (80,99)*	84 (64,93)*	80 (57,88)	83 (59,112)	40 (17,66)*	20 (9,40)*	362 (579,253)
Spring	SM	185	96 (84,100)*	91.9 (85,96)*	91.1 (85,95)*	87 (56,107)	76 (27,116)*	41 (12,75)*	267 (402,205)
Summer	AF	4827	88 (59,99)*	73 (47,91)*	63 (45,81)*	205 (144,253)*	34 (11,60)*	19 (6,41)*	1331 (2647,474)*
Summer	AM	384	90 (67,95)*	56 (35,68)*	56 (42,61)	50 (34,93)	20 (14,28)	15 (4,21)	449 (586,296)
Summer	SF	958	10 (0,62)	28 (12,48)	26 (15,50)	96 (46,221)	4 (3,19)	3 (2,7)	338 (855,196)
Winter	AF	9584	100 (94,100)*	94 (82,99)	84 (68,95)	92 (43,130)	55 (34,88)	40(22,66)	418 (1145,258)*
Winter	AM	438	99 (93.25,100)	93 (86,98)	82 (76,89)	113 (90,124)	57 (45,68)	42 (28,55)	273 (411,235)
Winter	SF	1666	98 (88,100)	95 (88,98)	92 (84,95)	55 (41,99)	96 (68,134)	58 (18,92)	311 (472,180)
Winter	SM	185	100 (99,100)*	97 (95,98)	87 (86,89)	99 (87,109)	64 (61,84)	55 (48,59)	316 (390,216)

that the following areas are regularly used for denning: Kangerlussuaq, the Blosseville Kyst, the inner parts of the Scoresby Sund fjord complex, the areas between Kong Oscars Fjord and Kejser Franz Joseph Fjord, Shannon, Dove Bugt, the areas between Île de France and Ingolf Fjord, and the coast at the Northeast Water.

The present study confirmed that adult female polar bears choose the areas between Kong Oscars Fjord and Kejser Franz Joseph Fjord and the coast at the Northeast Water for denning and these are important maternity denning areas.

Amstrup & Gardner (1994) suggested that polar bears that exploit the drifting pack ice until just before den entry have a less predictable choice of denning location that bears living on stable ice. This was also indicated in Wiig *et al.* (2003) where a female in different years entered maternity dens that were situated more than 500 km apart on the East Greenland coast. It is likely that some polar bears exploiting the dynamic pack ice in the East Greenland Current may choose highly alternating sites for maternity denning and that their choice depends on the extension and density of the pack ice before den entry in that particular year. However, this tendency was not confirmed by the present study but it must be emphasized that sample size was very small.

Larsen *et al.* (1983) noted that approx. 90 % of the tracks that were observed during the FRAM I expedition at approx. 83° N off Northeast Greenland were of females with small cubs. Based on the distance of such tracks from the coast and with the resemblance to the ice situation off the northern coast of Alaska where polar bears use maternity dens in offshore pack ice, Amstrup & DeMaster (1988) suggested that maternity dens may also be found on the multi-year pack ice in Northeast Greenland. However, this has not yet been confirmed during studies involving tracking of adult female polar bears (Born *et al.* 1997, Wiig *et al.* 2003, this study).

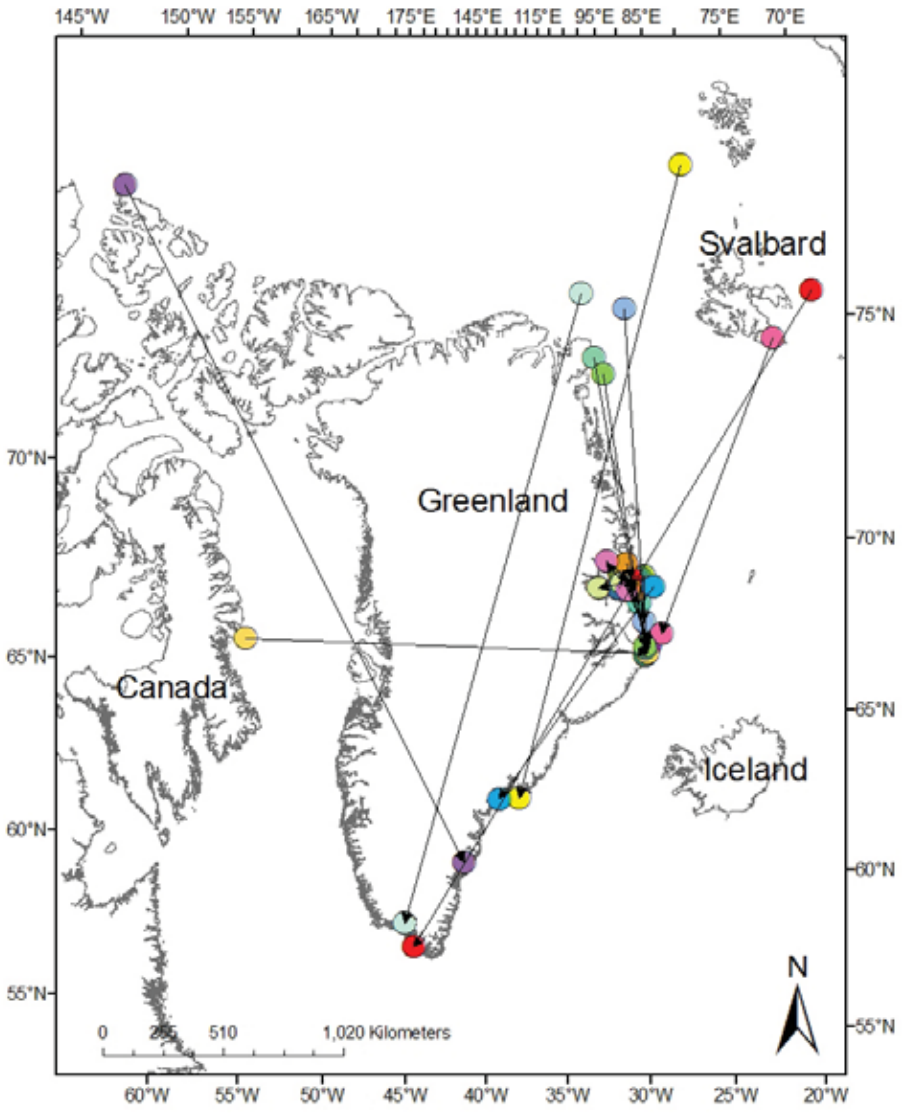
In conclusion: The 2007-2010 study supported the notion that the East Greenland coast between ca. 72° N and ca. 74° N and between ca. 78° N and ca. 82° N are important maternity denning areas for female polar bears.

Harvest recoveries and the relationship with other polar bear populations

Among 27 tags that were recovered in East and SW Greenland (i.e. in the East Greenland polar bear management unit), 22 (81 %) were polar bears that had been tagged in the East Greenland area (Figure 21). The majority of these (n = 15) were bears that were tagged in the central parts of East Greenland between ca. 72°35' N and 73°23' N between 1993 and 1975. They were shot by hunters in more and less the same area (i.e. between 69°55' N and 73°08' N) between 1974 and 1980 (Figure 21). Of six bears (3 females, 3 males) tagged north of 72° during 1979-1994, five were shot by hunters between ca. 70° and ca. 73° N in East Greenland. However, one was shot near Narsaq in SW Greenland confirming that bears that occur in SW Greenland belong to the East Greenland population. A 15-year-old male that was tagged in the pack ice on 17 March 2007 off Traill Ø (72°13' N, 19°24'W) as a part of the present study was shot near Isortoq in SE Greenland (65°33' N, 38°58'W) on 10 April 2010. The data support the earlier findings from satellite telemetry (Born *et al.* 1997, Wiig 1995, Wiig *et al.* 2003) that polar bears in East Greenland belong to one population which is separated to a large extent from neighbouring areas.

However, polar bears that were tagged in other polar bear populations were also recovered in East and Southwest Greenland. Three polar bears (2 males, 1 female) tagged in the Barents Sea population were recovered in SE and SW Greenland (tagging year/recovery year: 1967/1968; 1980/1986; 1989/1991). Furthermore, a female polar bear that was tagged in 1983 in the Baffin Bugt population was shot

Figure 21. Locations of bears marked in East Greenland and other polar bear management units and recovered in East Greenland between 1967 and 2010. Coloured dots are unique for each bear.



at the entrance to Scoresby Sund in 1992. A male that was tagged in 1993 in the Northern Beaufort Sea population in 1993 was shot in SE Greenland in 1996. This demonstrates that some (but presumably) very few polar bears from other populations migrate to East Greenland.

Five polar bears that were instrumented in the Svalbard area moved west northwest and had some overlap with East Greenland polar bears in the Fram Strait-northern Greenland Sea during spring and summer. Overlap, as defined as a polar bear tagged in Svalbard entering the 95% seasonal home range of bears from East Greenland, occurred during the spring and summer season specifically during the months of May, June and July (Figure 22). No overlap during the winter was detected. Hence, factors affecting East Greenland polar bears in their northern and offshore parts of their range may affect the Barents Sea population to an unknown extent.

Movement of marked bears into the East Greenland region indicates that there is a likely limited immigration to the East Greenland population of polar bears from other populations

In addition to the data summarized here there is information from satellite telemetry of migration to East Greenland. In the early 1990s, two polar bears instrumented with satellite radios in the Southern and Northern Beaufort Sea, respectively, visited

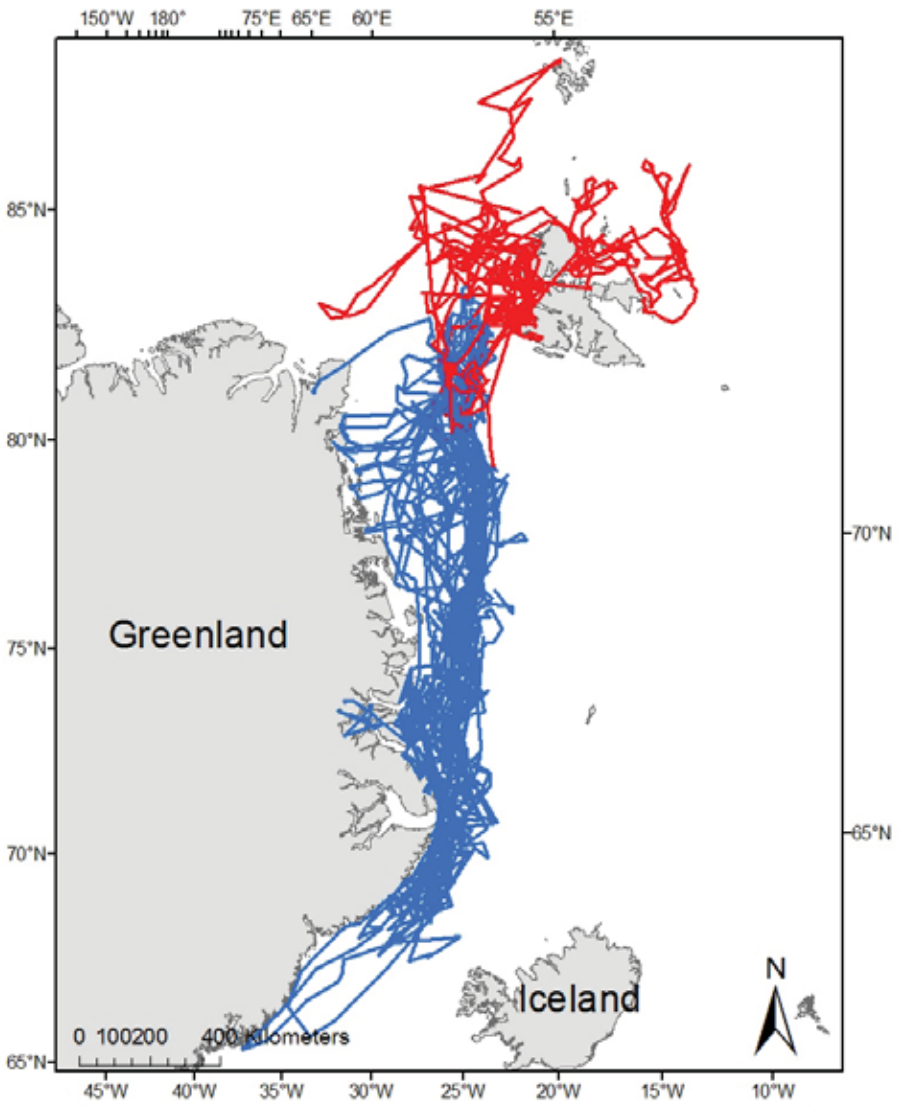


Figure 22. Tracks of polar bears monitored with satellite transmitters in East Greenland (2007-2010) and the Svalbard region (2000-2008, n = 5). The polar bears from Svalbard represent a sub-set of polar bears that have been tracked in this region. The five bears from Svalbard were selected for this study because they moved into the assessment area. The map shows that there is some overlap during spring and summer in Fram Strait and the northern Greenland Sea between polar bears from the East Greenland and the Barents Sea populations.

Northeast Greenland (Durner & Amstrup 1995, Durner *et al.* 2007, 2009). This indicates that some polar bears mainly from the active ice in the rim of the Polar Basin migrate to East Greenland, presumably reflecting the main movement of the drift ice in the Polar Basin and East Greenland. However, given the fact that over the years several hundred polar bears have been tagged in the Southern and Northern Beaufort Sea (e.g. Stirling 2002, Regehr *et al.* 2006 and references therein), the migration of bears from these areas to East Greenland appears to be negligible.

During 1966–1993, only 2 of 389 (0.5%) bears conventionally marked at Svalbard had been caught in the East and Southwest Greenland (Wiig 1995) despite an annual catch of about 90 polar bears there during this period (Born unpublished data). After 1993 and until present more than total of 1100 polar bears (including juveniles) have been tagged in the Svalbard archipelago (Aars, unpublished data), to our knowledge with no subsequent recoveries in East and Southwest Greenland.

Movement of polar bears that were instrumented with satellite transmitters in East Greenland (n = 9; Born *et al.* 1997, Wiig *et al.* 2003) and at southern Svalbard, Franz Josef Land and the Kara Sea (n = 105; Wiig 1995, Mauritzen *et al.* 2002) before 2000 did not show any overlap in habitat use. An exception was a polar bear that made an excursion from Kongsøya in the eastern part of the Svalbard archipelago towards Northeast Greenland at 82°–83° N and approx. 20° W in 2000 (Wiig *et al.* 2000, Mauritzen *et al.* 2002).

Existence of separate populations in the East Greenland and Barents Sea regions was further supported by the finding of significant differences in prevalence of various cranial traits in East Greenland and Svalbard-Franz Josef Land polar bears (Henrichsen & Sjøvold 1986, Henrichsen 1988, Sonne *et al.* 2007, Bechshøft *et al.* 2008a, b, c).

However, satellite telemetry indicates that there might be some overlap in distribution in the Fram Strait and East Greenland Sea by East Greenland and Svalbard polar bears. The majority of satellite radios deployed in Svalbard by the Norwegian Polar Institute since 1988 have been deployed in the southeastern parts of the archipelago (Wiig 1995, Aars *et al.* unpublished data). Only one out of 220 polar bears instrumented in this area made an excursion west where it came as close as approx. 100 km of the Nordostrundingen in Northeast Greenland (Aars *et al.* unpublished data). However, in the present context it is noteworthy that three out of 16 (approx. 19%) polar bears that were instrumented in northern and northwestern Svalbard in 2006 and 2007 made migrations north of Svalbard and towards Northeast Greenland and in one case into the Fram Strait (i.e. the assessment area), thereby overlapping with the range of the East Greenland polar bears. A polar bear tagged in central East Greenland during March 2007 came as close as 100 km from the north eastern corner of Svalbard. This indicates some overlap between the ranges of East Greenland and Svalbard polar bears and that a certain and yet undetermined proportion of the Barents Sea subpopulation of polar bears may potentially be affected by oil activities in East Greenland.

In conclusion: Existing information indicates that there is only limited exchange between the East Greenland and Barents Sea population of polar bears. Although polar bears from other populations than Barents Sea may also immigrate to East Greenland it seems that this immigration is limited. However, satellite telemetry indicates that some polar bears from the Barents Sea population enter the assessment area and therefore potentially may be affected by oil activities in East Greenland.

The catch

Polar bears are caught by subsistence hunters living in the former municipalities of Ittoqqortoormiit and Tasiilaq in East Greenland (e.g. Sandell *et al.* 2001) and are still an important way of income. In addition, an average of approx. 7 bears/year (range: 0–16/year) are taken by hunters living in Southwest Greenland and these bears have their origin in the East Greenland population (Born 2007).

In East Greenland, the majority of the catch activity takes place within approximately 100 km of the permanently populated areas and generally not far from the coast (Glahder 1995, Born 1983, Sandell *et al.* 2001). However, in some cases hunters from the community at the entrance to Scoresby Sund make sled trips on the fast ice in the fjords and along the coast to hunt polar bears as far north as the Dove Bugt (approx. 77° N) (Born 1983, Sandell *et al.* 2001). Apparently, it was common to make such trips in the 1970s and 1980s, but hunting activity in the areas north of Scoresby Sund decreased during the 1990s (Sandell *et al.* 2001).

In Greenland, quotas for the polar bear hunt were introduced 1 January 2006. The annual quota for the East Greenland subpopulation for the period 2007–2009 was 54 (30 in Ittoqqortoormiit, 20 in Tasiilaq and 4 in Southwest Greenland). This was raised to 64 in 2011 and 2012 (35 in Ittoqqortoormiit, 25 in Tasiilaq and 4 in Southwest Greenland) (Greenland Government 2012).

Prior to 2006 the catch fluctuated. Between 1993 and 2005 the catch from the East Greenland subpopulation averaged approximately 60 polar bears per year (range: 46–84; Born 2007). However, at the beginning of the 20th century catches were much larger, averaging more than 100 bears per year (Vibe 1967, Sandell *et al.* 2001, Rosing-Asvid 2006). Since the early 1900s the catch of polar bears from the East Greenland subpopulation has decreased significantly (Sandell *et al.* 2001). It cannot be precluded that this tendency reflects an overall decrease in the exploited population.

Future scenario and conservation status

Using 10 of the scenarios by the Intergovernmental Panel of Climate Change (IPCC) of projected decrease of sea ice and resource selection functions (RSF) based on data from satellite telemetry on polar bear habitat preferences including data from East Greenland (1993-1998), Durner *et al.* (2007, 2009) forecasted that optimal polar bear habitat in East Greenland will decrease substantially during the next 50–100 years. The decrease will be most pronounced during spring and summer. A decrease in sea ice in the southern range of the polar bears will imply that areas with optimal polar bear sea-ice habitat in Northeast and North Greenland will become more important. Hence, it is projected that the northern parts of the assessment area progressively will be of increasing importance to the East Greenland population of polar bears.

The prognosis of the increasing negative effects on polar bears of a future decline of sea ice was the main reason for listing the polar bear as 'Vulnerable' (VU) on the both the global and the Greenland Red List.

Sensitivity

While moving on pack ice the polar bears frequently enter the water to swim (Aars *et al.* 2007), thereby increasing their risk of becoming fouled in the case of an oil spill. In Svalbard, four polar bears that were monitored for between 12 and 24 months with satellite-linked dive recorders spent an average of 0.9 to 13.1% of their time per year in water. The maximum duration of swimming events ranged between 4.3 and 10.7 h, and dives reached 11.3 m depth (Aars *et al.* 2007). Polar bears are very sensitive to oiling as they depend on the insulation from their fur and because they may ingest toxic oil as part of their natural grooming behaviour (Øritsland *et al.* 1981, Geraci & St Aubin 1990). Therefore polar bears that have contact with oil are likely to succumb (Isaksen *et al.* 1998).

Female polar bears in dens seem to be rather tolerant to disturbance because the snow provides acoustic insulation. They will occasionally relocate if disturbed and will do so most frequently early in the denning season. There are examples of activities taking place rather close (500 m) to denning female bears without abandonment of the den (Linell *et al.* 2000). But there seem to be large variation in the individual thresholds among female bears with regard to leaving a den (Linell *et al.* 2000). Female brown bear with cups which have been forced to leave their den showed elevated cub mortality (Linell *et al.* 2000).

Overall conclusion

Polar bears make extensive use of the offshore sea ice in the assessment area throughout the year. The bears show a clear preference for areas with dense sea ice and therefore shift their distribution north in the assessment area during the open water season to exploit areas where drift ice remains during summer. The polar bears may den widely scattered along the east coast of Greenland. However, satel-

lite telemetry studies have indicated that the coastal areas between approx. 72° N and ca. 74° N and between ca. 78° N and ca. 81° N are traditionally used maternity denning areas. The lack of information on the size of the East Greenland polar bear population prevents any calculation of what fraction of the entire population may be negatively influenced by oil exploration and exploitation activities.

Walrus *Odobenus rosmarus*

E.W. Born

The distribution of Atlantic walrus in the East Greenland area (Figure 23) based on observations made by sealers, various expeditions and subsistence hunters living in the area – and catch statistics – was summarised by Born (1983), Dietz *et al.* (1985), Born (1990, 2005), Born *et al.* (1995) and Aastrup *et al.* (2005). Born *et al.* (1995) reviewed various man-made disturbance and industrial activities that potentially may negatively impact on walruses. The following review of distribution and abundance is based mainly on these sources. In addition, several studies involving satellite telemetry have provided information on movements, occurrence and activity of walruses in Northeast Greenland during 1989–2001 (Born & Knutsen 1992, 1997, Born

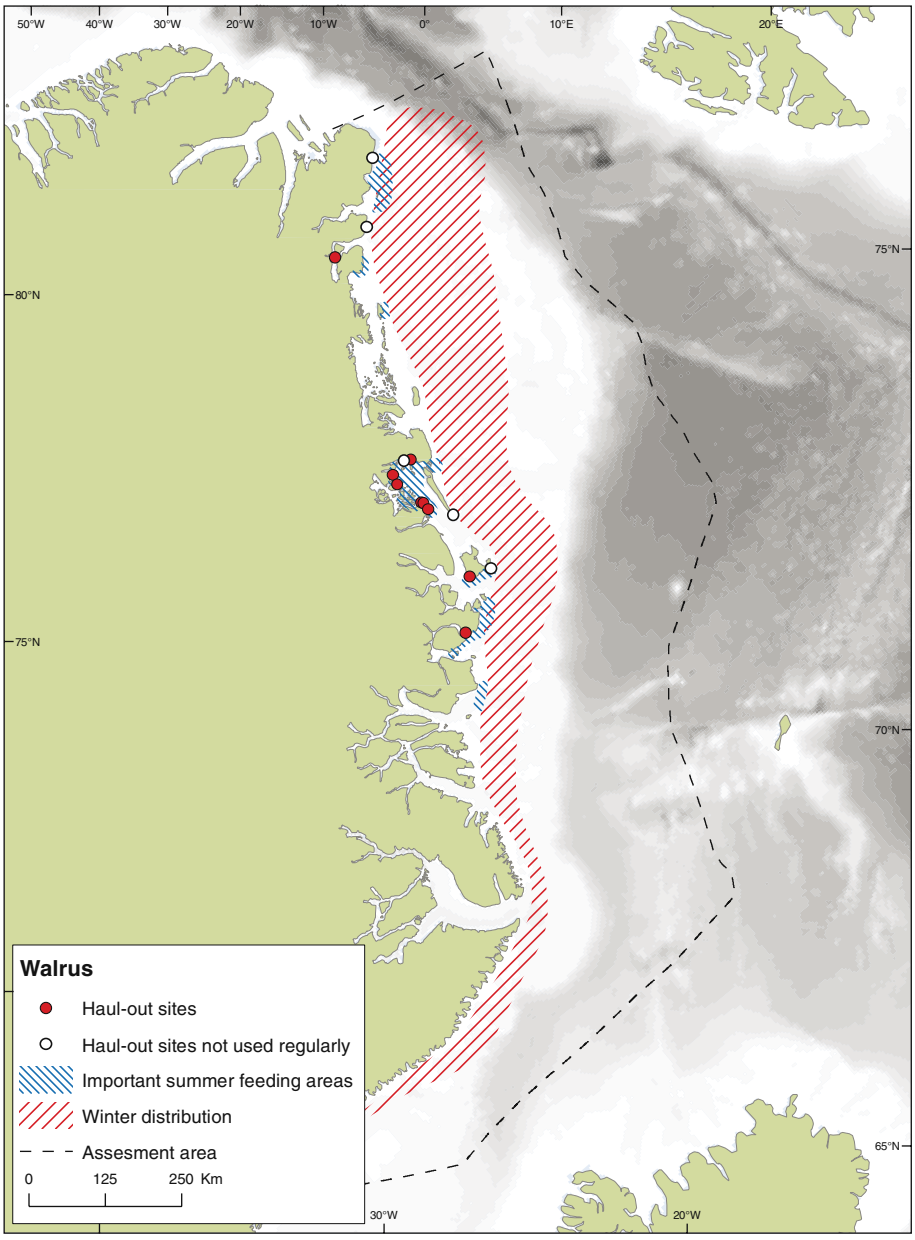


Figure 23. General distribution of walrus in the assessment area. Terrestrial haul-outs, both those regularly used and some which apparently are less frequently used are shown.

& Acquarone 2007, Born *et al.* 2003, 2005, 2009, Acquarone *et al.* 2006, NAMMCO 2009). The status of the walrus subpopulation in East Greenland was assessed by the North Atlantic Marine Mammal Commission in 1995, 2005 and 2009.

The following life history traits are relevant to evaluate of the potential effects on walruses from oil-related activities. Walruses are gregarious year round (Fay 1982, 1985). They 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 use terrestrial haul-outs ('*uglit*', singular '*ugli*') in the vicinity of shallow areas with suitable food and winter in waters with not too dense ice and predictable access to food (Born *et al.* 1995 and references therein). In East Greenland such habitat is mainly found north of approx. 73° N (Born *et al.* 1997). During the mating season (January–April; Born 2001, 2003 and references therein) male walruses engage in ritualized visual and acoustical display under water (Fay *et al.* 1984, Sjare & Stirling 1996, Sjare *et al.* 2003).

Distribution

In East Greenland walruses are mainly distributed north of the entrance to Scoresby Sund (approx. 70° N) (Born *et al.* 1997).

In several areas walruses are segregated by age and sex class for most of the year (Fay 1982, Born *et al.* 1995). This is also the case in East Greenland where there is a tendency that most adult females with young stay year round in the areas north of approx. 79° N whereas adult males make southward migrations along the coast to their traditionally used *uglit* (Born *et al.* 1997, NAMMCO 2009, Born *et al.* 2010).

The few historical observations of walruses along the coast of southeastern Greenland, between the Tasiilaq area (Ammassalik) and the entrance to Scoresby Sund, are concentrated around the fjord of Kangerlussuaq and at the shallow banks along the northern parts of the Blosseville Kyst, just south of the entrance to Scoresby Sund (Born *et al.* 1995 and references therein). A few walruses are occasionally caught in the Tasiilaq area. The seasonal distribution of catches indicates that walrus stragglers can occur in southeastern Greenland at all seasons with the possible exception of December (Born *et al.* 1997 and Figure 24); however, catch records (1993–2006) show a peak in June–September (Born *et al.* 1997 and Figure 26). This seasonal pattern may represent a combination of increased boating activity during summer and a movement of walruses south along the coast from their northern wintering areas on the east coast.

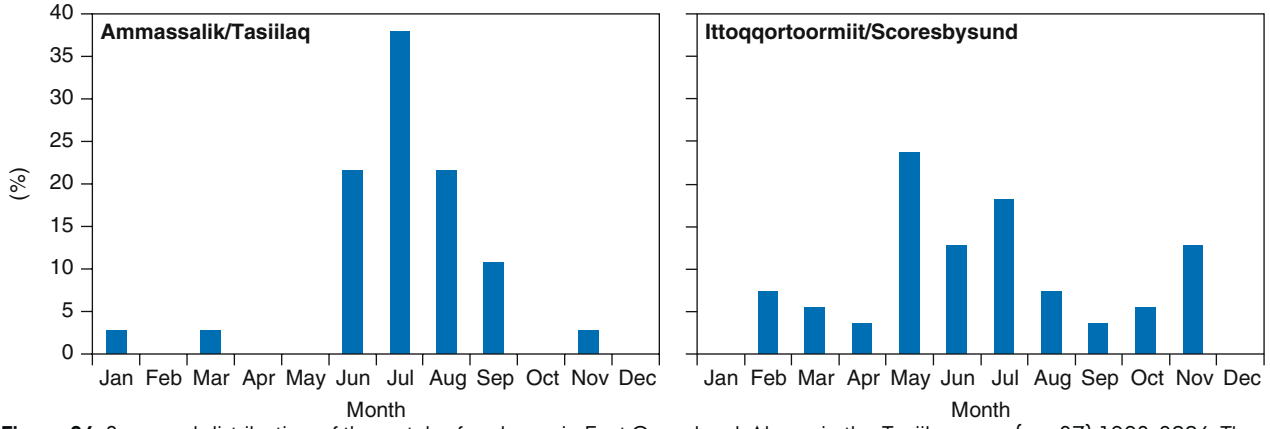


Figure 24. Seasonal distribution of the catch of walruses in East Greenland. Above in the Tasiilaq area (n = 37) 1993–2006. The years 1994 and 2000 in which 60 and 99 walruses were reported to have been landed are not included as they clearly represent an artefact (Born 2005). Below the Ittoqqortoormiit/Scoresbysund area (n = 55) 1993–2006. The years 1994, 1995 and 1999 in which 27, 46 and 26 walruses were reported to have been landed are not included either as the figures in these years are considered to be implausibly high (Born 2005). Source: APNN.

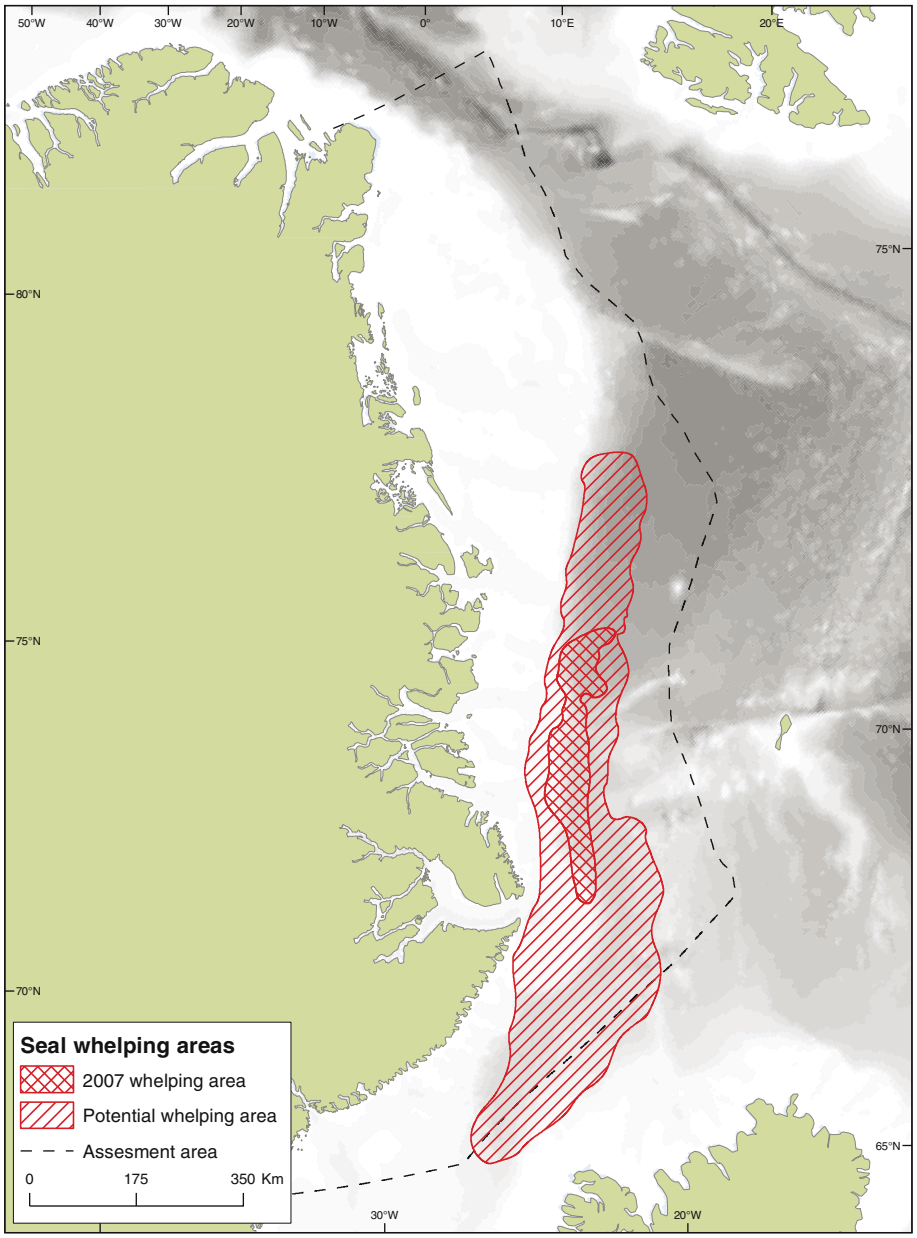
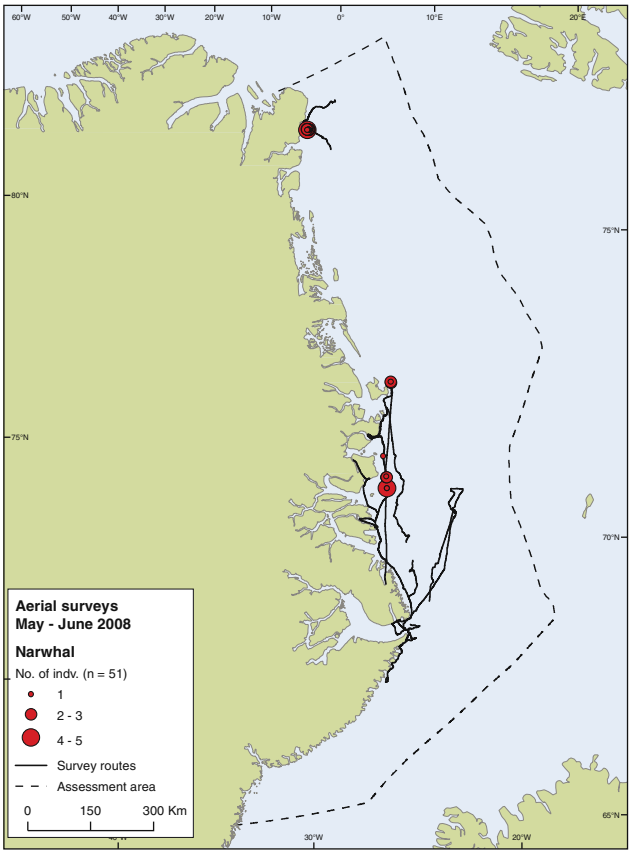


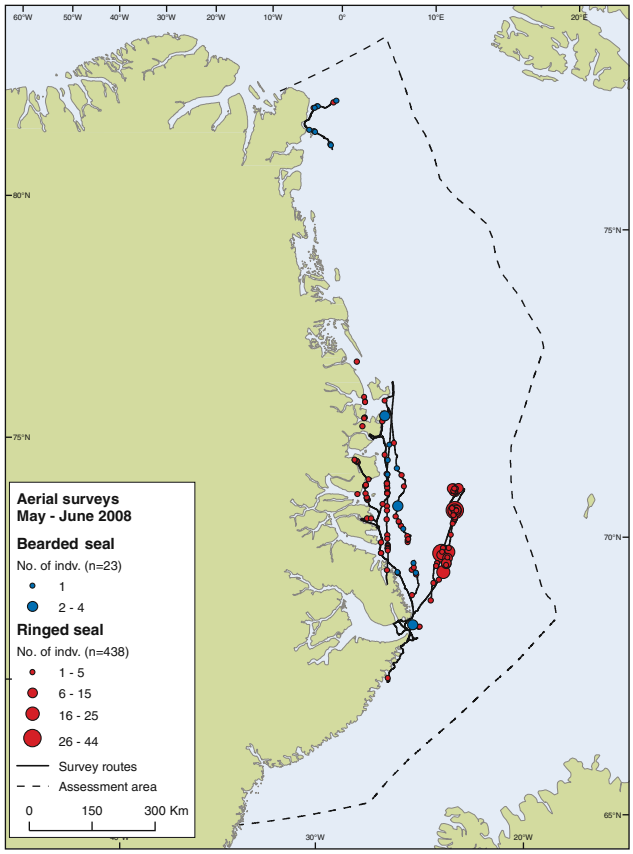
Figure 25. The potential and the actual 2007 whelping area for harp and hooded seals in the Greenland Sea. The potential area is where the whelping has been recorded in recent decades. Source: Øigård *et al.* (2008).

When the town of Ittoqqortoormiit/Scoresbysund was founded in 1924/25 at the entrance to Scoresby Sund, walruses were apparently common there. They also hauled out on land in this area during summer and wintered in the polynya at the entrance to this fjord system. After only a couple of years of intensive hunting walruses became scarce in the Scoresby Sund area, and only old males were observed occasionally during summer. It is probable that a resident group of walruses had been exterminated (Born *et al.* 1995, 1997).

Nowadays, single walruses or groups of 2–3 animals of both sexes and all age groups (except newborn) may occur at the entrance to Scoresby Sund in all seasons (Born 1983, Born *et al.* 1997) with a peak during May–July as reflected in the seasonal distribution of the catch (Figure 24). Similar to the situation further south this seasonal distribution of the catch may reflect both an increased hunting activity during spring and early summer, and an increased occurrence of walruses.

According to inhabitants living in Ittoqqortoomiit, the number of walruses frequenting this area has increased in recent years. The people ascribed this increase to the fact that walruses have been protected since the 1950s in the areas north of Scoresby Sund (Born 1983).





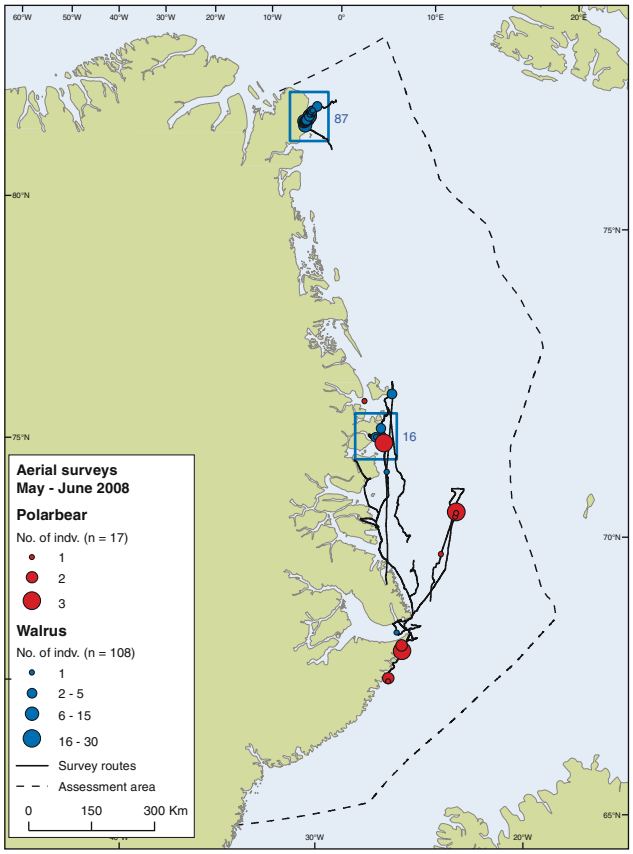


Figure 26. Observations of marine mammals during the NERI aerial survey in May and June 2008. The high numbers of ringed seals recorded on the ice far off shore may have been harp seals.

Observations of walruses between Scoresby Sund and the southern coast of Clavering Ø (approx. 74° N) are few, presumably because there is little or no suitable walrus habitat in this area. The waters are relatively deep, both in the fjords and along the outer coasts (Born *et al.* 1997).

At the end of the 19th century until some point during the first half of the 20th century, walruses were common and used several *uglit* in the Clavering Ø-Hochstetter Bugt area, where sizeable concentrations were occasionally seen. Nowadays, small groups of walruses are observed along the coast between Clavering Ø and the northern coast of Dove Bugt (approx. 77° N). In these areas, regularly used *uglit* are found on Sandøen at the entrance to Young Sund and Lille Snenæs on the northern coast of Dove Bugt. Recently the walruses have apparently started using several other places regularly for hauling out on the stretch of coast between ca. 74° and 77° N (Born *et al.* 1997, Born & Acquarone 2000, Gilg *et al.* 2003, Aastrup *et al.* 2005, Born & Acquarone 2007, Born *et al.* 2009, Born unpublished data).

Several observations of walruses have been reported at Cape Borlase Warren, Cape Wynn, Sabine Ø, Hvalros Ø and Lille Pendulum island at the promontory of Wollaston Forland. They also occur in the Kuhn Ø area and along the south coast of Shannon Ø. In these areas there can be open water during winter, and a polynya is present along the eastern coast of Wollaston Forland and southern coast of Shannon Ø (Born *et al.* 1997).

Walruses are common in the Dove Bugt area where they haul out on land regularly at Lille Snenæs (Born *et al.* 1997) and in recent years they have also been observed on land at Hvalrosodden (Born & Acquarone 2000), at Port Arthur (Gilg *et al.* 2003) and a few other sites (Born *et al.* 2009). Apparently only males use these haul-outs (Ibid.).

North of Dove Bugt walruses have been observed at several locations along the coast between Skærfjorden (approx. 77°30' N) and Kilen (approx. 81°14' N). Apparently they prefer the coastal areas between Dijmpha Sund (approx. 80° N) and Kilen where the water is shallow. A total of approx. 108 mainly adult female, young and newborn walruses were observed close to the coast between Kilen and Henrik Krøyer Holme on 3 June 1993 (Born *et al.* 1997). This is the highest concentration of walruses recorded in East Greenland in modern times. During a survey of the same area on 25 July 1993, 93 walruses were seen, of which 17 were recorded as small calves (Tahon & Vens 1994). During aerial surveys conducted in June 2008 (Boertmann *et al.* 2009a) and August 2009 (Born *et al.* 2009) walruses were observed between ca. 80°30' N and ca. 81°15' N mainly concentrated near the coast at Kilen (Figure 26, 27) (see section: Size of the East Greenland subpopulation). The walruses in this area (i.e. the Northeast Water Polynya area) were mainly females with calves of various ages including 0-year-olds. A terrestrial haul-out used by female and subadult walruses was located on southern Lynn Ø in Dijmphna Sund (Born *et al.* 2009).

Although the majority of walrus observations have been made close to the coast, miscellaneous observations made during 1863–1992 indicate that walruses can also occur several hundred kilometres offshore during spring and summer (i.e. April–August; half of the observations recorded were from July–August) (Dietz *et al.* 1984, Born *et al.* 1997). Satellite telemetry has revealed that some individuals make foraging excursions more than 150 km offshore from their *uglit* in East Greenland (Born & Acquarone 2007; Born unpublished data).

Important and critical areas – terrestrial haul-outs/*uglit*

The traditionally used *uglit* are an important element in the life history of walruses and walruses show great site tenacity to their *uglit*. In East Greenland it has been shown that some individually recognizable or tagged individuals have returned each summer to both the Sandø and Lille Snenæs *uglit* for many years (Born *et al.* 1997, Gilg *et al.* 2003, Born & Acquarone 2007). Although, a connection between groups of walruses using the different *uglit* has been observed (Born *et al.* 1997,

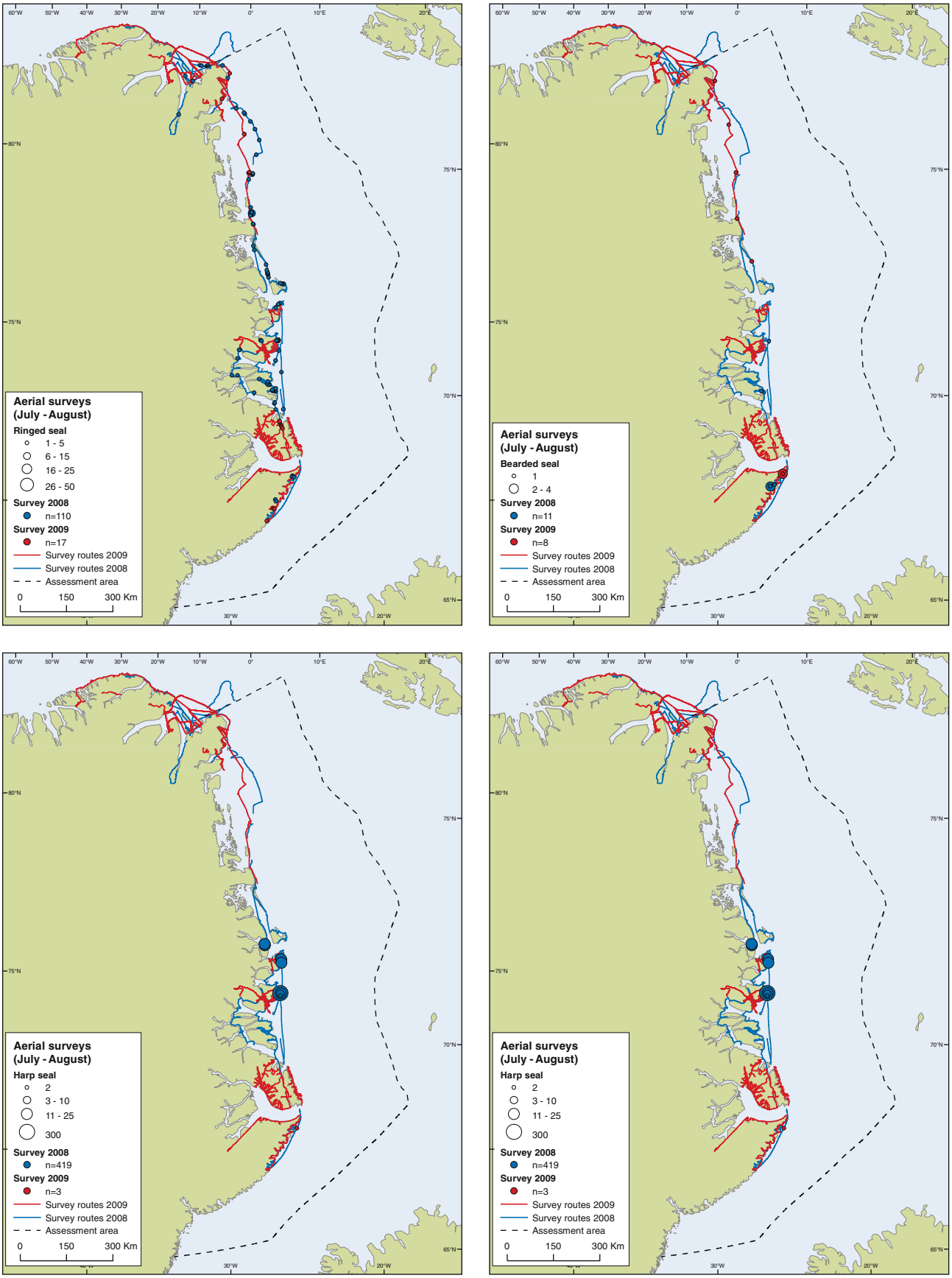


Figure 27. See text on page 120.

Born unpublished data) individual walruses usually use the same *ugli*, from which they make foraging excursions during the summer (e.g. Born *et al.* 1997, Born & Knutsen 1997, Born unpublished data).

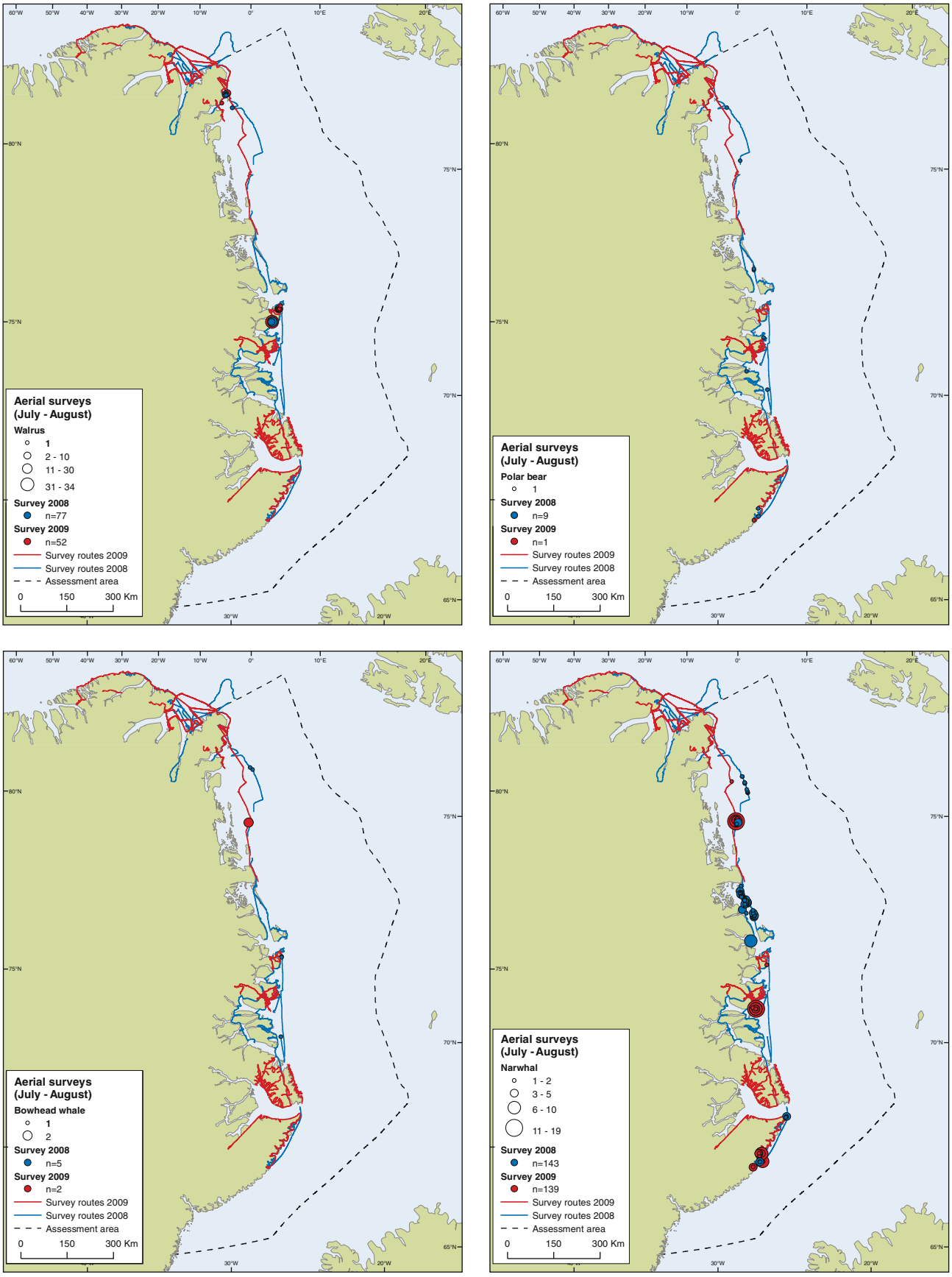


Figure 27. Observations of marine mammals during the NERI aerial surveys in July/August 2008 and 2009.

There are several *uglit* in the assessment area some are which seems to be more regularly used and more important than other: Sandøen at the entrance of Young Sund and Lille Snenæs in Dove Bugt. Extensive studies have been carried out in recent years at both sites. However, information obtained from aerial survey and satellite telemetry in 2009 and 2010 indicates that other *uglit* exists for which the long-term importance to walruses have not been determined (Born *et al.* 2009, Born unpublished data).

Sandøen is used regularly by a group of up to at least 81 different individuals (Born & Acquarone 2007). Apparently, the number of walruses using this *ugli* has increased since the early 1980s (Born *et al.* 1997). Although adult females with subadults and small calves occasionally have been observed at Sandøen like for example in 2010 (Born unpublished data) and close by in the Clavering strait during the aerial survey (Figure 27) in 2009, the group using this *ugli* primarily consists of adult males (Born *et al.* 1997, Born & Acquarone 2007).

The Lille Snenæs *ugli* is used each year by at least 50 adult males (Born & Knutsen 1992, 1997). The number of walruses hauling out on Lille Snenæs has increased significantly since the early 1950s, likely reflecting an overall increase in the East Greenland subpopulation of walruses (Born *et al.* 1997). In recent years walruses have also hauled out at the nearby sites Hvalrosodden (Born & Acquarone 2000) and Port Arthur (Gilg *et al.* 2003), also reflecting an increase in the population and an expansion of its range.

Tracking of 17 male walruses that were fitted with satellite transmitters on Sandøen in Young Sund in 2009 and 2010 and aerial surveys conducted along the shores of NE Greenland north of ca. 74° N in August 2009 have provided new information on *uglit* (NAMMCO 2009, Born *et al.* 2009, Born unpublished). Observations made during the aerial survey and information from high-accuracy re-locations of instrumented walruses indicate that at least 12 terrestrial sites (other than Sandøen and Lille Snenæs) are now used for hauling out between Clavering Ø and northern Dove Bugt for a variable length of time during summer. Apparently these *uglit* were mainly used by males and females (Born & Acquarone 2007, Born *et al.* 2010, Born unpublished data).

Other sites where walruses have also been observed on land include Kap Alf Trolle (southern tip of the island of Store Koldewey); and farther north in the Dijmphna Sund and Hanseraq Fiord areas at the coast of the Northeast Water (Dietz *et al.* 1985, Born *et al.* 1997). In August 2010 female walruses and subadults were hauled out on land on southern Lynn Ø in Dijmphna Sund in NE Greenland (Born *et al.* 2010).

There seems to be no regularly used *uglit* south of the entrance to Scoresby Sund.

Due to hunting, several *uglit* in the Scoresby Sund, Young Sund and Kuhn Ø areas were abandoned at the beginning of the 20th century (Born *et al.* 1997).

Females with calves have mainly been observed in the NEW, but during the July 2008 aerial survey females with calves were also seen in the in Clavering Stræde between Wollaston Forland and Sabine Ø (Boertmann *et al.* 2009a).

Important and critical areas – wintering areas

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.

Various sources (Dietz *et al.* 1985, Born *et al.* 1995, 1997, 2005) indicate that walruses winter in the following areas in East Greenland: the entrance to Scoresby Sund, the Gael Hamkes Bugt area at Kap Borlase Warren along Wollaston Forland and Sabine Ø, at Shannon Ø, and the southern tip of Store Koldewey Ø as well as farther north off Amdrup Land in the Eskimonæs and Antarctic Bugt area. In these areas there are recurring polynyas with shallow water. Tracking of walruses instrumented with satellite-linked radios revealed that they can occur in the pack ice up to about 200 km offshore during winter, between approx. 78° N and 81° N (Born & Knutsen 1992, Born *et al.* 1997). The presence of polynyas at Île de France and at Hold with Hope (Born *et al.* 1997 and references therein) suggests that walruses may also winter there. It is likely that walruses also winter at other places along the coast in the shear zone between land-fast ice and the moving pack ice.

Delineation of populations

Genetic studies indicate that the walruses in East Greenland constitute a separate subpopulation which has only limited exchange with neighbouring subpopulations in West Greenland and at Svalbard-Franz Josef Land (Cronin *et al.* 1994, Andersen *et al.* 1998, 2009b, Born *et al.* 2001). Satellite telemetry has supported the notion that walruses in East Greenland and at Svalbard-Franz Josef Land belong to two separate subpopulations as there has been no overlap in the ranges of the walruses that have been tracked in these two areas (Born & Knutsen 1992, Born *et al.* 2005, Born & Acquarone 2007, Wiig *et al.* 1996, Freitas *et al.* 2009).

Furthermore, genetic analyses (Andersen *et al.* 1998, 2009b, Born *et al.* 2001) and photo-identification of individuals (Born *et al.* 1997) indicate that walruses that occur in Scoresby Sund, Young Sund, Dove Bugt and in Northeast Water Polynya belong to one and the same population.

However, sporadic observations of walruses between eastern Greenland and Svalbard suggest that occasionally some individuals swim all the way across the Greenland Sea and Fram Strait (Dietz *et al.* 1985). The existence of such a connection was proven by the observation at Svalbard in 1992 of a walrus that had been tagged in eastern Greenland (77° N) in 1989 (Born & Gjertz 1993).

Movements

Seasonal movements along the coast have been demonstrated. Adult male walruses that were instrumented during summer at Lille Snenæs moved offshore during the period of formation of land-fast ice sometime in October. They subsequently moved north about 200–300 km offshore to winter in the Northeast Water area (Born & Knutsen 1992, Born *et al.* 2005), where apparently many (most?) of the adult female walruses occur year round (Born *et al.* 1997). The mating season in walruses is in winter with an apparent peak in January–April (Born 2001, 2003 and references therein). The movement north of adult male walruses and their wintering in the Northeast Water area indicate that this polynya is an important wintering and mating area.

The southward migration has not been documented. However, during July walruses return to their haul-outs in Dove Bugt and Young Sund. The reappearance in Dove Bugt in subsequent summers of individuals that were tracked during their fall migration shows a high degree of cyclic annual movement pattern and site tenacity (Born *et al.* 1997, Born *et al.* 2005).

Size of the East Greenland subpopulation

Based on miscellaneous observations, a rough estimate of 500 to 1 000 animals in the eastern Greenland subpopulation was tentatively suggested by Born *et al.* (1995, 1997), who believed that the estimate of 1 000 including compensatory adjustments for animals missed during surveys was closer to the real order of magnitude than the estimate of 500. A relatively large proportion of this population is distributed north of approximately 79° N during much of the year.

To determine the abundance of walruses in East Greenland, visual aerial surveys were conducted between ca. 74° N and 81°45' N during 12-19 August 2009. The surveys were designed as a combination of total counts of walruses at terrestrial haul-outs between ca. 74° and ca. 81°24' N and a systematic line-transect survey between 80°21' N and 81°24' N in the Northeast Water (NEW) area. Data on 'haul-out' and 'at surface' activity obtained from walruses that were monitored with satellite-linked transmitters in the area simultaneous with the aerial surveys were used to correct estimates of abundance for walruses that were not hauled out during the surveys. The corrected estimate of walruses in their prime distribution area in East Greenland in 2009 was 1 429 (95 % CI: 616-3,316). There are some reasons to believe that this may be a slight underestimate, so the survey indicates that the East Greenland stock probably numbers at least 1 500 walruses (Born *et al.* 2009, NAMMCO 2009).

When correcting for the proportion of animals that were not hauled out on land during the surveys an estimated 152 to 240 walruses primarily males and sub-adults were present along the coast south of ca. 77° N. The remainder (1 277 or ca. 90 % of total population) were in the NEW area north of ca. 80° N and west of ca. 9° W (Born *et al.* 2009).

Boertmann *et al.* (2009a) presented an estimate of abundance of walruses based on a systematic aerial survey conducted on 4 June 2008 in the NEW area. The abundance in the NEW area (not corrected for individuals that were not hauled out) was 470 walruses (95 % CI: 100-2207). Although this estimate is higher than the estimate obtained by Born *et al.* (2009) it had a wide confidence interval and was not statistically significantly different from the 2009-estimate. However, direct comparison between the estimate by Boertmann *et al.* (2009a) and that by Born *et al.* (2009) is not feasible. The survey in 2008 that involved a different aircraft and altitude and survey procedures was conducted at a different time of the year. Nevertheless, a higher encounter rate experienced in 2008 compared to 2009 may indicate that (1) a larger fraction of the East Greenland population of walruses was present in the NEW in 2008 or/and (2) the fraction hauling out on the ice was higher during the June 2008-survey than during the August 2009-survey. A third possibility of a seasonal immigration to NEW of walruses from the Svalbard region seems less plausible (Born *et al.* 2009).

Based on the population estimate of 1,000, the catch record and a net population increment of 2–5 %/year, Born *et al.* (1997) estimated that the East Greenland subpopulation numbered 1 500–1 900 animals in 1889 (i.e. before the initiation of intense catches by foreign sealers). Using a Baesian framework, Witting & Born (2005) estimated that the original East Greenland subpopulation numbered approx. 1 600 animals in 1889. Using the same model and the 2009-population estimate Witting *et al.* (2009) estimated that the 1889-population numbered 1 600 (95 % CI: 1,000-2,500) and concluded that the present population is close to carrying capacity.

The catch

Due to a general scarcity of walruses in southeastern Greenland, the catch in this region has always been very small (Dietz *et al.* 1984, Born *et al.* 1995, 1997). Since the 1980s the reported catch of walruses south of Scoresby Sund has averaged 3–4 per year (Born *et al.* 1995; Department of Fishery, Hunting and Agriculture (APNN), Nuuk, unpublished data).

In the Scoresby Sund area walruses are taken at the entrance to the fjord complex (Born 1983, Sandell & Sandell 1991). They can be caught in all seasons with a peak in May–August (Born *et al.* 1997 and Figure 24). Although a few subadults and adult females are occasionally killed in the Scoresby Sund area, the catch consists mainly of adult males (Born *et al.* 1997). This likely reflects the southward migration along the coast of adult males during spring and summer and the fact that adult male walruses usually are less wary than females and young (Born 2005).

During 1993–2006 (1994, 1995 and 1999 not included due to implausibly high numbers reported), an average annual catch of 5.0 walruses (SD = 3.4, range: 1–11 walruses, n = 10 years) has been reported from this area (APNN unpublished data) with no apparent trend ($F = 0.346$, $p = 0.571$, df: 9/1). The majority of the walruses landed in East Greenland are males (Born unpublished data). The Greenland quotas for the take of walrus from the East Greenland subpopulation for the three-year period 2007-09 were 30 in each year. Reported catches for 2007, 2008 and 2009 were respectively 10, 9, and 4 walruses (APNN *in litt.* 2009). To incorporate struck-but-lost the quota was reduced to 23 for 2009. The 2010-quota for East Greenland is 18 walruses (Anonymous 2010).

Between 1889 and the 1950s foreign sealers and hunters and trappers killed a substantial number of walruses in Northeast Greenland, leading to decimation of the population (Born *et al.* 1997).

Conservation status

Today walruses are totally protected within the National Park in North and Northeast Greenland. In 1951 (i.e. before establishment of the national park in 1974), they became protected north of 74°24´ N and since then the East Greenland subpopulation seems to have increased (Born *et al.* 1997, NAMMCO 2009).

To the south of the national park walruses are taken by hunters from Scoresby Sund and Tasiilaq (see previous section). These animals derive from the population further north. This hunt seems to be sustainable (Witting *et al.* 2009). The population is listed as 'Near Threatened' (NT) on the Greenland Red List, mainly due to the small numbers of individuals.

Sensitivity

Due to the highly localised distribution of the walruses within the assessment area, a large proportion of the population may be affected by a single and long-lasting incident – an oil spill or disturbance from permanent infrastructure or construction.

It is well known that walruses, particularly when hauled out on land, are sensitive to disturbance, including sailing, traffic on land, and flying (Born *et al.* 1995 and references therein). This was for example documented by Born & Knutsen (1990) who, based on fieldwork in the assessment area, concluded that air traffic should not go closer than 5 km to walrus haul-outs in order to minimise disturbance. The

DCE-guidelines to seismic surveys in Greenland designate specific walrus protection areas (Kyhn *et al.* 2011b).

An environmental impact assessment of shipping along the Northern Sea Route (the Northeast Passage) concluded that the walrus populations could be negatively impacted by disturbance from ship traffic and oil spills (Wiig *et al.* 1996).

The effect of oil spills on walruses has not been studied in the field. However, Born *et al.* (1995) and Wiig *et al.* (1996) speculated that if walruses do not avoid oil on the water, they may suffer if their habitats are affected by oil and that they, like other marine mammals, can be harmed by both short-term and long-term exposure.

Born *et al.* (1995) pointed to the fact that some features in the ecology of walruses make them more vulnerable to the harmful effects of spilled oil than are many other marine mammals:

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

The most important walrus areas in the assessment area are the *uglit* and their surrounding waters, the summer concentration areas (coasts of Hovgaard Ø, Amdrup Land, Kilen) and winter concentration areas (the Northeast Water and the Sirius Water Polynya).

3.8.2 Seals

A. Rosing-Asvid

Four species of seals occur in the assessment area and all four species give birth in the area. Two species (harp- and hooded seals) whelp and moult on the drift ice in dense concentrations, and the seals will spread out in the northeast Atlantic

outside and in between the whelping and moulting periods. Ringed- and bearded seals are believed to be more resident. Ringed seal can maintain breathing holes in winter ice that is more than 1 m thick and they give birth in lairs dug out in snow banks associated with a breathing hole. Bearded seals also make breathing holes, but only in relatively thin ice and they either winter in reoccurring leads and polynyas or they follow the pulse of the expanding and shrinking sea ice. They mainly give births in areas with easy access to open water.

Hooded seal *Cystophora cristata*

Distribution: The Greenland Sea population of hooded seals whelp and moult in the same area as the harp seals (Figure 25). This means that the position of the whelping areas depend on the distribution of the drift ice, although the whelping seals are usually found within the assessment area. The hooded seals are, however, more scattered on the ice than the harp seals. Moreover, the moulting period for hooded seals – June-early July – is later than that for the harp seals (April). The hooded seals will outside and in between the whelping and moulting season, disperse in the Northeast Atlantic, making long strays that might bring them as far as to the Norwegian coast or to the Faroe Islands (Folkow *et al.* 1996). Some hooded seals can, however, be found throughout the year in the assessment area, where the highest concentrations normally are found south of 75° N. very few (in total three) were observed during the aerial surveys in 2008 and 2009.

Biology: Hooded seals are deep divers regularly feeding below 500 m and down to 1 500 m (Andersen *et al.* 2009a). Adult seals mainly eat large fish and squids, while young eat mainly capelin and polar cod (Haug *et al.* 2004).

Population: The whelping hooded seals were surveyed in 2005 by Norwegian researchers, and they estimated approx. 70 000 adult seals, which produced approx. 15 200 pups (Øigård *et al.* 2008). A survey in 2007 resulted in an estimate of 15 370 pups (Øigård *et al.* 2008).

The catch: The hooded seal population in the Greenland Sea was strongly reduced by Norwegian sealers in the years following the Second World War. Quotas have regulated the sealing since the 1980s and the harp seals have doubled in numbers since then, whereas the hooded seals have failed to recover. Commercial catches of hooded seals have therefore been stopped, whereas subsistence hunting by Greenlanders is allowed to continue. The local hunt near Ittoqqortoormiit only takes 10-20 seals/year.

Conservation status: The population has an unfavourable conservation status (see above under 'Catch'). The hooded seal is, however, listed as of 'Least Concern' on the Greenland Red List, because the seals are still numerous and likely to recover with the present management plan.

Critical and important habitats: The hooded seals are most sensitive to both disturbance and oil spills during whelping and moulting when high densities of seals are assembled in the assessment area.

Harp seal *Phoca groenlandica*

Distribution: The Greenland Sea harp seal population has whelping areas within the assessment area (Figure 25). They whelp on drift ice in April and the lactation period is 10–12 days. After leaving the pups, adult and juvenile seals concentrate again in late April-May to moult on the ice. In the late 19th and early 20th centuries the whelping areas were usually located between 70° and 75° N and 10° W and

5° E. The moulting areas were previously located somewhat further north, between 75° and 76°30´ N and 10° W and 0° (Sergeant 1991). In recent years whelping areas have also been found within the latter boundaries (Figure 25).

Outside the whelping and moulting period, the harp seals disperse in the open-water areas, although often occurring in large flocks, and they mainly move eastward to the Barents Sea or southward along the Greenland coast (Folkow *et al.* 2004). Some will, however, stay in the assessment area throughout the year. Only few flocks were seen during the aerial surveys in 2008 and 2009 (Figure 27).

Biology: During winter the main prey of harp seals in the assessment area is capelin (*Mallotus villosus*), krill and amphipods (*Parathemisto* spp.), and during summer amphipods and polar cod (Haug *et al.* 2004).

Catch: Norwegian sealing vessels operate within the assessment area in the whelping season. The quota have for many years been relatively low in order to allow an increase in the population. In 2009, however, it was set to 40 000, which is a catch that would stabilize the population at the present level, but only 8 035 were caught (ICES 2009). The catches near Tasiilaq include harp seals from both the West Atlantic and the Greenland Sea population. The fraction of seals from the two areas is probably highly variable, but for management purposes it is set to fifty-fifty. This makes an annual Greenland catch on harp seals from the Greenland Sea population in the order 1 000-1 500/yr.

Conservation status: The population has a favourable conservation status as it has increased considerably since the 1980s (ICES 2009). The estimated population size in 2009 was about 750 000 (ICES 2009). The harp seal is listed as of 'Least Concern' (LC) on the Greenland and the global Red Lists.

Critical and important habitats: Whelping and moulting areas on the drift ice where dense concentrations of harp seals occur in spring are sensitive to both disturbance and oil spills (Figure 25).

Bearded seal *Erignathus barbatus*

Distribution: Bearded seals occur throughout the assessment area where suitable habitat is available, but they are not as numerous as the ringed seals (Figure 26, 27). They avoid the thick sea ice during winter when they usually are found in dynamic drift ice where cracks and leads give access to open waters, or in relatively thin ice where they can maintain breathing holes. The range of these bearded seals is unknown, but a pup has been tracked from Svalbard to the coastal areas in the assessment area (Gjertz *et al.* 2000), indicating that the seals in the assessment area are part of a large and widespread population. No particularly important areas for the species are known within the assessment area and only few were observed during the aerial surveys in 2008 and 2009 (Figure 27).

Biology: Bearded seals feed on fish, but a significant part of the diet consists of 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 (>300 m) and shrimps are found to be the most important prey in that area. Birth takes place in April–May on drifting ice or near ice edges with access to open water and the lactation period is estimated to be around 24 days (Gjertz *et al.* 2000).

The catch: Catch statistics show that bearded seals are taken near the Ittoqqortoormiit throughout the year. The annual catch in the assessment area is approx. 40 seal/year, most of which are caught during summer.

Conservation status: The population has a favourable conservation status, and the uniform and widespread distribution of bearded seals is believed to be a good protection against overexploitation (Anonymous 1998). The bearded seal is listed as 'Data Deficient' on the Greenland Red List.

Sensitivity: Bearded seals vocalise very often, especially during the breeding season in spring (Burns 1981); they may therefore be vulnerable to acoustic disturbance (noise) (Wiig *et al.* 1996). Their feeding habits also make them vulnerable to oil-polluted benthos. However, the dispersed distribution makes bearded seal less vulnerable on a population level to disturbance and oil spills than the more gregarious species.

Ringed seal *Phoca hispida*

Distribution: The ringed seal is common and widespread in the assessment area, both in the fjords and in the drift ice off the coast (Figure 26, 27). The main breeding habitat is considered to be coastal fast ice and consolidated drift ice. Ringed seals can maintain breathing holes in thick winter ice and they give birth in lairs made in snowdrifts associated with a breathing hole. The pups are born in late March and April and lactation lasts up to 7 weeks (Hammill *et al.* 1991).

Ringed seals have only been surveyed systematically in the southern part of the assessment area, where resting seals on fast ice were counted from aircraft in June. Densities in Scoresby Sund and Kong Oscars Fjord were estimated in the range 1.04 to 2.00 seal/km^2 (Born *et al.* 1998). This density range can probably be applied to several of the fjord systems in the assessment area.

During the aerial surveys ringed seals were observed through out the surveyed areas and mainly on fast ice and along ice edges (Figure 27).

Biology: A study of prey selection by ringed seals in the southern part of the assessment area found that the autumn diet was characterized by high numbers of *Parathemisto libellula*, and the spring diet was comprised primarily of polar cod (*Boreogadus saida*) (Labansen *et al.* 2010a).

The catch: The annual catch (by the inhabitants of Ittoqqortoormiit) of ringed seals in the assessment area is approx. 2 500 seals. However, many of the more than 10 000 seals caught annually in Southeast and Southwest Greenland are likely to be juvenile seals originating from the assessment area. The sale of ringed seal skins is important for local hunters and the meat is of high importance in the household economy. The overall catch from this population has been relatively stable for many years and is therefore considered to be sustainable.

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

Critical and important habitats: Breeding ringed seal depend on stable sea ice when they establish territories, whelp and nurse the pups. This stationary behaviour makes them vulnerable to disturbance and particularly to activities, which disrupt the stable ice. Ringed seals do not form whelping congregations as do harp and hooded seals and localised disturbance will therefore only influence a small fraction of the total population.

3.8.3 Baleen whales

F. Ugarte and L.M. Rasmussen

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

Bowhead whales are associated with sea ice and use the assessment area year round.

Rorquals are all believed to 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 Greenland Sea. However, very little information on these whales is available form the assessment area (Table 6).

The ship based surveys 1994-2010 revealed substantial numbers of rorquals in the Greenland Sea assessment area (Figure 28).

The rorquals migrate long distances to take advantage of summer peaks 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 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 when the ice-edge retreats during the summer months, as most models predict, and the area may become more important than at present for these species.

Baleen whales produce distinctive low frequency calls that can be detected over tens of kilometres (Širović *et al.* 2007) and which overlap with the noise from seismic sound sources (Figure 29). Documented reaction of baleen whales to seismic surveys and/or drilling activities include increased calling, shift the frequency of their calls and displacement (e.g. Ljungblad *et al.* 1988, Patenaude *et al.* 2002, Stone & Tasker 2006, Di Iorio & Clark 2010, Castellote *et al.* 2010). See also Section 9.1.1.

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

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 29). 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, aircraft and supply vessel activities.

Bowhead whale *Balaena mysticetus*

The bowhead whale occurs regularly in the assessment area, but numbers are very small. However the numbers of sightings have been increasing since the mid-1980 (Gilg & Born 2005, Boertmann *et al.* 2009b, Wiig *et al.* 2010). During the NERI aerial surveys five were observed in July-August 2008 and a female with a calf were seen in July 2009 (Figure 27). At least 11 different individuals were seen

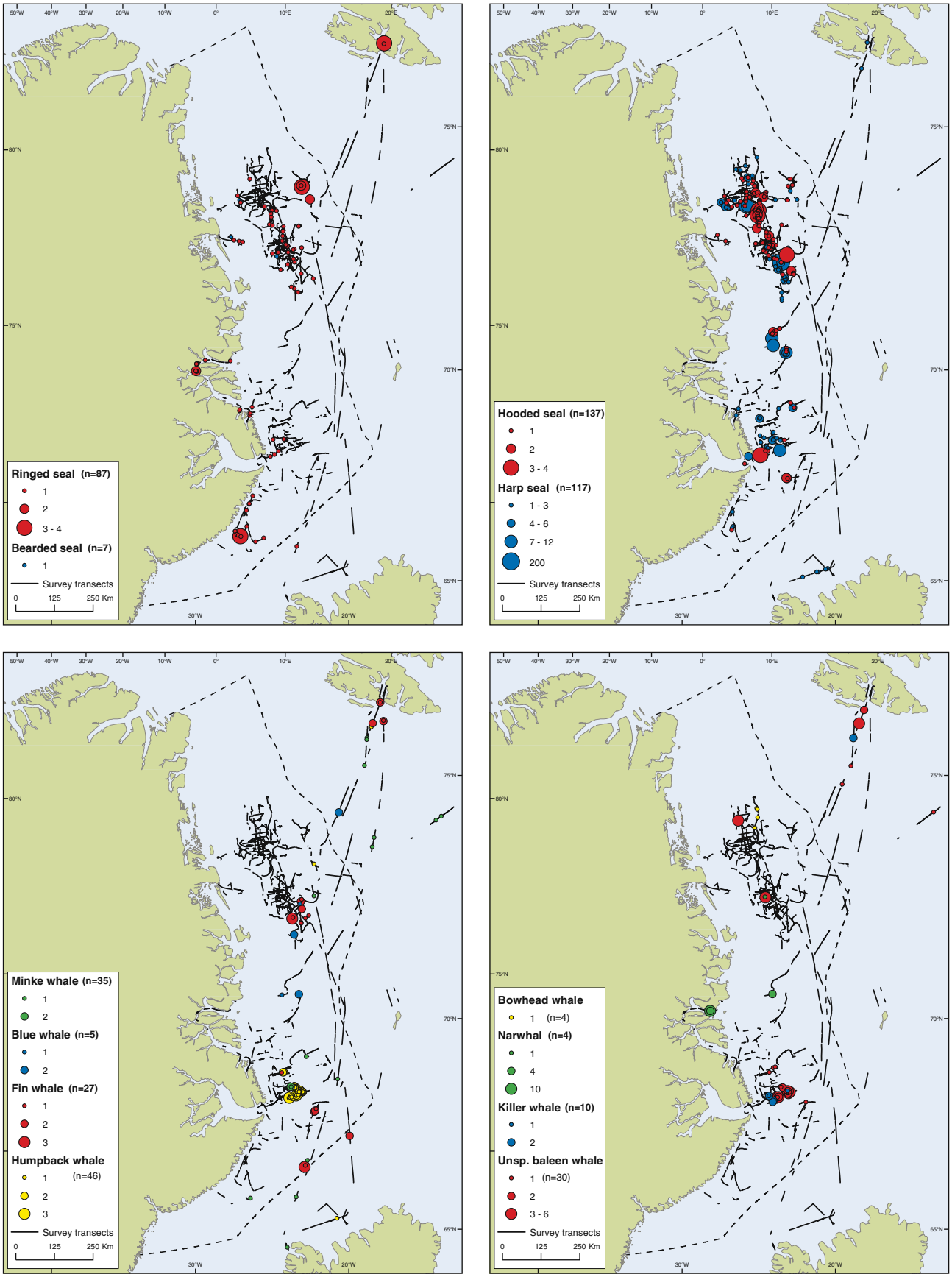


Figure 28. Marine mammal observations during seismic and fishery surveys in 1994, 1995, 2005, 2006, 2009 and 2010. All observations are given as dots.

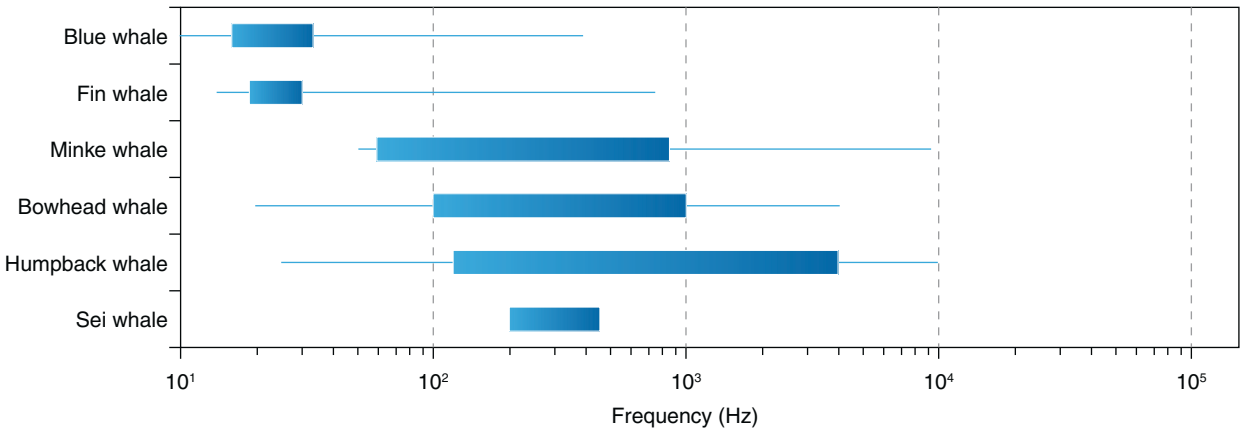


Figure 29. Known frequency ranges used by the baleen whales present in the Greenland Sea assessment area. The thick bar shows the range of the most common types of vocalisations, while the thinner line shows recorded extremes of frequency. Adapted from Mellinger *et al.* 2007.

in the Northeast Water Polynya during a GINR aerial survey for walrus in August 2009.

Distribution and stocks: The bowhead whales occurring in the Greenland Sea assessment area belong to the Spitsbergen stock, which are distributed in the marginal ice zone between Franz Josef Land and East Greenland.

In East Greenland they have in recent years been recorded between the Blosseville Kyst and the North East Water (Gilg & Born 2005, Boertmann *et al.* 2009b), usually along ice edges or in the marginal ice zone. Their winter quarters are probably in the Fram Strait, where a satellite tracked individual recently spend the winter (Lydersen *et al.* 2012).

Important and critical areas: The recent observations seem to confirm the old whaling grounds as especially important habitats (Gilg & Born 2005, Boertmann *et al.* 2009b). One of these whaling grounds is within the assessment area: the 'south fishing ground' or 'southern whaling ground', which was situated in the marginal ice zone off East Greenland between 72° and 75° N (Ross 1993). Also the Northeast Water Polynya seems, according to the many individuals seen in 2009, to be especially important, and the ice edge between the polynya and Île de France, may also be important, as a female with a calf was observed here in 2009 (Boertmann & Nielsen 2010a,b). An individual tracked by means of satellite in 2010 moved from a winter quarter in central northern (80° N) Greenland Sea to the southern whaling ground during May and June and was back in the winter quarter in November (Lydersen *et al.* 2012).

Conservation status: Bowhead whales have a high conservation value due to the rarity of the species. The Spitsbergen stock of bowheads was almost exterminated by two centuries of whaling (from 1611), and only a few individuals remained – until 1990s estimated at a few tens (Gilg & Born 2005). However, the recent sightings indicate that a recovery may occur, and the 'few tens' must now be fairly underestimated (Boertmann *et al.* 2009b, Wiig *et al.* 2010). Bowhead whale is considered as 'Critically Endangered' (CR) both on the national Red List (the Spitsbergen stock separately) and the global Red List (Boertmann 2008, IUCN 2011).

Sensitivity: Bowheads are sensitive to disturbance (noise), and may avoid areas with drilling and seismic surveys. Local populations may be displaced or reduced by increased traffic and oil activities (Wiig *et al.* 1996). Bowhead whale sensitivity to oil spills is unknown, but it has been speculated that bowheads are especially

vulnerable to fouling of their baleen, due to their skim feeding habits (Lowry 1993). The DCE-guidelines to seismic surveys in Greenland designate specific bowhead whale protection areas (Kyhn *et al.* 2011b).

Minke Whale *Balaenoptera acuterostrata*

Minke whales are the smallest rorquals 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 difficult to survey.

Minke whales feed on a large variety of prey, including small herding 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, into the ice edge. Winter breeding grounds are unknown, but may include tropical waters off the Caribbean and West Africa. Some individuals remain at high latitudes during winter.

Distribution and stocks: The occurrence of minke whales in the assessment area is unknown. At least a few were seen during the seismic survey in 2006 and as far north as 75° N; all to the east of the drift ice (Figure 28). Furthermore minke whales have been observed by GINR researchers (unpublished) working with other species at the ice edge within the assessment area during spring, and one was observed in the Northeast Water in May 1993 (Kapel & Berg 1994).

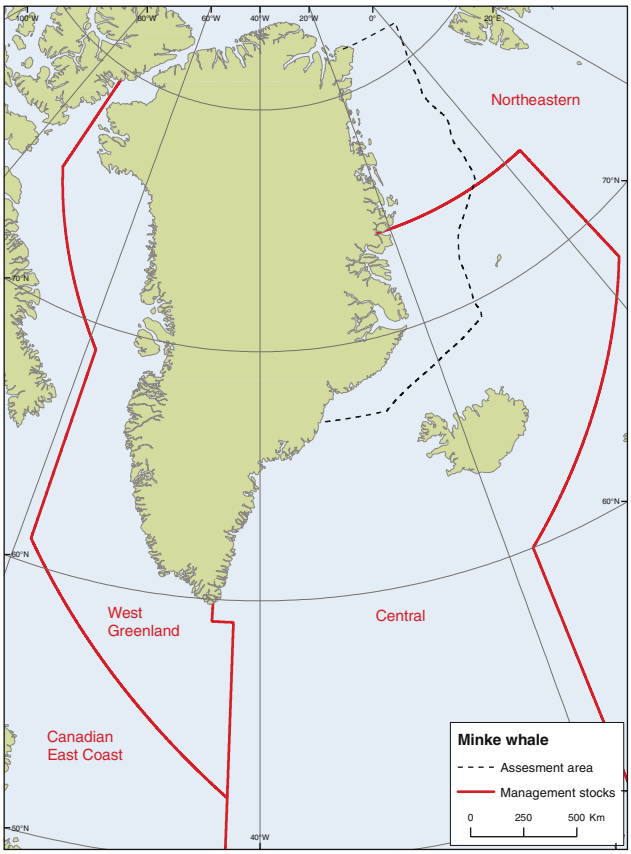


Figure 30. The four management stocks of minke whales in the North Atlantic. Two of them overlap the assessment area, but only whales from the central stock are frequent within the assessment area.

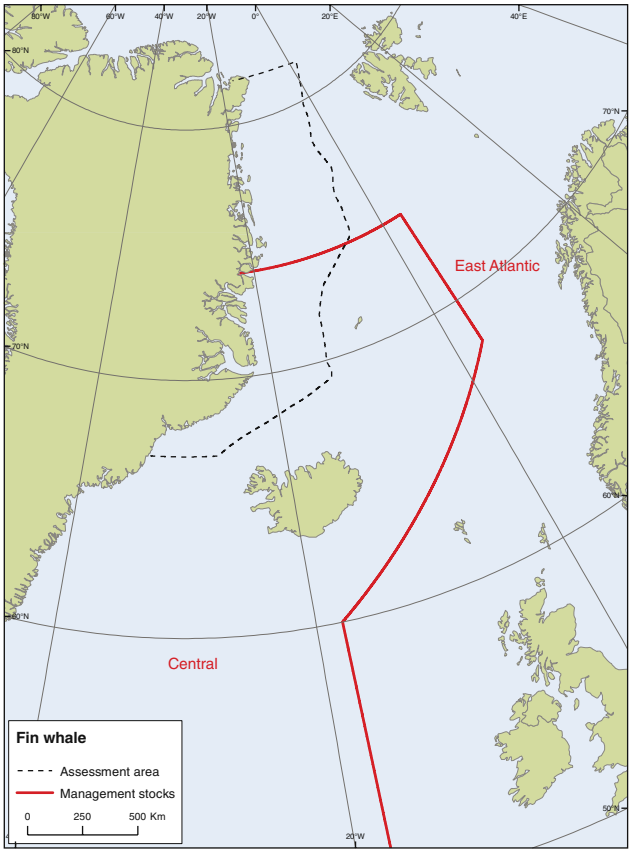


Figure 31. The delimitation of the two fin whale stocks in the North East Atlantic: Central and East Atlantic.

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).

The assessment area overlaps with two of the minke whale stocks from the North Atlantic: the Central Stock and the North Eastern Stock. Since the mid-1980s Norway, Iceland and the Faroe Islands have carried out several surveys in the ice-free waters of the Northeast Atlantic. These surveys do not tend to cover waters in the proximity of the ice edge and the assessment area is consequently very poorly surveyed.

There is no single estimate for the number of minke whales in the Central Stock. However, the Scientific Committee of the IWC agreed in 2008 (IWC 2008a) that the best estimates available for the three sub-areas of the central stock were 24,900 (CV 0.45), 10,700 (CV 0.229) and 23,600 (CV 0.26).

Based on a series of Norwegian surveys from 1996 to 2001, Skaug *et al.* (2004) estimated 107,205 minke whales (CV = 0.14) in the whole Northeast Stock. The authors also concluded that there are large annual variations in the number of minke whales migrating to the different areas within their range, indicating that minke whales do not present a strong site fidelity to specific feeding grounds. This year-to-year variation in regional minke whale abundance is probably related to changes in abundance and distribution of possible prey species.

Conservation: The population occurring in the assessment area has a favourable conservation status. Both the global Red List (IUCN 2011) and the Greenland Red List categorise the minke whale as of 'Least Concern' (LC).

Catch There is a quota of 12 minke whales per year for East Greenland. In 2010, 4 were taken in Ittoqqortoormiit and 5 in Tasiilaq.

Sensitivity: Minke whales in high and low latitudes have been recorded producing a variety of vocalisations, using frequencies that vary from a few kHz down to 60 Hz (Rankin & Barlow 2005). Underwater sound related to oil exploration and extraction can reduce the range at which whales can detect their sounds by masking (cf. the description for fin whale).

Sei whale *Baleanoptera borealis*

Sei whales are on average 14 m long and weigh 20–25 tonnes. They are very similar in appearance to fin whales, and usually a close look by an experienced observer is needed to tell these two species apart. Sei whales 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 2008b).

Distribution: 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).

A ship survey in Southeast and West Greenland encountered sei whales frequently in the same areas as fin whales (Heide-Jørgensen *et al.* 2007). The survey was

made in September 2005, and the resulting estimate was 729 sei whales (95 % CI 226–2358) in Southeast Greenland (to the south of the assessment area). This is an underestimation of the actual numbers of sei whales in East Greenland because the survey did not cover all the potential habitat of sei whales and because animals underwater at the time of the survey and animals missed by observers were not accounted for.

Sei whales in East Greenland 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 use the assessment area, but they probably occur within the same areas as fin whales.

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 2011) and as 'Data Deficient' (DD) on the Greenland Red List (Boertmann 2008).

Sensitivity: Oil activities that potentially can impact whales include seismic exploration, exploratory drilling, ship, helicopter and aircraft noise, discharges into the water, dredging, marine construction and exploitation drilling.

Rorquals, including fin 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). Due to their potential ability to communicate acoustically over very large distances, rorquals may be sensitive to acoustic pollution from sources such as seismic airguns, drilling, offshore construction, aircraft and supply vessels.

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.

They 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.).

Distribution: Blue whales occur frequently in the waters between Iceland and Greenland (south of the assessment area), and blue whales were also observed in the assessment area during the ship-based surveys (Figure 28). No important areas are known for blue whales within the assessment area. But a recent unconfirmed observation of a large concentration of blue whales east of Scoresby Sund indicates that such a site may be found east of the drift ice. Heide-Jørgensen *et al.* (2001) documented the movement of a satellite tagged blue whale from Iceland into the assessment area. Furthermore, there are historical records of blue whales in East Greenland before the population was depleted by whaling.

Their most important feeding grounds in the North Atlantic are in eastern North America (St. Lawrence Bugt, Newfoundland, Labrador) and the Greenland Sea/Denmark Strait area, including waters from northern and western Iceland and the waters of the assessment area (east of the drift ice).

Conservation: 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 recov-

ery since global protection was applied in 1966, but population size remains at a very low level (IUCN 2011). There are roughly approximately 1 500 blue whales in North Atlantic waters. Blue whales are categorised as 'Data Deficient' (DD) on the Greenland Red List. In the IUCN Red List, blue whales are classified 'Endangered' (EN) (IUCN 2011).

Sensitivity: Blue whales produce distinctive calls with low frequency and high intensity that can be detected over hundreds of kilometres (Širović *et al.* 2007). Due to their low densities and their ability to communicate acoustically over very large distances, blue whales are 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.

Fin whale *Balaenoptera physalus*

Fin whales are the second longest animal on the planet, with average lengths in the northern hemisphere of 19–20 m and average weights of 45–75 tonnes. They are probably the most common and widespread baleen whale within the assessment area. They are found worldwide from temperate to polar waters but are less common in the tropics.

Fin whales favour prey items 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.* 2007) indicate that at least several individuals remain at high latitudes in the North Atlantic year round. Passive acoustic monitoring in the Davis Strait showed that fin whales remained in the feeding grounds until the arrival of sea ice in late December (Simon *et al.* 2010).

Distribution and stocks: Fin whales occur in the assessment area mainly off the east side of the drift ice and mainly in the summer and autumn (Figure 28). There is however no information on their occurrence or biology there.

For management purposes, the IWC (International Whaling Commission) and the NAMMCO (North Atlantic Marine Mammal Commission) recognize two major fin whale stocks in the Northeast Atlantic: the Central North Atlantic and the Eastern North Atlantic (Figure 31).The ranges of these two stocks overlap with the assessment area. They may, however, form a single population comprised of individuals that move over very large areas. Current genetic research is trying to determine which of these two scenarios is true (Pampoulie *et al.* 2008).

A workshop of leading experts agreed in 2006 that for general purposes the best estimate of current abundance in the Central North Atlantic (including the Faroe Islands) was 25 800 (CV = 0.125) for the year 2001. The best estimate for the Eastern

North Atlantic was 4,100 (CV = 0.210) from a 1996–2001 survey series (NAMMCO-IWC 2006).

Since 1985, Iceland, the Faroe Islands and Norway have carried out a number of surveys for cetaceans in the North East Atlantic. These surveys indicate that the population in the Central North Atlantic increased from the 1980s to 2001 and had stabilised by 2007 (Pike *et al.* 2008).

The survey of 2007 was an international coordinated effort by Canada, Greenland, Iceland, the Faroe Islands, Norway and Russia. The survey area included a small southern portion of the assessment area, east of Scoresby Sund, where several fin whales were observed. That they also occur further north is evident from the ship based surveys (Figure 28).

Conservation: Fin whales globally have an unfavourable conservation status and are categorised as 'Endangered' (EN) on the global Red List (IUCN 2011). The reason for the global Red List category was an estimated worldwide reduction to below 50% of the population size 60–75 years before the assessment, mainly due to whaling in the southern hemisphere (IUCN 2011). However in the North Atlantic fin whales are abundant and the population here has a favourable conservation status, listed as of 'Least Concern' (LC) on the Greenland Red List.

Catch: Fin whales are not hunted in the assessment area.

Sensitivity: Oil activities that can potentially impact whales include seismic exploration, exploratory drilling, ship, helicopter and aircraft noise, discharges into the water, dredging, marine construction and exploitation drilling.

Rorquals, including fin 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). Due to their potential ability to communicate acoustically over very large distances, rorquals may be sensitive to acoustic pollution from sources such as seismic airguns, drilling, offshore construction, aircraft and supply vessels. 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 centre and peak frequencies decreased (Castellote *et al.* 2010). Further more, 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).

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 around the Cape Verde islands (Wenzel *et al.* 2009 and references therein).

Distribution: There are no in-depth studies of ecology, distribution or abundance of humpback whales in East Greenland, and the importance of the assessment area for this species is not known. A ship-based survey from 2005 off East Greenland, south of

Figure 32. The main feeding aggregation areas for humpback whales in the North Atlantic: Gulf of Maine, Eastern Canada, West Greenland Southeast Greenland and Eastern North Atlantic. Question marks indicate that the Eastern North Atlantic aggregation area may overlap the assessment area to higher degree than shown.

the assessment area, detected humpback whales in potential association with capelin aggregations (Heide-Jørgensen *et al.* 2007). The seismic surveys in the assessment area, particularly the 2006 survey, encountered many humpback whales, mainly to the east of the Scoresby Sund entrance, but even as far north as 75° N.

Humpback whales in the North Atlantic show high levels of site fidelity with occasional long-distance movements across four main feeding aggregations (Figure 32) in the Gulf of Maine, eastern Canada, West Greenland and the eastern North Atlantic (Stevick *et al.* 2006). Distances between re-sightings of individually recognizable whales suggest that humpback whales from the Eastern Feeding Aggregation move over very large distances between feeding grounds, such as from Iceland to Norway (Stevik *et al.* 2006).

In the future, reduction in summer sea ice due to global warming coupled with a potential range expansion of humpback whales in the Eastern Feeding Aggregation due to increasing population size may result in an increased use of the assessment area by humpback whales. The observations in 2006 may be the first sign of such a development.

Conservation: The population occurring in the assessment area has a favourable conservation status as it is abundant and increasing. The number of humpback whales around Iceland has been documented to increase at a rate as high as 11 % per year (Sigurjonsson & Gunnlaugsson 1990).

Whaling has seriously depleted all humpback whale stocks, and humpback whales were protected on a worldwide basis in the 1980s. Humpback whales are

listed as of 'Least Concern' (LC) in both the global IUCN Red List and the Greenland Red List (IUCN 2011, Boertmann 2008).

Sensitivity: 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 social feeding calls, as well as click-like sounds have been described. Humpback whale sounds are low- to mid-frequency, usually 30 Hz to 8 kHz, although up to 24 kHz may be reached. Peak frequencies tend to be around 315 Hz and 630 Hz (Parsons *et al.* 2008).

3.8.4 Toothed whales

F. Ugarte and L.M. Rasmussen

Five species of toothed whale are common in the northern North Atlantic and their distributions overlap with the assessment area: killer whale, pilot whale, white-beaked dolphin, bottlenose whale and sperm whale. The distribution of these species is not restricted to the Arctic. All are found in boreal waters, and sperm and killer whales occur in all oceans. Moreover, they all avoid densely ice-covered waters, so their use of the assessment area is restricted to the ice-free months. With the expected reduction in sea-ice cover due to climate change, they may become more frequent and stay for longer times in the assessment area.

Besides the five widely spread species of toothed whales mentioned above, there is one exclusively Arctic toothed whale found in the assessment area: the narwhal. The narwhal is a North Atlantic Arctic species presumably found in the assessment area year round. There is a second Arctic toothed whale, the white whale, which has a nearly circumpolar distribution that includes all Arctic waters except for East Greenland. Thus, the white whale is only a very rare visitor to the assessment area.

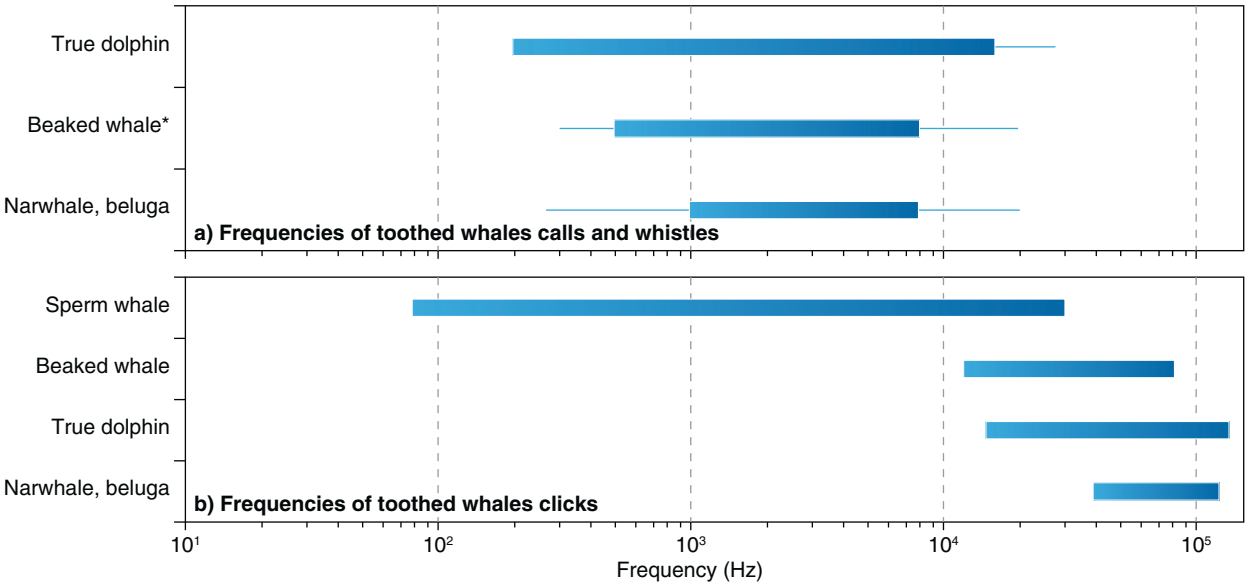


Figure 33. Known frequency ranges of pulsed calls and whistles (a) and echolocation clicks (b) made by toothed whales in the Greenland Sea assessment area. True dolphins (family Delphininae) include killer whale, pilot whale and white-beaked dolphin. Beaked whales (family Ziiphidae) include bottlenose whale. Narwhal and white whale are also included. Figure modified from Mellinger *et al.* 2007.

All toothed whales produce clicks for echolocation[1] and communication. In addition, killer whales produce pulsed calls comprising clicks in very rapid succession, and 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 cohesion. Whistles are important during short-range social contact. Figure 33 shows the frequency ranges of echolocation clicks, calls and whistles produced by toothed whales in the assessment area.

Long-finned pilot whale *Globicephala melas*

Distribution: The long-finned pilot whale occurs in temperate and subpolar zones and, according to most literature, ranges in the North Atlantic from Disko Bugt in the southern Baffin Bugt and Ungava Bugt in Davis Strait, 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 (APNN, unpublished data) show that pilot whales may occur as far north as Ittoqqortoormiit on the east coast in late summer and early autumn. They however apparently avoid ice-covered waters and will only come close to the coast in years with very little ice (Heide-Jørgensen & Bunch 1991).

Population: The pilot whales occurring in the assessment area (and the rest of Greenland) are likely to represent vagrants from a single North Atlantic population of which the size unknown, except that it is large.

In 1993, the population in the northeast Atlantic was estimated at 778 000 whales (Buckland *et al.* 1993).

Biology: Long-finned pilot whales are social and generally found in groups of 20–100 individuals. 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 occasionally caught by hunters from Tasiilaq and Ittoqqortoormiit, and the annual catches range between 0 and 19.

Conservation: Long-finned pilot whale is listed as of 'Least Concern' (LC) according to both the IUCN Red List and the Greenland Red List (IUCN 2011, Boertmann 2008).

Sensitivity: Pilot whales are probably as sensitive as other toothed whales to noise, disturbance, and oil spills. See text about toothed whales above.

White-beaked dolphin *Lagenorhynchus albirostris*

Distribution: White-beaked dolphins inhabit the North Atlantic Ocean in the cold temperate zone to subpolar waters. In the Northeast Atlantic they reach into the Arctic waters in the Barents Sea, around Spitsbergen and to East Greenland at approx. 74° N. They are the most common dolphin off southeastern Greenland, in Denmark Strait and the seas around Iceland (Reeves *et al.* 1999, Kinze 2009).

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

Up to 100 000 white-beaked dolphins inhabit the north-eastern Atlantic including the Barents Sea, the eastern part of the Norwegian Sea and the North Sea north of 56° N (Øien 1996).

Biology: White-beaked dolphins' primary habitat is in waters less than 200 m deep, especially along the edges of continental shelves. But they may also occur in deeper waters.

White-beaked dolphins feed mainly on a variety of small schooling fishes like herring, capelin, lesser sandeel and cod, but may also eat squid and crustaceans (Jefferson *et al.* 2008).

The species has been very little studied and very little is known about its biology and ecology. White-beaked dolphins are most often found in groups of 5–10, but occur also in larger groups and occasionally in their hundreds (Rasmussen 1999). When feeding, the dolphins are often associated with other species of whales. Young are mainly observed from June to August and migration patterns are unknown.

Catch: In Greenland, white-beaked dolphins are caught for subsistence. There are no catch statistics for this species prior to October 2005. From East Greenland, catches of white-beaked dolphins were reported only from Tasiilaq, south of the assessment area: Three in 2005, one in each of the years 2006, 2006 and 2007 and two in 2008.

Conservation: The IUCN (2010) Red List status of the white-beaked dolphin is of 'Least concern' (LC). On the Greenland Red List, the white-beaked dolphin is listed as 'Data Deficient' (DD). The white-beaked dolphin is not a target of commercial fisheries, but occasionally drowns as by-catch in fishing gear. The rate of fisheries by-catch is however low compared with other dolphin and porpoise species, and incidental catches are not thought to be high enough to represent a severe threat for white-beaked dolphins (IUCN 2011).

Sensitivity: White beaked dolphins are probably as sensitive as other toothed whales to noise, disturbance, and oil spills. See text about toothed whales above.

Killer whale *Orcinus orca*

Biology: Killer whales are top predators that occur in all oceans, but tend to concentrate in colder regions with high productivity. They feed on prey items that vary 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, each ecotype formed by one or more killer whale populations that share an ecological niche. 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.* 2007), 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 Northeast 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). Moreover, in Antarctica, three ecotypes feed on toothfish, 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.

Estimated, 10–15 000 killer whales occur in the Northeast Atlantic, but high concentrations are found only seasonally in Iceland and Norway (Øien 2000). An unknown proportion of Icelandic killer whales and the majority of Norwegian killer whales belong to a Scandinavian ecotype of herring-eating killer whale (Simon *et al.* 2007). These herring-eating killer whales form at least two separate populations that migrate following major herring stocks: the Icelandic summer-spawning herring and the Norwegian spring-spawning herring (Sigurjónsson & Leatherwood 1988, Similä *et al.* 1996).

After a collapse in the 1960s, the Icelandic summer-spawning herring stock increased in following decades, while rise in sea temperature has affected the distribution of the stock, which expanded in a westerly direction during the period 1996–2006 (ICES 2007). This expansion brings the northwest edge of the range of the Icelandic summer-spawning herring to overlap with the Greenland Sea assessment area, increasing the likelihood of finding herring-eating killer whales in this area. Killer whales following the Norwegian spring-spawning herring may also occur within the eastern edge of assessment area during summer. Killer whales that feed on marine mammals have been observed in Tasiilaq, south of the assessment area. These killer whales tend to have large home ranges, and those from southwest Greenland probably occur also in the assessment area.

Distribution: There is very little information about killer whales in East Greenland. Norwegian small-type whalers caught 136 killer whales south of the Greenland Sea assessment area between 1959 and 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.

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 almost all areas of Greenland, with exception of the assessment area north of Scoresby Sund, where survey effort was low. But killer whales seem to be absent in the coastal areas. Killer whales were reported off the pack-ice belt in East Greenland and on rare occasions during ice-free summers in Scoresby Sund.

Conservation: Killer whales are listed as 'Data Deficient' (DD), both globally (IUCN 2011) and nationally (Boertmann 2008).

Catch: Killer whales are hunted in Greenland, partly for human subsistence and partly to feed dogs, but also because they are considered as competitors to hunters. Between 1996 and 2006, killer whales were taken on two occasions in East Greenland off Tasiilaq, south of the assessment area. There are no reports of killer whale caught in the assessment area.

Figure 34. The general distribution of narwhal.

Sensitivity: The effect of the *Exxon Valdez* oil spill on killer whales has been described by Matkin *et al.* (2008), who monitored the demographics and group composition of killer whales from Prince William Sound 5 years prior to and 16 years after the 1989 oil spill. Killer whale groups in the proximity of the spill were unable to avoid the oil and suffered losses of up to 41 % in the year following the spill. Sixteen years later the groups had either not recovered at all or showed rates of increase lower than expected.

Narwhal *Monodon monoceros*

Biology: Narwhals are high Arctic mammals that feed primarily on Greenland halibut and other species of Arctic fish, shrimp and squid. Narwhals undertake regular migration between shallower summer grounds in fjords, where they apparently do not feed, and wintering grounds in deep and densely ice-covered waters, where they feed (Figure 34). They are gregarious, occurring usually in groups comprising a few to more than 100 individuals.

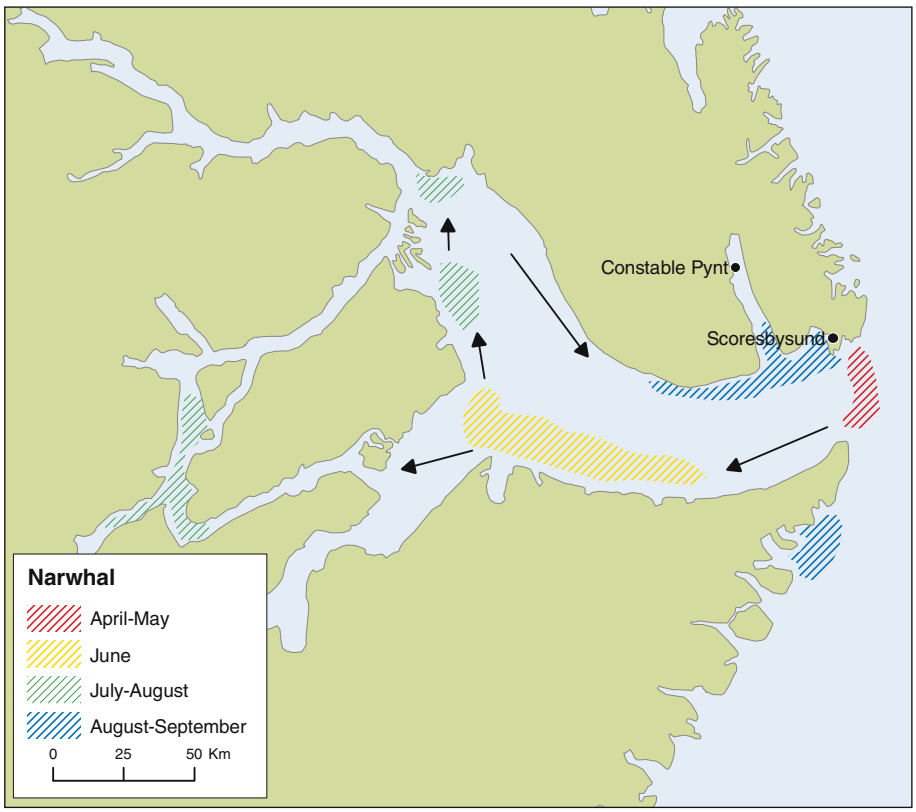


Figure 35. Annual narwhal movements in the Scoresby Sund complex, based on local information (Aastrup *et al.* 2005).

Distribution: Narwhals occur throughout the assessment area (Dietz *et al.* 1994). In winter primarily in the wide drift ice belt off the coast, and recently narwhals have been tracked from Scoresby Sund to winter habitats over the shelf break off the Blosseville Kyst (M.P. Heide-Jørgensen GINR pers. comm.). In summer narwhals occur along the coast, ice edges and in the fjords (Figure 26, 27, 28). Figure 35 shows the movements of the whales in the Scoresby Sund fjord complex as recorded by local hunters.

Population: Three systematic surveys have been carried out in the assessment area. In 1983 and 1984 narwhal abundance was estimated in Scoresby Sund and adjacent waters to be 300 and 102, respectively, based on aerial censuses (Larsen *et al.* 1994). The latest aerial survey in the areas available to hunters in East Greenland has been carried out in August 2008. The abundance of narwhals in the surveyed areas of East Greenland (Scoresby Sund and south to Tasiilaq) was 6 444 (95 % CI: 2,505–16,575) (Heide-Jørgensen *et al.* 2010a).

The narwhals in East Greenland are, like the whales in Baffin Bugt, probably divided in several subpopulations separated in their summer grounds. Current research by GINR aims at investigating the population structure and abundance of narwhals in East Greenland. Six satellite tracked individuals wintered in the pack ice off the Blosseville Kyst mainly outside the 500 m isobath (M.P. Heide-Jørgensen pers. comm.).

Catch: Narwhals are important quarry for the hunters in both Ittoqqortoormiit and Tasiilaq, because narwhal skin ('mattaq') and male tusks can be traded at considerable prices. The Ittoqqortoormiit hunters catch narwhals in the large Scoresby Sund fjord complex and along the northern part of the Blosseville Kyst. Hunters from Tasiilaq travel to Kangerlussuaq and the southern Blosseville Kyst (Glahder 1995). Catch statistics show an increasing catch in the assessment area, from 19 animals/year as an annual average in the period 1997–2003 to between 30 and 93 animals/year from 2004-2006. However, the catch statistics for East Greenland

most likely underestimate the real catch. Since 2009, catches of narwhals in East Greenland are regulated by quotas. These quotas follow the biological advice and narwhal catches are considered sustainable. The East Greenland quota for 2010 was 85 whales, of which 50 were allocated to Ittoqqortoormiit and 35 to Tasiilaq.

Conservation status: The narwhal population in the assessment area probably has a favourable conservation status, as the narwhals are fully protected within the National Park of North and Northeast Greenland. South of the national park, the catches are regulated by quotas.

The Scoresby Sund area seems to have been more important for summering narwhals prior to establishment of the town of Ittoqqortoormiit around 1925 (Dietz *et al.* 1994). However there is no information on population trends from East Greenland and the population is listed as 'Data Deficient' (DD) on the Greenland Red List (Boertmann 2008).

Critical and important habitats: Several of the fjord systems in East Greenland must be considered very important to the narwhals and this includes the Northeast Water, Dove Bugt, the Young Sund area, the Scoresby Sund fjord, fjords along the Blosseville Kyst, Kangerlussuaq and Sermilik. See Heide-Jørgensen *et al.* 2010 for a detailed list of important fjords.

In winter and spring the ice edge habitats are important feeding areas for narwhals

Sensitivity: Narwhals are generally believed to be sensitive to noise from seismic surveys, and drilling. Increased traffic and oil activities may cause displacement from critical habitats and reduction in the population. The DCE-guidelines to seismic surveys in Greenland designate specific narwhal protection areas (Kyhn *et al.* 2011b).

Sperm whale *Physeter macrocephalus*

Biology: 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 tonnes, 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 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 that weigh up to 400 kg (reviews in Rice 1989 and Whitehead 2003). Sperm whales in the Northeast Atlantic feed heavily on the deep water squid, *Gonatus fabricii* (Santos *et al.* 1999), favouring mature squid with mantle length of approx. 19 to 26 cm (Simon *et al.* 2003). Male sperm whales off northern Norway tagged with multi-sensor instruments feed both at shallow depths of about 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. 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 (*C. lum-*

pus), but redfish (*Sebastes marinus*), anglerfish (*Lophius piscatorius*), Atlantic cod (*Gadus morhua*) and blue whiting (*Micromesistius poutassou*) were also common.

Distribution: 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).

Based on ship surveys in July 2001, the estimated number of sperm whales between East Greenland and the Faroe Islands was 11 185 (CV 0.34, Gunnlaugsson *et al.* 2002). There was dense sea ice in East Greenland at the time of that survey, and thus coverage of the assessment area was very poor. Most of the sightings of sperm whales were in the Denmark Strait close to the southern part of the assessment area, or south, east and northeast of Iceland. There were no sperm whales seen in the proximity of the assessment area north of approx. 68° N. In Svalbard, sperm whales have been observed at the ice edge as far north as 80° N.

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 and Gyllensten 1998).

Conservation: Sperm whales were the target of commercial whaling for 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. Nowadays, sperm whales are not caught anywhere in the North Atlantic. On the Greenland Red List, sperm whales are listed as 'Not Applicable' (NA) and globally as 'Vulnerable' (VU) (Boertmann 2008, IUCN 2011).

Critical and important habitats: Sperm whales are often found feeding in deep, underwater canyons and on the deep side of steep continental slopes. But such feeding areas have not been identified in East Greenland waters.

Sensitivity: The echolocation clicks of sperm whales have a source energy flux density of up to 193 dB re 1 μPa^{2}s. 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 diminished when airguns were operating (Miller *et al.* 2009). The results of this study may not be representative for other parts of the world because these particular sperm whales lived in an area with heavy shipping traffic and a long history of oil activity; therefore the whales may have habituated to anthropogenic noise and stronger reactions may be expected elsewhere.

Northern bottlenose whale *Hyperoodon ampullatus*

Biology: 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

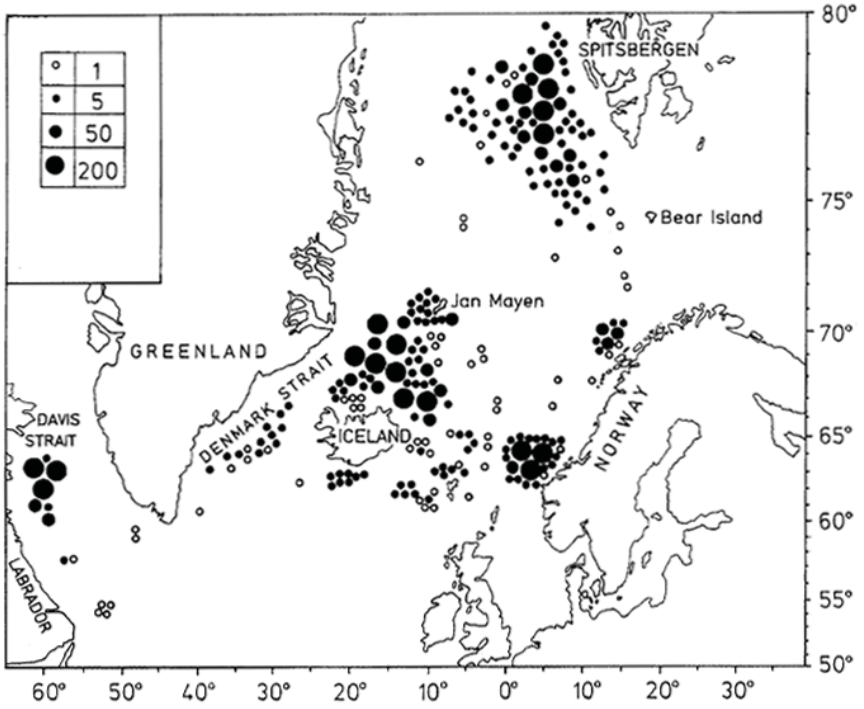


Figure 36. Localities of northern bottlenose whales caught by Norwegian Whalers in the period 1938-1972 (modified from Benjaminsen & Christensen 1979).

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, at the southern end 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 and 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: Northern bottlenose whales are the most frequently observed cetaceans around the Jan Mayen Ridge (Gunnlaugsson & Sigurjónsson 1990), just east of the assessment area. Within the area, they can be observed during summer in deep waters east of the East Greenland Current, especially associated with abrupt changes in the bottom topography, such as underwater mounts or canyons.

Catch: Northern bottlenose whales were the target of Norwegian whaling during two periods. The first period was from 1882 to the 1920s, when somewhere in the region of 60 000 northern bottlenose whales were taken. Approximately 5 800 whales were taken during the second period, from 1930 to 1973 (NAMMCO 1995). Norwegian catches were spread over much of the Northeast Atlantic, including the Greenland Sea and the Denmark Strait and, after 1959 some bottlenose whales were taken in West Greenland and eastern Canada (Figure 36). Norwegians stopped hunting bottlenose whales because the market for whale oil and meat for pets and farmed mink was no longer profitable.

Scottish sealers and whalers took approximately 1,961 bottlenose whales from 1856 to 1970, including catches in both the Davis Strait and the Greenland Sea (Thompson 1928, in NAMMCO 1995). The majority of these catches (1787) were from the period 1877–1892.

Before the studies from the Gully were published, a group of specialists assumed that bottlenose whales from the Northeast Atlantic (i.e. east of Kap Farvel) could be considered as a single population that migrated across several areas and numbered about 40000 whales (NAMMCO 1995). It was assumed that northern bottlenose whales migrate because whaling catches peaked in different months at separate whaling grounds.

Northern bottlenose whales are not taken by Greenlandic hunters.

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 2011, Boertmann 2008).

Critical and important habitats: Bottlenose whales are often found feeding in deep, underwater canyons and on the deep side of steep continental slopes, but such areas have not been located in East Greenland waters.

Sensitivity: Hooker *et al.* (2008) found increasing levels of persistent contaminants and CYP1A1 protein expression 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.

Northern bottlenose whales are often very curious and are attracted to ships operating in their habitat. But their ability to habituate to more permanent disturbance is not known.

See text about toothed whales and acoustic disturbance above.

3.8.5 Important and critical habitats for marine mammals

The marine mammals of the assessment area are dependent on open waters: seals and whales for breathing, polar bears for feeding. Therefore recurrent and predictive open waters among otherwise ice-covered areas will be critical to the ice-dependent marine mammals in the assessment area. The ice edges, the polynyas and the lead zones are such critical areas. Particularly the Northeast Water is extremely important to walruses, narwhals, bowhead whales, polar bears and probably also to ringed and bearded seals. The Sirius Water Polynya (off Wollaston Forland) is also very important to walrus, polar bear and bowhead whale. The third large polynya, at the entrance to Scoresby Sund is of similar importance to marine mammals as the Northeast Water (seals, walrus, narwhal, polar bear), and was the basis for the establishment of town of Ittoqqortoormiit. The marginal ice zone in the Greenland Sea is habitat for bowhead whales, narwhals (mainly in winter) and also for polar bears and walrus. It is, however, not possible to designate specific important areas in this zone, due to lack of knowledge and due to the highly dynamic occurrence. Finally some of the fast ice edges also seem to be important, especially the edge of the semi-permanent ice shelf between the Northeast Water and Île de France.

Polar bear denning areas are widespread along the coast, and it is not possible to point out specific important coastlines for this very sensitive habitat. There seems to be a tendency for higher densities of maternity dens north of approx. 68° N, and known regular denning areas include Kangerlussuaq; the Blosseville Kyst; the inner parts of the Scoresby Sund fjord complex; the areas between Kong Oscars Fjord and Kejser Franz Joseph Fjord; Shannon; Dove Bugt; the areas between Île de France and Ingolf Fjord; and the coast at the Northeast Water. The tracking reported in Box 8, identified several denning sites in the northern part of the assessment area.

Polar bears are dependent on ice cover, preferring relatively dense sea ice at the continental shelf where there are high concentrations of ringed seals.

Well-defined edges of the shore fast-ice are frequent in the polynyas and other parts of the assessment area. Along these there are often open waters and here narwhals and other Arctic marine mammals may congregate in spring e.g. off the mouth of the large fjord-systems. There is however no knowledge available on the pattern of occurrence at such sites, and it is most likely highly variable and not predictive on a fine scale.

Walruses are dependent on shallow feeding grounds with high densities of bivalves. They also need access to air for breathing and to suitable haul-out sites on ice or land. During winter, polynyas are extremely critical to the walrus population in the assessment area. There are many important summer feeding sites for walrus in the shallow waters between Young Sund and Germania Land.

Critical habitats on the ice are evident for the two seal species whelping and moulting in dense aggregations: the harp seal and the hooded seal. These areas are located on the drift ice in the eastern part of the assessment area and are highly dynamic in their position due to the variation and movements of the drift ice.

Narwhals spend the summer months in deep coastal waters; and many of the fjords on the Blosseville Kyst, some the inner parts of Scoresby Sund, the large fjords of Kong Oscar and Kejser Frantz Josef, as well as Young Sund, Dove Bugt and the Northeast Water are known to be important habitats.

During ice free periods, deep underwater canyons and step continental slopes may be important habitat for sperm whales and northern bottlenose whales, while zones with high concentrations of krill and schooling fish may be critical habitat for baleen whales. The location of such critical habitats are not known due to lack of data.

4 Natural resource use

D. Boertmann, H. Siegstad, F. Ugarte, M. Bjerre and A. Rosing-Asvid

4.1 Commercial fisheries

Very little commercial fishery takes place in the assessment area. However, a Greenland halibut fishery was developed in 2005 in the area between 67° and 71°30' N on the continental slope at water depth between 500–1000 m. The total fishery in this area amounted to about 1200 tonnes in 2005. Catches decreased to about 250 tonnes in 2006 but increased again to 700 tonnes in 2007. Within the assessment area only 204 tonnes on average were taken annually in 2005–2007 (Figure 37). This fishery is conducted from large trawlers, and no commercial fishing takes place from the only settlement within the assessment area (Ittoqortoormiit/Scoresbysund).

4.2 Subsistence hunting and fisheries

In 2010 the human population in the assessment area numbered 469 inhabitants, all living in the town of Ittoqqortoormiit/Scoresbysund since the adjacent settlements are abandoned today (Statistics of Greenland 2010). In 2007, 27 occupa-

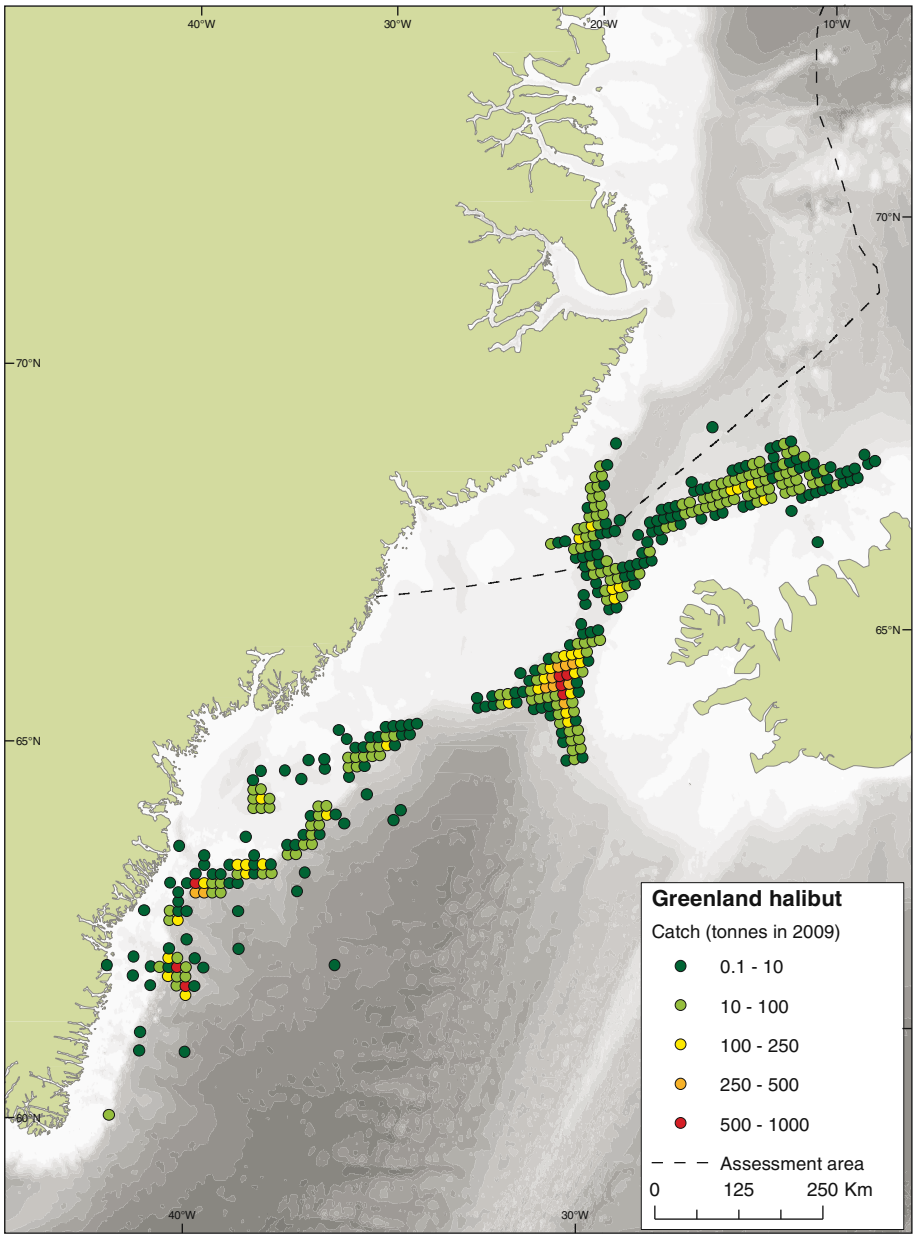


Figure 37. Distribution of the 2009 catches of Greenland halibut within and close to the assessment area.

tional hunters and 121 leisure hunters were registered (APNN 2009 *in litt.*). Hunters from Tasiilaq utilise the southernmost part of the assessment area. They move to the Kangerlussuaq-area mainly for hunting narwhal and polar bear (Glahder 1995).

4.2.1 Hunting

The hunt in the Ittoqqortoormiit-area takes place in the entire fjord complex and along the outer coasts of Liverpool Land and Blosseville Kyst. Transportation is mainly by means of dog sledge or snowmobil, and in the open-water season also from dinghy or small boat. Previously hunters went by dog sledge far north into the National Park to hunt polar bears in early spring, but this activity has apparently ceased in recent years (Aastrup *et al.* 2005).

The most important quarry from the marine environment is narwhal and polar bear, as well as ringed seal and harp seal. Other species that are taken in relatively lower numbers include walrus, bearded seal, hooded seal and seabirds. In recent years, also minke whale has been caught in the Ittoqqortoormiit-area.

The most important hunting areas are the ice edge of the polynya (winter, spring), which usually is very close to the city and also the coasts to the east and northeast of the town at Kap Tobin. During summer, narwhals are caught in the inner parts of the Scoresby Sund fjord complex and southwards along the Blosseville Kyst for example in the fjords around Turner Ø.

In the period 1972–1980 approx. 4000 ringed seal skins were traded annually in Ittoqqortoormiit. However, the number of seals caught may have declined, since the hunting statistics (introduced in 1993) only recorded about 2000 ringed seals in 1996. In 2008, 1167 ringed seals were reported to the hunting statistics in Ittoqqortoormiit. In Tasiilaq (including surrounding villages) 7536 (2008) ringed seals were reported (Table 7). Most of the seals caught by hunters from Tasiilaq area were taken south of the assessment area. In the years 2006-2009 the number of traded seal skins from Ittoqqortoormiit varied from 65 (2007) to 551 (2009) and in Tasiilaq in the same period from 1426 (2006) to 1139 (Statistics of Greenland 2010).

The annual polar bear catch in entire East Greenland (incl. the area outside the assessment area) comprised approx. 60 animals in the period 1999–2003 (Born & Sonne 2006). Since 1996, the hunt of polar bears in East Greenland has been limited by a quota of 30 bears per year to Ittoqqortoormiit and 20 to Tasiilaq. The reported hunt in 2010 was 30 and 23 respectively (APNN, unpublished data). All the bears from Ittoqqortoormiit and some of the bears from Tasiilaq are caught within the assessment area.

Quotas for narwhals in East Greenland were set for the first time in July 2009. The quota for Ittoqqortoormiit is 50 narwhals and for Tasiilaq 35. Between July and December 2010, there were 20 catches reported for Ittoqqortoormiit and 10 for Tasiilaq (APNN, unpublished data).

Table 7. Reported catch of seals in East Greenland in 2008 (Data: APNN unpublished).

Species	Ittoqqortoormiit	Tasiilaq
Harp Seal	7	3433
Ringed Seal	1167	7536
Hooded Seal	2	519

The IWC has set a quota of 12 minke whales annually for East Greenland, with possibility of transferring up to 3 whales from one year to the next. In 2010, 4 minke whales were caught in Ittoqqortoormiit and 5 in Tasiilaq (APNN, unpublished data). The catch from Ittoqqortoormiit was record high, and this could be interpreted as a changed distribution.

Hunters from Tasiilaq often stay at 'Skærgården' and make hunting trips into the Kangerlussuaq fjord or along the outer coast as far as Vedel Fjord at 28° W. In summer they travel by boat, hunting mainly narwhal and in spring, February–May, by dog sledge, hunting polar bear (Glahder 1995).

4.2.2 Fishery

No commercial fishery takes place out of Ittoqqortoormiit, and fishery activity for domestic use is rather limited. The most important species in this subsistence fishery is Arctic char, which is mainly caught along the coast of Hurry Inlet, at Sydkap inside the Scoresby Sund fjord and in some of the fjords of the Blosseville Kyst (Figure 14). Other species caught include spotted wolffish (*Anarchichas minor*), Greenland shark (*Microcephalus somniosus*) (used for dog food), Greenland halibut (*Reinhardtius hippoglossoides*), sculpin (*Myxocephalus scorpius*) and polar cod (*Boreogadus saida*) (Sandell & Sandell 1991, Petersen 1993).

4.3 Tourism

The tourist industry is one of three major sectors within the Greenland economy and is increasing significantly in importance in Greenland and indeed the Greenland Sea assessment area itself. The National Strategy of Tourism 2008–2010 plans a 10% increase per year in the number of cruise tourists alone (Department of Industry 2007), a trend which is very apparent in Ittoqqortoormiit.

The most important asset for the tourist industry is the unspoilt and authentic nature, which is particularly abundant in the coastal areas of the assessment area, e.g. in the National Park.

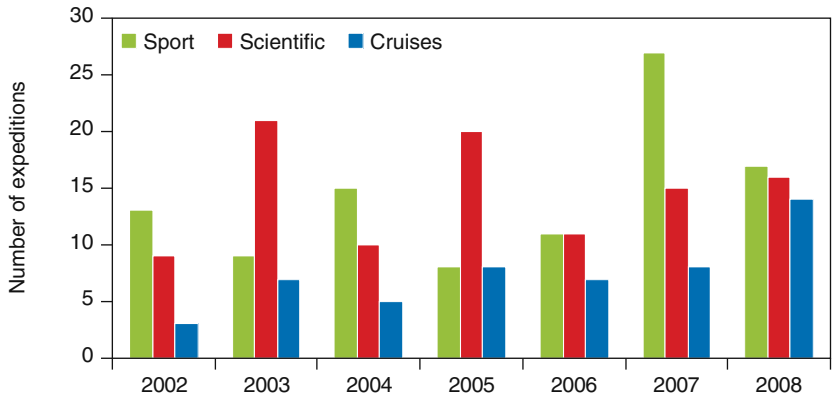
Two kinds of tourists visit the assessment area: tourists spending the night on land (hotels, camping, and other kinds of accommodation) and tourists from cruise ships. Tourists spending the night on land include those on scientific expeditions or those engaging in outdoor recreational activities, e.g. mountaineering and kayaking.

The tourists staying on land all arrive through the airport at Nerlerit Inaat/Constable Pynt, and operate usually from there or from Ittoqortormiit/Scoresbysund town, explaining why this type of tourism is concentrated in the southern part of the assessment area – mainly the Scoresby Sund Fjord and the southern part of the National Park.

Cruise ships may visit any ice-free coast during the summer, and they arrive either from Svalbard, moving southwards along the outer coast and into the fjord lands or they arrive from the south (Tasiilaq or Iceland) visiting mainly the town of Ittoqqortoormiit/Scoresbysund and the adjacent fjord land.

Both types of tourists have increased in numbers in the area in recent years. However, no statistics are available on the number of tourists and their regional distribution in Greenland. But hotel statistics show that only 5–10% of the overall total of 250 000 'bed nights' in hotels in 2006 were spent in Northwest and East Greenland (= the former municipalities of Qaanaaq, Upernavik, Uummannaq, Scoresbysund and Tasiilaq) (Statistics of Greenland 2010).

Figure 38. Number of expeditions in Northeast Greenland by year. Data provided by the former Danish Polar Centre (DPC).



Unspoilt wilderness, the trademark of Greenland tourism, is particularly available in Northeast Greenland, because of the very limited human population and the National Park of North and Northeast Greenland. Tourists expect unspoilt nature in the assessment area and when cruise ships come across 'spoilt nature', such as for instance flensing sites with unused narwhal carcasses, the story hits the international press with considerable impact.

Expeditions

The terrestrial and coastal parts of the assessment area are the destination of many types of expeditions, both scientific and recreational: natural history, mountaineering, kayaking, etc. (Figure 38).

Cruise ships

Cruise ships spend the majority of time in the coastal zone and sightings of marine mammals and birds are major highlights alongside the scenic views, historical sites and visits to the inhabited places. Figure 39 shows the number of cruise ships and passengers 1994–2007 calling at Ittoqqortoormiit.

Figure 39. Development in number of cruise ships (calls) and number of passengers 1994–2007 in Ittoqqortoormiit/Scoresbysund (Greenland Tourism pers. comm.).

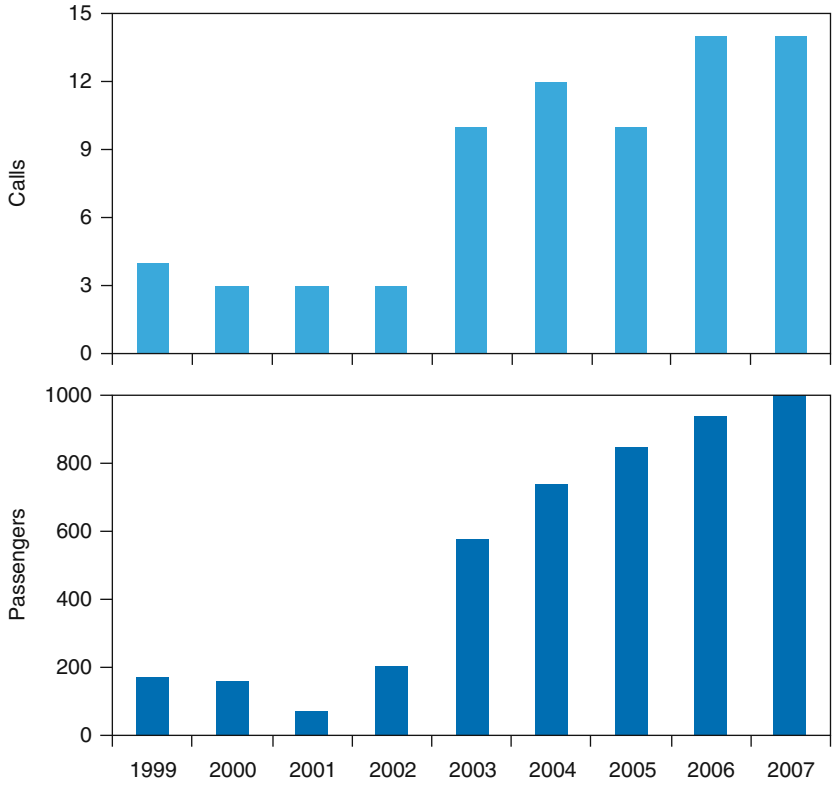
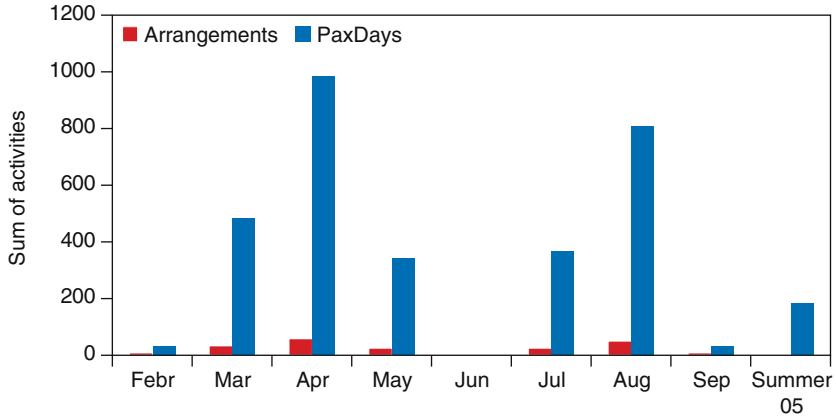


Figure 40. Sum of activities 2004-2007 by Nanu Travel, Ittoqqortoormiit (pers. comm.).



With the expected increase in cruise tourism and with more open water in the summer time, cruise ship activity will most likely intensify in the assessment area, in terms both of number of ships and people, but also in terms of visiting more and more remotely situated sites.

4.3.1 Ittoqqortoormiit/Scoresbysund

As the only town in the area, most tourists go through Ittoqqortoormiit. There is one locally based tour operator, Nanu Travel, and a couple of operators based in Iceland also organise activities. The annual temporal distribution of tourist activities is shown in Figure 40. Activities for tourists include:

Dog sled trips take place mainly in Liverpool Land in April/May when it is still cold, but the sun has returned from the dark winter period. The local operator, Nanu Travel, arrange about 600 sled passenger days, normally one day per tourist.

Kayaking takes place in the open-water season (July–September), and a number of tourists go kayaking in Scoresby Sund and the fjords of the southern part of the National Park each year.

Boat trips are arranged mainly as transport to landing sites for hiking or kayaking in summertime.

Hiking takes place in summer in the Scoresby Sund fjord complex or in the southern part of the National Park.

Trophy hunting (muskox) takes place in spring and mainly in Jameson Land.

4.3.2 The National Park

The National Park receives a few independent visitors (expeditions) and some cruise ships. Because of the sea ice most areas are only accessible for a short time of year.

Much of the tourist activity within the assessment area takes place in the coastal zone, which potentially can be exposed to oil spills. As the most important asset of the tourist activity in the area is the unspoilt nature, an extensive oil spill has the potential to seriously impact the local tourist activity and industry.

5 Protected areas and threatened species

D. Boertmann

5.1 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, only one in Disko Bugt has been incorporated as a protected area so far. Three of the Ramsar sites are found within the assessment area (Figure 41). These are all designated due to the presence of geese in internationally important numbers, i.e. more than 1 % of the flyway population (Egevang & Boertmann 2001).

5.2 National nature protection legislation

The major part of the land and fjord areas adjacent to the assessment area is designated as national park – The National Park in North and East Greenland (Fi-

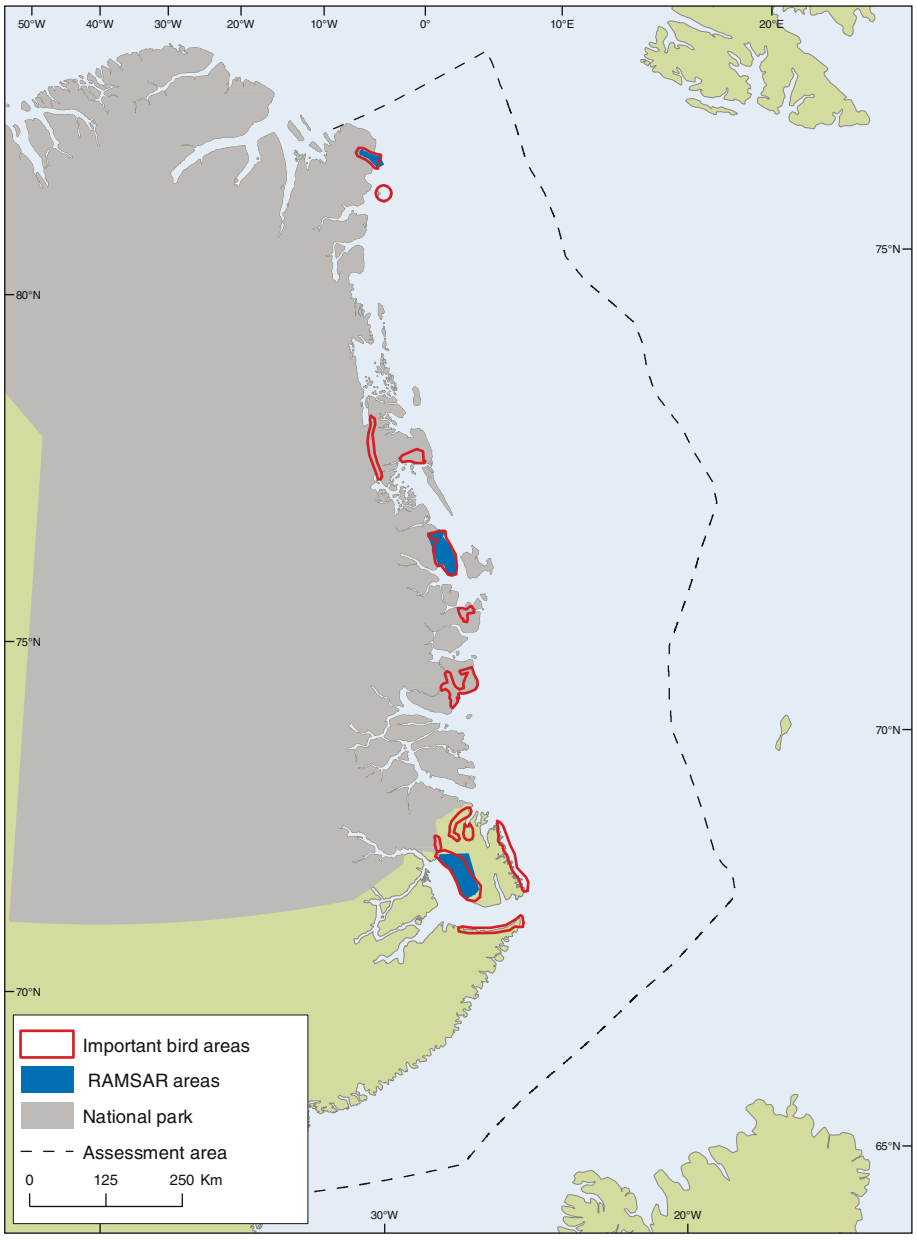


Figure 41. Areas protected according to the Greenland Nature Protection Law (National Park in North and East Greenland and Bird Protection areas), international conventions (Ramsar) and areas designated as Important Bird Areas (IBAs) by BirdLife International.

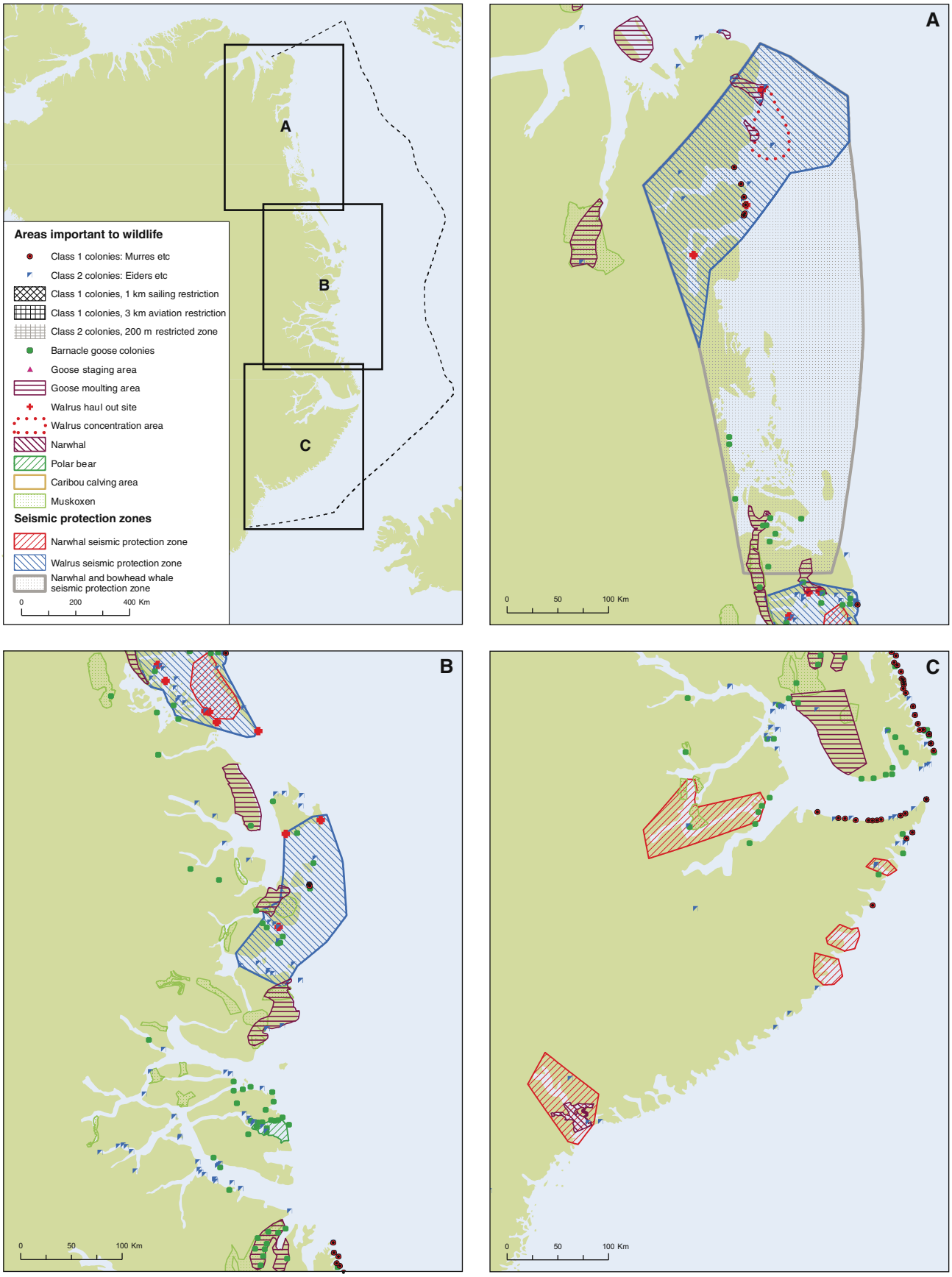


Figure 42. Areas designated as "important to wildlife" by Bureau of Minerals and Petroleum as a part of the field rules for prospecting and exploration activities. Seabird breeding colonies of the 'murre class' comprise the species: Thick-billed murre, little auk, kittiwake and fulmar. The 'eider class' comprise common eider, Arctic tern and gulls other than kittiwake. The narwhal areas include also the special areas where seismic activities are regulated in order to protect narwhals.

gure 41), with strict protection of nature and environment. However, it is allowed to explore for petroleum and minerals within the national park (Boertmann 2005, Aastrup *et al.* 2005). Management of the park is under revision, and zoning with varying management and protection is an option which is discussed.

There are no specific sites protected according to the Bird Protection Order within the assessment area, but all seabird breeding colonies and their immediate surroundings are generally protected from disturbing activities (*cf.* the map showing all known seabird breeding colonies). 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 (Figure 42). In relation to seismic surveys a number of protection areas for whales and walrus has been designated along the coasts (Figure 42) (Kyhn *et al.* 2011b).

Recently the available knowledge (including local knowledge) on ecosystem components of the National Park and adjacent areas was reviewed (Aastrup *et al.* 2005). This was updated in 2009 (Aastrup & Boertmann 2009), and a number of areas with important biological interests were identified (Figure 43).

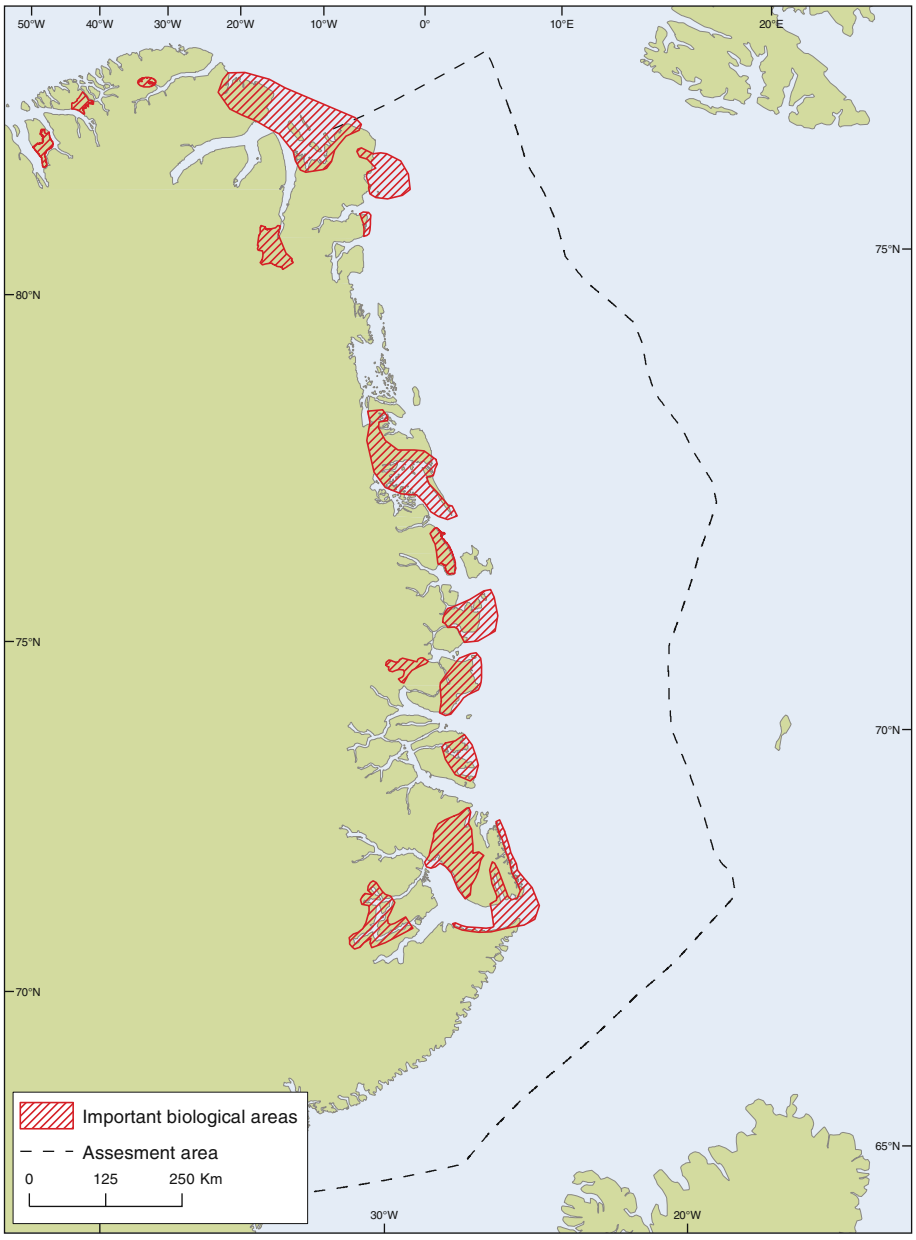


Figure 43. Areas with major biological interests in and adjacent to the National Park of North and Northeast Greenland designated during a review of available information (Aastrup *et al.* 2005, Aastrup & Boertmann 2009).

5.3 Threatened species

Greenland has red-listed (designated according to risk of extinction) four species of mammals and twelve species of birds (Table 8) occurring in the assessment area (Boertmann 2008).

A number of species have been categorised as 'Data Deficient' (DD) or 'Not Applicable' (NA) and they may become red-listed when additional information is available (Table 9).

Greenland has a special responsibility for species for which a significant part (>20 %) of the global population occurs witin the territory, implying that their global survival depends on a favourable conservation status in Greenland. National responsibility species occurring in the assessment area include one mammal and five birds (Table 9). However, also narwhal may be included here, but knowledge on numbers and the proportion in Greenland is unknown.

Within the assessment area there are some hot-spots containing threatened species (Figure 44), particularly the mouth of Scoresby Sund, the Sirius Water Polynya, the entrance to Dove Bugt and the Northeast Water including the islands of Henrik Krøyer Holme.

Threatened species on a global scale and occurring in the assessment area are listed in Table 10.

Table 8. Red-listed species occurring in the assessment area of the Greenland Sea assessment area.

Species	Greenland Red List status
Wolf**	Vulnerable (VU)
Polar bear	Vulnerable (VU)
Walrus	Near Threatened (NT)
Bowhead whale	Critically endangered (CR)
Great northern diver	Near Threatened (NT)
Light-bellied brent goose	Near Threatened (NT)
Gyr falcon**	Near Threatened (NT)
European golden plover**	Near Threatened (NT)
Whimbrel**	Near Threatened (NT)
Sabines gull	Near Threatened (NT)
Ross's 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)

*applies to the entire Greenland population, and red-listed because the population in West Greenland is decreasing, a trend not apparent in East Greenland. ** are not associated with the marine environment.

Table 9. National responsibility species (more than 20 % of global population in Greenland) and species listed as 'Data Deficient' (DD) or 'Not applicable' (NA) occurring in the assessment area. Only species which may occur in marine habitats are included.

National responsibility	Species listed as 'Data Deficient' (DD) species or 'Not Applicable' (NA)
Polar bear	Bearded seal
Pink-footed goose	Blue whale
Light-bellied brent goose	Killer whale
Barnacle goose	White-beaked dolphin
Knot	Narwhal (East Greenland population)
Black guillemot	Sperm whale
Little auk	Bottlenose whale

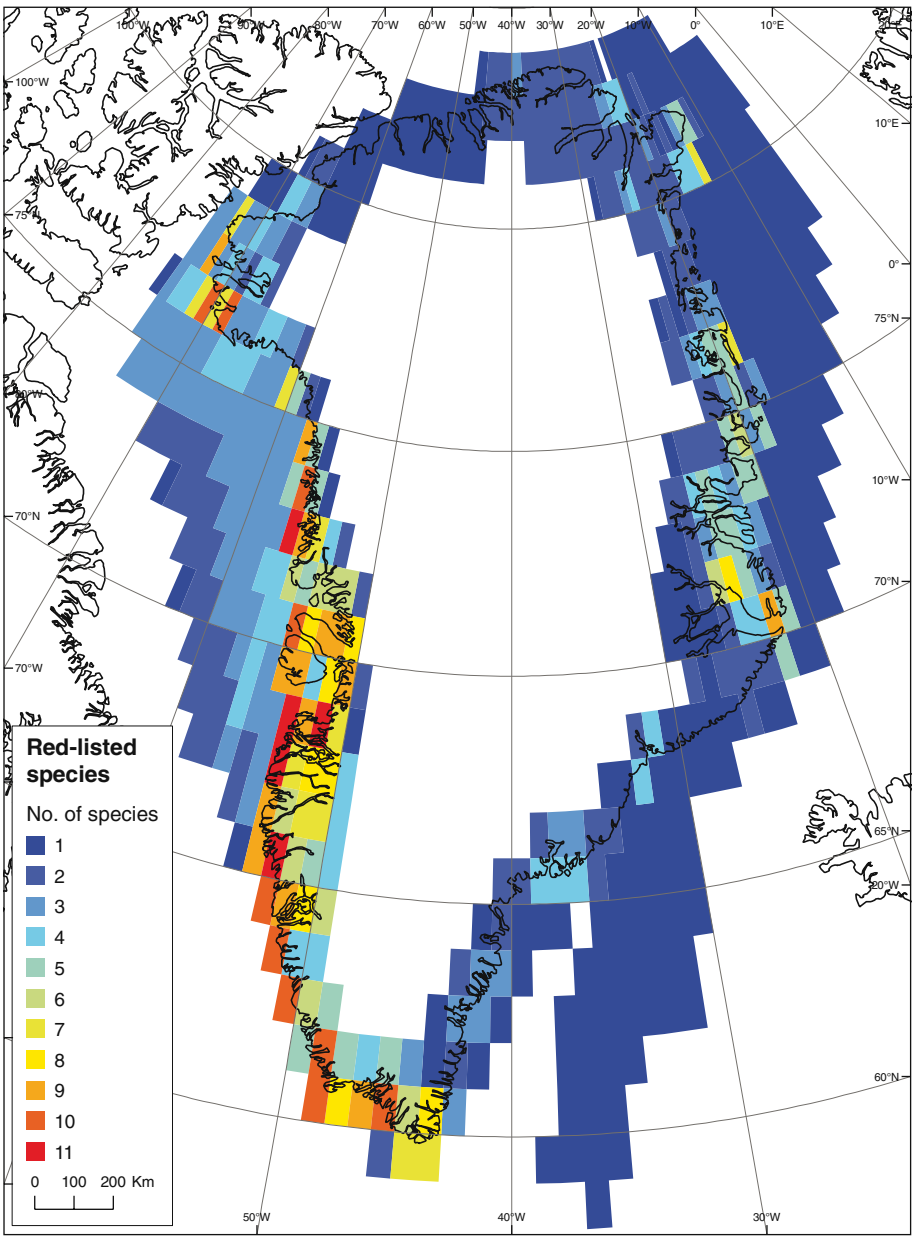


Figure 44. Distribution of Red Listed species in Greenland shown as number of species in 1° × 1° squares (Boertmann 2008).

5.4 NGO designated areas

The international bird protection organisation BirdLife International has designated a number of Important Bird Areas (IBAs) in Greenland (Heath & Evans 2000), and fourteen are within the assessment area (Figure 41). These areas are particularly important areas for birds and are areas which should be protected by national regulations. They 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. within the National Park, but many are without protection or activity regulations.

Table 10. Globally threatened species occurring in the assessment area (IUCN 2011).

Ivory gull	Near Threatened (NT)
Polar bear	Vulnerable (VU)
Bowhead whale, Spitsbergen population	Critically Endangered (CR)
Fin whale	Endangered (EN)
Blue whale	Endangered (EN)
Sperm whale	Vulnerable (EN)
Narwhal	Near Threatened (NT)

6 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.

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 been carried out at different locations around Greenland including the assessment area.

In West Greenland contamination from point sources has been surveyed and monitored at Maarmorilik (near Uummannaq) where 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 were assessed in 2002 (Glahder *et al.* 2003).

Environmental studies were performed at Mestersvig, located c. 10 km inland from Kong Oscars Fjord, in the central part of the assessment area where an underground lead-zinc mine was operated from 1956-1963. Potential impacts on the environment, e.g. due to deposition of tailings were monitoring between 1979 and 2001.

An environmental assessment performed by Johansen *et al.* (2008) documents that the former mine has caused a significant pollution with lead and zinc on-land, as well as in the river Tunnelelv and in Kong Oscars Fjord. Mine tailings and spill of concentrate are the main sources for the found pollution. The overall levels of zinc and lead have declined in biota and sediment but at a slow rate and it is expected that Kong Oscar Fjord will be affected for many more years.

6.1 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 based on Riget (2006) and results from the latest AMAP assessment (Riget *et al.* 2010).

6.1.1 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. In East Greenland polar bears mercury concentrations of 2.13-13.4 (liver) and 2.87-32.0 µg/g wet weight (kidney) were found. The Cd levels in ringed seals from Danmarkshavn reached up to 10 µg/g wet weight in livers of 10-15 years old animals, whereas in West Greenland (Upernavik) up to 30 µg/g wet weight were found in seal livers from the same age group.

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).

6.1.2 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 Bugt (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 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).

6.1.3 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 Wit *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 Bugt. 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).

6.1.4 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, a 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). Increasing levels are also documented in polar bears from East Greenland (Dietz *et al.* 2008).

6.1.5 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).

6.2 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 anthropo-

genic 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).

6.2.1 PAH studies in Greenland

Total petroleum hydrocarbons (TPH) and PAH levels were measured at possible natural seeps in the Disko Bugt area in 2005. Sediments and biota (blue mussels, shorthorn sculpins, and 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 Bugt 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 Bugt 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 Bugt and two from Nuussuaq Basin clearly displayed higher concentrations.

In 2008, sediment samples were taken at 15 coastal locations in the eastern Baffin Bugt in West Greenland. A set of 28 different polycyclic aromatic hydrocarbons (PAH) were analysed in the surface sediment layer (0-1 cm depth) (Sejr *et al.* 2010). At locations where PAH content was found to be elevated, additional samples from deeper within the sediment were processed. In general, PAH levels were low and could be regarded as background levels. 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 and from the harbour supporting 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 Bugt have been analysed in surface sediments. PAH levels were usually very low, except for one station. The higher PAH concentrations at this location could probably 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 were analysed offshore Disko Bugt to document background level prior drilling. PAH content in the analysed sediment was usually low.

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 concentrations.

6.3 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 East Greenland are generally higher than in the same species and tissues from West 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 Greenland Sea assessment area is still very limited.

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.

6.4 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).

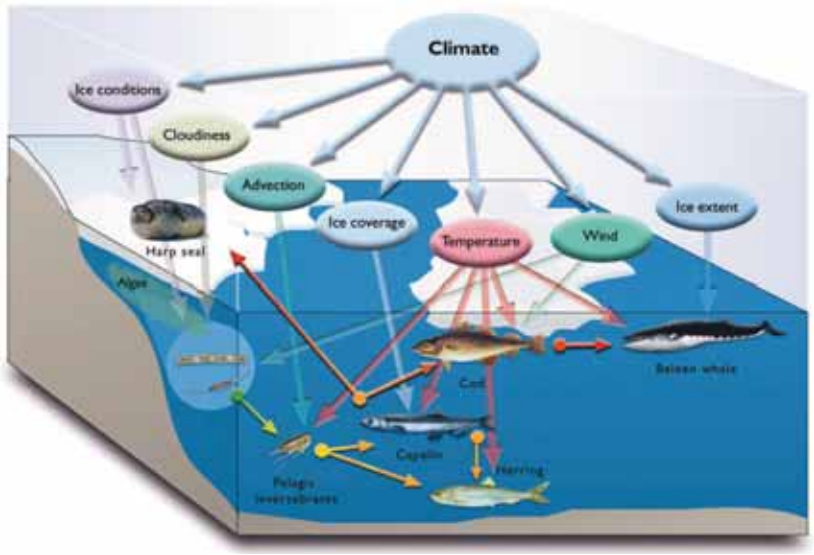


Figure 45. Different climate parameters that may impact the marine food chain, both directly and indirectly (From ACIA 2005).

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 Bugt/David Strait and a few populations of freshwater Arctic char (Figure 45).

Pollution effects have been especially investigated on polar bears since this species exhibit the highest levels of certain contaminants in the Arctic. In particular the populations from East Greenland and Svalbard (Norway) show high levels of contaminants (Kirkegaard *et al.* 2005, Sonne *et al.* 2004, 2005, 2006, 2007, 2009, Basu *et al.* 2008, 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.

7 Impact of climate change on the Arctic marine environment

D. Schiedek

7.1 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).

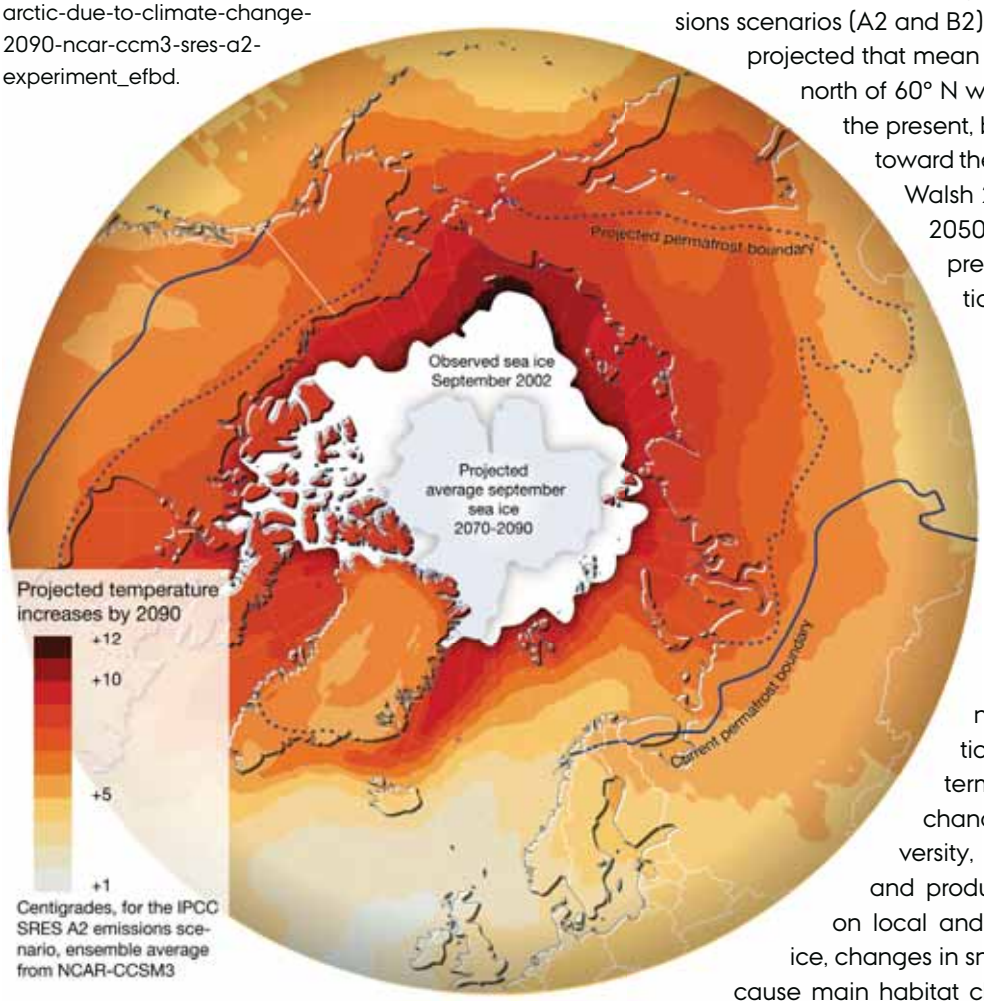


Figure 46. Projected temperature increases in the Arctic due to climate change, 2090 (NCAR-CCM3, SRES A2 experiment). From UNEP/GRID-Arendal Maps and Graphics Library 2008. Available at: http://maps.grida.no/go/graphic/projected-temperature-increases-in-the-arctic-due-to-climate-change-2090-ncar-ccm3-sres-a2-experiment_efbd.

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 46). 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 may include changes in species distribution and diversity, affecting 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 may 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

Table 11. Summary 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

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 11).

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.

7.1.1 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 *C. 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 runs 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 will lead to an increase in export production that is greater than the increase in primary production (Lavoie *et al.* 2010).

7.1.2 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 continues, 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). Such 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 fjordic and coastal (nearshore) Arctic waters has also been reviewed and future changes have been hypothesized (Weslawski *et al.* 2011). The predicted temperature rises 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 refugial area 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.

7.1.3 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 as well as Atlantic cod. The southern limits of colder water fish species, such as polar cod and capelin, are likely to move northward. Greenland halibut 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.* 2009).

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.

7.1.4 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.* (2008) 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 (e.g. 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 of sea ice. 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 km2 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).

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).

7.2 Interactions between climate change and contaminants

The Arctic environment is presently not only affected by climate change, but also by human releases of contaminants as indicated in Section 6 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 12.

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 being 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).

Biomagnification 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 bioaccumulation due to changes in transport, partitioning, carbon pathways, and bioaccumulation process rates. Magnitude and direction of these changes and resulting overall bioaccumulation in food webs is currently not

Table 12. 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)

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 bioaccumulation 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 bioaccumulation, 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 Bugt 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 bioaccumulation and biomagnification by altering bottom-up or top-down mechanisms controlling trophic food webs (Braune *et al.* 2005; Macdonald *et al.* 2003; 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 biomagnification potential.

Increased temperature and salinity linked to climate change could enhance the toxicity of some POPs and other pesticides in aquatic biota. Altered biotransformation 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).

7.3 Climate change implications for the Greenland Sea assessment area

Annual mean temperatures for selected stations in East 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).

Based on a regional study using the HIRHAM4 model a clear increase in air 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 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 the modelled present day situation (1961–1990). For the later period (2051–2080), winter temperature increases accelerate considerably according the model, reaching a temperature increase of 7–8°C throughout the Arctic and 12°C along the east coast (Figure 46). Precipitation is projected to increase by about 8 % by the middle of the century and by approx. 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).

The variability in oceanic primary production in the European sector of the Arctic Ocean in relation to changes in ice cover was modelled based on data from several cruises between 1995 and 2007 (Wassmann *et al.* 2010). It represents a time interval before the massive decline of sea ice in the summer of 2007. No evidence for a significant increase in gross primary production was found (Wassmann *et al.* 2010). It is expected, however, that increasing warming and ice melting in the Arctic will impact the structure and net metabolism of the planktonic communities, resulting in a shift towards a pelagic system that is dominated by net heterotrophic metabolism and characterized by food webs including harmful *Phaeocystis pouchetti* colonies. The dominant microbial loop in the upper water column are expected to lead to decreased exports of biogenic material to the sea floor and thus to a shift of the planktonic ecosystem from a CO_2 sink to a CO_2 source (Agusti *et al.* 2010).

Climate change is also expected to have an impact on organisms due to changes in the pH of the water. Presently, pH in the Arctic Ocean is relatively high. However, the increasing level of atmospheric CO_2 has resulted in a decline in the pH of the oceans. The general lower water temperature in the Arctic ecosystems will lead to much more severe acidification effects than in any other part of the world (ACIA 2005).

Acidification could have an impact on physiological responses of Arctic key species. Experiments performed on the brittle star *Ophiocten sericeum*, an important species also in the Greenland Sea, have documented changes in certain physio-

logical processes when exposed to both increased temperature and reduced pH (Wood *et al.* 2011). The potential implications of lower pH on Arctic species have also been discussed by Weslawski *et al.* (2011). They point out that within 50 years, species such as molluscs and crustaceans will not be able to produce their shells due to low pH and thus aragonite saturation.

Reduction of the annual sea ice cover, on the other hand, is expected to increase marine productivity in the high Arctic (Sejr *et al.* 2009). At present it is difficult to predict how increased productivity might influence the species composition and diversity.

Change in Arctic benthic ecosystems will also depend on the extent to which they are connected to boreal ecosystems. In those areas that are open and thus allowing exchange, new species will be advected northwards and existing species may be displaced (Weslawski *et al.* 2011).

Studies performed in West Greenland have shown that the previous warming period off Greenland had clear consequences for the abundance and distribution of key fish species such as Atlantic cod or capelin (Stein 2007, Drinkwater 2006, 2009) and distribution of other species (Jensen 1939, Jensen & Fristrup 1950). Furthermore, Jensen (1939) and Tåning (1949) documented changes in many other fish species (e.g. spotted wolffish and herring). Also distribution of benthic species such as blue mussels (*Mytilus edulis*) and common starfish (*Asterias rubens*) spread northward during the warming period 1920-1930. Some 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 (*Brosme 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).

For the east coast such information is presently not available. However, the studies performed in West Greenland clearly documented that a warming period resulted in a clear, radical shift in the abundance and occurrence of certain species, which will have significant impact on community structure and thereby the functioning of the ecosystem (Drinkwater 2009).

In order to understand the impact of climate change on Arctic marine food webs, the distribution of foraging little auks were studied in contrasting conditions in the Greenland Sea (Karnovsky *et al.* 2010). According to this study, the eastern side of the Greenland Sea has experienced recent warming, whereas the western side is still dominated by cold, Arctic water from the East Greenland Current. It was hypothesized that foraging little auks would be found in greatest abundance in cold Arctic waters, which provide more lipid-rich prey. As expected, the highest concentrations of large *Calanus* copepods (*C. glacialis* and *C. hyperboreus*) were found in the cold water of the East Greenland Current. Amount of foraging little auks was also highest in these waters, indicating a relationship that is likely to be disrupted by increasing water temperatures (Karnovsky *et al.* 2010).

To assess potential future impacts of ocean warming, a coupled atmosphere–ocean global climate model (AOGCM) was used to predict Greenland Sea sea-surface temperatures over the study area at the end of the 21st century (Karnovsky

et al. 2010). It was suggested that 4 of 8 little auk breeding colonies in the North Atlantic may be negatively impacted as temperatures exceed the thermal preferenda of large *Calanus*, the preferred prey of little auks during the breeding season.

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.

How and when polar bears will respond to climate change in different areas is uncertain, but for example Canadian populations are expected to decrease due to reduction in sea ice cover (Stirling & Parkinson 2006). An improved understanding of habitat use and factors affecting the movement patterns of polar bears in these areas will allow insights into how polar bears will respond to climate change (Derocher *et al.* 2004). Such a study has been initiated as a one of the projects related to this SEIA (see Box 8).

Future scenario and conservation status

Using 10 of the scenarios by the Intergovernmental Panel of Climate Change (IPCC) of projected decrease of sea ice and resource selection functions (RSF) based on data from satellite telemetry on polar bear habitat preferences including data from East Greenland (1993-1998), Durner *et al.* (2007, 2009) forecasted that optimal polar bear habitat in East Greenland will decrease substantially during the next 50–100 years. The decrease will be most pronounced during spring and summer. A decrease in sea ice in the southern range of the polar bears will imply that areas with optimal polar bear sea-ice habitat in Northeast and North Greenland will become more important. Hence, it is projected that the northern parts of the Greenland Sea assessment area progressively will be of increasing importance to the East Greenland population of polar bears.

The prognosis of the increasing negative effects on polar bears of a future decline of sea ice was the main reason for listing the polar bear as 'Vulnerable' (VU) on the both the global and the Greenland Red List.

As pointed out in Section 6, many persistent organic pollutants reach high levels in polar bears due to their high-fat diet and high trophic position, and concentrations of several POPs were particular high in East Greenland (Letcher *et al.* 2010). Recent studies on polar bears suggest that pollutants impact the endocrine system, immune system, and subsequent reproductive success of polar bears (Derocher *et al.* 2004, Sonne 2010). If polar bears become food stressed and their immune system is further challenged, it is possible that they may become more vulnerable to disease or parasites.

Studies on bowhead whales from the Disko Bugt area and their primarily food (Heide-Jørgensen *et al.* in review) have shown they primarily feed on *Calanus hyperboreus* and *C. glacialis*. The more Atlantic *C. finmarchicus* is also part of the diet. Changes in the distribution of the three copepod species due to climate change favouring *C. finmarchicus*, which is a smaller and faster reproducing copepod species with lower lipid content. 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.

7.4 Concluding remarks

The examples given in this section 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 in the Greenland Sea.

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 what the adaptation capacity of native species is 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.

8 Impact assessment

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8.1 Methodology and scope

The following assessment is based on available background information compiled from studies published in scientific journals and reports, from previous NERI technical reports (e.g. Aastrup *et al.* 2005, Aastrup & Boertmann 2009) and from the information collected by the Marine Mammal and Seabird Observers (MMSO) on the ships carrying out seismic surveys in the region. An important contribution is the information collected during the specific background studies initiated as a part of this SEIA (see Section 11). This information is all summarised in the previous Sections 2 to 7. Despite this, it is important to stress that the background knowledge from the assessment area still is much more limited than it is for the licence round areas in the waters off West Greenland.

8.1.1 Boundaries

The assessment area is the area described in the introduction (Figure 1). This is the region which potentially can be impacted by the activities and particularly by a large and long-lasting oil spill deriving from activities in the expected licence areas. However, it cannot be excluded that the area affected might be even larger, including coasts both northwest and south of the assessment area and waters and coasts within the Norwegian (e.g. Jan Mayen) and Icelandic EEZs.

The assessment includes, as far as possible, all activities associated with an oil field, from exploration to decommissioning. The almost permanent presence of sea ice in large parts of the assessment area makes it difficult (or even impossible) with the present technology to operate in the area, but in this assessment it is assumed that exploration activities will take place in the summer and autumn (July–September) when ice conditions are relatively light.

Production activities will, if approved and initiated, take place throughout the year. How potential production facilities will be constructed is presently not known, but the setup could be similar to that described from the Disko West area by the APA study (2003), *cf.* Section 8.2.5.

8.1.2 Impact assessment procedures

The first step of an assessment is to identify potential interactions (overlap/contact) between petroleum activities and ecosystem 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 (VECs) has been applied.

VECs can be species, populations, biological events or other environmental features that are important components to the local ecosystem, 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) as well as processes such as the primary production spring bloom.

The VECs selected here are typical representatives of the ecosystem and are species, groups of species (e.g. seabirds), habitats (e.g. tidal/subtidal zone) and events (e.g. pelagic hotspots) which potentially can be impacted by oil activities in the assessment area.

The spatial extent of effects is indicated as local or regional. 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 temporal extend of effects vary from immediate over short term to long term or even permanent.

Quantification of the potential impacts on ecosystem components is very difficult. The spatial overlap of the expected activities cannot be assessed as it is not known where oil activities will take place. Furthermore, the physical properties of potentially spilled oil are likewise not known. Moreover, there is still a lack of knowledge concerning important ecosystem components and how they interact. In addition, climate change also impacts the ecosystems, complicating assessment of impacts from oil activities.

Many sources have been drawn upon to assess impacts form oil activities. Especially important in this respect are the Arctic Council Oil and Gas Assessment (AMAP 2010), 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 2003a). Relevant research results on toxicology, ecotoxicology and sensitivity to disturbance has 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.

8.2 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.

8.2.1 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 that receive the echoed sound waves from the seabed. The sound source is an array of airguns 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 (Kyhn *et al.* 2011b)). Regional seismic surveys (2D seismics) are charac-

terised by widely spaced (over many kilometres) survey lines, while the more localised surveys (3D seismics) usually cover small areas with densely spaced lines. Rig site investigations and shallow geophysical investigations use comparatively much smaller sound sources than used during 2D seismic surveys. 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.

8.2.2 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 and probably also in East Greenland 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 the Greenland Sea 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 in total generated 2 262 m^3 cuttings and 6 000 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, Kyhn *et al.* 2011b).

8.2.3 Drilling mud and cuttings

Drilling mud is used to optimise drilling operations. Mud was previously oil-based (OBM), but due to the toxicity, this has now been replaced mainly by water-based muds (WBM) or for drilling under certain difficult conditions by synthetic-based muds (SBM). However, OBM is still used under conditions when it 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.

8.2.4 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.

8.2.5 Other exploration related activities

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

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

8.2.6 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.

8.2.7 Produced water

Produced water is by far the largest 'by-product' of oil production. 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 substances 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 bioaccumulate. The produced water moreover contributes to the majority of the oil pollution discharge during normal operation, e.g. in Norway up to 88 %.

Produced water has usually been discharged to the sea after a cleaning process which reduces the amount of oil to levels accepted by the authorities (in the North Sea sector of Norway, for example, 40 mg/l or 30 mg/l as recommended by OSPAR). Discharges of produced water and chemicals to the water column appear to have acute effects on marine life only in the immediate vicinity of the installations due to the dilution effect. But long-term effects of the releases of produced water have not been studied, and several uncertainties have been expressed concerning, for example, the hormone-disrupting alkylphenols and radioactive components with respect to toxic concentration, bioaccumulation, etc (Meier *et al.* 2002, Rye et. al. 2003, Armsworthy *et al.* 2005).

8.2.8 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 exhausts per day (LGL 2005). But also flaring of gas and trans-shipment of produced oil contribute to emissions. The emissions consist mainly of greenhouse gases (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.

8.2.9 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 west of Disko Island in southern Baffin Bugt. Something similar could be expected for the Greenland Sea 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.

8.2.10 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 ecological populations and even to species (Skjoldal *et al.* 2007).

9 Impacts of the potential routine activities

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9.1 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 or less free of ice. However, in 2010 and 2011 seismic surveys were carried out in lightly ice covered waters aided by an icebreaker.

Environmental impacts of exploration activities relate to:
- Noise from seismic surveys and drilling
- Cuttings and drilling mud
- Disposal of various substances
- Emissions to the air
- Placement of structures

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

9.1.1 Assessment of noise

Noise from seismic surveys

The main potential impacts on fish and marine mammals from the seismic sound generators include:
- physical damage: injury to tissue and auditory damage from the sound waves
- disturbance/scaring: behavioural impacts, including masking of underwater communication by marine mammals.

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

In Arctic waters there are certain special conditions 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 very strong in convergence zones far (>50 km) from the sound source, and this is particularly evident in stratified Arctic waters. This has recently been documented by means of acoustic tags attached to sperm whales, which recorded high sound pressure levels (160 dB re 1 µPa, peak to peak) more than 10 km from a seismic array (Madsen *et al.* 2006).

Another issue rarely addressed is that airgun arrays generate significant sound energy at frequencies many octaves higher than the frequencies of interest for geophysical studies. This increases concern regarding potential impacts, 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 recovery 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 on an inshore reef did not move away from airgun sounds with peak pressure levels as high as 218 dB (at 5.3 m relative to 1 µPa peak to peak) (Wardle *et al.* 2001). The reef fish showed involuntary startle reactions but did not swim away unless the explosion source was visible to the fish at a distance of only approx. 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 sandeel (*Ammodytes marinus*) (Hassel *et al.* 2004). No immediate lethal effect on the sandeel was observed, either in cage experiments or in grab samples taken during night when sandeel were buried in the sediment (Hassel *et al.* 2004).

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

Impact of seismic noise on zoo- and ichtyoplankton

Zooplankton and fish larvae and eggs (= ichtyoplankton) cannot avoid the pressure wave from the airguns and can be killed within a distance of less than 2 m, and sublethal injuries may occur within 5 m (Østby *et al.* 2003). The relative volume of water affected is very small and population effects, if any, are considered to be very limited in e.g. Norwegian and Canadian assessments (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 (Mosbech *et al.* 2007a). The reason is that 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 of Atlantic cod 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 short term and catches would return to normal after the studies. The effect was moreover more pronounced for large fish compared with 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 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 the 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 different results (Vold *et al.* 2009): Catch rates of Atlantic cod, ling, tusk 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 were 2D and scattered in time and space, why major influences on the fisheries was not expected.

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 cannot 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 than the experiments.

It is therefore difficult to assess the effect on the offshore Greenland halibut fisheries, because reactions of this species have not been studied. However, if catches are reduced by a seismic survey, the effect is most likely temporary and will probably only affect specific fisheries for a shorter period (weeks). The fishery of Greenland halibut

in the assessment area is small compared to the overall Greenland fishery (Figure 37). However, the trawling grounds are restricted in area (specific depths at approx. 1 500 m); why alternative fishing grounds may be difficult to find within the asesssment area if the Greenland halibut are displaced by seismic activity.

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

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.

Impact of seismic noise on marine mammals
Responses of marine mammals to noise fall into three main categories: physiological, behavioural and acoustic (Nowacek *et al.* 2007). Physiological responses include hearing threshold shifts and auditory damage. Behavioural responses include changes in surfacing, diving and heading patterns, and may result in avoidance of the impacted area or reduced feeding success. Acoustic responses include changes in type or timing of vocalisations. In addition, there may be indirect effects associated with altered prey availability (Gordon *et al.* 2004).

Despite the fact that quantifying the reaction of marine mammals to antropogenic noise is logistically challenging, there is strong evidence for behavioural effects on marine mammals from seismic surveys (e.g. Ljungblad *et al.* 1988, Patenaude *et al.* 2002, Gordon *et al.* 2004, Stone & Tasker 2006, Nowacek *et al.* 2007, Compton *et al.* 2008, Miller *et al.* 2009, Di Iorio & Clark 2010).

Mortality has not been documented, but there is a potential for physical damage, primarily auditory damage (Nowacek *et al.* 2007). Under experimental conditions temporary elevations in hearing threshold (TTS) have been observed (Richardson *et al.* 1995, National Research Council 2005). 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 2004).

In the USA a sound pressure level of 180 dB re 1 µPA) (rms) or higher is adopted by the US National Marine Fisheries Service as a mitigation standard to protect whales (NMFS 2003, Miller *et al.* 2005a). This exposure criterion is poorly defined from a measuring point of view and has little experimental support. Thus Southall *et al.* (2007) have proposed a reorganisation of exposure criteria, allowing more room for differences in sensitivity between different species 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 in 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 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 have also been reported to change the acoustic characteristics of their sounds (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 sound. 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, although they occasionally came closer (McCauley *et al.* 2000). In the Beaufort Sea, autumn-migrating bowhead whales avoid areas where the noise from exploratory drilling and seismic surveys exceeds 117–135 dB and they may avoid the seismic source by distances of up to 35 km (Reeves *et al.* 1984, Richardson *et al.* 1986, Ljungblad *et al.* 1988, Brewer *et al.* 1993, Hall *et al.* 1994, NMFS 2002, Gordon *et al.* 2004); 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 been observed as close as 100 m from operating airgun arrays, potentially close enough to sustain physical damage (NERI unpublished).

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

In West Greenland waters satellite tracked humpback whales, utilised extensive areas and moved between widely spaced feeding grounds; they therefore most likely still had access to alternative foraging areas if they were displaced from one area by seismic activities (Dietz *et al.* 2002, Heide-Jørgensen & Laidre 2007). However, given the expected extent of seismic activities in Greenland, there is a risk of cumulative effects if multiple surveys occur at the same time in adjacent areas.

The US National Marine Fisheries Service defines the radii about a seismic ship with received sound levels of 180 dB (re 1 µPA, rms) as the distances within which some cetaceans are likely to be subject to behavioral 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.* (2002) found no reaction of sperm whales to a seismic survey operating at tens of km's away. More recently, Dunn & Hernandez (2009) did not detect changes in the behaviour of blue whales that were at 15–90 km from operating airguns. The authors estimated that the whales experienced sounds of less than 145 dB (re 1µPA) and concluded that, while their study supports the current US-NMFS guidelines, further studies with more detailed observations are warranted (Dunn & Hernandez 2009).

An acoustic effect widely discussed in relation to whales and seismic surveys is the masking effect of communication and echolocation sounds. There are, however, no studies which document such effects, mainly because the experimental set-ups are extremely challenging. Masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures.

The whales in the assessment area use a wide range of frequencies (from <10 Hz to >100 kHz, Figure 29), why seismic sound sources (<300 Hz) are likely to overlap in frequency with at least some of the sounds produced by these whales especially the baleen whales incl. bowhead whale (e.g. Gordon *et al.* 2004). It is however uncertain at which distance from an array the received sound pressures will be high enough to mask biologically significant sounds.

Due to the low frequency of their phonations, baleen whales, followed by seals would be the marine mammals most affected by auditory masking from seismic surveys (Gordon *et al.* 2004). For instance, blue whales increase their calling rate during seismic surveys, probably as a compensatory behaviour to the elevated ambient noise (Di Iorio & Clarck 2010). Likewise, changes on the acoustic parameters of fin whale calls in the presence of operating airguns indicate that fin whales also modify their acoustic behaviour to compensate for increased ambient noise (Castellote *et al.* 2010).

Masking is more likely to occur from the continuous noise from drilling and ship propellers and this 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 is a pronounced release of masking.

Sperm whales showed diminished forage effort during air gun emission, but it is not clear if this was due to masking of echolocation sounds or to behavioural responses of the whales or the prey (Miller *et al.* 2005b, 2009).

The most noise-vulnerable whale species in the assessment area will be narwhal, blue whale and bowhead whale, and there will be a risk of temporary displacement from critical habitats. Other whales occurring in summer and autumn will also be sensitive. This applies to regional 2D seismics.

In case of 3D sesimic surveys there will be a risk of more prolonged displacement – perhaps for a whole season – from critical habitats especially for walruses, narwhals, bowhead whales and blue whales. Cumulative impacts of several 3D surveys either simultaneously or in succession, may be more severe.

In general, seals display considerable tolerance to underwater noise (Richardson *et al.* 1995), confirmed by a study in Arctic Canada in which ringed seals showed only limited avoidance to seismic operations (Lee *et al.* 2005). In another study, ringed seals had habituated to industrial noise (Blackwell *et al.* 2004). However 'hauled-out' walruses and whelping hooded and harp seals on the drift ice may be disturbed and displaced by the activity (not by the seismic noise), although the whelping period is early in the spring at a time when seismic surveys are not possible.

Mitigation of impacts from seismic noise

Mitigation guidelines generally recommend a soft start or ramp up of the airgun array each time a new line is initiated (review by Compton *et al.* 2008). Although not verified by experiments or observations, this approach is commonly consid-

ered '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 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, convergence zones where very high sound pressures may occur far from the sound source may be out of sight of the observer. Moreover is visibility often hampered by fog, and late in the season the nights become dark.

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

The DCE-guidelines for seismic activities in Greenland waters designate a number of protection areas where seismic surveys shall be avoided or regulated to protect narwhals, bowhead whales and walruses (Kyhn *et al.* 2011b).

Finally, it is recommended that local authorities and the hunters' organisations are 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 seismic activities are taking place.

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

In the DCE-guidelines to seismic surveys (Kyhn *et al.* 2011b) following best practice is recommended (in line with the JNCC 2010 recommendations):

- The airgun array should not be larger than needed for the specific survey.
- Use of mitigation gun. The mitigation gun is the smallest airgun in the array in terms of energy output (dB) and volume (in^3). Output from the array should be reduced to the mitigation gun as outlined below.
- A safety zone of 500 m from the airgun array shall be applied.
- An injury zone of 200 m shall be applied. If marine mammals are observed within 200 m during full power, the output shall be reduced to the mitigation gun until the mammal has left the zone.
- A pre-shooting search shall be conducted before commencement of any use of the airguns. If waters are less than 200 m deep, this search shall last 30 min. If waters are more that 200 m deep, it shall be extended to 60 min. If marine mammals are spotted within the safety zone, the ramp-up procedure shall be delayed 20 minutes, from the time when the animal has left the safety zone (or the ship has moved so far that the animal is outside). The pre-shooting search can be initiated before the end of a survey line, while the airguns are still firing.
- The array shall not be started at full power, but individual airguns should be added one by one or if not possible, output of each airgun slowly increased by manipulation of pressure (ramp-up or soft start procedure).

- The ramp-up procedure shall occur over a period of about 20 min and can occur while the survey ship is en route to the starting point of the transect line.
- Ramp-up should not be initiated if marine mammals are inside the array or within the safety zone (500 m) of the array. If marine mammals are discovered within this safety zone during the ramp-up procedure, the airguns shall be reduced to the mitigation gun, and a new ramp-up procedure initiated when the mammal has left the safety zone – i.e. at least 20 min. after the last sighting.
- If proper ramp-up cannot be performed for technical or other reasons, other measures should be taken to assure that no animals are within the safety zone at start up.
- Passive Acoustic Monitoring (PAM) of vocalizing whales shall be deployed for monitoring purposes during start up at night or during periods when the sea state is above 3. Especially in areas with bowhead whales.
- If the array is shut down for any reason while on the transect line it can be re-initiated at full power given that the silent break is not longer than 5 min. Otherwise a full ramp-up procedure should be followed.
- During line changes the array output should be reduced to the mitigation gun, if the transit time is longer than the time it takes to conduct a ramp-up and a full ramp-up should be initiated prior to arrival at the next line. If transit time is less than 20 min the array can be operated during transit, preferably at reduced power output (the mitigation gun).
- Two Marine Mammal and Seabird Observers (MMSO) shall be posted on the source vessel (where the airguns are deployed from) and minimum one should be continuously on the look-out particularly for whales and seals during the pre-shooting search and when airguns are operated.
- Observation of marine mammals during shooting and inside the safety zone may not lead to shutdown, but if marine mammals are observed within the 200 m injury zone of the array, output should be reduced to the mitigation gun until the marine mammals are outside the 200 m zone again.
- A log of marine mammal observations should be kept on the ship and reported as part of the cruise report.
- Airguns should not be used outside the transect lines, except in the cases mentioned above (ramp-up prior to arrival and on short transit lines) and for strictly necessary testing purposes. Testing the array at full power shall be initiated with a ramp-up procedure as above.

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 13)

The most sensitive VECs in the assessment area are the narwhals, bowhead whales, blue whales and walrus. Narwhals occur widely along the fast-ice edge in spring and summer and many later move into the fjords. At both habitats concentrations may occur, as for example in the Northeast Water Polynya and in Scoresby Sund, and at such sites there is a risk of displacement from critical habitats. The impact is most likely temporary, but may include reduced availability to hunters in the southern part of the assessment area.

Bowhead whales are also sensitive to seismic surveys. Effects from seismic surveys will also be temporary and include potential displacement from critical habitats. Important areas for this endangered species include the Northeast Water, the ice

Table 13. Overview of potential impacts from a single seismic survey (both 2D and 3D) on Greenland Sea VECs and important occupations based on VECs (hunting and fishing). 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. The assessment of potential impacts assumes the application of current (2011) mitigation guidelines.

VEC	Typical vulnerable organisms	Overlap	Risk of impact on critical habitats	Potential impacts – worst case with current regulation			
				Displacement 2D	Displacement 3D	Sublethal effects	Direct mortality
Pelagic hotspots	copepods, amphipods, fish eggs, fish larvae	small	no	no	no	insignificant (L)	insignificant (L)
Tidal/subtidal zone	bivalves	no	no	–	–	–	–
Demersal fish and seabed fauna	Greenland halibut	pot. large	no	short term (L)	short term (L)	none	no
Ice fauna	polar cod	small	no	short term (L)	short term (L)	none	no
Seabirds		small	no	–	–	–	–
Walrus	–	small	yes	short term (L)	short term (L)	insignificant	no
Seals	ringed seal, harp seal, hooded seal	small	no	short term (L)	short term (L)	insignificant	no
Whales	narwhal, bowhead, blue whale	pot. large	yes	short term (L)	short term (L)	pot. significant	no
Polar bear		small	no	short term (L)	short term (L)	insignificant	no
Comm. fisheries	–	pot. large	yes	short term (L)	short term (L)	–	–
Hunting	–	small	no	short term (L)	short term (L)	–	–

edge south to Germania Land, the MIZ further south to Scoresby Sund and probably the former Southern Whaling Ground

Blue whales are likewise sensitive to seismic surveys; they are endangered at a global scale and occur in the assessment area at the same time as seismic activity takes place. However, more data is needed to identify critical habitats.

Walruses occur gregariously at specific feeding grounds and may be displaced by seismic activity nearby.

As seismic surveys are temporary, the risk of long-term impacts from single surveys is low. But long-term impacts have to be assessed if a number of surveys are carried out simultaneously or in the same potentially critical habitats in consecutive years (cumulative effect).

The only fishery which can be impacted by seismic surveys is the relatively small Greenland halibut fishery in the southern part of the assessment area. There is a risk of a temporary displacement of fish from the trawling grounds.

Noise from drilling rigs

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

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

In order to assess possible effects of noise produced by a drilling ship, underwater sound recordings were taken in West Greenland in Sept 2010 and the emitted noise from the drill ship *Stena Forth* during operation was quantified. The measured noise levels are similar to those known from other drill ships and are above those reported from semi-submersibles and drill rigs. It corresponds to fast moving merchant ships with source levels of up to 184-190 dB re 1 µPa during drilling and maintenance work, respectively. Both drilling and maintenance work results in tones that are higher than the background noise levels at ranges of 16-38 km from the ship and can be regarded as substantial noise source (Kyhn *et al.* 2011b).

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 believed that this communication can be masked by the noise. Also seals (especially bearded seal) and walrus communicate when underwater. However, systematic studies on whales in relation to noise from drill rigs are limited. It is generally expected that whales are more tolerant of fixed noise than noise from moving sources (Davis *et al.* 1990). Effect of auditory masking from boat noise has been demonstrated for white whales and killer whales in Canada (Foote *et al.* 2004, Scheifele *et al.* 2005). In Alaskan waters migrating bowhead whales avoided an area with a radius of 10 km around a 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).

Bowhead whales, blue whales, narwhals and walruses are again the most sensitive VECs in this context, and there is a risk of their displacement from critical habitats. Particularly walruses are sensitive because they are dependent on highly localised feeding areas. In the Baffin Bay off West Greenland, particularly narwhals follow specific and delineated migration pathways. Similar pathways may also be used in the assessment area.

Other baleen whales on shelf waters, as well as sperm whales and bottlenose whales on the continental slope could be displaced by drilling operations.

Conclusion on noise from exploration drilling rigs (Table 14)

Walruses, narwhals, blue whales and bowhead whales are especially at risk from being temporarily displaced from critical habitats by the noise from an exploration drilling rig. If alternative habitats are available no effects are expected, but if more rigs operate in the same region there is a risk of cumulative effects and displacement, even from alternative habitats.

Other noise

Nowacek *et al.* (2007) report that only one study (Patenaud *et al.* 2002) has documented responses of whales to aircraft. They measured behavioural reactions of bowhead whales to a Bell 212 helicopter at altitudes lower than 150 m and lateral distances of less than 250 m.

Table 14. Overview of potential noise and discharge impacts from a single exploration drilling on Greenland Sea VECs and important occupations based on VECs (hunting and fishing). 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 13 for details and explanation.

VEC	Typical vulnerable organisms	Overlap	Risk of impact on critical habitats	Potential impacts – worst case with current regulation		
				Displacement	Sublethal effects	Direct mortality
Pelagic hotspots	copepods, amphipods, fish eggs, fish larvae	small	no	–	–	–
Tidal/subtidal zone		no	no	–	–	–
Demersal fish and seabed fauna	Greenland halibut, corals, sponges	small.	yes	short term (L)	minor	no
Arctic char		no	no	–	–	–
Ice fauna	polar cod	small	no	short term (L)	minor	no
Seabirds	thick-billed murre, little auk, ivory gull etc.	small	no	short term (L)	no	no
Walrus		small	yes	short term (L)	no	no
Seals	ringed seal, harp seal, hooded seal	small	no	short term (L)	no	no
Whales	narwhal, bowhead, blue whale	small	yes	short term (L)	minor	no
Polar bear		small	no	short term (L)	no	no
Com. fisheries		small	no	–	–	–
Hunting		small	no	–	–	–

9.1.2 Drilling mud and cuttings

Drilling creates substantial quantities of wastes composed of rock cuttings and the remnants of drilling mud (cf. Section 8.2.3), all usually discharged to the sea floor beneath the drill rig, where the physical and chemical properties of the substrate can be changed (Breuer *et al.* 2008) and the fauna can be impacted.

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. However, OBMs may be used for special drillings, but then the used mud is injected into wellbores or brought to land for treatment after the drilling.

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 rather 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 more 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.* 1999).

Field studies on impacts from WBMs are relatively few. A few specially designed surveys indicated that effects are restricted to a distance of less than 100 m from the platforms (Schaaning *et al.* 2008 and references therein). The use of WBM combined with cleaning of the cuttings may therefore limit the effects on the benthos to highly localised areas around each exploration drill site. 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 also sensitive to suspended material in the water column (Freiwald *et al.* 2004, SFT 2008). The Northwest Atlantic Fisheries Organisation (NAFO) considers coldwater coral reefs and sponge fields, as vulnerable marine ecosystems (VMEs) on line with other important habitats such as seamounts and hydrothermal vents. However, coral reefs and sponge gardens have not been documented (so far) from the assessment area. As the seabed at all drill sites in Greenland shall be surveyed for these organisms, it should be possible to avoid impacts on them.

Multiple drilling carried out when a field is developed may cause more widespread effects on the benthic fauna.

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 also 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 10.2.6), but such discharges will not be allowed in the assessment area.

Despite the results reported in Chapter 3.4, 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. 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 re-use 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. The zero-discharge policy of the Barents Sea is now abandoned and regulation of discharges is in line with the other Norwegian offshore areas (Anonymous 2011).

It is generally assessed that the impacts from water based muds are limited, why they usually are released to the marine environment when the drilling is over, especially when they only contain environmentally safe chemicals. Such chemicals can be those which are classified as 'green' (PLONOR) or 'yellow' by OSPAR. But in general these chemical 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 14)

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.

9.2 Appraisal activities

The activities during the appraisal phase are similar to the exploration activities (see Section 8.2.1-2.4) and the impacts are the same. However, there is an increased risk of cumulative impacts as these activities usually take place over several years.

9.3 Development and production activities

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

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

9.3.1 Produced water

During production several by-products and waste products are produced and have to be disposed of in one way or another. Produced water is by far the largest contribution from an oil field (see Section 8.2.6).

Generally it is assessed that the environmental impacts from produced water are small due to dilution. However, long-term effects of the release of produced water are unknown (Rye *et al.* 2003). There is particular concern on the hormone-disrupting phenols, the radioactive components and the nutrients in relation to toxic concentrations, bioaccumulation, fertilisation, etc. (Rye *et al.* 2003).

Impacts on the marine environment from produced water can be reduced by injecting it into wellbores. This is not always possible (STF 2008) and when discharg-

ing produced water, international standards (OSPAR) must then 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 high in produced water (e.g. up to 40 mg/l ammonia). When released to the sea, these nutrients may act as fertiliser, impacting the composition of the primary producers (planktonic algae) (Rivkin *et al.* 2000 in Armsworthy *et al.* 2005).

Even though oil concentrations in produced water 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 (0-5 000 m) and different directions from oil platforms in Norway. In addition, two reference locations were used, both 8 000 m away from the respective platforms. 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. 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 ice gives reason for concern, because there is a risk of accumulation just below the ice, where degradation, evaporation, etc are slowed, and sensitive under-ice ecosystems including eggs and larvae from the key species polar cod may be exposed (Skjoldal *et al.* 2007).

9.3.2 Other discharged substances

Besides produced water, discharges of oil components and different chemicals occur in relation to deck drainage, cooling water, ballast water, bilge water, cement slurry and testing of blow-out 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 (IMO, OSPAR and MARPOL) and use environmentally safe 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 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 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 area least affected 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 soon, and within a few years the convention hopefully 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 transport of organisms attached to the hull of the ships.

9.3.3 Placement of structures

The construction of subsea wells and pipelines has the potential to destroy important habitats on the seafloor. However, there is limited knowledge on such sites in the assessment area; although some areas are important for walrus and common eider which feed on benthic mussels and other invertebrates (Figures 18, 23). An assessment of the impact of subsea constructions must wait until production site location is known and site-specific EIAs and site specific studies have been carried out.

Structures may also have a disturbance effect, particularly on marine mammals which may be displaced from important habitats. Most vulnerable in this respect are the walruses, narwhals, blue whales and bowhead whales.

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 2010). 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 in West Greenland has been conducted by GINR (Merkel 2010).

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 and many die from exhaustion or collision (Bourne 1979, Jones 1980). Such migrations do not 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. A 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 fisheries due to exclusion (safety) zones. These areas, however, are small compared with the total fishable area. A drilling platform incl. 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 fisheries are generally assessed 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.

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 female polar bears. Denning areas are critical to polar bear populations, but dens are apparently rather dispersed on the coast and their location probably varies between seasons.

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

When dealing with placement of structures, particularly inland and in coastal habitats, aesthetic aspects must be considered in a landscape conservation context. The risk of spoiling the impression of unspoilt wilderness, an essential component of the National Park of North and Northeast Greenland, 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 erection of structures.

9.3.4 Noise/Disturbance

Noise from drilling and the positioning of vessels is described under the exploration heading (Section 9.1.1). These activities continue during the development and production phase, supplemented by noise from many other activities. If several production fields are active for example in one of the polynyas, the impacts of noise particularly on bowhead whales, blue whales, narwhals and walrus must be addressed. Bowhead whales in the Beaufort Sea avoided close proximity (up to 50 km) to oil rigs, which resulted in significant habitat loss (Schick & Urban 2000), an impact which also could occur in the assessment area, depending on location.

Masking of the communication and echolocation sounds of whales and seals are widely discussed in the literature (see Section 9.1.1 for seismic noise) and constitute a likely effect from drill rigs. It is, however, not possible to assess any impacts at the moment, as there is very little experience to draw on from field studies. An assessment will require specific knowledge of the actual placement of drill rigs and other equipment, as well as field data from exploration drilling in the area.

One of the more significant sources of noise during development and production is ships and helicopters used for intensive transport operations (Overrein 2002). Ships and helicopters are widely used in the Greenland environment today, but the level of these activities is expected to increase significantly in relation to development of one or more oil fields within the assessment area. Supply ships will sail between offshore facilities and coastal harbours. Shuttle tankers will sail between

crude oil terminals and the trans-shipment facilities on a regular basis, perhaps even in winter. The loudest noise levels from shipping activity result from large ice-breakers, 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, which is the case in the southern part of the assessment area, where narwhals and walruses are hunted from motor boats. 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 land or ice will be sensitive to this activity, and there is a risk of displacement of the walruses from important feeding grounds. Denning polar bears are apparently relatively tolerant to noisy activities as their snow dens provide acoustic insulation (Linell *et al.* 2000).

Seabird concentrations are also sensitive to helicopter flyover. The most sensitive species are thick-billed murres at breeding sites. They will often abandon their nests for long periods of time and there is also a risk that they push their egg or chick out over the edge when scared off from their breeding ledges, resulting in a failed breeding attempt (Overrein *et al.* 2002). There are only two breeding colonies for this species in the region, both at the entrance to Scoresby Sund.

Concentrations of moulting geese and seaducks occur at several sites in the region, such as the king eiders in one of the fjords of Blosseville Kyst and long-tailed ducks in many shallow bays. 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 the 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.* 2004) found damage consistent with blast injury in the ears of humpback whales trapped in fishing gear after blasting operations in the area. In this case, the blasting did not provoke obvious changes in behaviour among the whales, even though it may have caused severe injury, suggesting that whales may not be aware of the danger posed by loud sound. Such impacts are, however, local and will mainly be a threat on an individual level.

9.3.5 Air emissions

The large amounts of greenhouse gases released from an oil field will increase the total Greenland emission significantly. The emission from Statfjord in Norway (Section 8.2.7), for example, is twice the total 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 its 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 and 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 4000 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, reservations were made in the case of Greenland.

9.3.6 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 include also human activities 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 example, 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).

Another example is seabird hunting which takes place in the entrance of Scoresby Sund. In this area there are two breeding colonies of thick-billed murres, which are

the most desired seabird quarry. These colonies are declining at least partly due to unsustainable hunting activities. Seabirds rely on a high adult survival rate, which gives the adult birds many possibilities to reproduce. Extra mortality due to an oil spill or sublethal effects from contamination from petroleum activities have the potential to be additive to the hunting impact and thereby enhance the population decline. The birds from these colonies are particularly vulnerable during the swimming migration, which is performed by flightless adults (due to moult) and chicks still not able to fly.

9.3.7 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 by OSPAR in HOCNF and by 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).

Based on knowledge concerning site-specific biological, oceanographic and sea-ice conditions, discharges of drilling mud and cuttings should occur at or near the seafloor or at a suitable depth in the water column to prevent large sediment plumes. Such plumes have the potential to affect benthic organisms, plankton and productivity and may also impact higher trophic levels such as fish and mammals. The discharges should be evaluated at on a case-by-case basis.

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 polar bears and oil activities):

- Den concentration 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 hill sides.

- 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.

9.3.8 Conclusions on development and production activities

Drilling will continue during development and production phases, and drilling mud and cuttings will be released 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 discharge 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 surrounding the long-term effects of the radionuclides and hormone-disruptive chemicals. These effects shall be mitigated by regulation, monitoring of the sites and new technology to clean the water or reinjection.

There will be a risk of release of non-native and invasive species from ballast water, and this risk will increase with the effects of climate change. Thus ballast water management following international standards has to be in place.

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, blue whales, bowhead whales, narwhals and walruses. There is a risk of permanent displacement of populations from critical habitats and therefore 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 the impact on the unspoilt landscape, and besides these, negative impacts on the local tourist activities must be expected.

The commercial fishery may by effected by closure zones if rigs, pipelines and other installations are placed in the Greenland halibut fishing grounds. But the impact on the fishery will probably be low.

There is a risk of reduced availability to hunters of quarry species, because these can be displaced from traditional hunting grounds.

In Greenland, 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 the Precautionary Principle, BEP (e.g. PAME 2009) and BAT can do much to reduce emissions to air and sea. Finally monitoring of impacts is essential.

9.4 Decommissioning

Impacts from decommissioning activities are mainly noise at the sites and from traffic, assuming that all material and waste are taken out of the assessment area and deposited at safe sites. There will also be a risk of pollution from accidental releases. However, decommissioning activities are short-term and careful planning and adoption of BAT and BEP would minimise impacts.

In this context, it would be wise in the planning phase to design installations for easy removal when activities are terminated.

10 Impacts from accidental oils spills

D. Boertmann, A. Mosbech, S. Wegeberg, D. Schiedek and F. Ugarte

10.1 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 be a major hindrance for oil spill response, even in the summer period. The winter darkness, harsh weather and the complete lack of infrastructure in the major part of the assessment area will also contribute to the efficiency of an oil spill recovery for example in case of a spill in the Northeast Water Polynya.

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 blow-out during drilling, which in contrast to the tanker spill, are continuous and may last for many days. As a worst case, the deep-water blow-out from the *Macondo*-well can be mentioned, as it lasted 87 days before it was capped by relief-drilling. Blow-outs usually have their origin on the platform, but it may also be from the wellhead on the seafloor (subsea blow-out).

10.1.1 Probability of oil spills

The probability of large oil spills is low. However, the risk cannot be eliminated and in a frontier area it is difficult to calculate the risk based on experience from more developed areas. In relation to the oil drilling in the Barents Sea it has been calculated that statistically a blow-out 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 estimated to be higher than for an oil spill from a blow-out (Anonymous 2003).

Drilling in deep waters[2] and ultra deep waters[3] 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).

It should be mentioned that there is a risk of oils spills from other sources in the assessment area. A German trawler/weathership, 'Sachsen' was scuttled during the Second World War in Hansa Bugt at Sabine Ø in 1943. The wreck is still there with an estimated 60 tonnes of fuel oil in the tanks, which could rupture and cause a significant oil spill in a very sensitive area (M. Elander pers. comm.).

[2] >600 m according to Norwegian (NORSOK) standards – which are adopted by Greenland authorities and between 1000 and 5000 feet ~305-1 524 m according to US authorities (cf. Graham *et al.* 2011).

[3] >5 000 feet ~1 524 m according to US authorities (cf. Graham *et al.* 2011)

10.1.2 The fate and behaviour of spilled oil

Previous experience with spilled oil in the marine environment gained in other parts of the world shows that fate and behaviour of the oil vary considerably. Fate and behaviour depend on the physical and chemical properties of the oil (light oil or heavy oil), how it is released (surface or sub-sea, instantaneous or continuous) and on the conditions of the sea into which it is spilled (temperature, ice, wind and current). I 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 preliminary 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 (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 potentially 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 subsea blow-out, 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 waters where the melt water from the glaciers can disperse widely in the coastal areas.

Subsurface spills
Blow-outs 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 blow-out 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 blow-out 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. DMI modelled a subsurface spill in West Greenland, and here the oil quickly floated to the surface (Nielsen *et al.* 2006), while a SINTEF model made in relation to the drilling in 2000 off Nuuk in West Greenland estimated that oil would not reach the surface at all, but would 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.

10.1.3 The experience from the *Maconco*-spill

Very little information is available to support environmental impact assessments of deep-sea oil exploration and possible effects from spills under such circumstances. In the context of the present assessment, it is therefore relevant to review and assess the knowledge gained and observations from the event at the *Macondo*-well in the Gulf of Mexico in 2010, where the *Deepwater Horizon* drilling rig exploded and sank with the release of large quantities of crude oil at a great depth. The environmental impacts of the spill are, at the time of writing, not yet really understood or described (Graham *et al.* 2011, Schrope 2011), and it has not been possible to include clear conclusions in this SEIA. However, a natural resource damage assessment is being prepared (Graham *et al.* 2011).

The water depth in the licensing area is much shallower (up to 530 m) than at the *Macondo*-well, why it could be expected that a subsea oil spill would behave differently and for example not form the subsea plumes of dispersed oil. However, the *Ixtoc*-spill in the Mexican Gulf in 1979 was also a subsea spill, but in waters only 50 m deep. Subsea plumes of oil apparently also was formed there (Jernelöv 2010), why it is relevant to discuss the experiences form the *Macondo*-spill in present context.

Extent of the spill

On 20 April 2010, the *Deepwater Horizon* drilling rig exploded and sank in the Gulf of Mexico, with 11 fatalities and many injured. Oil spilled out at approximately 1 500 m depth for 84 days with total estimates of more than 840 000 tonnes of oil released into the ocean (Camilli *et al.* 2010, Crone & Tolstoy 2010). It has been estimated that 25 % of the oil was removed by emergency operations, 25 % evaporated or dissolved, 28 % was dispersed either naturally or with the aid of chemicals, and 22 % formed slicks or tar balls and ended up on the sea bottom or washed onto shores (Schrope 2011). Gas, primarily methane, also leaked from the damaged wellhead in amounts corresponding to $6.6 \times 10^5 - 1.2 \times 10^6$ kg gas per day (Kessler *et al.* 2011). As part of the mitigation strategy, large amounts of the oil dispersant Corexit 9500 was injected directly at the wellhead (2 900 000 l) as well as at the sea surface (4 059 854 l) in order to disperse the oil (Hemmer *et al.* 2011).

Subsea plumes and oil concentrations

The *Macondo*-well oil spill in the Gulf of Mexico in 2010 was unusual in size, location and duration (but similar to the *Ixtoc* blow-out in 1979, also in the Gulf of Mexico), and revealed new and previously undescribed ways spilled oil could be distributed in the environment, although this probably also happened during the *Ixtoc* spill in waters only 50 m deep (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site at the sea floor in waters more than 1 500 m deep. Dispersants were applied at the wellhead, and huge subsea plumes of dispersed oil were formed at different depths, moving long distances with prevailing currents (Diercks *et al.* 2010a, Thibodeaux *et al.* 2011). Oil also settled on the ocean floor far from the spill site (Schrope 2011). The oil dispersed at the wellhead and had a very slow buoyant migration towards the surface, which allowed volatile hydrocarbons to be dissolved in the water column. Addition of dispersants at the wellhead may have contributed to the formation of huge plumes of dispersed oil at different depths, ranging between 800 and 1 200 m, although it is likely that subsea plumes would have formed even in the absence of dispersants (Graham *et al.* 2011). The physico-chemical processes governing the behaviour and fate of hydrocarbons in water under high pressure and at low temperature (~5° C) are poorly understood (Thibodeaux *et al.* 2011), but include the interplay of gas and oil fractions, the solubility of various components, and potential formation of gas hydrates (Camilli *et al.* 2010, Hazen *et al.* 2010).

Two months after the spill, evidence of oil was observed in gradients away from the wellhead site following isopycnal surfaces (Camilli *et al.* 2010, Diercks *et al.* 2010b, Reddy *et al.* 2011). The reported plumes moved in consistence with current patterns in the region and consisted of a major plume reaching over 35 km in length between 1 000 and 1 200 m depth, with total PAH concentrations ranging from 29.4 µg/l to 189 µg/l (Diercks *et al.* 2010b), as well as a more diffuse plume between 50 and 500 m depth with a lower total PAH concentration range than the deeper plume (Camilli *et al.* 2010). Within 3 km of the wellhead, total PAH levels were above 150 µg/l, and subsurface plume samples consisted predominantly of smaller petroleum compounds such as methylnaphthalenes and other two-ringed PAHs, compared to surface samples (Diercks *et al.* 2010b, Reddy *et al.* 2011). For reference, concentrations of 161 µg/l methylnaphthalene have been reported to induce mortality and sublethal effects in copepods (Calbet *et al.* 2007). Any effect assessments of complex oil spills must consider that mixtures of PAHs have been reported to display additive effects (Barata *et al.* 2005).

Studies of deep-water blow-out events have predicted that a substantial fraction of the released oil and gas would become suspended in pelagic plumes, and this may take place even in the absence of added dispersant agents (Johansen *et al.* 2001). The fate of oil in 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 deep waters (Joye & MacDonald 2010). In the Gulf of Mexico, natural oil seeps contribute to the marine environment with estimated 140,000 t oil annually (Kvenvolden & Cooper 2003), so there should be an intrinsic potential for microbial degradation, in that the responsible organisms are present (Hazen *et al.* 2010). This was confirmed by observed bio-degradation rates faster than expected in the deep plumes at 5° C.

However, microbial degradation of oil may have derived effects such as oxygen depletion, which in deep water may persist for long periods, because oxygen is not replenished *in situ* by photosynthesis as is the case for surface waters (Joye & MacDonald 2010).

Dispersants

The use of dispersants is a balance between avoiding on one hand severe direct effects of oil on coastal environments and seabirds on the surface, and on the other hand possible toxic effects of oil and dispersants in the water column and on the seabed.

Unique to the *Macondo* event, large amounts of dispersants were applied directly at the spill site at 1 500 m depth in order to mitigate the effects of the outflowing oil. Almost 8 000 m^3 of dispersants were applied altogether at the spill site during the spill (Kujawinski *et al.* 2011). Of these, close to 3 000 m^3 were injected directly at the wellhead at the seafloor. Use of dispersants under deep-sea conditions has not been done before the *Macondo* event. Surfactants, which were key ingredients in the applied dispersant, were found to follow the subsea oil plumes and did not reach the sea surface, but underwent slow degradation. Concentrations of the dispersant reached 10-100 µg/l Corexit between 1 and 10 km from the injection site (Kujawinski *et al.* 2011). The observed dispersant concentrations and dispersant-to-oil ratios are lower than those tested in published assays with no effects (Judson *et al.* 2010). Acute effects from the used dispersant (Corexit 9500A) have also been assessed alone and in mixtures with oil from the Gulf of Mexico (Hemmer *et al.* 2011). Lethal concentration values, where mortality reached 50% (LC_{50}) in static tests of 48- and 96-hour exposures, indicated that Corexit 9500A

had generally similar toxicity to other available dispersants when tested alone, but was less toxic as a mixture with crude oil (Hemmer *et al.* 2011). Test organisms were two aquatic species, a mysid shrimp (*Americamysis bahia*), and a small estuarine fish local to the Gulf of Mexico, the inland silverside (*Menidia beryllina*). The test results are thus not directly applicable to Arctic conditions.

Biodegradation

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

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

Effects on plankton

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

Fish and fisheries

Little is known on the possible biological impacts of the *Macondo* spill on fish stocks in the Gulf of Mexico. Initially, there were some concerns regarding a massive impact on fish stocks, as the spill coincided with the spawning season of many fish species. One report presents evidence to the contrary. A study of juvenile fish in shallow sea grass habitats along the coast north of the spill site showed higher catches than a 5-year normal (Fodrie & Heck 2011). The authors conclude that no

immediate losses of cohorts or shifts in species composition were found after the oil spill. They attribute the results to a lack of exposure, since large amounts of the spilled oil were retained in deep waters.

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

Effects on mammals, birds and turtles

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

Summary

The oil spill in connection with the accident of the *Deepwater Horizon* rig was one of the first and largest oil spill events recorded in a deep-sea environment. It presented several unique problems, especially for the mitigation efforts. Some issues were specific for the event (cause and chronology) and may not be of relevance in other spill events. Other conditions may have a more general character. For instance, the difficulty in reaching the point of the outflowing oil and gas because of its great depth, led to restrictions and delays of the mitigation effort, a fact that Jernelöv (2010) use to argue for a two-rig strategy (enabeling quick drilling of a releif well) when new areas are explored. The spilled oil was distributed differently compared to other large spills (e.g. *Exxon Valdez*), as large quantities were found in subsurface plumes, which followed local current systems in boundary layers. Smaller amounts than expected of the spilled oil reached the sea surface and eventually sensitive ecosystems along the coastlines of the Gulf of Mexico. During the event, unprecedented large amounts of dispersants were applied directly at the great depth of the spill, with the aim of dispersing the oil. The mixture of oil and dispersants may in combination have represented a serious threat to pelagic and benthic organisms, but laboratory studies have not indicated any serious potential effects yet. No negative effects have yet been documented on fish or plankton communities, although initial studies indicate transfer of petroleum hydrocarbons into zooplankton species.

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

10.1.4 The DMI oil spill simulations

As part of this SEIA of oil activities in the assessment area, DMI has prepared a number oil drift and fate simulations for hypothetical oil spills in the assessment area (Nielsen *et al.* 2008).

The simulations were carried out for three hypothetical spill events all located on the shelf of the assessment area. The locations were selected by GEUS to represent potential sites for offshore well drilling. The crude oil, Statfjord, a medium-type crude oil (API density 886.3 kg/m³), 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 (Figure 47).

For the 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 very large spills with a very low probability of occurrence.

Three one-month wind periods have been selected within the design year July 2004–June 2005.

A total of 18 oil spill scenarios with continuous release have been simulated: 3 release sites, 3 simulation periods and 2 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 as well as the lengths of shoreline affected are calculated. When the spill is located far offshore, the coast is not affected by any of the chosen wind conditions. Only two of the spills are predicted to reach the shore. One from a spill site off Scoresby Sund reaches the southern Blosseville Kyst in October and one at approx. 75°30' N reach coasts between Shannon and Hold With Hope in April.

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 based on the oil spill simulations in southern Baffin Bay (Nielsen *et al.* 2006, Mosbech *et al.* 2007a). DMI (*in prep.*) elaborates further on this issue, when modelling subsurface spills in the waters off South Greenland.

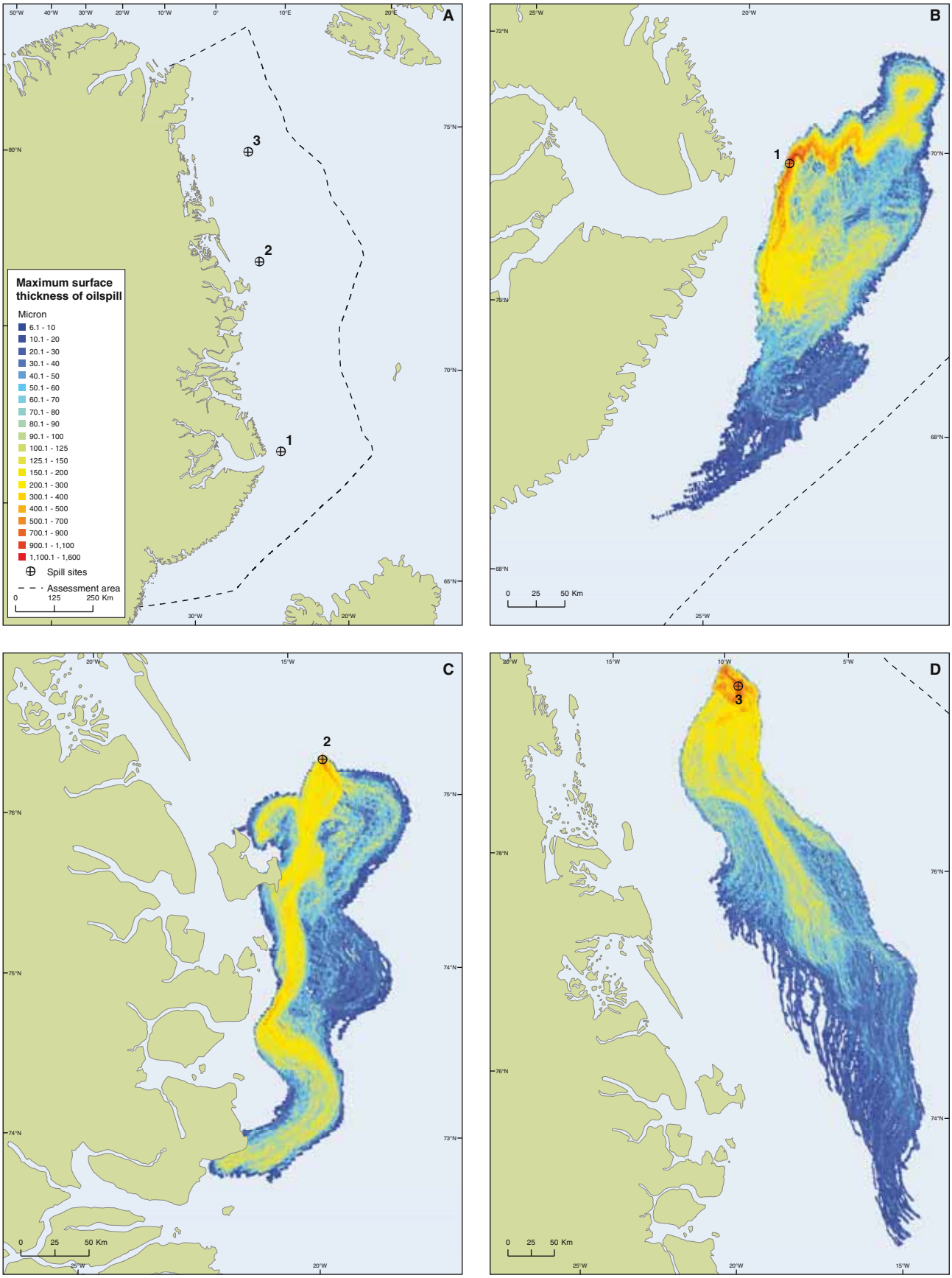

Figure 47. Examples of the DMI oil spill trajectory simulations. Map A shows the four spill sites. The maps B-D show the entire area swept by three different surface spills. The scale indicates the maximum thickness of the sea surface oil layer attained in the different cells during the 30 day simulation periods. B is a continuous spill from site 1 in August 2004. C is a continuous spill from site 2 in April 2005. Map D is a continuous spill from site 3 in October 2004. Note that C hits the coasts, while the two other spills are far from any coasts.

10.1.5 The SINTEF oil spill drift simulations

In addition to the DMI simulations, SINTEF also have carried out some simulations in relation to description of oil spills in ice in the Greenland Sea (Johansen 2008). Only very preliminary results were available when this report was written, but overall they agree fairly well with the DMI results.

10.1.6 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 it would 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.

10.1.7 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 bioavailability of the oil components. The toxic components can increase the potential for acute toxicity to marine organisms. The rate and extent to which oil components dissolve in seawater depends mainly on the amount of water-soluble fractions (WSF) 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.

PAHs are among the toxic components of crude oil (see Section 6.2). The highest PAH concentration found in the water column in Prince William Sound within a six-week period after the *Exxon Valdez* spill was 1.59 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 blow-out 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.* 2010b). 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.* 2008a). 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.

10.2 Oil spill impacts

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) effects.

Table 15 gives an overview of potential impacts from a large oil spill.

Table 15. Overview of potential impacts from a large surface oil spill on Greenland Sea VECs and important occupations based on VECs. The assessment of potential impacts assumes the application of current (2011) mitigation guidelines, see text and Table 13 for details and explanation.

VEC	Typical vulnerable organisms	Potential overlap	Risk of impact on critical habitats	Potential impacts		
				Displacement	Sublethal effects	Direct mortality
Pelagic hotspots	copepods, amphipods, fish eggs, fish larvae	large	yes	–	moderate (L)	moderate (L)
Tidal/subtidal zone	fauna and flora	large	yes	long term (L)	major (L)	major (L)
Demersal fish and seabed fauna	Greenland halibut, seabed fauna	large	yes	short term (L)	moderate (L)	moderate (L)
Ice fauna	Polar cod	large	yes	short term (L)	major (L)	major (L)
Arctic char		large	yes	long term (L)	major (L)	moderate (L)
Seabirds	thick-billed murre, little auk, common eider etc.	large	yes	short term (L)	major (R)	major (R)
Walrus		large	yes	long term (L)	major (R)	moderate (R)
Seals	ringed seal, harp seal, hooded seal, bearded seal	large	yes	short term (L)	moderate (R)	moderate (R)
Whales	narwhal, bowhead, blue whale	large	yes	short term (L)	moderate (R)	minor (L)
Polar bear		large	no	short term (L)	major (R)	major (R)
Com. fisheries		large	yes	short term (R)	–	–
Hunting		large	yes	short term (R)	–	–
Tourism		large	yes	long term (R)	–	–

10.2.1 Oil spill impact on plankton and fish

Adult fish

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, fish such as cod and salmon 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. In coastal areas the situation is more complicated and oil may be trapped in bays and inlets resulting in high mortality among adult fish. Arctic char, a common and important species in the coastal waters of the assessment area, will be vulnerable during such conditions.

Adult fish are able to metabolise oil, so they may recover from intoxication, but they may also act as vectors of toxic oil residues to higher levels in the food chain.

Fish eggs and larvae

Eggs and larvae of fish are more sensitive to oil than adults. Theoretically impacts on fish larvae may be significant and reduce 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 water 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 blow-out lasting less than two weeks, while very long-lasting blow-outs 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 48).

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-

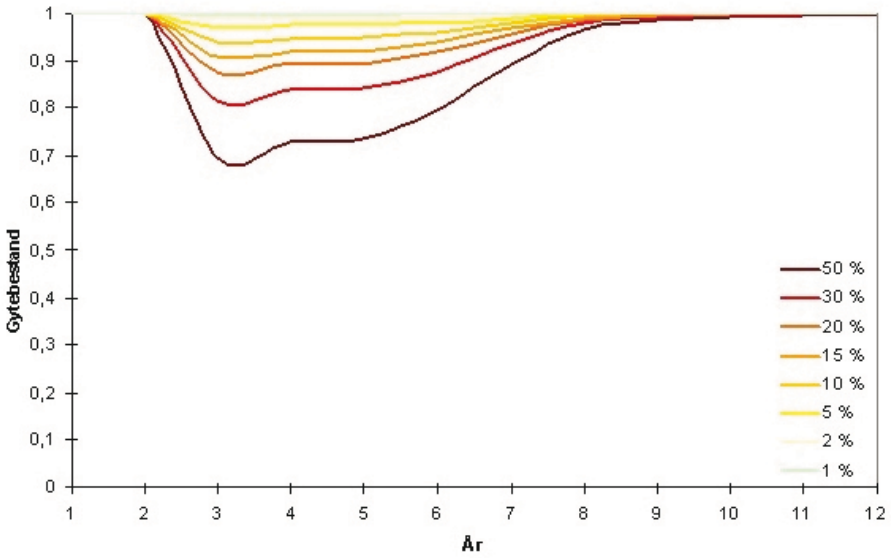

Figure 48. Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of eggs and larvae due to a large' worst case' oil spills. Gydebestand = spawning stock, År = year. Sources: Anonymous (2003) and Johansen *et al.* (2003).

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.

There is no knowledge available on concentrations of eggs and larvae in East Greenland waters. However, the highly localised spawning areas with high concentrations of egg and larvae for a whole stock near the surface, as known from the Lofoten-Barents Sea, are not likely to occur. The overall picture is that the relatively few fish larvae are widespread, although perhaps occurring in patches which may hold somewhat elevated densities. 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 Greenland halibut also are found deeper and will therefore be less exposed to harmful oil concentrations from an oil spill, unless the oil is released from a subsea blow-out.

Greenland halibut probably do not spawn in the assessment area (see Section 3.6.1 above), but if spawning occurs, it must be expected that a surface oil spill only will impact on a smaller proportion of a season's production of eggs and/or larvae than modelled for cod in the Barents Sea. However, a subsea blow-out may have effects on this species, because it spend most of its time on the seabed. Polar cod eggs in contrast 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 spill under ice will tend to accumulate in the same space, there is a potential risk of overlap and impacts on the recruitment of the polar cod population. Presently, we have no knowledge on potential aggregations of spawning polar cod and subsequent accumulation of eggs and larvae. But if such occur, an oil spill may have the potential to impact recruitment and stock size. Which again may cause effects up in the trophic web, as polar cod is an ecologically 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 and 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 blow-out 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 oil spill would only impact a minor part and not pose a major threat (Anonymous 2003). However, the *Calanus* species are known to concentrate

in localised deep water habitats for hibernation. In light of the *Macondo*-spill, the effects of a subsea spill on such concentrations are very relevant to study a.o. because impacts on such concentrations may travel up in the food chain.

Recent studies showed 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 on zooplankton from a surface spill to more acute and severe impacts in case of a large sub-surface spill.

Important areas for plankton including fish 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 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 where high biological activity of the pelagic food web from phytoplankton to fish larvae is concentrated in the surface layers. However, the winter period may also be very sensitive to subsea oil spills where copepods aggregate for the winter.

10.2.2 Oil spill impacts on benthic flora

The direct impact of an oil spill on benthic flora will be mass mortality among macroalgae along oiled shores, a mortality caused by 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 strong fluctuations in the *Fucus* cover during the recovery. Some areas are still considered as recovering (NOAA 2010). The observed 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) during the Baffin Island Oil Spill (BIOS) study.

The scenarios of the *Exxon Valdez* accident and the 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 total mortality of adult *Fucus* and probably scalded much of the rock surface and thereby *Fucus*-germlings. In the long term, though, no significant difference was observed on *Fucus* dynamics at oiled and unwashed 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 (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.

The available knowledge on algae – both in taxonomical and ecological respects – in the assessment area is still too fragmentary to assess impacts of oil spills.

10.2.3 Oil spill impacts on benthic fauna

Bottom-living organisms (benthos) are generally very sensitive to oil spills and high hydrocarbon concentrations in the water. The sensitivity of many benthic species have been studied in the laboratory and a range of 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 cause 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 of the seabed or from oil spills potentially can cause a significant reduction in the total species richness for a long time.

10.2.4 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 10.1.5 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 9.3.1).

10.2.5 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). In these habitats oil concentrations in the water column can build up to levels that are lethal to adult fish and invertebrates (e.g. McCay 2003). Many of the animal populations from the nearshore areas in Prince William Sound 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).

The knowledge on which fish species utilise the nearshore environment in the assesment area is very sparse. At least Arctic char occur here when they aggregate before moving up into their native rivers to spawn and winter, and capelin probably also occur and spawn in the southernmost parts. There are indications that this species is moving the range towards north, perhaps becoming an important species in the nearshore environment in the future. Both capelin and arctic char will be very sensitive to oil spills

In coastal areas where oil may be buried in the sediment, among boulders and imbedded in crevices in rocks, chronic oil pollution may persist for decades and cause small to moderate effects (Table 15). 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 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 these patches may be a source for continued exposure to oil especially for species feeding on fauna in and on the sediments, such sea otters and many birds (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, spray containing oil was carried by wind to fields and grasslands close to the coast where the vegetation was impacted.

10.2.6 Oil spill impacts on fish and fisheries

Tainting by oil residues in fish meat is a severe problem related to oil spills. Fish exposed even to very low concentrations of oil in the water, in their food or in the sediment where they live may be tainted, leaving them useless for human consumption (GESAMP 1993). 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.

A very important issue in this context is the reputational damage an oil spill will cause on fish products from the affected areas. To avoid even the risk of marketing contaminated products, it will be necessary to suspend fishery activities in an affected area, (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, although this do not apply to the assessment area, because the commercial fishery is so limited (see below). But in general, 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 of fisheries 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 (a year after the incicent), 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' after the oil spill in 1989 (NOAA 2010).

The fishery for Greenland halibut in the assessment area is very small (annual catch 2005-2007 approx. 250 tonnes) compared to the total for Greenland as a whole (approx. 35,000 tonnes), so closure of the fishery for a season will only have minor economic consequences, and none on the local community in the assessment area, as there is no commercial fishery taken place from here.

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 to oil may also take longer than in temperate fish (Skadsheim *et al.* 2009).

10.2.7 Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Schreiber & Burger 2002). Birds which rest and 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 the water. But all seabirds face the risk of coming into contact with spilled oil on the surface. The particular vulnerability is caused by the feather plumage. Oil soaks easily into the plumage and destroys its insulation and buoyancy properties. Therefore, oiled seabirds readily die from hypothermia, starvation or drowning. Birds may also ingest oil by cleaning their plumage and by feeding on oil-contaminated food. Oil irritates the digestive organs, damages the liver, kidney and salt gland function, and causes anaemia. Sublethal and long-term effects may 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 a small oil spill in such areas may cause very high mortalities among the birds present. The high concentrations of seabirds found at coasts and polynyas (e.g. breeding colonies, moulting areas, spring staging areas; Figures 18 and 19) 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 due to oiling. To assess this issue, extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem are necessary (Figure 49).

The seabird populations 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 a pair can only raise a single chick in a breeding season. This results in a very slow population turnover, which is counterbalanced by a very long expected life span of 15–20 years or more. Seabird populations with such a strategy are therefore particularly vulnerable to additional adult mortality caused for example by an oil spill.

If a breeding colony of birds is completely wiped out by an oil spill it must be re-colonised from neighbouring colonies. Re-colonisation is dependent on 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 Ittoqqortoormiit/Scoresbysund area, there will be no or only few birds available for re-colonisation of a site.

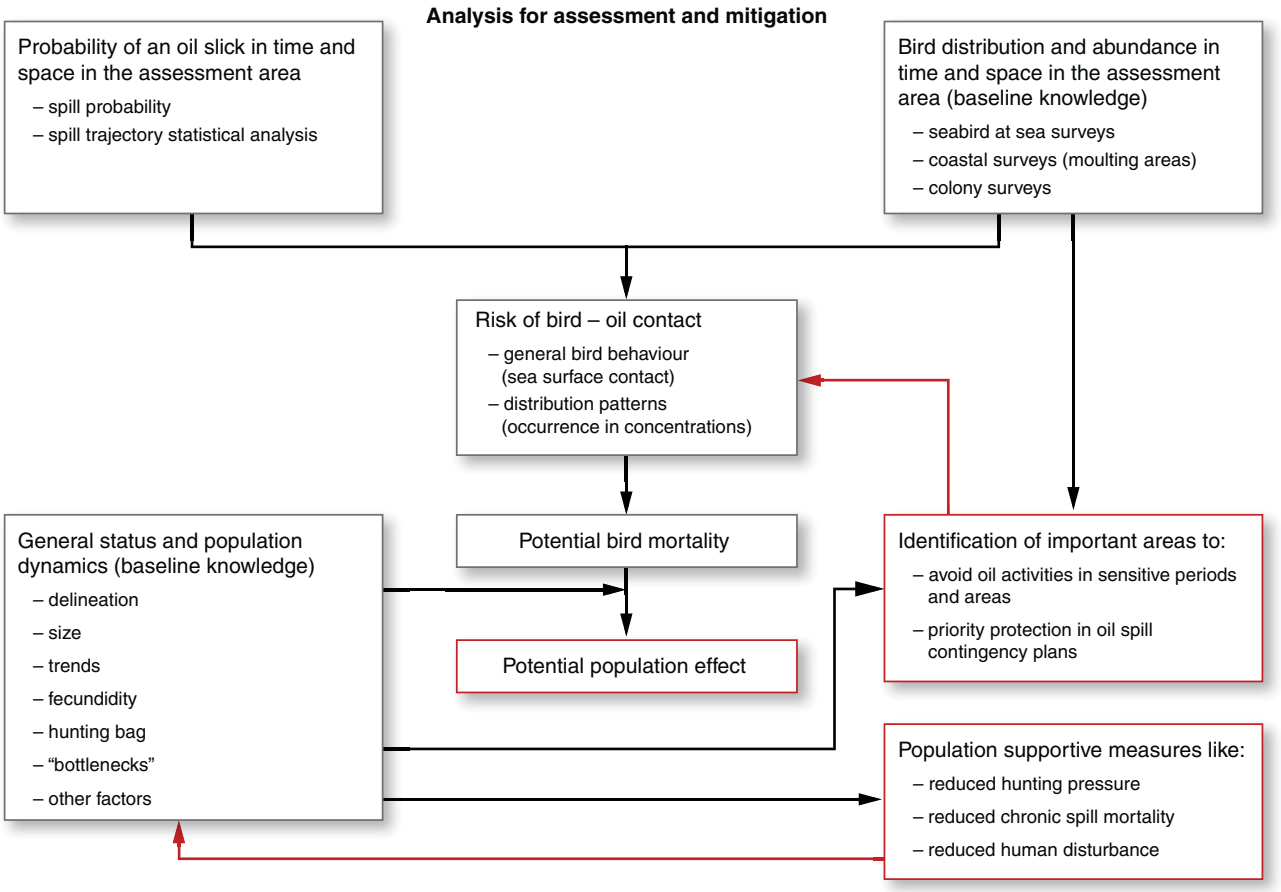

Figure 49. Basic principles of assessing a seabird populations vulnerability to oil spills. Black lines indicate main analysis of effects on bird populations, red lines analysis of potential mitigative measures. Indirect effects not included for simplicity.

The 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 was rather fast and probably caused by the fact that there were several unaffected colonies in neighbouring areas and the populations are not subject to hunting.

Only two breeding colonies of thick-billed murre are known from the assessment area. They are both situated at the entrance to Scoresby Sund. Here the birds assemble on the water below the colony and also at feeding areas far from the colony. Another risk situation is when the chicks and flightless adults leave the colony on a swimming migration. The breeding population is declining and therefore particularly sensitive to additional mortality. Another factor making this population particularly sensitive to increased mortality is the fact that neighbouring colonies are very far away. The nearest are found in Iceland and on Svalbard.

Other important bird colonies where the population could be severely impacted by an oil spill in the assessment area include kittiwake colonies at several sites, the large common eider colony at Daneborg and the very large little auk colonies at the entrance to Scoresby Sund. Common to all these colonies is that they are situated at polynyas where open water is accessible in spring and where many birds congregate

A very important seabird breeding colony is found on the islands of Henrik Krøyer Holme at the southern edge of the Northeast Water Polynya. The largest assemblage of red-listed ivory gulls in Greenland is found here and also the rare (and red-listed) Ross's gull occur besides many Arctic terns, Sabines gulls and common

eiders. Such a colony is highly vulnerable to oil spills, and completely inaccessible as far as oil spill response is concerned due to its remoteness and because it usually is surrounded by sea ice even in summer.

There are numerous other seabird colonies which will be at risk to spilled oil from the assessment area (Figure 15).

Moulting areas
Moulting concentrations are also vulnerable to oil spills with potential population effects. The aerial survey in July 2008 showed that common eiders moult in flocks distributed along many coasts, however relatively dispersed and without very large concentrations. Long-tailed ducks were more concentrated and assembled at specific bays and coasts, but usually in relatively low numbers. Satellite tracking of common eiders and long-tailed ducks in 2007 and 2008 indicate, consistent with the aerial survey, that the post-breeding moult generally takes place close to the breeding areas (Box 1 and 5). In contrast, king eiders were only found moulting at one site, a fjord on the Blosseville Kyst. A large proportion of the East Greenland population may be assembled here to moult and therefore potentially very vulnerable to oil spills.

Migration concentrations
More than 5 million seabirds from Svalbard and possibly Arctic Russia migrate through the assessment area in autumn and again in spring. These birds stage during the migration and may become exposed to oil spills. However, no information on concentration areas and the relation to the ice distribution is available. But potentially numerous seabirds may be killed and breeding populations far outside the assessment area can be impacted by oil mortality in the assessment area.

10.2.8 Oil spill impacts on marine mammals

Marine mammals are generally less sensitive to oiling than many other organisms, because individuals (except polar bears, see below) are rather robust to fouling and contact with oil. This can be explained by the fact that at least the adults are not dependent on an intact fur layer for insulation. They rely on a thick layer of blubber instead. However, both seal pups and polar bears are exceptions and are much more sensitive to direct oiling (St. Aubin 1990 and references therein).

Nevertheless, some marine mammal populations in the assessment area are particularly sensitive to oil spills, and some conditions also increase the risk for marine mammals to be exposed and impacted.

Whales apparently do not avoid oil-contaminated waters and they seem not able to detect oil (Harvey & Dalheim 1994, Anonymous 2003b), and contact with oil may cause a number of sublethal effects. Immediate contact with the oil will be through the skin and perhaps the eyes. If oil is swallowed, the baleen and the gastrointestinal tract are likely to be injured (Albert 1981, St. Aubain *et al.* 1984). Not much is known about the toxic effects of oil on whale skin, but the oil is likely to adhere and possibly stay for a long time on the skin, perhaps causing a toxic effect. Ingestion of oil can also be toxic. Baleen whales feed by filtration through the baleen plates. Spilled oil fouling the baleen plates most likely will affect filtration, but this issue has not been thoroughly tested. It will likely depend on factors such as the quality of the oil and the water temperature (Braithwaite *et al.* 1983, Werth 2001).

The effects of oil on seals were reviewed by St. Aubin (1990). 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.

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.

A special problem may occur in ice-covered waters. Here marine mammals may be forced to surface in an oil spill caught in the restricted open waters and here risk 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). Harbour seals found dead shortly after the *Exxon Valdez* oil spill also 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).

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, will oil in the fur reduce the insulation properties. Polar bears live in ice-covered waters and the population density is low and probably also declining. The polar bear population is considered as vulnerable (IUCN 2011) due to climate change, which reduces their habitat, the ice-covered Arctic waters.

It is difficult to assess the impacts of an oil spill on seals and whales in the assessment area. There is at least a risk of major impacts on individuals if oil is trapped in a polynya or along an ice edge, where also marine mammals assemble. The occurrence of marine mammals in specific sites can be significantly altered and hunting in the Ittoqqortoormiit/Scoresbysund area may thereby be affected.

Among the marine mammal VECs ocurring in the assessment area, the walrus population is particularly vulnerable due to the gregariousness of the species, as opposed to the highly dispersed bearded seal and ringed seal populations. Harp seals and hooded seals are vulnerable during the whelping season when they assemble in high densities at whelping areas on the sea ice and particularly the pups can be fouled by oil. The bowhead and the blue whale are especially vulnerable because their populations are very small and the survival of single individuals could be crucial for the recovery of the populations.

10.2.9 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 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).

10.2.10 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' (Petersen *et al.* 2003), and here it is documented that delayed, chronic and indirect effects of marine oil pollution occur (Table 16). Oil persisted in certain coastal habitats beyond a decade in surprisingly high amounts and in highly toxic forms. The oil was sufficiently bioavailable to induce chronic biological exposure and had long-term impacts at the

Table 16. From Petersen *et al.* 2003. See text.

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.

population level. Heavily oiled coarse sediments formed subsurface reservoirs of oil in intertidal habitats where it was protected from loss and weathering. In these habitats e.g. harlequin ducks, preying on 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, and ducks here had lower survival, their mortality rate was 22% instead of 16%; their body mass was lower and they showed a decline in population density as compared with stable numbers on un-oiled shores (Petersen *et al.* 2003). The oil still lingers in the environment and both the harlequin duck and other populations of coastal birds were as late as in 2010 assessed as 'recovering' (NOAA 2010).

Many coasts in the assessment area in East Greenland have the same morphology as those of Prince William Sound, where oil was trapped. Similar long-term impacts must therefore be expected if oil hits on the coasts of the assessment area. The High Arctic conditions in the assessment area may even prolong the impact period in relation to that experienced in Prince William Sound, where effects can be measured after more than 20 years.

Another possible long-term effect in Prince William Sound was the collapse of the herring stock in 1993. This collapse has been related to the sublethal effects of PAH on herring 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).

10.2.11 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, winter darkness and harsh weather prevent effective oil recovery methods.

An important tool in oil spill response planning and implementation is oil spill sensitivity mapping. This has been performed in West Greenland (Mosbech *et al.* 2000b, 2004a, 2004b, Stjernholm *et al.* 2011), but not yet in the assessment area.

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 human induced population stressors (such as hunting), in order to increase their ability to compensate for extra mortality due to an oil spill (see Figure 49).

10.3 Seasonal summary of oil spill sensitive areas in the western Greenland Sea

10.3.1 Winter (October–April)

During this season the sea is covered by ice, except for the polynyas where more or less open water is present and east of the MIZ. Marine mammals are active and present in winter especially sensitive are walrus, narwhal and bowhead whale, while polar bear, ringed seal and bearded seal occur more widespread and are less sensitive. The marine mammals will be especially concentrated at the very limited open waters or along the MIZ and in the polynyas. Here they will be highly exposed to oil spills and will be sensitive to disturbing activities. They have very few or no alternative habitats available during this time of the year.

Narwhals winter in the waters over the shelf break off the Blosseville Kyst, and probably also in similar areas further north.

Polar bears occur throughout the area with concentrations of maternity dens along the coasts of the northern part.

Hooded and harp seals assemble in the whelping area in the drift ice in March (Figure 25), and are sensitive to both oil spills and disturbance. The postion and size of the whelping area show strong variation between years.

Almost no birds are present when ice covers all the coasts, but they arrive during April and May and are particularly numerous where polynyas reach the coasts and expose the shallow feeding grounds. Migrant seabirds en route to breeding areas in Svalbard and Russia pass through during April and May, probably in their millions.

Polar cod spawn under the ice in late winter and the eggs accumulate under the ice, where they are particularly exposed to oil spills.

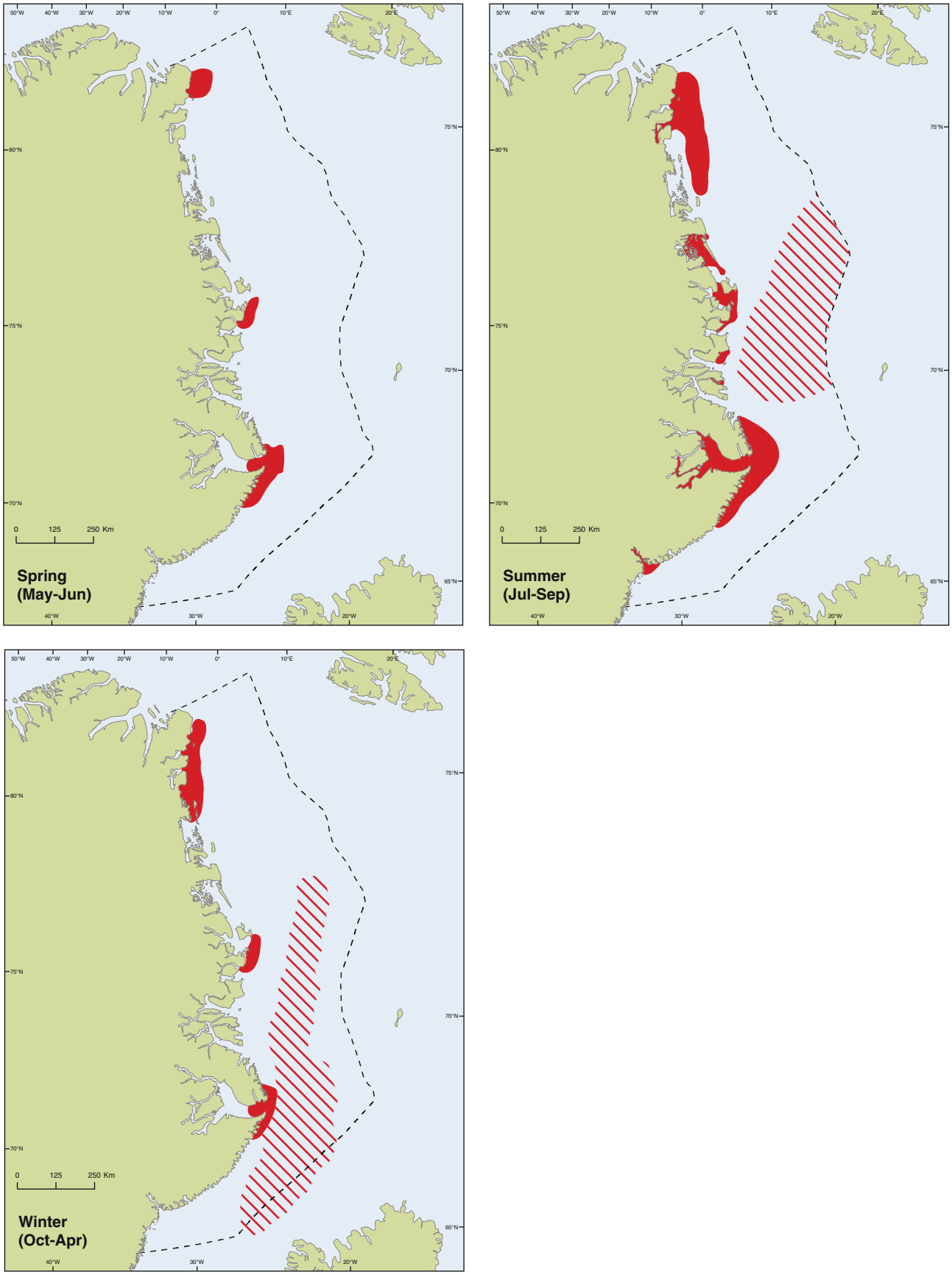

Figure 50. Areas sensitive to oil spills. Based on current knowledge and may be subject to changes, when new information is acquired. Hatched areas are tentative sensitive areas: In winter the whelping area for hooded seal, which shows strong inter annual variation in distribution, and in summer the "Southern Whaling Ground", where bowhead whales probably still congregate and where little auks moult.

Figure 50 shows particularly important and oil spill sensitive areas in the assessment area during winter.

10.3.2 Spring (May–June)

The sea ice gradually disintegrates and retreats and open-water areas increase, starting in polynyas and along fast-ice edges. In coastal habitats the shore lead opens and gradually becomes wider given access to open waters for waterbirds.

The spring bloom is initiated in the open waters and many seabirds assemble in the polynyas, especially off Scoresby Sund, in the Sirius Water and in the NEW polynya. These aggregations are highly sensitive to oil spills, and a worst-case accident in the Scoresby Sund polynya may kill hundreds of thousands of little auks and thousands of other seabird species, mainly thick-billed murre and common eider.

As the ice retreats, blue, minke, humpback and fin whales move in from the south and the east into their feeding grounds in the icefree parts of the assessment area. Sperm whales and bottlenose whales occupy the deep waters to the east of the continental slope. The winter whales also move further into the assessment area and may be concentrated at ice edges for example in the fjord mouths.

Figure 50 shows particularly important and oil spill sensitive areas in the assessment area during the spring period.

10.3.3 Summer, open-water season (July –September)

This is the open-water season, when the drift ice is rather dispersed and almost all coasts have at least a narrow stretch of open water (shore lead). The fast ice is completely gone in most fjords.

Concentrations of marine mammals have been located at several sites: Bowhead whales in the NEW and along the ice edge between NEW and Île de France, and the former whaling area – the Southern Whaling Ground – may still be an important feeding area for bowhead whales. Narwhals are numerous in the NEW, in Dove Bugt, in the Scoresby Sund fjord complex and along the Blosseville Kyst. Walruses assemble in the coastal waters of NEW, Dove Bugt and Wollaston Forland, Shannon and Hochstetter Forland. Baleen whales, e.g. blue whales, are probably numerous in the southeastern part of the assessment area, but there is no knowledge at hand to designate important areas.

Seabirds assemble in and near the breeding colonies especially at the coasts of the Scoresby Sund polynya. Other seabird aggregations occur along the coasts where seaducks assemble to moult, e.g. in some of the fjords of Blosseville Kyst and at the sites identified from the tracking studies (Box 1, 4, 6). Little auks assemble in moulting areas far offshore in the eastern parts of the assessment area.

Late in this season the huge Svalbard populations of little auks and thick-billed murres move on autumn migration through the assessment area in company with a significant part (probably more than 50%) of the breeding population of the threatened ivory gull (from North Greenland, Svalbard and Arctic Russia).

Arctic char assemble in coastal waters at river mouths before moving into the freshwater spawning and wintering grounds.

Figure 50 shows particularly important and oil spill sensitive areas in the assessment area during the summer period.

11 Background studies and information needs

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11.1 Background studies

To support this SEIA a number of background studies were initiated in 2007. These studies should fill some of the information gaps and provide baseline data for planning, monitoring and regulatory purposes. These studies are completed now, and the results are included in this report.

The background studies included:

- Oil drift and fate modelling off NE Greenland by DMI (Nielsen *et al.* 2008).
- Statistical oil drift simulations east of Greenland by SINTEF (Johansen 2008).
- Oil fate and behaviour in ice-covered waters off NE and NW Greenland, by SL ROSS (2008).
- Polar bear studies, presented in Box 8.
- Mapping of important areas for marine mammals and coastal seabirds in spring and summer (Boertmann *et al.* 2009a, b, Boertmann & Nielsen 2010a, b, Gilg *et al.* 2009).
- Little auk and thick-billed murre studies are presented in Box 3 and 4 (Mosbech *et al.* 2012).
- Migration studies of seaducks and other waterbirds, presented in Box 2, 5 and 7.

11.2 Information needs

Having completed the initial background studies it is clear that a substantial amount of environmental background studies are still required including both regional strategic studies and project specific studies. These studies are necessary to provide adequate data for future site-specific EIA-reports, to designate sensitive areas, to regulate activities and as a baseline for both monitoring and 'before and after' studies in case of impacts from large accidents. Furthermore, the dynamics of climate variability is a confounding factor that needs to be included in the baseline.

Below is an annotated list of research and information needs related to hydrocarbon activities in the Greenland Sea assessment area. The East Greenland area is, compared to other regions of Greenland, poorly studied with regard to biological activity and the list below is not exhaustive, new needs may appear, for example when the implications of climate change become more apparent.

Beside the specific research needs listed below, there is a range of needs generic to oil activities in the arctic, cf. the Arctic Council's Oil and Gas Assessment (AMAP 2010). These should be addressed by cooperative international research initiatives, where Greenlandic participation can secure that specific Greenland perspectives are included. The most important of these are also listed below. The specific Greenland Sea knowledge gaps, identified below, could be addressed by studies funded by future license holders.

11.2.1 Specific science needs for Greenland Sea assessment area

Identification and ecology 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 larvae, zooplankton, and seabirds and marine mammals feeding on the lower trophical levels. The sites are sensitive to oil spills and possibly release of produced water. How subsea oil spills may impact such sites is unknown and should be addressed.

How: By surveys recording densities of seabirds and marine mammals, hydrographical features and plankton and fish densities (acoustic surveys), including remote sensing and modelling of oceanographic data. The natural potential for microbial degradation of oil components should also be studied.

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 subsea 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. 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: Oil spills and produced water can damage fish, especially egg and larvae and can result in tainting of adult fish. In addition, adult fish can be displaced by noisy activities.

How: Dedicated surveys a.o. carried out simultaneously and from the same observation platforms as the hot-spot study described above.

Seabirds – distribution and abundance of breeding birds, migration and moulting 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 especially in previously un-surveyed areas and at unsurveyed times of the year; 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, concentration areas and abundance (esp. bowhead whale, blue whale, narwhal, hooded seal), relationship to sea ice (esp. polar bear), stock identity and movements (esp. narwhal), general biological knowledge of less known species (ringed seal and bearded seal)
Relevance: Marine mammals are sensitive to oil spills and to noisy activities. Many of the species occurring in the assessment areas are on the list of endangered species both in a national context and an international (IUCN-redlist). To mitigate impacts, knowledge as specified above is important.

How: Tracking studies by means of satellite transmitters and dedicated surveys (ship, aircraft) in combination with some of the surveys described above.

Marine mammals – reactions to noise from drilling and seismic surveys
Relevance: Marine mammals are sensitive to noise, there is a risk of displacement from critical habitats, and the most important knowledge gaps to address include: effect studies on narwhals and cumulative impact on whales from activities in several licence blocks.

How to address gaps: Controlled exposure field studies; passive acoustic monitoring; satellite tracking.

11.2.2 Science needs generic to the arctic

The effects of oil, different oil components and drilling additives 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. Degradation of toxic substances under Arctic conditions is also important to address, and assessment criteria and adequate monitoring strategies should be established.

Below are listed some important questions, which should be addressed before production activities are initiated off East 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 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 on marine mammals,
- Degradation rates and toxicity of oil and degradation products in water and sediments under Arctic conditions.
- Fate and behaviour of oil spills in ice.
- Impacts from subsea oil spills on concentrations of hibernating copepods (*Calanus*).

In relation to drilling mud and cuttings:

- Degradation rates and toxicity of mud chemicals and their degradation 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 its constituents in ice-covered waters,
- Biological effects, bio-accumulation and sensitivity of the different components on key species (e.g. polar cod).

Contaminants

- Interactions between impacts of oil related pollution and contaminants such as POPs and heavy metals in species from the assessment area.

In relation to noise from activities esp. seismic surveys

- Dispersal of sounds in stratified waters.
- Full spectrum measurements and modelling of the dispersal of airgun pulses in arctic waters.

11.2.3 Ecotoxicological monitoring

Assessment criteria have to be established in order to use biological indicators to assess if impacts are unacceptable or not. 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 Greenland Sea are not available for establishing such criteria. Knowledge concerning species' sensitivity, assessment criteria as well as adequate monitoring strategies, will be relevant to have at hand before drilling activities are initiated.

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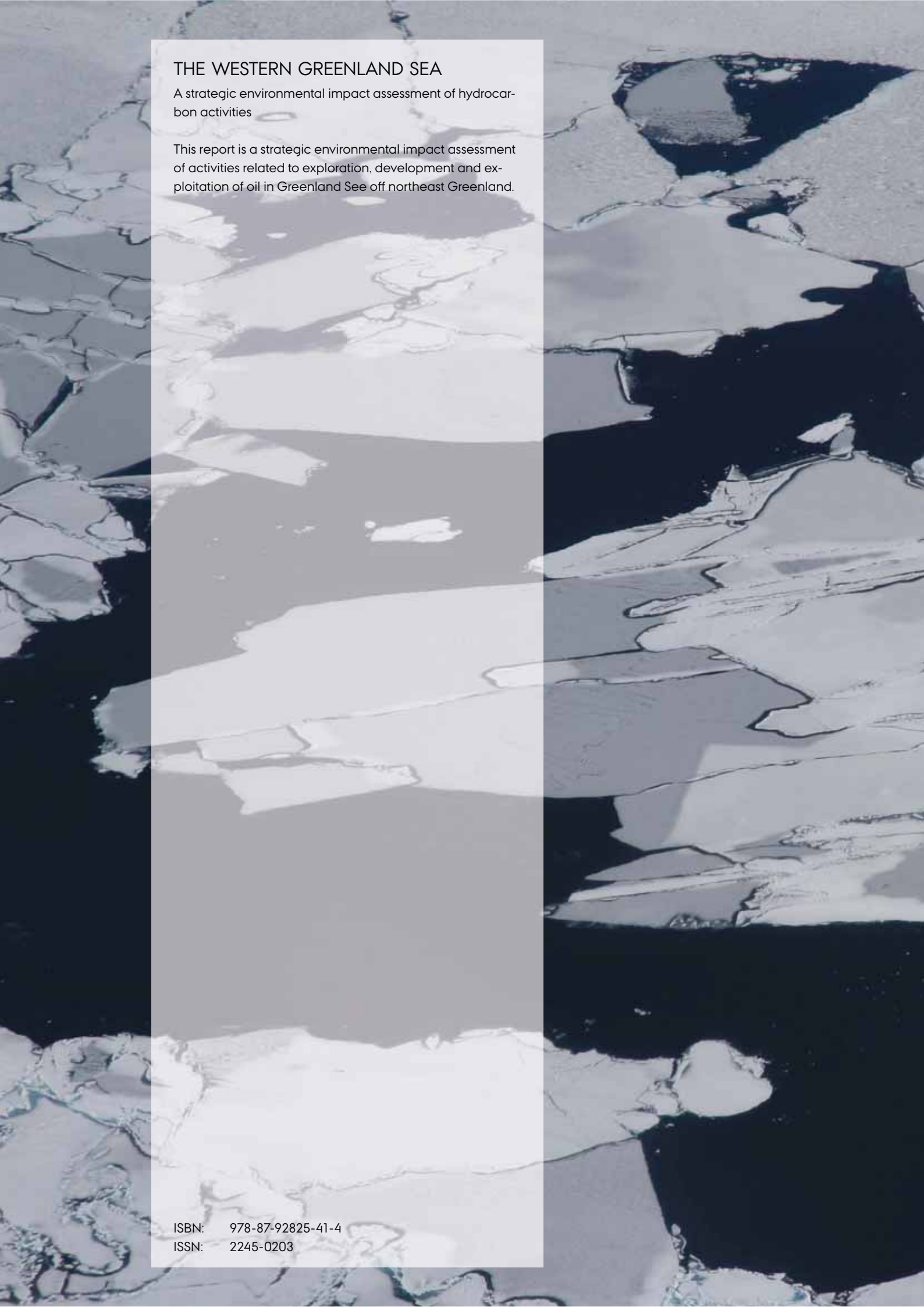

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