



# BAFFIN BAY

An updated strategic Environmental Impact Assessment  
of petroleum activities in the Greenland part of Baffin Bay

Scientific Report from DCE - Danish Centre for Environment and Energy

No. 218

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DCE - DANISH CENTRE FOR ENVIRONMENT AND ENERGY



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## Preface

A preliminary Strategic Environmental Impact Assessment (SEIA) was made before the eastern Baffin Bay was opened for an oil licensing round in December 2009 and this SEIA was updated in 2011 ([Link](#)). That SEIA covered activities related to exploration, development and exploitation of hydrocarbons in the sea off Northwest Greenland between 71° and 78° N (the KANUMAS West area). It was prepared by DCE – Danish Centre for Environment and Energy and The Greenland Institute of Natural Resources (GINR). The draft SEIA was subjected to a public consultation process and was part of the decision process prior to opening of the area.

Subsequently an Eastern Baffin Bay Strategic Environmental Studies Plan 2011-2014 was developed based on the analysis made in the SEIA report. It was designed to provide high priority supplementary studies to fill identified major information gaps at the overall strategic level. The studies plan was developed in cooperation with the Bureau of Minerals and Petroleum (BMP) (now Environment Agency for Mineral Resources Activities (EAMRA)), it focused on information needed as a baseline and for planning and regulatory purposes and it was financed by license holders in the area.

The studies program included projects on intertidal flora and fauna, fish, sea-birds and marine mammals as well as development of toxicological methods for monitoring in the Arctic and an updated SEIA. The studies focus on the entire eastern Baffin Bay; hence, each study contributes with important information to the overall updated strategic assessment.

The new data are presented and used for the revised impact assessment in this updated SEIA-report, which constitutes the concluding part of the Eastern Baffin Bay Strategic Environmental Studies Plan 2011-2014.

## Summary and conclusions

The Greenland part of Baffin Bay between 71° N and 78° N (Figure 1) was opened for petroleum exploration in 2010 and seven licenses were granted by the Bureau of Minerals and Petroleum (BMP). A preliminary strategic environmental impact assessment (SEIA) of activities related to oil exploration and exploitation was published in 2009 before the area was opened (Boertmann et al. 2009). This preliminary SEIA was updated with new information obtained from environmental studies carried out by the Greenland Institute of Natural Resources and Aarhus University in 2011 (Boertmann & Mosbech 2011), and now, with the present report, the SEIA is updated again based on data from a strategic environmental study program carried out in the years 2011-2014.

The report is written by DCE – Danish Centre for Environment and Energy – and the Greenland Institute of Natural Resources (GINR).

The assessment area is shown in Figure 1. This is the region that potentially could be impacted by a large oil spill deriving from activities within the license areas, although oil could drift beyond the borders of this area. The area to the south of the assessment area is covered by another SEIA of hydrocarbon activities in the Disko West license area (Boertmann et al. 2013).

### The environment

The physical conditions of the study area are briefly described focusing on oceanography and ice conditions, i.e. presence of icebergs and sea ice in winter and spring. One of the most important features within an environmental context is the large polynya between Greenland and Ellesmere Island in Smith Sound. This is named the North Water Polynya, and is an area where the winter ice is sparse and where open waters occur early in spring, facilitating a very early start of the primary production.

The study area is situated within the Arctic region, with all the typical biological properties of this climatic region: a relatively simple food web from primary producers to top predators and with a few species playing a key role in the ecology of the region. The most significant ecological event in the marine environment is the spring bloom of planktonic algae, the primary producers in the food web. These are grazed upon by copepods, including the *Calanus*-species, which constitute important key species in the food web in the assessment area.

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

The macroalgae are found along shorelines attached to hard and stable substrate, and may occur at a depth of more than 50 m. Biomass and production of littoral and sub-littoral macroalgae can be significant and are important for the higher trophic levels of the food web.

In and on the underside of the sea ice a specialised ecosystem exists: the sympagic flora and fauna. Algae living in and on the ice are grazed by small crus-



taceans, which sustain populations of polar cod which again are important food to ringed seals and seabirds.

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

Seabirds are abundant with several species present in the study area. Many species breed in dense colonies along the coasts, seabirds assemble in certain fjords and bays to moult, and millions of seabirds migrate through the area on their passage between breeding sites within the assessment area and in Arctic Canada and their winter grounds primarily off Newfoundland. Some of the most important and numerous species are common eider, thick-billed murre and little auk.

Thick-billed murre, common eider, black-legged kittiwake and ivory gull are all threatened (red-listed) in Greenland due to declining, or in case of the common eider, previously declining populations. Furthermore, some of these species are designated as species of national responsibility (which means that the population in Greenland is so large that the local management of the species is vital to the global population), for instance the little auk.

Marine mammals are significant components of the ecosystem. Four species of seals, walrus, several species of whales and polar bear occur in the assessment area. The area is particularly important for marine mammals in winter because vulnerable species such as narwhal, white whale (beluga), bowhead whale, walrus and polar bear occur in significant numbers.

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

Important areas and biological hotspots have been identified. Among these is the North Water Polynya where large seabird breeding colonies are found on the coasts and marine mammals occur in high numbers both summer and winter.

Melville Bay is very important for narwhals, as a discrete stock spend the summer here.

The coasts of the Upernavik district are very important for breeding seabirds (several significant breeding colonies) and for migrating marine mammals, especially narwhal and white whale.

In the southwestern part of the assessment area, there is an important wintering area for narwhals.

All these areas are designated as 'ecologically valuable and sensitive marine areas' (Christensen et al. 2012) and they are designated as 'Arctic marine areas of heightened ecological and cultural significance' (AMAP/CAFF/SDWG 2013).

The living resources of the assessment area are utilised by the local human population. Commercial fisheries are aimed at northern shrimp and Greenland halibut, and the products of these activities (also from other parts of Greenland) constitute the most important export commodities from Green-

land. Subsistence hunting and fishery are targeted at many species of marine mammals, seabirds and fish. The coastal zone of the region is very important for these activities.

Tourism is a growing industry in Greenland and now counts as the country's third largest economic activity. The number of guests visiting the assessment area is small but increasing. The coastal marine areas are an important asset for the tourist activities.

Knowledge of background levels of contaminants such as hydrocarbons and heavy metals is important for the assessment of the sensitivity and environmental impacts from petroleum activities and the current situation is described.

Owing to long-range transport into the Arctic, the levels of certain contaminants, i.e. organochlorines, are high in Greenland, particularly at the higher trophic level (for example whales, polar bears). In addition, new persistent pollutants, such as brominated flame retardants and perfluorinated chemicals, have now appeared. Levels of petroleum compounds, including PAHs, are relatively low and are regarded as background concentrations, except in polluted areas such as harbours where higher levels can be found. The present knowledge concerning the relationship between contaminant loads and biological impact, including sub-lethal health effects or impairments of biota, is still limited.

Climate change will have profound impacts on the ecosystems and their components in the Arctic, including the assessment area. Changes in the distribution of species are to be expected, such as northward displacement of true Arctic species and species from temperate regions becoming more abundant. Alterations in the distribution and abundance of key species at various trophic levels could for example have significant and rapid consequences for the structure of the ecosystems with implications for its functioning but also for fisheries and hunting. For some species and populations, climate change may act as an additional stressor in relation to existing impacting factors, leading to higher sensitivity to oil spill incidents. Another threat from climate change is the risk of introducing alien and invasive species by ship fouling and ballast water. The Greenland waters have so far largely been spared, but increasing water temperatures will increase the threat.

### **Assessment**

The assessment presented here is based on our present knowledge of the abundance and distribution of species and their tolerance and threshold levels toward human activities in relation to oil exploration and production. However, since the Arctic is changing due to climate change, conclusions and assessments may need to be adjusted in the future.

### **Normal operations – exploration**

Exploration activities are temporary, probably lasting some years, and involve different license areas. They will, in the assessment area, take place during the ice free seasons, i.e. summer and autumn. Seismic surveys have been conducted until October, and exploration drilling probably has to be terminated by the end of 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 installations be removed. If oil or gas is found, and appraisal shows it to be economically feasible to exploit, activities will proceed until the field is emptied for recoverable oil and this may last several decades.

During exploration, the main environmental impacts derive from 1) noise generated either by seismic surveys or the drilling platforms and 2) from releases to the sea and the atmosphere, primarily cuttings, drilling mud and greenhouse gases.

### **Seismic surveys**

Noise from a seismic survey has the potential to scare adult fish away from fishing grounds, but this effect is temporary and normal conditions will re-establish after some days or weeks after the end of the seismic survey, the time period depending on fish species. Fishery may be affected negatively by seismic surveys, and the fisheries at risk in the assessment area are those of Greenland halibut and northern shrimp. The halibut fishery takes place in inshore areas far from the license blocks and no impacts are expected on that fishery. Shrimp fisheries are not known to be impacted by seismic surveys, and it is not likely that the fishery inside the assessment area will be reduced if seismic surveys overlap with the fishing grounds.

It is well known that seismic noise can scare away marine mammals and the most sensitive species in the Baffin Bay assessment area are bowhead whales, narwhals, white whales and walrus. Walrus do usually not occur when seismic surveys take place. White whales will primarily overlap with the seismic season in late autumn when they migrate through the assessment area. Bowhead whales are most frequent in spring because their main migratory pathway in autumn is along the Canadian coast. Therefore, impacts on the populations of these species from seismic surveys in the license-blocks will most likely be small or can, in the case of white whale migration, be mitigated. However, if aided by icebreakers, seismic surveys potentially may occur in areas where especially white whale and walrus are present.

The situation for the narwhal is considerably different as a discrete stock spends the summer in Melville Bay (Box 13). This stock is particularly exposed to seismic surveys in the northern Baffin Bay (where the active license blocks are situated), both during their summer stay near the coast and glaciers and during their autumn migration through the assessment area. Concern for displacement of narwhal migration routes and timing has been expressed, especially because some unusual ice-entrapments occurred in 2008-2010 in Baffin Bay (Heide-Jørgensen et al. 2013d) following summers with seismic activity.

Other species, such as fin, blue, humpback and especially minke whale, may also be displaced from important habitats, but the significance of the assessment area for these species is generally low and no concentrations are known, so impacts on these populations probably will be small or insignificant.

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

### **Other noise**

Noise from drilling rigs is continuous, and the most vulnerable species in the assessment area are narwhal, white whale, bowhead whale and walrus. There

is a risk for displacement of these species from important habitats and hunting grounds. The temporal overlap between most of these species and exploration drilling will, however, be short and restricted to late autumn, and the degree of impacts will depend on the amount of exploration activities going on.

Again, the narwhals, occurring in the Melville Bay in summer, will be more at risk for impacts from the continuous noise from a drilling platform and the associated ship traffic.

### **Discharges and emissions**

During drilling operations, drilling mud (if water based) and cuttings will be released to the seabed, resulting in local impacts on the benthic fauna. Strict regulation based on specific toxicity tests of the mud chemicals and monitoring of effects on the sites is essential to mitigate impacts. Chemicals to be released in the Greenland environment must comply with OSPAR (HOCNF) standards for *low or no harm to the environment*. However, knowledge of degradation and toxicity of even the environmentally safe chemicals under Arctic conditions is very limited, so use and discharge should be thoroughly monitored and evaluated, including further testing of degradation and toxicity.

Oil-based (OBM) mud may be used, but only under strict regulation in order to prevent any release to the environment. The use of OBMs can contribute to reduce environmental impacts on the seabed, as these muds have to be transported to land for proper treatment or be reinjected.

During exploration drilling, there is a risk of oil spills (see below).

Moreover, exploration drilling is an energy demanding process emitting large amounts of greenhouse gases. The drilling of three wells in West Greenland in 2010 increased the Greenland greenhouse gas contribution that year by 15%.

### **Normal operations – development and production**

Development and production activities are difficult to evaluate when their location and the level of activity are unknown. Overall, impacts will depend on the number of activities, how far they are scattered, and also on their duration. 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 having the potential to cause severe environmental impacts.

### **Emissions and discharges**

Drilling activities will continue during development and production phases, and drilling mud and cuttings will be produced in much larger quantities than during exploration (see above).

The release of produced water gives reason for environmental concern. Recent studies have indicated that the content of oil can impact fish far from the release site, and there is also evidence of effects on several of the other marine ecosystem components. If produced water is released under ice, sensitive communities and polar cod eggs and larvae will be exposed. The best way to mitigate these effects is to prohibit discharge (i.e. the produced water must be reinjected into old well bores) or alternatively to completely clean the water before release.

There could be a risk of release of non-native and invasive species from ballast water and ship hulls, and this risk will increase with the effects of climate change. 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.

### **Noise**

Noise caused by the drilling activities, ship and helicopter traffic can affect marine mammals and seabirds. The most sensitive species are the colonial seabirds, bowhead whales, narwhals, white whales and walrus. There is a risk of permanent displacement of populations from critical habitats and thus for negative population effects.

If hunted populations are displaced, their availability to hunters may change.

### **Placement of structures**

Placement of structures has both biological and aesthetic impacts. The biological impacts mainly include permanent displacement from critical habitats – walrus being the most sensitive in the assessment area. Aesthetic impacts primarily include impacts on the pristine onshore landscape, which again may have an impact on the local tourist industry.

The commercial fishery may be affected by closure zones if rigs, pipelines and other installations are placed in the Greenland halibut fishing grounds.

### **Cumulative impacts**

There is a risk of cumulative impacts in case several activities occur simultaneously or consecutively. Seismic surveys, for example, have a high potential to exert cumulative impacts, in particular on marine mammals. Cumulative impacts may also occur in combination with other human activities, such as fishery and hunting.

### **Mitigation of environmental impacts from normal operations**

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. Application of BEP, BAT and international standards (for example OSPAR (HOCNF)) and guidelines (for example Arctic Council) can contribute to reduce emissions to air and the sea. Furthermore, a discharge policy, as for example planned for the Barents Sea, will contribute substantially to minimise impacts.

### **Accidents – oil spills**

The accident due to the activities described above with the most severe environmental consequences is a large oil spill. Such oil spills may occur either during drilling (blowouts) or from storing or transport of oil.

Nowadays, large oil spills are rare due to the technical progress and the improving HSE policies. However, the risk cannot be eliminated and in an area with the presence of sea ice and icebergs, such as Baffin Bay, the probability of an accident is increased.

Large oil spills have the potential to impact the marine ecosystem on all levels, from primary production to the top predators. A large oil spill represents a threat at population level (AMAP 2010), and the impacts may last for more than 20 years as documented in Prince William Sound in Alaska after the *Exxon Valdez* spill in 1989. Oil spills have the potential to drift with winds and currents and impact shores and waters far from the spill site. In case of a spill from a well in one of the licence blocks in the assessment area, coast and waters not only in Greenland but also in Canada will be threatened.

Effects of an oil spill may also be intensified because of the much more difficult operating conditions for an oil spill response in the Arctic. Only 14% of the oil was recovered/burnt off during the *Exxon Valdez* oil spill and 25% during and after the *Deepwater Horizon* spill in the Gulf of Mexico. The ice is one major obstacle, the lack of infrastructure is another and the winter darkness is a third major factor contributing to reduce the efficiency of an oil spill response in the Baffin Bay.

Recovery lasted more than 20 years in Prince William Sound. It will take much longer time in the Baffin Bay assessment area due to the Arctic conditions, and the more difficult and limited ways to clean up spilled oil there – with the risk of leaving much more oil in the environment – will also contribute to longer effects.

#### **Primary production and plankton**

It is expected that a surface oil spill in open waters far from the coast of the assessment area will have only low impacts on primary production due to the large temporal and spatial variation of the primary production. Localised high primary production may be reduced; however overall production will probably not be significantly impacted due to the large areas where the primary production takes place.

The same may be true for localised concentrations of plankton and fish/shrimp larvae if they occur in the uppermost part of the water column. However, on a broad scale, no or only minor effects are expected on these ecosystem components.

If subsea plumes of dispersed oil are generated in the Baffin Bay area, as observed during the *Deepwater Horizon*-blowout, impacts on primary production, zooplankton and fish/shrimp larvae in the water column are more likely to occur compared with the surface spill situation.

#### **Impacts on the seabed**

Bottom-living organisms such as bivalves, crustaceans or fish are vulnerable to oil spills; however, no effects are expected in the open sea unless the oil sinks to the seabed. In shallow waters (< 10-15 m), highly toxic concentrations of hydrocarbons can reach the seafloor with possible severe consequences for local benthos and thus also for species utilising the benthos – especially walrus, eider and king eider. Again, a subsea spill with the size and properties of the spill from the *Deepwater Horizon* incident in the Mexican Gulf, which produced large subsurface plumes of dispersed oil, holds the potential also to impact the seabed communities in deep waters.

#### **Impacts on fish**

A surface spill is not expected to impact adult fish stocks in the open sea. Adult fish will avoid the oil, but very small oil concentrations may lead to tainting, rendering such oil-exposed fish impossible to sell. An oil spill in ice-

covered waters may pose a risk to populations of polar cod, an ecological key species. Any significant impacts on polar cod stocks may be transferred up in the food web (to other fish, seabirds and marine mammals). Another exception is a subsea spill, which could impact the fish both directly or through the food. Greenland halibut will also be exposed in both ways because they move up in the pelagic waters to feed.

In coastal areas, fish stocks may be impacted from oil spills, and here especially stocks of capelin, lumpsucker and Arctic char are at risk. Capelin and lumpsucker can be exposed when they spawn in the tidal zone or in shallow waters right off the coast and Arctic char when they migrate to and from the river where they spawn and winter.

### **Impacts on seabirds**

In the open sea, seabirds are usually more dispersed than in coastal habitats. However, in the assessment area there are some very concentrated and recurrent seabird occurrences for example in polynyas and in the shear zone. Post breeding concentrations of staging birds (such as thick-billed murres, Box 5) may also be vulnerable. Such concentrations of seabirds are extremely sensitive to oil spills and population effects may occur in case of oil in one of these habitats. The most important concentrations are the breeding thick-billed murres, the breeding little auks and migrating thick-billed murres (especially those on swimming migration). Migrating little auks may avoid the most oil polluted areas because they quickly move to the Canadian side of Baffin Bay. There are many other breeding concentrations of seabirds inside the assessment area, and some of the populations of less common species (such as Atlantic puffin) are very vulnerable to oil spills.

Several nationally red-listed (threatened) species occur in the marine environment and populations of these will be exposed to potential oil spills in the assessment area. The little auk is not red-listed, but it is a national responsibility species in Greenland, because a vast majority of the world population is found within the assessment area. A major oil spill could seriously affect the viability of this population.

### **Impacts on marine mammals**

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

Whales, seals and walrus are also vulnerable to oil spills, particularly if they have to surface in oil slicks. Baleen whales may get their baleens smothered with oil and ingest oil. The extent to which marine mammals will actively avoid an oil slick and how harmful the oil will be to fouled individuals is not known, but whales have been observed moving directly into oil spills.

Whales and seals are sensitive to inhaling oil vapours, and particularly narwhals, white whales, bowhead whales, walrus, ringed seal and bearded seal could be vulnerable during an oil spill in winter when the availability of open waters is limited by the sea ice. There is also a risk of indirect impacts on walrus and bearded seal populations through contamination of benthic fauna, especially at shallow (< 10-15 m) feeding grounds where oil may reach the seafloor.

### **Impacts on fisheries and hunting**

An oil spill in the open sea will affect fisheries mainly via temporary closure in order to avoid contamination of catches. The duration of the closure will depend on the duration of the oil spill, weather conditions, etc. Even though the offshore fisheries for Greenland halibut within the assessment area are small (compared with other Greenland fisheries for this species), a closure zone will probably extend further south and cover a much larger area, including both Greenland and Canadian fishing grounds.

Oiled coastal areas would also be closed for fisheries for a period. There are examples of closure for many months due to oil spills, particularly if oil is caught in sediments or on beaches. The inshore fishery for Greenland halibut within the assessment area is important on a national scale, and a closure of these fishing areas will have significant economic consequences.

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

### **Impacts on tourism**

The tourist industry in the assessment area will also experience negative effects from a large oil spill.

### **Oil in ice**

Another especially vulnerable feature is ice-covered waters. Spilled oil will be contained between the ice floes and on the rough underside of the ice. In this case, oil may be transported in an almost un-weathered state over long ranges and may impact the environment, for example seabirds and marine mammals, far from the spill site when the ice melts. Oil may also be caught along ice edges and in the shear zone where sensitive species and ecosystem elements, such as primary production, zooplankton, polar cod, seabirds and marine mammals, aggregate. Particular concern has been expressed for polar cod stocks. This fish spawns in late winter, and the eggs accumulate just below the ice where spilled oil will also accumulate.

### **Long-term impacts**

If an oil spill reaches the coasts of the Baffin Bay assessment area, long-term effects of residual oil buried in the beach sediments must be expected, as described for Prince William Sound.

### **Mitigation**

Oil spills should be prevented and avoided by high HSE levels, knowledge of the risks and by applying the BAT and BEP principles throughout the operations. If a spill occurs, efficient contingency plans must be in place, including access to adequate equipment and oil spill sensitivity maps identifying the most sensitive areas. However, there are still no effective methods for an oil spill response under winter conditions in a region such as the Baffin Bay assessment area.

### **In conclusion**

The coastal zone of the assessment area is particularly sensitive because of its high biodiversity, including concentrations of breeding and moulting seabirds. The high sensitivity is also related to the fact that oil may become trapped in bays and fjords where high and toxic concentrations can build up in the water column and impact both seabed fauna and organisms in the water column, e.g. fish assembling at spawning sites. Local fishermen and hunters use the coastal zone of the assessment area intensively and an oil spill will



threaten their livelihood. Finally, the experience from Prince William Sound in Alaska shows that long-term impacts occurred in the coastal zone where oil was buried and preserved in certain environments .

### **Information needs**

Since the first edition of this SEIA, a program for high priority background supplementary studies was carried out: Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014 (see Section 11). The aim of this program was to fill major information gaps at the overall strategic level, and it focused on information needed as a baseline and for planning and regulatory purposes. The results (or preliminary results) are included in the present document.

However, many more topics have to be covered to provide adequate data for operational purposes, and a number of studies – both of local character, but some also with a more general Arctic outreach – are proposed in Section 12. Moreover is it proposed, in case it is decided to develop and exploit oil in the assessment area, to develop an integrated monitoring plan to support ecosystem based management of the activities. Such monitoring requires the establishment of an ecological baseline.

# Sammenfatning

## Strategisk miljøvurdering af olieaktiviteter i den grønlandske del af Baffin Bugt, ny opdateret udgave

I 2010 blev den grønlandske del af Baffin Bugt mellem 71° og 78° N åbnet for olieefterforskning. Inden da havde DCE – Nationalt Center for Miljø og Energi – og Grønlands Naturinstitut foretaget en foreløbig strategisk miljøvurdering (SMV) af olieaktiviteter i den region, som forventedes at kunne blive påvirket af aktiviteterne, herunder oliespild, der kan drive langt væk fra et spildsted (Boertmann et al. 2009). Området, som omfattes af vurderingen, ses på Figur 1. Det kaldes generelt for vurderingsområdet (*the assessment area* eller *Baffin Bay assessment area*).

Syv tilladelser (blokke/licensområder) blev tildelt ansøgende olieselskaber i december 2010. To af disse blev leveret tilbage i 2016, og de resterende fem er i januar 2017 under tilbagelevering.

Den foreløbige SMV blev opdateret i 2011 (Boertmann & Mosbech 2011) med resultater fra en række miljøstudier udført af Aarhus Universitet og Grønlands Naturinstitut, og nu foreligger hermed den anden reviderede version af denne SMV. Heri indgår nye resultater fra et strategisk miljøstudieprogram udført i perioden 2011-2014 (se Kapitel 11) samt viden indsamlet som en del af myndighedernes miljøkrav til opererende selskaber (f.eks. observationer foretaget af observatører (MMSO) på de skibe, der har udført seismiske undersøgelser).

Den nye version er ligesom de tidligere udarbejdet af DCE og Grønlands Naturinstitut og for Miljøstyrelsen for Råstoffer i Grønland.

Formålene med en strategisk miljøvurdering er 1) at danne grundlag for politiske beslutninger, 2) at gøre rede for det vidensgrundlag, som benyttes ved myndighedsbehandlingen og -reguleringen af olieselskabernes aktiviteter, og 3) at bidrage med opdateret viden til selskaberne, når de skal udarbejde miljøvurderinger af deres specifikke aktiviteter eller miljøafvejninger, hvis de skal vælge mellem forskellige metoder til at bekæmpe oliespild (*Net Environmental Benefit Analysis* – NEBA).

Rapporten beskriver primært det marine miljø med både fysiske og biologiske forhold. Ud over mere generelle beskrivelser omtales også beskyttede områder, truede arter, niveauer af forurenende stoffer samt udnyttelse af de biologiske ressourcer. Baseret på disse beskrivelser af den nuværende situation vurderes de potentielle miljømæssige konsekvenser af olieaktiviteter i vurderingsområdet. Endelig gives der en oversigt over viden, der vil være nødvendig at tilvejebringe fremover som baggrundsviden til udarbejdelsen af miljøvurderinger, miljøafvejninger, myndighedsregulering af aktiviteter m.m.

### Områdets biologi

Vurderingsområdet er beliggende i den højarktiske zone og viser de for denne zone karakteristiske biologiske træk: forholdsvis lav biodiversitet (dyrelivet på havbunden undtaget), korte fødekæder og områder med meget høje koncentrationer af organismer. Den lave biodiversitet modsvares af at visse arter er uhyre talrige, og nogle af disse er nøglearter i fødekæderne. Det betyder, at dyr fra de højere trofiske niveauer er afhængige af disse arters forekomst i tid og rum. Endelig er det karakteristisk at mange organismer har et højt indhold

af fedtstoffer, som virker dels som reserve til perioder uden fødetilgang dels som isolation mod kulde. Dette høje indhold af fedtstoffer har særlig betydning i forbindelse med forurening af miljøet, fordi mange af de forurenende stoffer er fedtopløselige og derved kan ophobes i dyrenes fedtvæv.

Det vurderede område er rigt i biologisk/økologisk forstand. Primærproduktionen om foråret er visse steder meget høj, der er rige dyresamfund på havbunden, ligesom der er store og meget vigtige forekomster af både fugle og havpattedyr. Blandt fuglene er der i både national og international beskyttelsessammenhæng vigtige arter, og flere er klassificerede som truede på både den grønlandske og den internationale rødliste, herunder arter som polarlomvie, ederfugl, ride, havterne og lunde. Blandt havpattedyrene er der tilsvarende vigtige arter som isbjørn, hvalros, narhval, hvidhval og grønlandshval.

Et meget væsentligt biologisk område er det store polynye, Nordvandet, beliggende mellem Qaanaaq-området og Ellesmere Island. Her er mere eller mindre isfrit om vinteren, og om foråret starter primærproduktionen meget tidligere end i de omkringliggende isdækkede områder. Dette medfører koncentrationer af havpattedyr og fugle, som bl.a. har gjort det muligt for mennesker at etablere sig permanent i området. Langs de grønlandske kyster af dette polynye yngler f.eks. mere end 80 % af den globale bestand af den meget talrige søkonge; vurderet til mere end 30 millioner par. Der er her tale om en national ansvarsart, idet hele verdens bestand er afhængig af den grønlandske bestands trivsel. De vigtige arter af fugle og havpattedyr, som er nævnt ovenfor forekommer særligt talrigt i polynyet.

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

### **Olieaktiviteter**

Aktiviteterne fra en komplet livscyklus for et oliefelt er kort beskrevet og så vidt muligt vurderet, med vægt på de aktiviteter og hændelser, som erfaringsmæssigt giver de væsentligste miljøpåvirkninger. Da der ikke er erfaringer med udvinding af olie i Grønland, kan vurderinger af aktiviteter i denne forbindelse imidlertid ikke være konkrete og 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* (AMAP 2010) ([Link](#)). Endvidere er der inddraget viden fra det i 2010 store undersøiske olieudslip i den Mexicanske Golf, omend erfaringerne herfra stadig er noget begrænsede.

### **Vidensgrundlag**

Vurderingerne i rapporten tager udgangspunkt i de eksisterende klimatiske forhold. Men klimaændringerne forventes at påvirke miljøet væsentligt i vurderingsområdet i de kommende årtier, og det medfører væsentligt ændrede leveforhold. Især isens forekomst er under stadig forandring. Disse ændringer betyder, at nogle arter reduceres i forekomst og udbredelse mens andre begunstiges, ligesom nye arter vil indvandre fra syd og etablere sig i vurderingsområdet.

Vurderingerne bygger tillige på den tilgængelige biologiske viden, som i mange sammenhænge stadig er mangelfuld. Der blev i 2007 indledt en række

studier for at forbedre vidensgrundlaget, og resultaterne heraf var grundlaget for den første reviderede SMV. Heri foresloges et nyt strategisk miljøstudieprogram, som skulle udfylde yderligere væsentlige videnshuller. Resultaterne fra dette program er baggrunden for denne anden reviderede version af SMV'en.

### **Miljøvurdering af efterforskningsaktiviteter**

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

Hvis efterforskningen ikke påviser olie eller evt. gas, vil aktiviteterne ophøre, og alt udstyr fjernes. Findes der derimod olie, som efter en *appraisal*-periode viser sig mulig at udnytte, vil aktiviteterne overgå til udvikling af et oliefelt med afgrænsningsboringer, efterfulgt af etablering af infrastruktur og derpå en egentlig udvinding af den fundne olie (se nedenfor).

De væsentligste påvirkninger fra efterforskningsaktiviteter er forstyrrelser fra støjende aktiviteter (f.eks. seismiske undersøgelser, fra boreplatforme og helikopterflyvning) og udledninger til det omgivende miljø i form af boremudder, borespåner og drivhusgasser m.m. fra brug af brændstof ved de mange aktiviteter.

### **Efterforskning – støj og seismiske undersøgelser**

Seismiske undersøgelser skaber høje lydniveauer i det marine miljø og har potentiale til at bortskræmme især fisk og havpattedyr. Virkningerne er normalt forbigående og begrænsede, men man skal være opmærksom på de særlige 3D-seismiske undersøgelser, der er meget intensive i begrænsede områder, og desuden på de kumulative virkninger af flere seismiske undersøgelser i de samme områder (samtidigt eller efter hinanden f.eks. i gennem flere år).

Blandt havpattedyrene vurderes narhval, hvidhval, grønlandshval og hvalros som de mest sårbare over for seismiske undersøgelser. Det tidsmæssige overlap mellem seismiske undersøgelser og tilstedeværelsen af hvalros, hvidhval og grønlandshval vil dog være begrænset, for hvalros og hvidhval til det sene efterår; og for bestandene af disse arter vurderes påvirkninger af seismiske undersøgelser som små og som mulige at forebygge. Situationen for narhval er anderledes, idet der i Melville Bugt forekommer en lokal bestand om sommeren, som kan blive udsat for seismisk støj både om sommeren og om efteråret, når den trækker sydover gennem vurderingsområdet. Der er risiko for, at denne bestand kan blive fordrevet fra vigtige opholdssteder eller ændre trækruter på grund af seismiske undersøgelser. Dette er særligt udtalt, hvis der foregår samtidige seismiske undersøgelser i flere licensblokke (som i 2012 – se Box 13).

Der er også en risiko for at seismiske undersøgelser kan påvirke fiskeri på rejer og hellefisk i vurderingsområdet. Rejer påvirkes dog normalt ikke af seismiske undersøgelser, og der forventes ikke negative påvirkninger af dette fiskeri. Fiskeriet på hellefisk kan forventes at gå ned i en periode efter en seismisk undersøgelse som overlapper fiskeområderne. Virkningen er midlertidig og formentlig også lille, idet der ikke er rapporteret om nedgang i

hellefiskefangster andre steder i Grønland, hvor seismiske undersøgelser har overlappet med trawlfiskeri efter hellefisk.

Støj fra boreplatforme er også midlertidig (så længe der udføres efterforskningsboringer), men er i modsætning til støjen fra seismiske undersøgelser vedvarende, og kilden er stationær. Igen er hvidhval, narhval, grønlandshval og hvalros de mest sårbare, idet de undgår sådanne støjkilder og dermed kan fortrænges fra vigtige opholdssteder. Da overlappet mellem efterforskningsboringer og tilstedeværelsen af hvalros, hvidhval og grønlandshval i vurderingsområdet er kortvarigt, vil risikoen for påvirkninger af disse arter dog være lille, mens narhvalbestanden igen er i risiko for at blive eksponeret gennem hele sommeren og i træktiden.

Endelig foregår der ofte intensiv transport til og fra en boreplatform med helikopter. Den trafik har potentiale til at skræmme især fuglebestande og forebygges ved planlægning af faste flyveruter og -højder.

Traditionelle fangstområder og -pladser kan påvirkes ved, at fangstdyrs forekomst eller trækruter ændres; effekten på fangsten kan dog gå i begge retninger.

### **Efterforskning – udledninger til omgivelserne**

Hvis der ved en efterforskningsboring benyttes vandbaseret boremudder, vil spåner og mudderrester normalt blive udledt til havbunden efter endt boring. Boremudder indeholder en lang række kemikalier, og disse samt den fysiske påvirkning fra spånerne kan påvirke dyrelivet på og i bunden lokalt (ud til ca. 250 m's afstand) omkring udledningsstedet. I Grønland må normalt kun miljøvenlige stoffer udledes, dvs. de, som er klassificerede efter OSPAR-konventionens *Harmonised Offshore Chemical Notification Format* (HOCNF) eller som "grønne" og "gule" af de norske myndigheder. De "sorte" kemikalier må ikke benyttes i Grønland, og de "røde" kemikalier skal undgås; der kan dog gives dispensation i særlige tilfælde.

Boremudder baseret på olie kan benyttes, hvis det kan gøres uden at udlede rester til miljøet. Der kan nemlig være miljømæssige fordele ved at benytte det i stedet for vandbaseret boremudder. Det skal dog sikres, at det transporteres til land og her behandles miljømæssigt forsvarligt.

Der skal desuden foretages undersøgelser af bundforholdene, før boremudder og -spåner kan udledes. Disse undersøgelser skal sikre, at sårbare levesteder ikke påvirkes. Når udledningerne er afsluttet, skal der også udføres tilsvarende undersøgelser for at kontrollere, om bestemmelserne er fulgt, og om de har virket.

Efterforskningsboring er en energikrævende aktivitet, som medfører store udledninger af drivhusgasser og andre forbrændingsluftarter. De tre boringer i 2010 forøgede således den årlige grønlandske udledning af drivhusgasser med 15%.

Den værste udledning til miljøet i forbindelse med efterforskningsaktiviteter er olie. Det forekommer ved uheld under boring og transport – se nedenfor.

### **Udvikling og produktion**

Det er vanskeligt at vurdere påvirkninger fra udvikling og udnyttelse af et oliefelt i vurderingsområdet, når hverken aktiviteternes placering eller omfang er kendt. Generelt vil påvirkningerne vare længe (årtier), og mange af

aktiviteterne har potentiale til svære miljøpåvirkninger. Påvirkningerne vil dog også afhænge af antallet af aktiviteter, deres fordeling i området og af hvor længe de pågår, og i den sammenhæng er de kumulative påvirkninger væsentlige.

### **Udledninger fra produktion og udvikling**

Boringer vil blive udført i stor udstrækning i disse faser, for at afgrænse et oliefelt og for at etablere produktionsbrønde, ligesom de seismiske undersøgelser fortsætter. Dette medfører store udledninger af boremudder og -spåner, hvis ikke disse affaldsstoffer kan deponeres i gamle brønde eller bringes til land.

Den udledning, som giver mest bekymring mht. miljøpåvirkninger, er de meget store mængder af produktionsvand, der pumpes op sammen med olien, og som skal bortskaffes. Dette vand indeholder små mængder olie samt mange forskellige mere eller mindre miljøbelastende stoffer, som f.eks. akut giftige stoffer, tungmetaller, radioaktive stoffer, stoffer med hormonvirkning og stoffer med gødningsvirkning. Nogle af disse stoffer kan desuden ophobes i fødekæderne (bio-akkumuleres). Norske undersøgelser har påvist påvirkninger i fisk meget langt fra udslipskilderne, men generelt savnes der viden om produktionsvands langtidspåvirkninger i miljøet. Hvis produktionsvandet udledes under is, kan man forestille sig, at særligt polartorsk kan påvirkes, fordi disses æg og larver samles lige under isen om foråret. Den bedste måde at forebygge påvirkninger fra produktionsvand er ved at lede det tilbage i gamle brønde (*re-injection*).

Ved skibstransport af olie væk fra et produktionssted skal der udledes ballastvand, som medfører en risiko for at introducere ikke-hjemmehørende og invasive arter. Derfor skal ballastvand behandles og udledes efter særlige regler. Invasive arter har hidtil ikke været noget væsentligt problem i Arktis, men risikoen vil stige i takt med klimaændringerne og den mere intensive trafik af tankskibe, som et producerende oliefelt vil medføre.

Endnu en væsentlig udledning i forbindelse med produktion af olie er drivhusgasser. Et producerende oliefelt vil bidrage markant til Grønlands udledning af disse. Som sammenligning kan nævnes, at et af de store norske olie-felter i dag udleder mere end dobbelt så meget CO<sub>2</sub>, som Grønland samlet udleder hvert år.

### **Støj fra produktion**

Støj fra boringer og positionering af borerigge vil fortsætte i udviklings- og produktionsfasen og kan også her medføre, at hvaler skræmmes bort fra vigtige fødesøgningsområder. Dette er særligt problematisk, hvis flere produktionsfelter er aktive samtidig. Støj fra skibe (inkl. isbrydere) og helikoptere, nu mere hyppigt end i efterforskningsfasen, kan også medføre bortskræmning af både havpattedyr og fugle fra vigtige områder. De mest sårbare arter i vurderingsområdet i denne sammenhæng er de kolonirugende havfugle, grønlandshval, narhval, hvidhval og hvalros.

Traditionelle fangstområder kan også blive påvirket ved, at fangst dyr skræmmes væk herfra. En måde at forebygge effekterne af og tilvænne dyr til støj fra flyvning vil være brug af faste flyveruter og -højder.

### **Produktionens fodaftryk**

Installationer til havs og etablering af infrastruktur kan lokalt påvirke dyresamfund på havbunden, og der er en risiko for at ødelægge vigtige fourage-

ringsområder for dyr, der dykker for at æde bunddyr, eksempelvis hvalrosser og ederfugle. Installationer på land kan lokalt påvirke ynglende fugle, hindre fjeldørreders opgang til gydeområder, påvirke den kystnære flora og fauna samt påvirke det æstetiske indtryk af uberørt landskab. Sidstnævnte kan få betydning for turismen.

Fiskeri vil i denne sammenhæng påvirkes af de sikkerheds/afspærringszoner (typisk 500 m), som etableres rundt om midlertidige eller permanente installationer til havs, særligt hvis de skal etableres i de områder, hvor der fiskes intensivt efter hellefisk og rejer.

### **Kumulative effekter**

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

### **Forebyggelse**

Miljøpåvirkninger fra aktiviteterne i forbindelse med både efterforskning, udvikling og produktion begrænses bedst ved nøje regulering og planlægning baseret på:

- indgående viden om det miljø der skal arbejdes i.
- strikse HSE- (*Health, Safety and Environmental*) procedurer.
- implementering af *Best Available Technology* (BAT), *Best Environmental Practice* (BEP), forsigtighedsprincippet og internationale miljøstandarder (f.eks. OSPAR og HOCNF).

### **Oliespild**

Det miljømæssigt værste uheld, der kan forekomme ved de ovennævnte aktiviteter, er et stort oliespild. Et oliespild kan opstå under selve boringen (*blow-out*), hvor råolie strømmer frit ud fra brønden. De kan også opstå i forbindelse med opbevaring eller transport af både brænd- og råolie. AMAP (2010) vurderer, at risikoen for oliespild i Arktis er størst i forbindelse med transport af olie. Store oliespild forekommer sjældnere og sjældnere, fordi de tekniske forhold og sikkerhedsforanstaltninger til stadighed forbedres. Risikoen er imidlertid altid til stede (jf. det store spild i den Mexicanske Golf i 2010), og i et område som Baffin Bugt er den forhøjet på grund af havis og isbjerge.

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

Store oliespild kan potentielt påvirke alle niveauer af det marine økosystem, fra primær-producenter til top-prædatorer, og de kan medføre en så høj dødelighed, at hele bestande kan blive reduceret i antal. De negative påvirkninger kan vare i årtier, som det er dokumenteret efter oliespildet i Prince William Sound i Alaska.

Virkningerne af et oliespild i Baffin Bugt-området kan blive alvorligere end i sydligere farvande. Under det store spild i Prince William Sound i Alaska i 1989 blev 14 % af olien aktivt opsamlet eller brændt af, og det tilsvarende tal under udslippet i den Mexicanske Golf i 2010 var 25 %. I Baffin Bugt skal man ikke forvente, at der kan samles mere op, snarere tværtimod, da både havis, vintermørke og manglende infrastruktur bidrager til at gøre et oliespildsberedskab mindre effektivt end i Prince William Sound (se endvidere nedenfor).

Kysterne og havområderne i Prince William Sound var mere end 20 år om at vende tilbage til de oprindelige forhold efter oliespildet i 1989, og det må forventes, at kysterne i Baffin Bugt-området vil være endnu længere tid om det på grund af de mere arktiske forhold.

### **Oliespild og primærproduktion og plankton**

Primærproduktion og plankton er vidt udbredt i de åbne havområder og udviser stor variation i forekomst (både i tid og rum) og i naturlig dødelighed. På stor skala vil et oliespild på havoverfladen derfor næppe kunne påvirke disse elementer, selvom der lokalt vil kunne forekomme høj dødelighed.

Et undersøisk oliespild, som det fra *Deepwater Horizon*-katastrofen i den Mexicanske Golf i 2010, dannede udstrakte undersøiske skyer af dispergeret olie på forskellig dybde, og sådanne må forventes at kunne påvirke primærproduktion og zooplankton kraftigere end et overfladespild.

### **Oliespild og fiske- og krebsdyryngel**

Generelt er æg og larver fra fisk og krebsdyr mere sårbare overfor olie end de voksne individer, og under uheldige omstændigheder, hvor oliespild falder sammen med høje koncentrationer af fiskelarver/æg, kan rekrutteringen til bestandene tænkes at blive påvirket. Sådanne høje koncentrationsområder for fiskelarver og -æg er ikke påvist i vurderingsområdet, og det er ikke sandsynligt, at fiske- og rejebestande på det åbne hav vil blive påvirket af oliespild.

### **Oliespild og bundfauna**

Bundlevende organismer som muslinger og krebsdyr er meget sårbare overfor oliepåvirkning, omend der ikke forventes nogen effekter på det åbne hav, medmindre olien synker til bunden. Derimod kan høje koncentrationer af olie nå havbunden på lavt vand (< 10-15 m) og her slå bundlevende dyr ihjel over store områder. Det kan derefter medføre, at bestande af hvalros, ederfugl og kongeederfugl, som udnytter disse bunddyr, må søge til alternative områder for at fouragere.

I tilfælde af et undersøisk spild er der risiko for, at dispergeret olie kan nå havbunden på store dybder og dermed påvirke det dyreliv, der forekommer her.

### **Voksne fisk**

Der forventes ikke påvirkninger fra et overfladespild på voksne fisk i det åbne hav, primært fordi fisk undgår olien. Det vil til dels også gælde et stort undersøisk oliespild, hvor bundlevende fisk dog kan være mere udsatte, og her kan hellefisk tænkes at være sårbare.

I de kystnære områder, hvor høje og toksiske koncentrationer af olie kan opbygges i beskyttede bugter og fjorde, vil fiskebestande derimod kunne påvirkes, og i vurderingsområdet er særligt lodde, stenbider og ørred sårbare.



## **Fugle**

Fugle er særligt sårbare over for oliespild på havoverfladen, idet olie forårsager en høj dødelighed. I Baffin Bugt-området forekommer mange forskellige fuglebestande, som kan påvirkes negativt af oliespild. Ynglefuglene omfatter store og/eller vigtige (i beskyttelsessammenhæng) kolonier af polarlomvie, søkonge, ride, ederfugl, havterne og lunde, ligesom der er vigtige forekomster af fældende kongeederfugle. Polarlomvier er særligt sårbare overfor olie, når ungerne har forladt reden, idet fuglene da foretager et svømmetræk gennem hele vurderingsområdet bort fra ynglekolonien (se Box 5). Søkongerne derimod ser ud til at flyve direkte til fældepladser i den canadiske sektor af Baffin Bugt, hvor de vil være mindre udsatte for oliespild fra de grønlandske licensblokke (se Box 7).

## **Havpattedyr**

Isbjørnen er det af havpattedyrene, som er mest sårbar overfor direkte påvirkning af olie, og forøget dødelighed kan forventes, hvis et område med tæt bjørnebestand rammes. Da arten i forvejen er listet som truet på både den grønlandske og den internationale rødliste på grund af klimaændringer og overudnyttelse, er bestanden i vurderingsområdet sårbar over for oliespild.

Hvaler og sæler er mindre sårbare over for olie på kroppen end isbjørne, men vil være udsatte for at indånde oliedampe i tilfælde af, at de dykker ud i et oliespild, hvilket især er tænkeligt i havområder med is. I denne sammenhæng er særligt narhval, hvidhval, grønlandshval, hvalros, remmesæl og ringsæl sårbare, men bestandene vil næppe blive påvirket i væsentlig grad.

## **Fiskeri, fangst og turisme**

Fisk, der opholder sig i vand med selv meget lave oliekoncentrationer, får afsmag af olie i kødet, og blot risikoen for at markedsføre sådanne fisk gør, at fiskeriet i et oliepåvirket område må lukkes. Det lukkes desuden for at undgå, at lokale beboere indtager olieforurenede fødevarer. I Baffin Bugt vil fiskeriet efter hellefisk og rejer blive påvirket økonomisk af en sådan lukning, og det må forventes, at også fiskeområder der grænser op til vurderingsområdet kan lukkes. Varigheden et sådant stop i fiskeri og fangst afhænger af forskellige omstændigheder, men f.eks. var der områder, der var lukkede op til et år efter det store olieudslip i den Mexicanske Golf i 2010.

Turismeerhvervet må også forvente nedgang, hvis et stort oliespild rammer vigtige kyststrækninger.

## **Olie i is**

Ved et oliespild i isdækket farvand vil olien indledningsvist blive fanget mellem og under isflagerne. Isen vil i første omgang være med til at begrænse udbredelsen af et oliespild, men da isen holder på olien, kan den (i tilfælde af drivis) også transportere den over lange afstande (uden væsentlig nedbrydning), og olien kan således påvirke miljøet, f.eks. havfugle og havpattedyr, langt fra det oprindelige udslip. Oliens kan også blive fanget langs iskanter eller i is-randzonen, hvor der især om foråret kan forekomme store og sårbare koncentrationer af primærproduktion, havfugle og havpattedyr.

I Baffin Bugt er der særlig bekymring for polartorsk, fordi de gyder sent på vinteren, og æg og larver samles lige under havisen, hvor også spildt olie kan samles. Meget høj dødelighed kan forventes, og da polartorsk er en nøgleart i økosystemet, kan påvirkninger op i fødekæderne tænkes.

### **Langtidsvirkninger**

Langtidspåvirkninger i det kystnære miljø registreredes i op til 20 år efter oliespildet i Prince William Sund i Alaska i 1989. De forekom især, hvor olien var indlejret i sediment, mellem sten, i muslingebanker eller i klippesprækker, og de kunne især måles i fugle, der udnytter kystzonen. Tilsvarende må forventes, hvis olie skyller ind på kysterne i Baffin Bugt-vurderingsområdet.

### **Forebyggelse af oliespild**

Oliespild skal først og fremmest forhindres. Det gøres ved nøje myndighedsregulering, strikse HSE- (*Health, Safety and Environmental*) procedurer, nøje planlægning og implementering af *Best Available Technique* (BAT), *Best Environmental Practice* (BEP) og anvendelse forsigtighedsprincippet.

Sker der et spild, skal effektive beredskabsplaner være på plads inklusive teknisk udstyr og kort, som udpeger de mest følsomme områder på kysterne. I den forbindelse er det vigtigt at påpege, at der endnu ikke findes metoder til effektiv bekæmpelse af oliespild på havet under vinterforholdene i Baffin Bugt.

### **Oliespild, sammenfatning**

Oliespild kan give anledning til de værste miljøpåvirkninger i forbindelse med olieeftersøgning og -udnyttelse i Baffin Bugt, og det er kystzonen, som er mest sårbar. Her findes den høje biodiversitet, og her er der risiko for at høje koncentrationer af giftige oliestoffer i vandet kan opstå i bugter og fjorde. Det er også her, at lokalbefolkningen henter en stor del af deres udkomme i form af fangst og fiskeri. Og endelig er det i kystzonen, at der er risiko for langtidsvirkninger. Det udelukker dog ikke, at der kan forekomme alvorlige påvirkninger på miljøet på det åbne hav, hvor særligt store koncentrationer af havfugle forekommer og kan blive ramt af oliespild.

### **Manglende viden og nye undersøgelser**

På trods af de i 2007-2011 og i 2011-2014 gennemførte undersøgelser (se Kapitel 11) er der stadig mangel på information om økologiske komponenter og processer i Baffin Bugt. En foreløbig identifikation af vidensbehov i forhold til en miljømæssig forvaltning og regulering af kommende olieaktiviteter i Baffin Bugt findes i Kapitel 11. Der er behov for miljøviden til planlægning af oliespildsberedskab, til udarbejdelse af aktivitetsspecifikke VVM-redegørelser, til udpegelse af særligt sårbare områder, til regulering af olieaktiviteter, til brug for selskabernes miljøafvejninger (NEBA) og som *baseline* i tilfælde af, at effekterne af et oliespild eller anden ulykke skal vurderes. Desuden skal der løbende foretages vurderinger af, hvordan det ændrede klima påvirker de forskellige elementer i Baffin Bugts økologiske sammenhænge.

Der bør udvikles en miljøovervågningsplan for Baffin Bugt-området, og den bør ligge klar, hvis olieproduktion indledes fra en eller flere af licensblokkene. En sådan plan skal støtte udviklingen af økosystembaseret forvaltning af fremtidige olieaktiviteter i Baffin Bugt – se nærmere i Kapitel 11.

# Eqikkaaneq

## Baffinip Ikerani Kalaallit Nunaata imartaani uuliasiornerit avatangiisitigut naliliivigineqarnerat nutartigaq

2010-imi Baffinip Ikerani Kalaallit Nunaata imartaani avannarpassitsit 71° aamma 78° akornanni uuliaqarneranik misissueqqissaarnissaq aammaaneqarpoq. Tamanna sioqqullugu Danmarkimi Avatangiisinik Nukissiutinilu Misissuisoqarfik kiisalu Pinngortitaleriffik piffinni misissueqqissaarnernit sunnerneqarsinnaasutut naatsorsuutigineqarsinnaasuni avatangiisinik utaqqiisaasumik naliliippat – tassunga ilanngullugit uuliakoornertit ungasissumut tissukaanqarsinnaasut ilanngullugit naliliivigineqarput (Boertmann et al. 2009). Piffik naliliivigineqartoq Titartagaq 1-imi takuneqarsinnaavoq. Tamanna piffittut naliliivittut taagorneqassaaq.

Misissueqqissaarnissamut akuersissuteqarfiit arfineq marluk uuliasiorneritseqatigiiffinnut qinnuteqartunut december 2010-imi tunniunneqarput. Kingorna taakku tallimaannanngorput tassami piffissap misissueqqissaarfissap aallarteqqaarnerani ingerlatseqatigiiffiit ilaasa akuersissutit pissarsiatik utertissimammattigik.

Aarhus Universititip aammalu Pinngortitaleriffiup avatangiisinik misissuinerinik qassiinik tunngaveqarluni avatangiisinik naliliigallarnerit 2011-imi nutarterneqarput (Boertmann & Mosbech 2011), maannalu tassa naliliinerup taassuma suliarinerata aappaa saqqummiunneqarpoq. Naliliineq paasisanik nutaanik 2011-2014-imi avatangiinik nalilersuisarnermit pissarsiaasunik imaqarpoq (takuuk kapitali 11) kiisalu ingerlatseqatigiiffinnut misissueqqisaartunut pisortaniit avatangiisit pillugit piumasaqaatit aallaavigalugit ilisimalikkanik imaqarluni (soorlu umiarsuarni nipit atorlugit immap naqqanik misissuisuni miluumasunut imarmiunut alaatsinaattoqartitsinermit paasisanik).

Suliarinera nutaaq siusinnerusukkut pisimanertulli Kalaallit Nunaanni Aatsitassaleriffimmi Avatangiisinut Aqutsisoqarfik sullillugu Danmarkimi Avatangiisinut Nukissiornermullu Misissuisoqarfimmit kiisalu Pinngortitaleriffimmit suliarineqarpoq.

Periusissiorfissamik avatangiisinik naliliinermit siunertaasartut tassaappat 1) politikkikkut aalajangiinissamut tunngavissuissalluni 2) ilisimasatigut tunngavigineqartut, oqartussatut nalilersuinermit atorveqartut aammalu uuliasiorneritseqatigiiffiit sulinerannut malittarisassiornermit atorveqartut nassuiassallugit kiisalu 3) uuliasiorneritseqatigiiffiit suliatik aalajangersimasut pillugit avatangiisinik nalilersuiniartillugit ilisimasanik nutaanik atugassaqartissallugit imaluunniit uuliakoortoqartillugu periaatsinik assigiinngitsunik toqqaanarnerini ilisimasanik nutaanik pissaqartissallugit.

Nalunaarusiami imaani avatangiisit qanoq pissuseqarneri uumassuseqarnikkullu qanoq issusii annermik nassuiarneqartarput. Ataatsimut nassuiarnerisa saniatigut aamma oqaluttuarineqarput piffiit illersugaasut, uumasut navianartorsiorneritaasut, sananeqaatit mingunnartut qanoq annertutiginersut kiisalu uumassusilinnik atuineq qanoq ingerlanersoq. Massakkut pissutsit qanoq issusiinik nassuiaanerit tunngavigalugit piffimmi naliliiviusumi uuliamik misissueqqissaarnerit avatangiisinut sunniutigiunnagaat naliliiffigineqartarput. Kiisalu avatangiisinik naliliinerit, avatangiisinik oqimaalutaanerit, suliat pillugit oqartussatut maleruagassiornerit allallu ingerlanneqassappata ilisimasat suut pisariaqartinneqarumaarnerisut aamma takussutissiorneqassappat.

## Uumassusillit tamaani ittut

Piffik naliliiviusoq issittumi avannarpasissumiippoq, taamalu ittut uumasuseqarnikkut ilisarnaatigisaanik takussutissaqarluni: uumassusillit assigiinn-gissitaartut ikittuinnaapput (immap naqqani uumasut eqqarsaatigissanngik-kaanni), nerisareqatigiit ikittuinnaapput, aammalu piffinni uumassusillit amerlasoorujussuusarlutik. Uumasut assigiinn-gissitaartut ikittuinnaanerat illuatungilerlugulusooq uumasut ilaat amerlasoorujussuusarput, taakkulu ilaat nerisareqatigiinnermi pingaaruteqarluinnartarlutik. Tassa imaappoq nerisareqatigiinni qaffasinnerusumi inissisimasunut uumasut taakku qaquguk-kut sumilu takkunnissaat apeqqutaalluinnartarpoq. Aamma uumassusillit amerlaqisut assut orsoqartarput, ilaatigut nerisakilaarfimmik nalaanni inuus-utisassaminnik ilaatigullu issimut/nillimut illersuutigisaminnik. Assut orso-qarnerat mingutsitsineq eqqarsaatigalugu pingaaruteqarpoq tassami minguit ilarpasui orsumi arrortarput taamalu uumasuit orsuini eqiterussinnaallutik.

Piffik naliliiviusoq uumasuseqassuseq eqqarsaatigalugu pisoorsuuvoq. Uu-massusillit inuussutissaasut upernaakkut pinngorartarnerat piffiit ilaanni annertoorujussuusarpoq, immap naqqa uumasuqarluarpoq aammalu an-nertuunik pingaarutilinnillu timmiaqarfeqarlunilu miluumasunik imarmio-qarfeqarluni. Timmissat eqqarsaatigalugit timmissat ilaat nunami nammin-ermi nunanilu tamalaani illersuineq eqqarsaatigalugu pingaaruteqarpoq arlallillu Kalaallit Nunaata nunallu tamalaat nalunaarsuiffianni navianar-torsiortunut ilaallutik, soorlu appat, mitit, taatera, imeqqutaallat aamma-lu qilannat. Miluumasut imarmiut eqqarsaatigalugit aamma uumasut pin-gaarutillit naammattuugassaapput soorlu nannut, aarrit, qilalukkat qernertat qaqortallu kiisalu arfiviit.

Uumasuqarfik pingaarutilerujussuaq tassaavoq Aakkarnersuaq, Qaanaap Ellesmere Islandillu akornanniittoq. Tamanna ukiuugaluartumiluunniit am-majuartuuvoq upernaakkullu eqqaminiittunut sikuusunut naleqqiullugu an-nertoorujussuarmik uumasuaqqanik pinngorarfiunerulluni. Taamaannera pissutaalluni miluumasorpasuumik imarmiunik timmissanillu katersuuff-issuuvoq, ilaatigullumi inuit tamatuma eqqaanut nunassivissinnaasiman-erannut tamannarpiaq pissutaavoq. Assersuutigalugu aakkarnersuarmut tamaanga Kalaallit Nunaata sineriaani nunarsuarmi appaliarsuit 80 %-iinit amerlanerusut, apparit 30 millionit sinnerlugit amerlassuseqarunartut, pi-aqqiortuupput. Timmissat miluumasullu imarmiut pingaarutillit tamakkua oqaatigineqartut amerlaqalutik pingaartumik aakkarnersuarmiittarput.

Qalerallit kinguppaallu nalilersuiffigineqartup kujasinnerusortaani anin-gaasarsiutaapput aammalu tamaani sinerissami najugalinnut piniarneq aal-isarnerlu inuuniutaapput pingaarutilerujussuit.

## Uuliasiornerit

Uuliasiorfimmi ingerlataasartut tamarmiusut annertunerusumik avatangi-isinut misilittakkat tunngavigalugit sunniuteqarnerusartut sapinngisamik salliutillugit nalilersorneqarput. Kalaallit Nunaannili uuliamik qalluinikkut misilittagaqqanngimmat ingerlatamut taamaattumut tunngatillugu naliliinerit piviusunik tunngavilernagit allanili assingusunik atugaqarfiusuni misilittak-kat sapinngisamik tunngaviginiarneqarput. Pingaartumik Alaskami Prince William Sound-imi 1989-imi uuliaarluerneq pillugu naqitarpasuit, aamma-lu norskit Barentshavet-mi (2003) uuliasiornermut tunngatillugu avatangi-isinik nalilersuinerat, aamma Issittumi Siunnersuisoqatigiit "*Arctic Oil and Gas Assessment* (AMAP) pissarsiorfigineqarput. Mexicop Kangerliumarnan-

gani 2010-mi aprilimi uuliamik aniasoorujussuarnerup avatangiisinut sunniutaanik ilisimasanik najoqqutarineqarput naak tassannga misilittakkat sulikilleqaraluartut.

### **Ilisimasatigut toqqammavigineqartut**

Nalilersuinerni silap pissusia atuuttoq toqqammavigineqarpoq. Kisiannili ukiuni qulikkuutaani aggersuni sila pissusiisa allanngornerisa avatangiisinut sunniuteqalerumaarnerat ilimagineqarpoq. Pingaartumillu sikuusarnerata allannguuteqarnissaa ilimagineqarpoq. Tamanna inuuniarnikkut allanngornernik sunniuteqarumaarpoq aammalu uumasut ilaasa ikilinerannik najortagaasalu allanngornerannik ilaasalu iluaquserneqarnerannik kinguneqarumaarluni, aammalu uumasut nutaat kujasinnerusumii takkukkumaarput piffimmilu naliliviusumi najugaqalerlutik.

Naliliinerni uumassusillit pillugit ilisimasat pigineqartut toqqammavigineqarput, naak arlalissuarnut taakku tunngatillugu taakku amigaateqartaraluartut. Misissuinerit arlalissuit 2007-mi ilisimasat toqqammaviusinnaasut pitsanngorsarniarlugit aallartinneqarput, tassanngalu paasisat avatangiisit pillugit periussiorfiusumik naliliinermi siullermi suliareqqitami toqqammavigineqarlutik. Nalunaarusiami tassani periussiorfiusumik avatangiisitigut misissuinerit nutaat ilisimasanik amigaatigineqartunik pingaarutilinnik pisarsiviusussat siunnersuutigineqarput. Misissuinerit taakkunanga paasisat periussiorfiusumik avatangiisinik naliliinerit nutartikkat aappaanni matumani tunngavigineqarput.

### **Misissueqqissaarnerit avatangiisitigut naliliivigineqarneri**

Ujarlernikkut ingerlatat utaqqiisaannaagallarput, amerlanertigut tamakkua ukiualuit ingerlasarput akuersissuteqarfimmilu tunniunneqartumi siamasisumik ingerlanneqartarlutik. Aammalu sikuersimanerata nalaani taamaallaat tamakkua ingerlanneqartarput, imaappoq aasaanerani ukiakkullu. Nipit atorlugit immap naqqanik misissuinerit oktoberip tungaanut ingerlanneqartarput. Misiliilluni qillerinerit septemberip naanerani sikunialinnginnerani unitsinneqarsimasussaapput, uuliaqarfik aniasuulissagalarpat allamik periarfissaqassanngippat atugassamik sillimmataasumik qillerinissaq periarfissinniarlugu.

Ujarlerneq uuliaqarneranik, imaluunniit gassimik malussarfiunngippat ingerlatat unitsillugit atorlut tamakkerlutik peerneqassapput. Uuliamilli piffissap piffissap nalilersuiffiusup kingornagut iluaqutigineqarsinnaasumik nassaartoqarpat taava ingerlatat uuliasiorfiliorninngussapput nassaap sumut killeqarnera paasiniarlugu qilleriffinngussaaq, kingornalu atorlutersuutit ikkussorneqassapput taamalu uuliasiornivinnngussalluni (kingulianiittoq takuuk).

Ujarlernikkut ingerlatat sunniutiginerusartagaat tassa nipiliorluni ingerlatat (nipit atorlugit immap naqqanik misissuinerit, qilleriveqarfimmiit pisorpaluk aammalu helikoptereralunneq) kiisalu avatangiisinut aniatitat soorlu qilleriviup marrartaa, qillerutip nungoornerluikui aammalu maskiinat aniatiaat gassit silamik kiatsikkiartortitsisartut.

### **Misissueqqissaarnerit - Nipiliorneq aammalu nipit atorlugit immap naqqanik misissuinerit**

Nipit atorlugit immap naqqanik misissuinerit nipiliorfiusaqigamik aalisakanik miluumasunillu imarmiunik nujoqqatsitsisinnaapput. Sunniutaat nalinginnaasumik qaangiuttarput killeqarlutillu, kisiannili misissuinerit suku-

miisut eqqumaffigilluartariaqarput piffinni annikitsuni nipiliorfiusaqigamik, aammalu piffimmi ataatsimi nipit atorlugit immap naqqanik misissuisarnerit arlallit ataatsimut sunniutaat eqqumaffigisariaqarput (misissuisarnerit ataatsikkut ingerlanneqartut imaluunniit tullerriaat, soorlu ukiut qassiit ingerlaneranni).

Miluumasut imarmiut akornanni qilalukkat qernertat qaqqortallu, arfiviit kiisalu aarrit nipit atorlugit immap naqqanik misissuinerit misikkarinnerpaatut isigineqarput. Kisianni nipit atorlugit immap naqqanik misissuinerit kiisalu aarrit, qilalukkat qaqqortat kiisalu arfiviit nalliuttarfiisa ataatsikkut pisarnissaat killeqassaaq; aarrit aammalu qilalukkat qaqqortat eqqarsaatigalugit ukiarluarnerani; aammalu uumasut taakku eqqarsaatigalugit nipit atorlugit immap naqqanik misissuinerit immap naqqanik sunniutissaat annikitsuinnaassussatut isigineqarput pinaveersaartinneqarsinnaassallutillu. Qilalukkat qernertat eqqarsaatigalugit pissutsit allaapput, taakkumi Qimusseriarsuaq aasakkut aalajangersimasumik najortarpaat, taamalu aasaanerani tamaaniinnerminni ukiakkullu kujammukaartillutik piffimmi naliliiviusumi nipit atorlugit immap naqqanik misissuinerit sunnerneqarsinnaallutik. Qilalukkat qernertat uninngaartarfimminnit pingaarutilinnit imaluunniit ingerlaartillutik aqquutigisartakkaminnit ingalatsinneqarsinnaapput nipit atorlugit immap naqqanik misissuinerit pissutigalugit. Pingaartumillu ingalatinneqarsinnaapput misissuinessamat akuersissuteqarfinni arlalinni nipit atorlugit immap naqqanik misissuinerit ataatsikkut arlallit ingerlanneqassagaluarpata (soorlu 2012-ilmi - Takuuk illerfiusaq 13).

Aamma nipit atorlugit immap naqqanik misissuinerit piffimmi naliliiffiusumi raajarniarnermut qaleralinniarnermullu sunniuteqarsinnaapput. Raajalli nipit atorlugit misissuinerit nalinginnaasumik sunnerneqarneq ajorput, raajarniarnerullu pitsaangitsumik sunnerneqarnissaa naatsorsuutigineqanngilaq. Nipit atorlugit immap naqqanik misissuinerit qaleralinniarfiusartut nalaanni pisimappata aalisarnerup appariarnissaa naatsorsuutigineqarsinnaavoq. Sunniutaalli ataavartuunaviannigilaq, annikitsuinnaassagunarporlu tassami Kalaallit Nunaanni kilisalluni qaleralinniarfiutigalutik nipit atorlugit misissuiffiusuni aalisarnerup appariarneranik nalunaaruteqartoqarsimanngimat.

Qilleriviit nipiliorneri aamma ataavartuunngillat (tassa misissueqqissaarluni qillerisoqarallartillugu nipiliorfiusarlutik), kisiannili nipit atorlugit immap naqqanik misissuinerit paarlattuannik nipit taakku ataavartuupput aammalu aallaaviat uninngaannartuulluni. Aamma tamatumani qilalukkat qaqqortat qernertallu, arfiviit kiisalu aarrit sunnertianerpaasussapput nipiliorfinnik taamaattunik ingalatserisaramik taamalu najortagannaamminni pingaarutilinni ingiarsimaneqarsinnaallutik. Misissueqqissaarluni qillerinerit aammalu aarrit, qilalukkat qaqqortat arfiviillu nalliusimaarnerisa ataatsikkut pinissaat sivikitsuinnaassussamat uumasut taakku sunnerneqarsinnaassusiat annikitsuinnaassaaq, qilalukkalli qernertat aammaarlutik aasaanera tamaat aammalu ingerlaarnerminni nipiliorfigineqarsinnaapput.

Aammattaaq qulimiguullit atorlugit qillerivimmut tassanngalu angallattoqartaqaaq. Angallanneq taanna pingaartumik timmissanut nujoqqatsitsisinnaavoq, tamannalu angallavissanik aalajangersimasunik portussutsinillu aalajangersimasunik pilersaarusiornikkut pinaveersaartinneqarsinnaalluni.

Qangaaniit piniarfiusartut piniakkat nalliuttarnerinit ingerlaartarfiilluunniit allanngornerinit sunnerneqarsinnaapput; sunniutigisartagaalli aamma illua-tungaanut sammisinnaavoq.

### **Misissueqqissaarnerit – avatangiisinut aniatitsinerit**

Misissueqqissaarluni qillerinermi marraq imermik akulik atorpeqarsimapat qillerinerup kingorna qillernerlukut marraallu sinnera nalinginnaasumik immap naqqanut aniatinneqartarpoq. Qillerutip marrartaa akuutissanik assigiinngitsunik akoqartarpoq kiisalu taakku aammalu qillernerlukut uumasunut immallu naqqanut aniatitsiviup eqqaaniittumut sunniuteqarsinnaapput (250 meterit missaat tikillugit). Kalaallit Nunaanni akuutissat avatangiisinut uloriananngitsut kisimik aniatinneqarnissaat akuerisaavoq, tassa tamatumani pineqarput akuutissat nunat tamalaat isumaqatigiissutaat OSPAR-imi akuerisaasut imaluunniit norgemiut oqartussaasa akuutissat ulorianaateqanngitsutut aalajangigaat. Akuutissat "qernertut" Kalaallit Nunaanni atoqqusaanngillat aammalu akuutissat "aappalaartut" pinngitsoorniarneqassallutik, taamaattorli immikkut pisoqartillugu immikkut akuersissuteqarfigineqarsinnaallutik.

Sinneruttut avatangiisinut aniatinneqassanngippata qilleriviup marrartaa uuliartalik atorpeqarsinnaavoq. Taassuma atornissaa avatangiisit eqqarsaatigalugit imertalimmiit pitsaanerusinnaavoq. Kisiannili nunaliaannerrata nunamilu passunneqarnerata avatangiisinut ajoqutaannginnissaa qularnaarneqassaaq.

Aammattaq qilleriviup marrartaanik qillernerlukunillu aniatitsisoqalersinagu immap naqqata qanoq issusia misissuiffigineqarsimassaaq. Taama ittunik misissuisarnikkut uumasooqarfiit innarliasut sunnerneqannginnissaat qularnaarneqassaaq. Aniatitsinerit naammassippata aamma taama ittunik misissuisoqassaaq aalajangersakkat malinneqarsimanersut iluaqutaasimanersullu paasiniallugu.

Misissueqqissaarluni qillerinerit nukimmik atuiffiusaqaat aammalu gassinik silaannarmik kiatsikkiartortitsisartunik allanillu ikumanerlukunik assut aniatitsiviusarlutik. 2010-imi qillerinerit pingasuusut Kalaallit Nunaata gassinik kiatsikkiartortitsisartunik aniatitsineranik 15 %-imik annertunerulersitsipput.

Misissueqqissaartoqartillugu aniatitsinerit ajornersaat tassaavoq uuliamik aniatitsineq. Tamanna pisarpoq qillerinerup assartuinerullu nalaani ajutoortoqarsimatillugu – ataaniittoq takuuk.

### **Ineriartortitsineq tunisassiornerlu**

Uuliasiornerit sumiinnissaa qanorlu annertutiginnissat ilisimanngikkaanni piffimmi naliliiffiusumi uuliasiorfimmik ineriartortitsinerup qalluinerullu qanoq sunniuteqarnissaat nalileruminaappoq. Nalinginnaasumik sunniisimaneq sivisusarpoq (ukiut qulikkaarit) aammalu suliallu amerlaqisut anner-tuunik avatangiisinut sunniuteqartussaallutik. Aammali qanoq amerlatiginerat, piffimmi qanoq agguataarsimanerat aammalu qanoq sivisutigisumik ingerlanneqarnerisut apeqqutaassaaq, kiisalu taamaattoqartillugu tamakku ataatsimut kattullutik sunniutaat annertussallutik.

### **Tunisassiornermit ineriartortitsinermillu aniatitsinerit**

Uuliaqarfiup qanoq annertutiginera paasiniallugu aammalu qillikkamik qalluiffiusussamik pilersitsiniarluni qillerinerit amerlasoorujussuit ingerlanneqartarput, aammattaq nipit atorlugit immap naqqanik misissuinerit ingerlateqqinneqartarlutik. Tamatumuunakkut qillerutit marraannik qillernerlukunillu aniatitsinerit annertusaqaat eqqagassat tamakku qillerivitoqqanut maqinneqarsinnaanngikkaangata imaluunniit nunaliaaneqarsinnaasanngikkaangata.

Aniatitsineq avatangiisit eqqarsaatigalugit aarlerinartoqarnerpaaq tassaavoq uuliamik qalluitilluni imeq uuliamut ilanngullugu qallorneqartartoq aammalu arlaatigut iginneqartussa. Imeq taanna annikitsumik uuliartaqartarpoq kiisalu avatangiisinut annerusumik minnerusumilluunniit akornutaasartunik akoqartarluni, soorlu toqunartunik, saffiugassanik oqimaatsunik, sananeqaatinik radiup qinngornilinnik, sananeqaatinik hormoninut sunniuttartunik aammalu sananeqaatinik naasunut uumasuaqqanullu naggorinnartunik. Aamma akuisa ilaat tamakku nerisareqatigiinni eqiterullutik annertusiartorsinnaasarput. Norgemiut misissuinerisigut aniatitsivinniit un-gaseqisumi aalisakkat sunnerneqartarnerat paasineqarpoq, ataatsimulli isigalugu erngup uuliamik qalluinermit qaqqineqartartup avatangiisinut piffissami sivisuumi qanoq sunniuteqarnera ilisimasaqarfigilluarneqanngilaq. Sikup ataanut aniatitsisoqarpat eqalukkat sunnerneqarnissaat takorloorneqarsinnaavoq taakkumi suaat qullugiaasaallu upernaakku sikup ataaniittarmata. Uuliamik qalluinermit erngup qallukkap sunniutaanik pinaveersaartitsiniaraani qilligatoqqanut aniatitsineq pitsaernerpaajusarpoq.

Uuliamik qalluivimmiit uuliamik umiarsuit atorlugit assartuinermit imeq orrarinnaveersaat aniatittariaqarpoq, taamalu uumasut tamaaniittanngikkaluit ingiaasartullu tikiunneqarsinnaallutik. Taamaammat imeq orrarinnaveersaat malittarisassat immikkut ittut malillugit suliarineqarlunilu anitinneqassaaq. Uumasut ingiaasartut maannamut Issittumi annerusumik ajornartorsiutaasimangillat, kisiannili silap allanngoriartornera ilutigalugu aammalu uuliaqarfiit kingunerisaanik orsiaassuit angallannerujartortillugit uumasunik ingiaasartunik tikiussisoqarnissaa ilimanarnerujartussaaq.

Uuliasiornermissaaq aniatinneqarluartartut tassaapput gassit kiatsikkiartortitsisartut. Uuliamik qalluiffik Kalaallit Nunaata aniatitsineranut anner-tusaataassaqaq. Sanilliussilluni oqaatigineqarsinnaavoq norgemi uuliamik qalluiviit annerit ilaat ataaseq ullumikkut Kalaallit Nunaata CO<sub>2</sub>-mik aniatitsineranit tamarmiusumit marloriaataa sinnerlugu annertunerusumik aniatitsisarmat.

### **Uuliamik qalluisoqartillugu nipiliorneq**

Qillerinernit qilleriviillu inissinniartarnerinit nipiliornerit ineriartortitsinerup qalluinerallu nalaani ingerlaqqissapput, tamatumannissaarlu arferit nerini-arfinnaaminnit pingaarutilinnit nujoqqatsinneqassapput. Qalluiviit ataatsikkut arlallit ingerlalissappata tamanna ajornartorsiutaanerulissaaq. Umiarsuit (amma sikusiutit) kiisalu qulimiguullit nipiliornerat misissueqqissaarnerup nalaaniit suli akulikinnerulissaaq aammalu piffinnit pingaarutilinnit timmissat miluumasullu imarmiut nujoqqatsissinnaallugit. Piffimmi naliliiffiusumi tamatumunnga atatillugu uumasut ajornartorsiornerpaajusussat tassaassapput timmissat imarmiut erniortut, arfiviit, qilalukkat qernertat qaqortallu aammalu aarrit.

Aamma piniartarfitoqqat piniagassat nujoqqanneratigut sunnerneqarsinnaapput. Timmisartut ingerlaarnerinit nipiliornerit sunniutaannik annikil-lisaataasinnaasoq aammalu uumasut nipiliornerit sungiussitinniarnernanut aqqutigineqarsinnaasoq tassaavoq timminermit aqqutinik portussutsinillu aalajangersimasunik atuisarneq.

### **Qalluinerup isissaasunik allannguineri**

Immami atortulersuutit aammalu attaveqaatinik pilersuiffillu atortulersuinerit immap naqqata uumasunut sunniuteqarsinnaapput aammalu uumasut immap natermiuinik neriniartartut neriniarfinnaavinik pingaarutilinnik ase-ruisinnaallutik. Assersuutigalugu taakku tassaapput aarrit aammalu mitit.



Nunami atortulersuutit timmissanut piaqqiortunut sunniuteqarsinnaapput, eqalunnut majutsaaliuisinnaallutik, sinerissap naasuinik uumasuinillu sunniinnaallutik, kiisalu nunap attorneqanngitsup kusanassusianut sunniuteqarsinnaallutik. Kingulliullugu taaneqartoq takornariartitsinermut sunniuteqarsinnaavoq.

Imaani atortorissaaruteqarfiit pingaartumik qaleralinniarluarfiit raajarniarfillu eqqaanni pilersinneqassappata taakku avaatigut isumannaallisaavimik killiliineq pissutigalugu (annermik 500 meteriusumik) aalisarnej sunerneqassaaq.

### **Sunniutit kattunneri**

Suliat ataatsikkut arlallit ataatsikkut, imaluunniit tulleriiginnarlutik ingerlanneqarpata sunniutit attarmoorlutik annerulernissaat ilimanaateqassaaq. Assersuutigalugu nipit atorlugit immap naqqanik misissuinerit attarmoorlutik sunniutaat assut annertusisinnapput. Aamma sunniutit attarmoorlutik annertusisarnerit inuit piliaannut allanut atatillugit sunniussinnaapput, soorlu piniarneq eqqarsaatigalugu, imaluunniit aamma silap allanngorneranik ilaqarunik suli sunniutaat annerulersinnaapput.

### **Pinaveersaartitsineq**

Misissueqqissaarnermi, ineriartortitsinermi qalluinermilu avatangiisinut sunniutit pitsaanerpaamik killilersimaarneqarsinnaapput sukumiisumik malittarisassaqartitsinikkut aammalu makku tunngavigalugit pilersaarusiornikkut:

- avatangiisinut suliffigisassanut sukumiilluinnartumik ilisimasaqarnikkut
- peqqissuseq, isumannaallisaaneq avatangiisillu pillugit sukangasuunik malittarisassaqarnikkut
- periaatsinik pitsaanerpaanik, avatangiisit eqqarsaatinik suleriaatsinik pitsaanerpaanik, mianersuussinissamik aammalu nunat tamalaat avatangiisinut piunasaqaataanik atuinikkut.

### **Uuliamik maqisoorneq**

Suliani taaneqareersuni avatangiisitigut ajutoornerit annerpaat pisinnaasut tassaapput annertuumik uuliamik maqisoornerit. Aamma uuliamik maqisoorneq qillerinerup nalaani namminermit pisinnaavoq, tassa uulia suliarineqanngitsoq uuliaqarfimmit anialersinnaammat. Aamma uuliap ingerlatissap kiisalu uuliap suliarineqanngitsup toqqortarineqarnerini angallanneqarneriniluunniit pisinnaavoq. AMAP (2010) naliliivoq Issittumi uuliamik maqisoornissamut ilimanaateqarnerpaaq tassaasoq uuliamik asartuineq. Uuliamik maqisoornerit annertuut qaqutigooraluttuinnarput teknikkikkut atortorissaarutit isumannaallisaanerillu pitsanngorsarneqartuarnarat pissutigalugu. Taamaattorli taama pisoqaratarsinnaanera ilimanaateqartuaannarpoq (soorlu 2010-imi Mexicop kangerliumarngani uuliamik maqisoornersuaq), aammalu piffinni Baffinnip Ikerasut ittuni maqisoornissaq ilimanaateqartarpoq immap sikusarnera iluliaqartarneralu pissutigalugit.

DMI maqisoorfiit sisamat aallaavigalugit Baffinip Ikerani uuliaarluinerit qanoq tissukaanqarnissaannut naatsorsuusiorsimavoq. Naatsorsuinerit inernerit naapertorlugit uuliaarluernerit avasissumi pisut nunamut nalinginnaasumik pisarnaviannngillat, pissutsilli aalajangersimasumik periarpata sine-ria 100 km arlalinnik annertussusilik uuliaarluernermit eqqugaasinnaavoq.

Uuliaarluernerit annertuut imaani uumassusileqarfiit sukutsitaanik tamanik eqquisinnaapput, tassa uumasuaqqaniit kiisortut annersaannut sunniussin-naallutik, imalu toqussutaatigisinnaasarpud uumasoaqatigiikkuutaat ilivitsut ikilerujussuarsinnaasarlutik. Kingunerluutit ukiunik qulikkuutaanik arlalin-nik sivisussuseqarsinnaapput, soorlu Alaskami Prince William Soundimi ta-manna uppernarsarneqartoq.

Baffinip Ikerani uuliaarluernerup sunniutai imartani kujasinnerusuniittu-niit ajornerusinnaapput. 1989-imi Alaskami Prince William Soundimi ma-qisoornersuaqarmat uuliap 14 %-ia katersorneqanngikkuni ikuallanneqarpoq, kisitsillu taanna 2010-imi Mexicop Kangerliumanersuani maqisoorneqarmat 25 %-iuvoq. Baffinip Ikerani uulia annertunerusoq katersorneqassasoq naat-sorsuutigisariaqanngilaq, akerlianik immap sikua, kaperlannera aammalu attaveqaatilunnera pissutigalugit uuliaarluernissamat upalungaarsimaneq Prince William Soundimiit ajornerussaaq (tulliuttut takukkit).

Prince William Soundimi sineriak imarlu ukiut 20-it sinnerlugit 1989-mi uuliaarluerneq sioqqullugu pissusitoqqamissut iliniarsarippud, Baffinillu Ike-rani pissutsit suli sivinerusumik pissusitoqqamissut iliniarsarinissaat naat-sorsuutigisariaqarpoq issittumiissutsi pissutigalugu.

### **Uuliaarluerneq aammalu inuussutissat pilierartortarnerat kiisalu uumasuaqqat**

Inuussutissat uumasuaqqallu pilierartortarnerat imartani ammasuni siamma-sittaqaq aammalu qaqugukkut sumilu pisarnerat allanngorartaqaluni aam-malu toquinnartartut amerlassusiat allanngorartaqaluni. Taamaammat ataat-simorsuaq isigigaanni uuliamik immap qaanni maqisoorneq tamarsuarnut sunniunnaviarunanngilaq naak piffiit ilaanni annertuumik toqoraataasussaa-galuarluni.

Immap naqqani maqisoorneq, soorlu 2010-imi Mexicop Kangerliumanersu-ani qillerivimmi *Deepwater Horizon*mi pisutut ittoq immap iluani itissutsini assigiinngitsuni uuliamik nuarlussuurtut siammarfiusartoq inuussutissat pinngorarnerannut uumasuaqqanullu immap qaani maqisoornermiit sun-niuteqarnerussasoq naatsorsuutigisariaqarpoq.

### **Uuliamik maqisoorneq kiisalu aalisakkat peqquillu kinguaassiornerat**

Aalisakkat peqquillu suaat qullugiaallu nalinginnaasumik inerisimasuniit uuliaarluernermit navianartorsiortitaanerusarput, aammalu uuliaarluerneq qullugissat / suaat amerlatseruttornera pippat uumasoaqatigiikkuutaat sun-nigaanissaat takorloorneqarsinnaavoq. Piffimmi naliliiffiusumi amerlasuunik annertuumik aalisakkat qullugiaqartarnera aammalu suliaqartarnera takus-utissaqanngilaq, aammalu avataani aalisakkat raajallu uuliaarluernermit sunnerneqarnissaat ilimananngilaq.

### **Uuliaarluerneq aammalu immap naqqata uumasui**

Immap natermiui soorlu uillut peqquillu uuliamit sunnertiasorujussuupput, naak avataani uulia immap naqqanut kivinngippat sunnerneqarnissaat ili-mananngikkaluaqisoq. Kisianili uulia annertoq immami ikkattumi immap naqqanut pisinnaavoq (10-15 meterinit ikkannerusumi) taamalu piffimmi an-neritoqisumi immap natermiui toqorassallutik. Tamatuma kingorna aarrit, mitit arlariit, natermiunik tamakkuninnga inuussuteqartuusut allamukarlu-tik neriniartariaqalissappud.

Immap naqqani maqisoortoqarpat uulia siammartoq itinersuarmi immap naqqanut pisinnaavoq taamalu takanani uumassusilinnut sunniuteqarsinnaalluni.

#### **Aalisakkat inersimasut**

Immap qaani uuliaarluernerup avataani aalisakkanut inersimasunut sunniuteqarnissaa naatsorsuutigineqanngilaq aalisakkat uulia ingalassimani-artarmassuk. Aamma immap iluani annertuumik uuliaarluertoqarpat taamaassaaq, aalisakkalli natermiut sunnerteqqajaanerussapput, tamatumani qalerallit sunnertianerussallutik.

Sinerissami, kangerliumanerni kangerlunnilu oqquunerusuni uulia toqunartoq eqiteruppat aalisakkat sunnerneqarsinnaassapput, piffimmilu naliliiffiusumik pingaartumik ammassaat, nipitsat aammalu eqaluit sunnertianerussallutik.

#### **Timmissat**

Timmissat uuliaarluernermit sunnertiaqaat uulia toqussutaasaqimmat. Baffinip Ikerani assigiinngitsorpassuarnik timmiaqarpoq uuliaarluernermit eqqugaasinnaasunik. Timmissat erniorfii annertuujunngikkunik pingaaruteqartut (illersugaaffii) tassaapput appat, appaliarsuit, taateraaf, mitit, imequtaallat aammalu qilannat erniorfii, aamma mitit isasarfii pingaarutillit tamaaniipput. Appaat tingisimasut uuliamit sunnertiaqaat erniuffimminniit naluumallutik piffik naliliiffiusoq tamaat aqutigisarmassuk (takuuk Il-lerfiusaq 4). Appaliarsuilli Baffinip Ikerata ilaani Canadamut tungerliusumi isasarfimminnut ingerlaannarlutik timmisarpassapput, tassanilu Kalaallit Nunaata tungaani uuliamik misissueqqissaarnissamut akuersissuteqarfiusunit annikinnerusumik uuliaarluernermit sunnerneqarsinnaassapput (takuuk Il-lerfiusaq 7).

#### **Miluumasut imarmiut**

Miluumasut imarmiut akornanni nannut uuliaarluernermit sunnertianerpaajupput, nanoqarfiulluartulu eqqaat eqqorneqassagaluarpat toqusartut amerlanerulernissaat naatsorsuutigisariaqarpoq. Nannut silap allanngorneranit piniarneqarpallaarnerminnullu navianartorsiortitaasutut kalaallit nunallu tamalaat allattuiffiineereermata nannut piffimmi naliliiffimiittut uuliaarluernermit sunnertiasuussapput.

Arferit puisillu timimikkut nannuniit uuliaarluernermit sunnertiannginerupput, kisiannili uuliaarluerfiusumi aqqassagunik uuliat aalaannik najuussisinnaapput, piffimmilu sikulimmi tamanna ilisimanarnerussaqaq. Tamatumani qilalukkat qernertat qaqortallu, arfiviit, aarrit, ussuit aammalu natsiit sunnertiasuussapput, ataatsimoortukkuutaalli tamarmiullutik annerusumik sunnerneqarnissaat ilimanarpallaanngilaq.

#### **Aalisarneq, piniarneq aammalu takornariartitsineq**

Aalisakkat annikitsuinnarmilluunniit uulialimmiissimagaangata nerpii uuliasunnilersarput, uuliasunnittunillu nioqquteqariataarsinnaaneq piinnarlugu uuliamik sunniuteqarfiusumi aalisarneq unitsinneqartariaqarpoq. Aamma aalisarneq unitsinneqassaaq tamaani najugaqartut aalisakkanik uuliamik mingutsitaasunik neqereqqunagit. Baffini Ikerani qalerallinniarneq raajarniarnerlu taama matusinermit sunnerneqassapput, naatsorsuutigisariaqarporlu aalisarfiittaaq naliliiviup sanilerisaaniittut matuneqartariaqassasut. Aalisaqusiunnaarnerup piniacquusiunnaarnerullu qanoq sivisutiginissaanut pissutsit assigiinngitsut apeqqutaapput. Assersuutigalugu 2010-imi

Mexico Kangerliumanersuani uuliamik maqisoornerup kingorna aalisarfiit ilaat ukioq ataaseq tikivillugu matoqqatinneqarput.

Aammattaq sinerissat pingaarutillit uuliaarluernermit eqqugaappata takor-nariartitsinerup appariarnissaa naatsorsuutigisariaqarpoq.

### **Uulia sikumi**

Immami sikuusumi uuliamik maqisoortoqassappat uulia siku akornanni uninngaanalissaaq. Uulia aallaqqaamut uuliamik siammatsaaliuisuusaaq, aammali sikut uuliamik tigummisutut issammata (sikut saatsersut eqqarsaatigalugit) uuliaarluernerit ungasissumut assartorneqarsinnaassapput an-nerusumik nungujartoratik, taamalu uulia maqileqqaarfimminiit ungasiqisu-mi avatangiisinut, soorlu timmisanut imarmiunut aammalu miluumasunut imarmiunut sunniuteqarsinnaassalluni. Aamma uulia sikup sinaavani iker-sisimaneqarfinniluunniit unissinnaavoq, tamakkunanilu pingaartumik uper-naakkut inuussutissat pinngorarfiit annertuut sunnertiasorujussuussapput, aammalu timmissat imarmiut miluumasullu imarmiut sunnertiassaqa-lutik.

Baffinip Ikerani pingaartumik eqalukkat aarleqqutigineqarput, taakku ukiuk-kut kingusissukkat suffissarput taavalu suaat qullugiaallu sikup atinnguani uuliap aamma unerarfigisinnaasaani katersuuttarlutik. Toqorarujussuarnis-saat naatsorsuutigineqarsinnaavoq, aammalu eqalukkat uumassusileqarfinni pingaaruteqarmata nerisareqatigiinnut annertuumik sunniuteqarsinnaaner-at takorloorneqarsinnaavoq.

### **Sivisuumik sunnigaaner-at**

Sinerissami sunnigaaner-at sivi-sooq Alaskami 1989-imi Prince William Sound-imi uuliaarluernerup kingorna ukiut 20 tikillugit sunniusimavoq. Pingaartu-mik tamanna marrarmi, ujaqqat akornanni, uiloqarfinni imaluunniit qaarsut quppaanni malunniussimavoq, pingaartumillu timmissani sinerissami ner-iniartuusuni uuttorneqarsinnaalluni. Aamma Baffinip Ikerani piffimmi nal-iliiffiusumi sinerissamut uulia tipissagaluarp-at taama pisoqarnissaa naatsor-suutigisariaqarpoq.

### **Uuliaamik maqisoornerup pinaveersaartinneqarnera**

Uuliamik maqisoornermik pingaarnerpaamik pinngitsoortinniartariaqarput. Taamaaliortoqassaat oqartussat sukumiisunik malittarisassaqaartitsinerisigut, sukangasunik peqqissusermut, isumannaallisaanermut avatangiisinullu mal-ittarisassaqaarnikkut, sukumiisumik pilersaarusiornikkut kiisalu atortoris-saarutit pitsaanerpaat, avatangiisitigut periaatsit pitsaanerpaat aammalu mi-anersuussisussaatitaanerup atortinneqarnerisigut.

Maqisoortoqaraluarpat upalungaarsimanermut pilersaarutit pitsaasut pia-reersimassapput, aamma teknikkikkut atortorissaarutit kiisalu nunap immal-lu assingi sinerissami sunnertianerpaanik nalunaarsuiffiusimasut ator-neqas-sallutik. Tassunga atatillugu pingaaruteqarpoq tikkuassallugu Baffinip Ikerani ukiuunerani uuliamik maqisoornerup akiornissaanut periaatsunik pitsaasunik sul-i nassaassaqaanngimmat.

### **Inerniliineq – uuliamik maqisoorneq**

Baffinip Ikerani uuliaqarnermik misissueqqissaarnermi qalluinermilu uulia-mik maqisoorneq avatangiisitigut ajornerpaamik sunniuteqarsinnaavoq, sineri-allu sunnertianerpaajususaalluni. Tamaaniipput uumassusillit tama-laarpasuit, aammalu kangerliumaner-ni kangerlunnilu uuliap toqunartui eqiterussinnaaqa-lutik. Aammattaq piffiit tamakku inuit aalisarlutik pini-

arluutillu pissaqarfigilluartarpaat. Aammattaaq sineriak sivisuumik sunnersimaneqarsinnaavoq. Imaanngilarli avataa sunnerneqarnaviannngitsoq, taamaanimi timmiarpassuaqartarpoq uuliaarluernermit eqqugaasinnaasunik.

### **Ilisimasat amigaataasut misissuinerillu nutaat**

Naak 2007-2011-mi aammalu 2011-2014-imi misissuisoqarsimagaluartoq (takuuk kapitali 11) Baffinip Ikerani uumassusileqarfiit immikkoortortaasa ilaat pissutsillu allanngorarnerisa ilaat pillugit paasissutissat amigaatigineqarput. Avatangiisinik aqutsineq eqqarsaatigalugu ilisimasat pisariaqartinneqartut aammalu Baffinip Ikerani siunissami uuliaqarfimmi sulianut malittarisassanngortussat sueneri kapitali 11-imi utaqqiisaasumik oqaatigineqarput. Uuliamik maqisoornermut upalungaarsimanissamut pilersaarusiornissaq eqqarsaatigalugu, avatangiisit pillugit naliliilluni nalunaarusiornissamut, piffiit eqqortiasut suussusii tikkuarsinnaanngorumallugit, uuliasiornerit malittarisassiorsinnaanngorumallugit, uuliasioritseqatigiiffiit avatangiisinik nalilersuinerannut atortussamik aammalu uuliaarluinerit allalluunniit ajutoornerit naliliivigisinnaajumallugit pissutsit massakut qanoq issusii ilisimajumallugit avatangiisit ilisimasaqarfigineqartariaqarput. Aammattaaq silap allanngoriartornera Baffinip Ikerani uumassusileqarfiit immikkoortuinut assigiinngitsunut qanoq sunniuteqarnersut paasiumallugu ingerlaavartumik naliliisoqartariaqarpoq.

Baffinip Ikerani avatangiisinik malinnaanermut pilersaarusiortoqartariaqarpoq, aammalu uuliasiornermut akuersissuteqarfimmi ataatsimi arlallinniluunniit uuliamik qalluisoqaleraluarpat taanna piareersimasariaqarluni. Pilersaarut taama ittoq siunissami Baffinip Ikerani uuliasiorluni sulianik aqutsinermut uumassusileqarfinnik tunngaveqartumut tapertaassaaq – erseqqinnerusumik takuuk kapitali 11.

# 1 Introduction

This document is an updated strategic environmental impact assessment (SEIA) of expected oil activities in the Greenland part of Baffin Bay and it replaces the version from 2011. The 2011 edition was initiated and funded by the Bureau of Minerals and Petroleum (BMP) and prepared by the National Environmental Research Institute (NERI) and the Greenland Institute of Natural Resources (GINR). The updated version has been funded by EAMRA and prepared by DCE – Danish Centre for Environment and Energy – and GINR.

In 2010, seven exclusive exploration and exploitation licences were awarded in the Baffin Bay licensing round area, and activities were initiated in 2011 (Figure 1). However, in 2015, the two southernmost blocks were handed back and the remaining five are currently (January 2017) in the process of being handed back. This indicates that no exploration activities will take place in the Baffin Bay in the near future and at least not before a new licencing round have been carried out in December 2017.

For the assessment, many sources of information, including impact assessments of oil activities from more or less similar areas, have been used. In particular, the assessment from the Lofoten-Barents Sea area in Norway (Anonymous 2003b) and Report to the Storting No. 8 (2005) and No. 10 (2010), concerning the integrated management of the marine environment of the Lofoten-Barents Sea area, have been drawn upon because the environment there is comparable to West Greenland waters in a number of respects. Another important source of information is the Arctic Council's working group's (AMAP) Oil and Gas Assessment (AMAP 2010) available on the AMAP homepage ([www.amap.no](http://www.amap.no)). In addition, the extensive scientific literature and various reports from the *Exxon Valdez* oil spill in 1989 have been valuable sources of information.

The SEIA describes the environment and the potential impact of oil activities at a generic and regional level. The potential impacts are in principle described in relation to a zero-oil activity scenario. However, as climate change and development in fisheries and hunting and other human activities may cause ecological changes that are hard to predict, the zero-oil activity scenario is somewhat hypothetical.

The report assesses only impacts on the natural environment. Social and socio-economic aspects will be treated in other contexts.

It is important to stress that a SEIA does not replace the need for Environmental Impact Assessments (EIAs) of specific hydrocarbon activities in the Baffin Bay area. The SEIA provides an overview of the environment in the assessment area and in the area potentially impacted by the activities. It identifies the major potential environmental impacts associated with expected offshore oil and gas activities. The SEIA also identifies knowledge and data gaps, highlights issues of concern, and recommends actions for mitigation and planning. The first version of the document also contributed to the knowledge base that the politicians drew upon when they decided to open the Greenland part of Baffin Bay for hydrocarbon exploration. Finally it provides information for the preparation of EIA-reports on hydrocarbon activities in the Baffin Bay licence blocks.

An important issue in this assessment context is climate change, which affects both the physical and the biological environment, and according to CAFF (2013): *Climate change is by far the most serious threat to biodiversity in the Arctic*. In

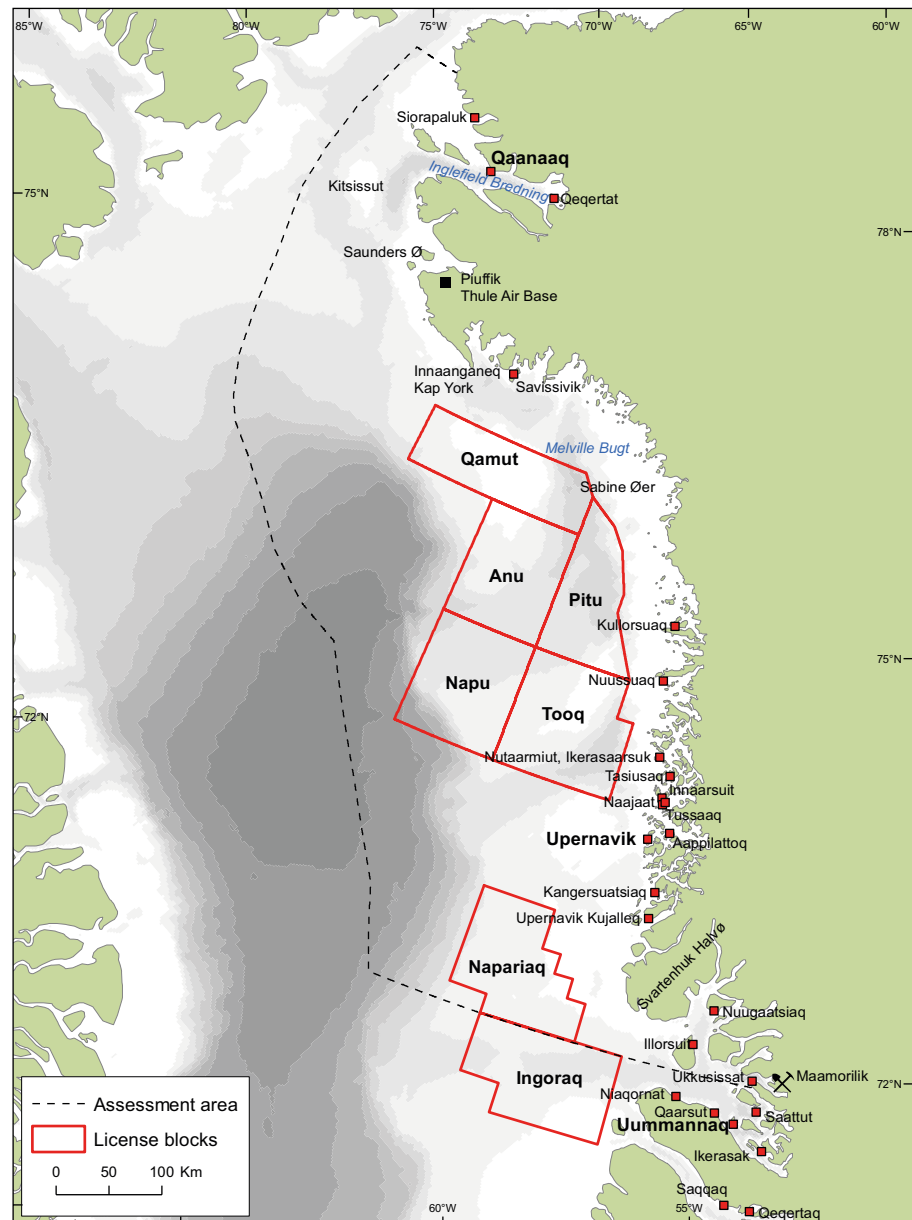
a marine region such as the assessment area covered by this report, especially changes in ice cover are significant, as they result in marked changes in ecosystems and wildlife dependent on the ice (Wassmann et al. 2011, CAFF 2013), and in the terrestrial parts of the assessment area significant changes include increases in temperature and winter precipitation (Christensen et al. 2016).

Most of the data used for this SEIA have been sampled over a number of decades, and as oil activities, particularly development and exploitation, may be initiated more than 10 years from now, future environmental conditions may be very different from the conditions described in this report. It will therefore be important to acquire updated information on key issues along with the continuing oil activities, and this report proposes to consider an integrated and adaptive monitoring program (including biodiversity, climate, contaminants, human activities, etc.) for the Baffin Bay area.

### 1.1 Coverage of the SEIA

The offshore waters and coastal areas between 71° N and 78° N (from Uummannaq Fjord northwards to Smith Sound) are the areas in focus, as it is the region potentially most affected by hydrocarbon activities, particularly acci-

**Figure 1.** The assessment area and the originally awarded seven license blocks from the licensing round in 2010. Two of these were handed back in 2016 (Ingoraq and Napariaq) and the blocks Tooq, Napu, Anu, Pitu and Qamut are in January 2017 in the process of being handed back. Towns and settlements are shown by red symbols. Main towns are indicated with bold types, and these names are also used for the regions. The mining symbol show the lead-zinc mine at Maamorilik.



dental oil spills originating from activities in the licence blocks granted in 2010 (Figure 1). This area will be referred to as ‘the assessment area’. However, the oil spill trajectory models developed by DMI indicate that oil may spread outside the boundaries of this area and into the Canadian EEZ (Nielsen et al. 2008).

The assessment area covers waters of the former municipalities of Uummannaq, Upernavik and Qaanaaq (also termed Avanersuaq). The major towns in the area are Upernavik and Qaanaaq, with Uummannaq just to the south of the assessment area. There are moreover three settlements in Uummannaq, 11 settlements in Upernavik and three in Qaanaaq (the settlement Moriussaq was recently abandoned). In total, the region has 3560 inhabitants (Statistics of Greenland 2015). In addition, the US Airforce base at Pituffik – Thule Air Base – is situated in the area, and has a staff of approx. 400 people.

All the former municipalities in northwest Greenland (between Kangaatsiaq and Qaanaaq) are now merged to a single municipality: Qaasuitsup Kommunia.

## 1.2 Acronyms and abbreviations

AMAP	=	Arctic Monitoring and Assessment Programme, working group under the Arctic Council
APNN	=	Ministry of Fisheries, Hunting and Agriculture, Greenland Government
AU	=	Aarhus University, Denmark
BACI	=	Before After Control Impact
BAT	=	Best Available Technique
bbbl	=	barrel of oil
BC	=	black carbon
BEP	=	Best Environmental Practice
BFR	=	Brominated flame retardants
BIOS	=	Baffin Island Oil Spill project
BMP	=	Bureau of Mineral and Petroleum, Greenland Government
BOP	=	BlowOut Preventer
BTEX	=	Benzene, Toluene, Ethylbenzene and Xylene, constitute a part of the VOCs
BTX	=	Benzene, Toluene and Xylene components in oil, constitute a part of the VOCs
CAFF	=	Conservation of Arctic Flora and Fauna
chl. <i>a.</i>	=	chlorophyll <i>a</i>
CI	=	Confidence Interval
CITES	=	Convention on International Trade in Endangered Species of Wild Fauna and Flora (the Washington Convention)
CRI	=	Cuttings Re-Injecting
CTD	=	Conductivity, Temperature and Depth
CV	=	Coefficient of Variation
COY	=	Cub Of the Year, DCE - Danish Centre for Environment and Energy
DDT	=	Dichloro-Diphenyl-Trichloro-ethane
DEGN	=	Department of Environment, Government of Nunavut
DHI	=	Danish Hydraulic Institute
DKK	=	the Danish currency, <i>kroner</i>
DMI	=	Danish Meteorological Institute
DPC	=	Danish Polar Centre
dw	=	dry weight



EAMRA	=	Environment Agency for the Mineral Resources Activities, Greenland Government
EBSA	=	Ecologically or Biologically Significant Areas
EDCS	=	Endocrine-disrupting chemicals
EEZ	=	Exclusive Economic Zone
EIA	=	Environmental Impact Assessment
EPA	=	U.S. Environmental Protection Agency
ERL-ERM	=	International sedimentary quality guidelines
EVOS	=	<i>Exxon Valdez</i> Oil Spill Trustees Council
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
HCB	=	Hexachlorobenzene
HCH	=	Hexachlorocyclohexane
HELCOM	=	Baltic Marine Environment Protection Commission - Helsinki Commission
HOCNF	=	Harmonised Offshore Chemical Notification Format (OSPAR)
HSE	=	Health, Safety and Environment
ICES	=	International Council for the Exploration of the Sea
IMO	=	International Maritime Organisation
IUCN	=	International Union for Conservation of Nature
IWC	=	International Whaling Commission
JCNB	=	Canada/Greenland Joint Commission on Conservation and Management of Narwhal and Beluga
JNCC	=	Joint Nature Conservation Council (UK)
LRTAP	=	Convention on Long-Range Transboundary Air Pollution
lw	=	lipid weight
MARPOL	=	International Convention for the Prevention of Pollution from Ships
MIZ	=	Marginal Ice Zone
MODU	=	Mobile Offshore Drilling Unit
NAFO	=	Northwest Atlantic Fisheries Organisation
NAMMCO	=	The North Atlantic Marine Mammal Commission
NAO	=	North Atlantic Oscillation
NEBA	=	Net Environmental Benefit Analysis
NERI	=	National Environmental Research Institute, University of Aarhus, Denmark.
NGO	=	Non-Governmental Organisation
NMDA	=	N-methyl-D-aspartate
NOW	=	North Water Polynya
NSO	=	Nitrogen Sulphur Oxygen compound
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
PAME	=	The Protection of the Arctic Marine Environment working group (Arctic Council)
PBDE	=	Polybrominated diphenyl ethers
PCB	=	Polychlorinated biphenyls
PDO	=	Pacific Decadal Oscillation
PFC	=	Perfluorinated compounds

PFOS	=	Perfluorooctane sulfonate
PLONOR	=	OSPAR list over Substances Considered to 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)
ppb	=	parts per billion
ppm	=	parts per million
PROBAS	=	The Danish Product Register Data Base
PSSA	=	Particularly Sensitive Areas
PTS	=	permanent elevation in hearing threshold shift
PTT	=	Platform Terminal Transmitter
rms	=	root mean squared
SBM	=	Synthetic based drilling mud
sd	=	Standard deviation
SEIA	=	Strategic Environmental Impact Assessment
SM	=	Synthetic drilling mud
SSOR	=	Sub Surface Oil Residues
SWG	=	Scientific Working Group of the Canada-Greenland Joint Committee on Polar Bears
t	=	tons
TAC	=	Total Allowable Catch
TBT	=	Tributyltin
TPAH	=	Total Polycyclic Aromatic Hydrocarbons
TPH	=	Total Petroleum Hydrocarbons
TTS	=	temporary elevation in hearing threshold
UNEP	=	United Nations Environment Programme
USCG	=	United States Coast Guard
UTC	=	Coordinated Universal Time
VEC	=	Valued Ecosystem Components
VOC	=	Volatile Organic Compounds
VSP	=	Vertical Seismic Profile
WAF	=	Water Accommodated Fraction
WBM	=	Water based drilling mud
WSF	=	Water Soluble Fraction
ww	=	wet weight

## 2 Summary of petroleum activities

D. Boertmann & J. Fritt-Rasmussen

Oil/gas project life cycles usually comprise several, to some degree overlapping, phases. 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 facilities for production, handling, refining and shipment including pipelines are constructed and maintained. Production requires maintenance of equipment, waste management, environmental monitoring, storage and refining etc. Finally, during decommissioning, wells are plugged, all structures and facilities are dismantled and removed, and the surrounding environment may be restored. These phases occur over long periods of time, usually several decades and will also occur simultaneously in an oil field. In the North Sea for example, oil exploration was initiated in the 1960s, the first well came on stream in 1975, production continues today and exploration still takes place.

### 2.1 Seismic surveys

The purpose of seismic surveys is to obtain knowledge of the subsurface geology in order to locate and delimit oil/gas fields, to identify drill sites and later, during production, to monitor developments in the reservoir. Marine seismic surveys are usually carried out by a ship that tows a sound source and a cable with hydrophones which receive the echoed sound waves from the seabed. The sound source is an array of airguns (for example 28 airguns with a combined volume of 4330 inch<sup>3</sup>) that generate a powerful pulse at 10-second intervals. Generally, sound absorption 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 Kyhn et al. 2012). Regional seismic surveys (2D seismic) for locating reservoirs are characterised by widely spaced (over many kilometres) survey lines, while the more localised surveys (3D seismic) for identifying drill sites usually cover small areas with densely spaced (for example 500 m) lines. Rig site investigations, vertical seismic profiling and shallow geophysical investigations use comparatively much smaller sound sources than to 2D seismic surveys. For example, during site surveys a single airgun (150 inch<sup>3</sup>) may be applied.

### 2.2 Exploration drilling

One or more exploration wells are drilled to determine if a prospect exists and to gain further data on the subsurface conditions. If a hydrocarbon reservoir is encountered the well is normally tested to see whether the reservoir is viable for production. Wells unsuitable for further development are sealed below the seabed and tested to ensure that they are fully secure before being abandoned.

Offshore exploration drilling takes place from Mobile Offshore Drilling Units (MODU) such as drill ships or semi-submersible platforms, both of which were used in West Greenland in 2010 and 2011. A drillship is a maritime vessel modified to include a drilling rig and special station-keeping equipment. The vessel is typically capable of operating in deep water. A semi-submersible platform is a particular type of floating vessel that is supported primarily on large pontoon-like structures submerged below the sea surface. Most

of the potential oil exploration areas in West Greenland waters are too deep for using a third type of drilling platform, the jack-up rigs, which are built to stand on the seabed.

The MODU is connected to the blowout preventer (BOP) on the seabed by a marine riser containing the drill and different pipes i.a. for circulating the drill mud and controlling the BOP.

It is assumed that the drilling season in the waters of Baffin Bay will be limited to summer and autumn due to the presence of ice and harsh weather conditions during winter and spring. The season is moreover shortened to allow enough time to drill a relief well before ice prevents operations if a blowout does occur.

Drilling requires disposal of cuttings and drilling mud. The strategic EIA of oil activities in the Lofoten-Barents Sea assesses that approx. 450 m<sup>3</sup> cuttings are produced and approx. 2,000 m<sup>3</sup> mud is used per well (Akvaplan-Niva & Acona 2003). The drilling of the three exploration wells in the Disko West area in 2010 generated between 665 and 900 m<sup>3</sup> cuttings/well and in total 6000 tons of drilling mud.

The energy consumption is very high during drilling, resulting in emissions of combustion gases such as CO<sub>2</sub>, SO<sub>2</sub> and NO<sub>x</sub>.

High levels of underwater noise are generated during drilling, mainly from the propellers securing the position of floating rigs (cf. impact section of this report).

### **2.3 Drilling mud and cuttings**

Drilling muds are used to optimise drilling operations, including cooling and lubricating the drill bit, transporting cuttings from the well bore to the surface, counterbalancing pressure in the well in order to prevent blowout, stabilising and sealing borehole wall, preventing sedimentation or corrosion etc. The muds are either water based (WBMs), oil based (OBMs) or based on synthetic fluids (SBMs). Today and due to environmental concerns, OBMs and SBMs are only used where the mud and the cuttings can be brought to land for treatment or can be deposited safely. After the drilling, water based muds (low toxic) and the cuttings are usually released to the seabed, where they may impact the seabed fauna in the immediate vicinity (Section 9.1.2). Cuttings and mud can also be re-injected into old wells; however this has not yet been possible in Greenland.

The drilling mud contains several chemicals to optimise the performance, and these chemicals may be toxic and slowly degradable, including: barite and bentonite, polymers, surfactants, emulsifying agents, pH adjusting chemicals, silicates, chemicals for removal of oxygen, sulphide and carbon dioxide, biocides, corrosion inhibitors, lubricants, inhibitors, etc. (cf. impact section of this report).

The drilling mud is circulated from the drill platform to the drill bit through a closed system allowing re-use of the mud and separation of the cuttings on the platform.

## **2.4 Appraisal drilling**

If promising amounts of oil and gas are located during the exploration, the commercial potential is appraised by establishing the size of the reservoir and the most appropriate production method. This appraisal may take several years to complete. Several wells are drilled to delimit the reservoir, and well logging and testing activities provide data on the hydrocarbon-bearing rocks, properties of the hydrocarbons, flow rate, temperatures and pressures in the well. If a reservoir is proved commercial, the operator may then proceed to development.

Especially well testing implies flaring of oil and gas together with the use and release to the sea of various chemicals, occasionally including radioactive compounds.

## **2.5 Other exploration activities**

Exploration includes several other activities, among these helicopter flights between drill sites and land-based facilities. Helicopters are very noisy and have a high potential for scaring birds and marine mammals over a range of many kilometres.

## **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.

How production will take place and be developed in Greenland offshore areas is unknown. However, 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 such a production facility, crude oil subsequently has to be transported by shuttle tankers to a trans-shipment terminal, most likely in eastern Canada.

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

## **2.7 Produced water**

Produced water is by far the largest 'by-product' of the production process. On a daily basis, some Canadian offshore fields produced between 11,000 and 30,000 m<sup>3</sup>/day (Fraser et al. 2006), and the total amount produced on the Norwegian shelf peaked in 2007 with 190 million m<sup>3</sup> and has since then stabilised at a level of around 160 million m<sup>3</sup> (Norsk olje & gass 2014). Produced water contains small amounts of oil and chemicals from the reservoir or added during the production process. Some of these chemicals are acutely toxic, are radioactive, contain heavy metals, have hormone disruptive effects or act as nutrients that may influence primary production (Lee et al. 2005). Some are persistent and have the potential to bio-accumulate. Moreover, the produced water constitutes the major part of oil pollution during normal operations, in Norway for instance up to 88%.

Produced water has usually been discharged to the sea after a cleaning process that reduces the amount of oil to levels accepted by the authorities (for example 30 mg/l as recommended by OSPAR). For the North Sea there are also restrictions on the total amount that may be discharged over specified periods (in the UK for instance 1 ton in any 12-hour period from a well. By applying BAT, Norwegian operators have committed themselves to further reduce these levels, and in 2013 the average content was 12.1 mg/l (Norsk olje & gass 2014). Due to the dilution effects, 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. Yet long-term effects of the releases of produced water need to be studied (for example as initiated by the Research Council of Norway 2012), and several uncertainties have been expressed concerning, for example, the hormone-disrupting alkylphenols and radioactive components with respect to toxic concentrations, bioaccumulation, etc. (Meier et al. 2002, Rye et al. 2003, Armsworthy et al. 2005, Bakke et al. 2013). Widespread background pollution (measured in fish) from the oil production in the North Sea, for instance with PAHs has been recorded (Balk et al. 2011), and this may derive from produced water, disposed drilling mud and accidental spills.

## **2.8 Air emissions**

Emissions to the air occur during all phases of petroleum development, including seismic surveys 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<sup>3</sup> exhaust per day (LGL 2005). Flaring of gas and trans-shipment of produced oil also contribute to emissions. The emissions consist mainly of greenhouse gases (CO<sub>2</sub>, CH<sub>4</sub>), NO<sub>x</sub>, VOC and SO<sub>2</sub>. In particular, the production activities create large amounts of CO<sub>2</sub>. Thus, the emission of CO<sub>2</sub> from the large Norwegian Statfjord field was slightly less than 1.5 million tons in 2003 (Statoil 2004), and the drilling of the three exploration wells in 2010 in the Dis-ko West area resulted in the emission of 105,000 tons CO<sub>2</sub>.

Another very active greenhouse gas is methane (CH<sub>4</sub>), which is released in small amounts together with other VOCs from produced oil during trans-shipment.

## **2.9 Other activities**

Decommissioning is initiated when production is no longer economically viable. The activities include plugging of wells and removal of all infrastructure and facilities. The environmental concerns relate primarily to the large amounts of waste material, which has to be disposed of or regenerated. In case of land-based activities, the surrounding environment should be restored.

## **2.10 Accidents**

There are serious, acute and long-term environmental concerns in relation to accidents and off-normal operations. As expressed by the Oil and Gas Assessment by AMAP (2010), the major issue of environmental concern for the marine Arctic environment is a large oil spill, which particularly in ice-covered waters represents a threat to animal populations and even species. See further in Section 11.

## 3 Physical environment

D. Boertmann

This section provides a short account of some of the most important physical components of the assessment area. Other components are treated by the Danish Meteorological Institute (Pedersen et al. 2011), which previously also reviewed weather, sea and ice conditions in the area (Valeur et al. 1996, [Link](#)). Information can also be found in the oil spill sensitivity atlases prepared for the assessment area (Stjernholm et al. 2011, Clausen et al. 2012, 2016) and in the new AMAP assessment 'Adaptation Actions for a Changing Arctic' (in prep. for publication in 2017).

The assessment area lies within the Arctic climate zone, implying that the average July temperature does not exceed 10°C. The Arctic zone is divided into the Low Arctic (average July temperature higher than 5°C) and the High Arctic (average July temperature below 5°C). The major part of the assessment area is located within the High Arctic. It is also far north of the Polar Circle, with continuous daylight in the summer and continuous darkness in the winter months.

The most significant feature in the physical marine environment is the presence of icebergs and sea ice throughout a large part of the year (Section 4.4) while permafrost is widespread in the inland areas (Christiansen et al. 2010b).

The offshore part of the assessment area is the Baffin Bay. The shelf (depths below 200 m) is generally rather narrow; that is < 50 km. Outside the shelf, depths reach more than 2,000 m in central parts of the bay.

### 3.1 Weather

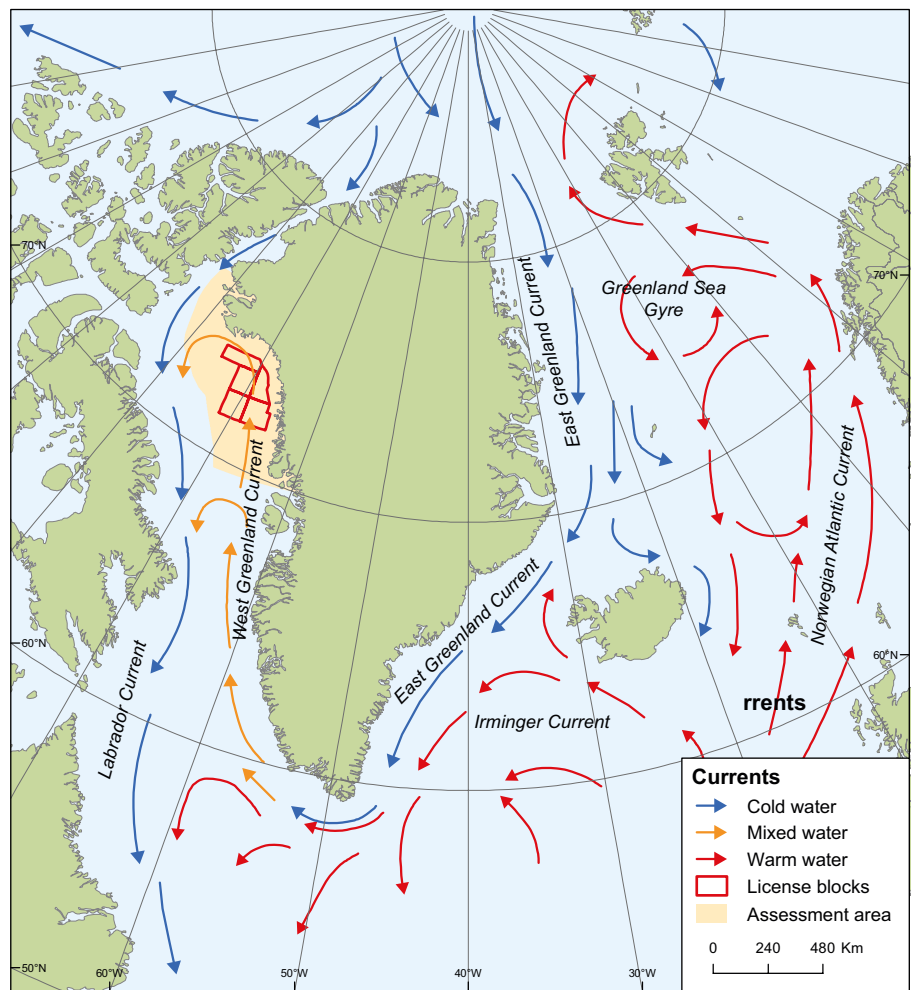
The weather conditions in the area are very variable with many hazards to marine operations, such as frequent fog, strong winds and icing conditions. More detailed descriptions can be found in the oil spill sensitivity atlases for West Greenland which now cover the coast as far north as 77° N (Mosbech et al. 2004a, 2004b, Stjernholm et al. 2011, Clausen et al. 2012, 2016, [Link to sensitivity atlases](#)).

### 3.2 Oceanography

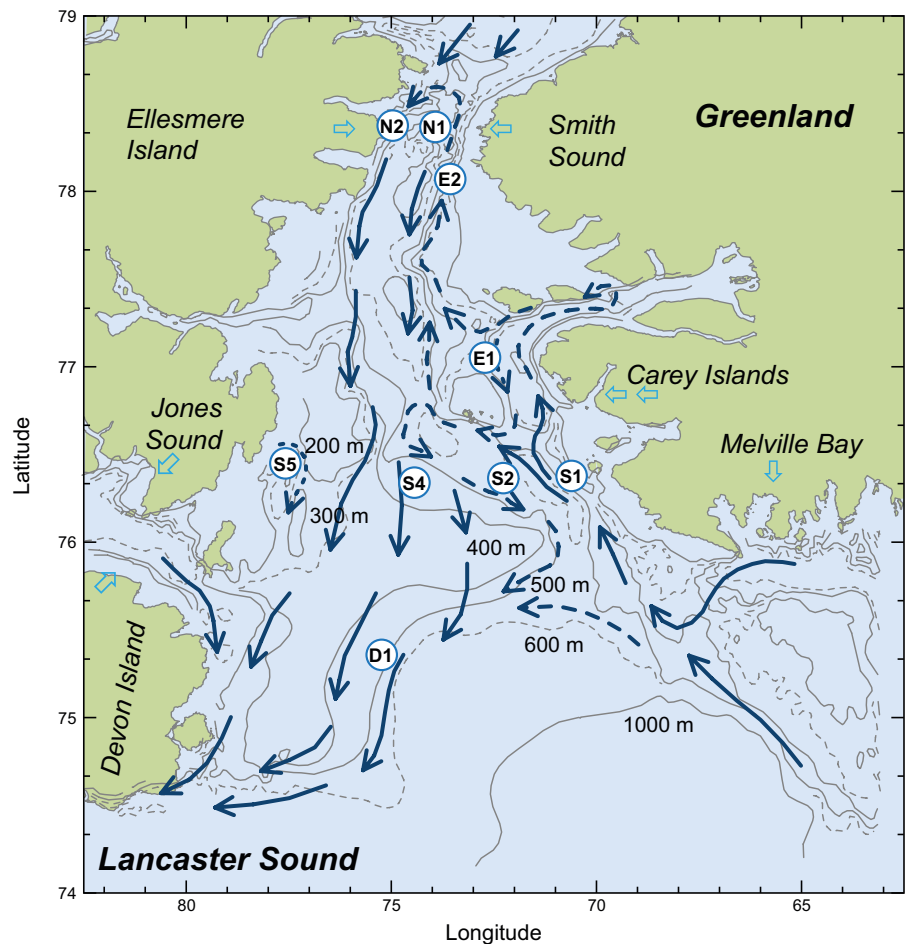
#### 3.2.1 Currents

The most important current in the assessment area is the West Greenland Current, which convect relatively warm and high saline Atlantic water all the way to Qaanaaq. This water derives from the Irminger Current (Figure 2). In the northern part of the assessment area, where the North Water Polynya is situated, there is a strong southward flow of cold water and ice from the Arctic Ocean (Figure 3). When the inflow of ice from the north is blocked by an ice bridge in the Nares Strait, the continued drift out of the northern Baffin Bay is sufficient to create the North Water Polynya, without oceanic heating. Cold Arctic waters of lower salinity flow over the remnant of the warm flow that continues northward. However, upwelling near the Greenland coast forced by Ekman transport brings the warm water to the base of the turbulent surface layer where it is entrained (Melling et al. 2001, Kwok 2007, Dumont et al. 2010).

**Figure 2.** Major sea surface currents in the northern Atlantic. The licence blocks shown are those which were active in June 2016. However, since then three have been handed back.



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





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

A fifty-year long time series of temperature and salinity measurements from West Greenland oceanographic observation points reveals strong inter-annual variability in the oceanographic conditions off West Greenland. However, the tendency is now towards increased water temperatures and reduced ice cover in winter (Hansen et al. 2007, Stirling & Parkinson 2006, Cavalieri & Parkinson 2012).

### 3.2.2 Bathymetry

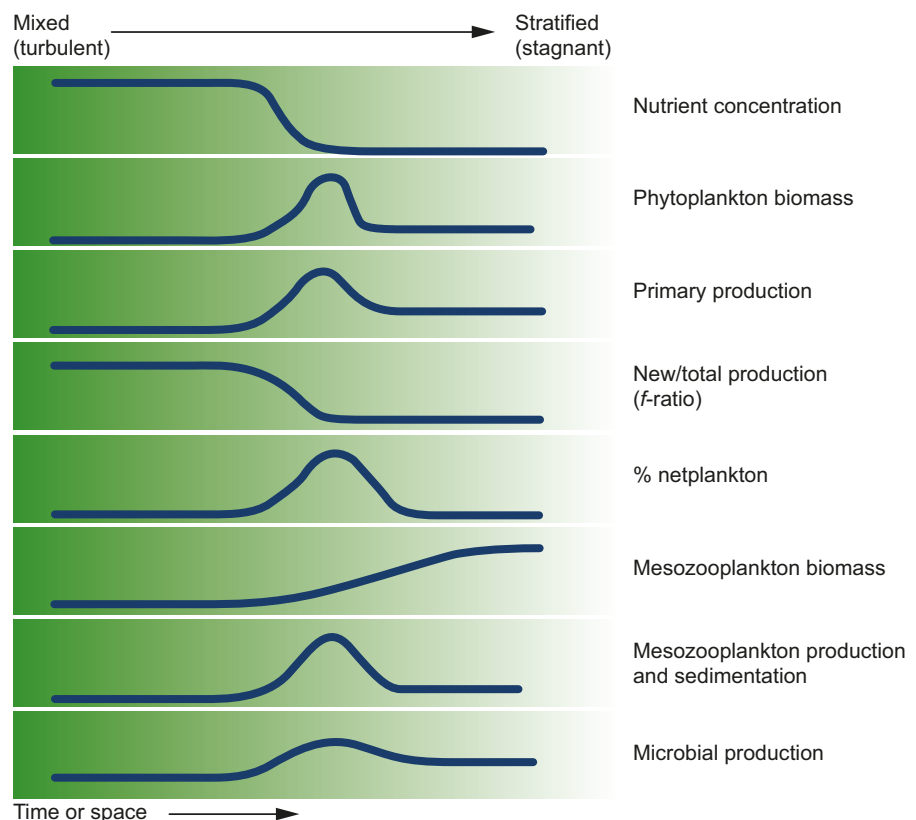
The bathymetry of Baffin Bay with shallow sills both to the north and south creates a relatively isolated body of cold, deep, polar water, unique among the Arctic seas.

The water depth ranges between 60 m and 2386 m inside the 14 licence blocks from the licence round in 2010 and between 95 m and 2073 m within the presently active licence blocks. The deepest areas are found in the Napu licence (block 8).

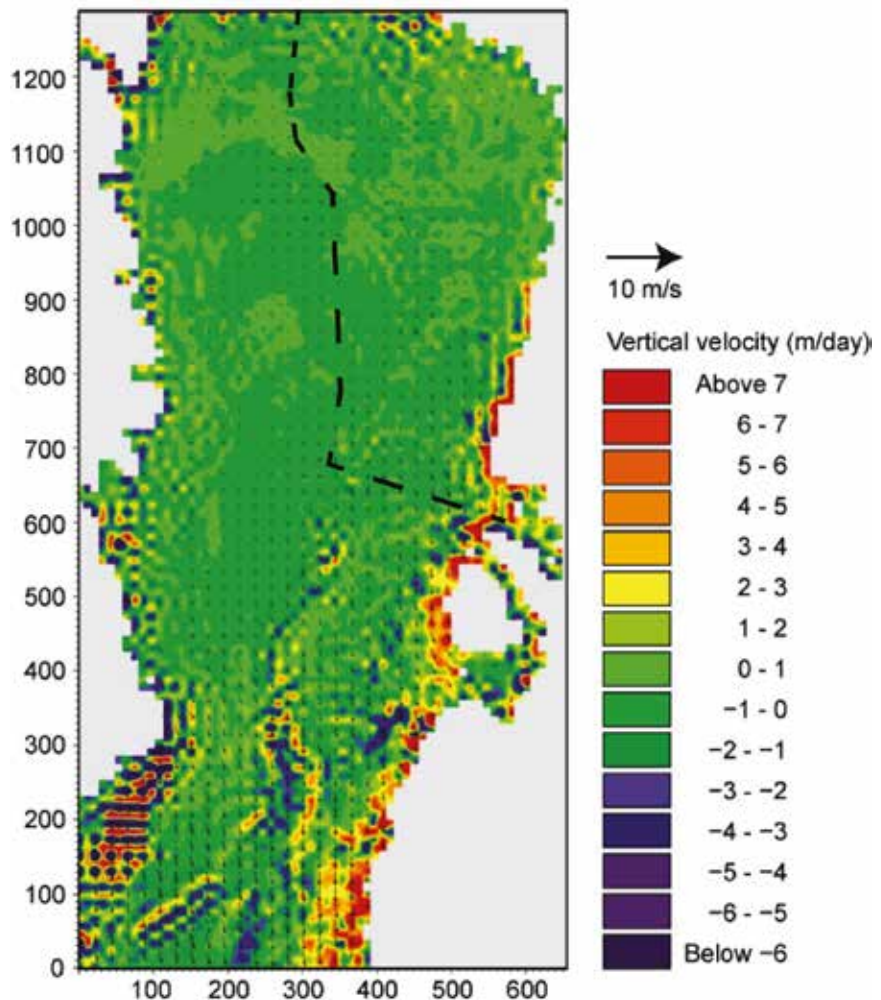
### 3.2.3 Hydrodynamic discontinuities

Hydrodynamic discontinuities are areas where different water masses meet with sharp boundaries and steep gradients between them (Figure 4). They can be upwelling events where nutrient-rich water is forced upwards to the upper layers, fronts between different water masses or ice edges (including marginal ice zones). Upwelling often occurs along the steep sides of the banks driven by the tidal currents, with upwelling usually alternating with downwelling.

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



**Figure 5.** Upwelling and downwelling areas along the West Greenland coast (assessment area indicated by dashed line). The map is the result of the Hybrid Coordinate Ocean Model (HYCOM), which models the daily mean value of vertical velocity at 20 m depth, and wind speed in Baffin Bay. The present figure shows daily mean values on the 24 April, 2005, which is a frequent feature during spring. The colour scale shows the daily mean value of upwelling velocity ( $\text{m day}^{-1}$ ), and the arrows show wind speed. Large vertical velocity suggests up/down-welling or large mixing at 20 m depth. For this specific date there is strong upwelling along the Greenland west coast, especially to the south of the assessment area. Within the assessment area the vertical currents are found only along the coasts. The model set up is described in detail in Ribergaard et al. (2006).



Hydrodynamic simulations performed as part of the Disko West assessment program (just to the south of the assessment area) revealed some significant upwelling areas of which some are located within the present assessment area (Figure 5).

### 3.3 The coasts

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

### 3.4 Ice conditions

Two types of sea ice occur in the assessment area: shore fast ice, which is stable and anchored to the coast, and drift ice, which is very dynamic and consists of floes of varying size and degree of density. In addition to sea ice, icebergs originating from calving glaciers are very frequent. The description of ice conditions given here is based on a DMI contribution to the Oil Spill Sensitivity Atlas covering the coasts south of  $72^\circ\text{N}$  (Clausen et al. 2012) and an overview report from DMI (Pedersen et al. 2011).

#### 3.4.1 Fast Ice

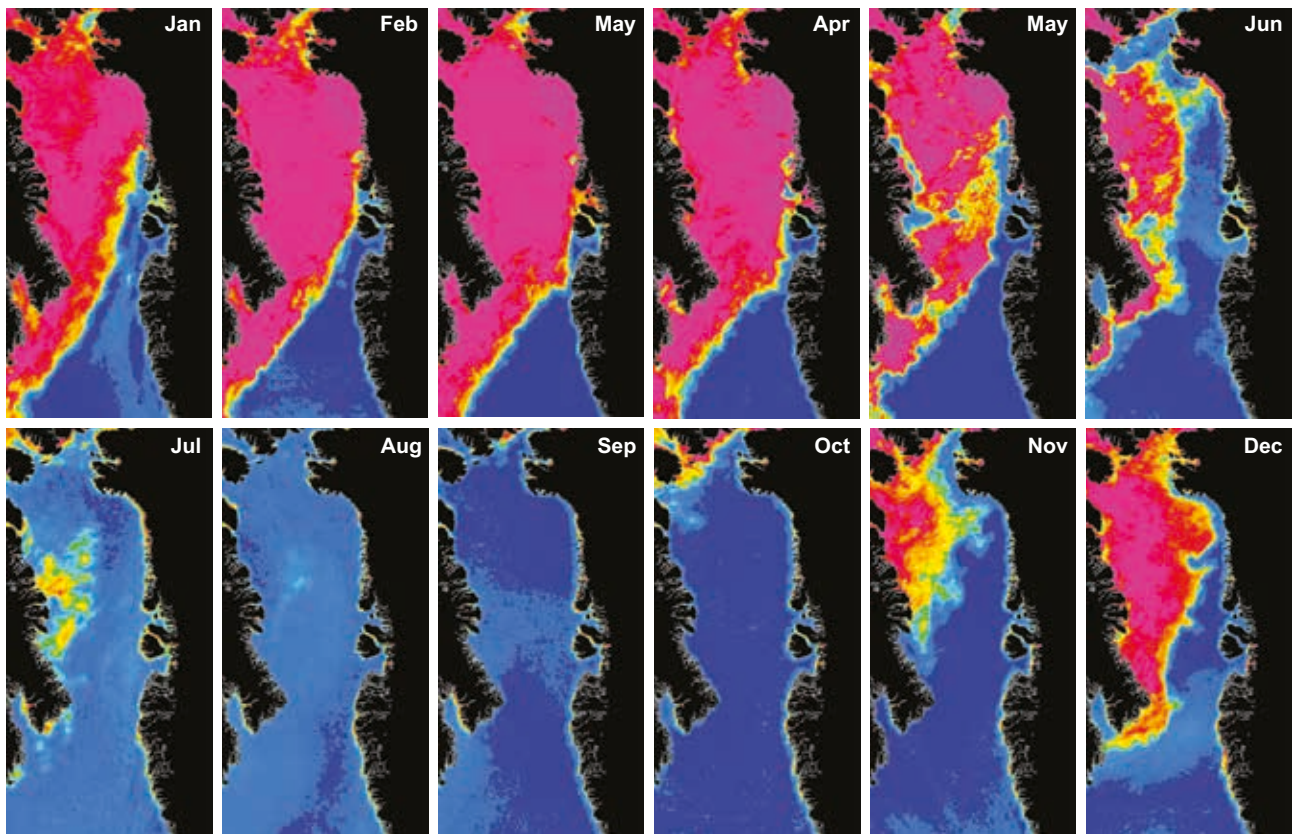
Fjords, bays and coastal waters are covered by shore fast ice usually from December to May, although areas with strong currents may remain open

throughout the winter and freeze up may start in November in the interior parts of the fjords.

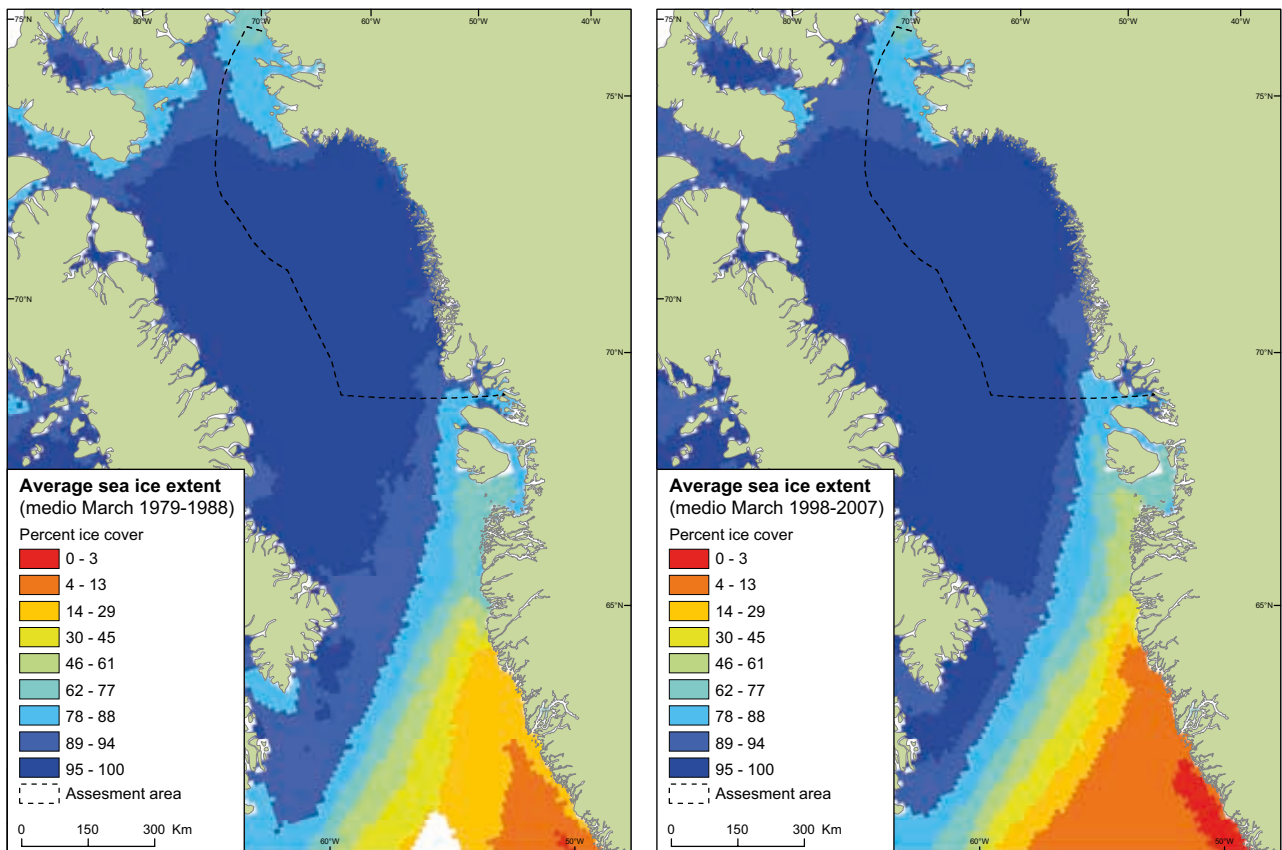
### 3.4.2 The drift ice

The drift ice in the assessment area is often referred to as 'The West Ice' because it is formed to the west of Greenland, and it is a significant feature of the Baffin Bay environment. During November and December ice gradually builds up from the west and encloses the Greenland coast from January. The maximum extent of the ice is usually seen in late March, when the break-up slowly commences from the southeast along the West Greenland coast (along the shear zone) towards north. In late July the area is usually completely ice free, although fields of drift ice may remain in the area throughout summer (Taylor et al. 2001).

The predominant sea ice type in Baffin Bay is first-year (annual) ice. Small amounts of multi-year ice of Arctic Ocean origin drift to the western parts of the bay from Lancaster Sound or the Nares Strait; however, the multi-year ice from these waters mainly drifts through the Canadian part of Baffin Bay (Kwok 2007). At the end of the freeze-up season, first-year ice in the thin and medium categories dominates in the eastern parts (up to about 100 km from the Greenland coast). The western and central parts of Baffin Bay are dominated by medium and thick first-year ice categories, mixed locally with small amounts (1-3 tenths) of multi-year ice (Figures 6, 7). The thickness of the drift ice at end of freeze-up increases towards the north, from approx. 75 cm off Disko Island to 120-150 cm in the northern Baffin Bay (in a severe winter), and the land fast ice in Melville Bay is probably even thicker, 130-180 cm (Valeur et al. 1996).



**Figure 6.** Distribution of ice in the Baffin Bay area in 2010. Images based on Multichannel Microwave Radiometer (AMSR and SMMR). Red and magenta indicate the very dense ice (8-10/10); while yellow indicate somewhat looser ice. The loosest ice (1-3/10) is not recorded. (Data sources: DMI).



**Figure 7.** The average sea-ice extent (mid-March) as percentage ice cover in West Greenland waters. Left: in the period 1979-1988; Right: in the period 1998-2007. Blue colours indicate highest percentage ice cover, red indicate lowest while white show areas without data. Decreasing ice cover is apparent in the late period, especially south of the assessment area. Data sources: Ocean and Sea-ice (EUMETSAT).

The dominant size of ice floes ranges from less than 100 m wide to vast floes larger than 50 km. These floes are often made up of consolidated lesser floes and they continuously break apart and freeze together.

In recent years both the extension of the winter ice and the ice cover period have been significantly reduced (Stirling & Parkinson 2006, Pedersen et al. 2011, Parkinson & Cavalieri 2012).

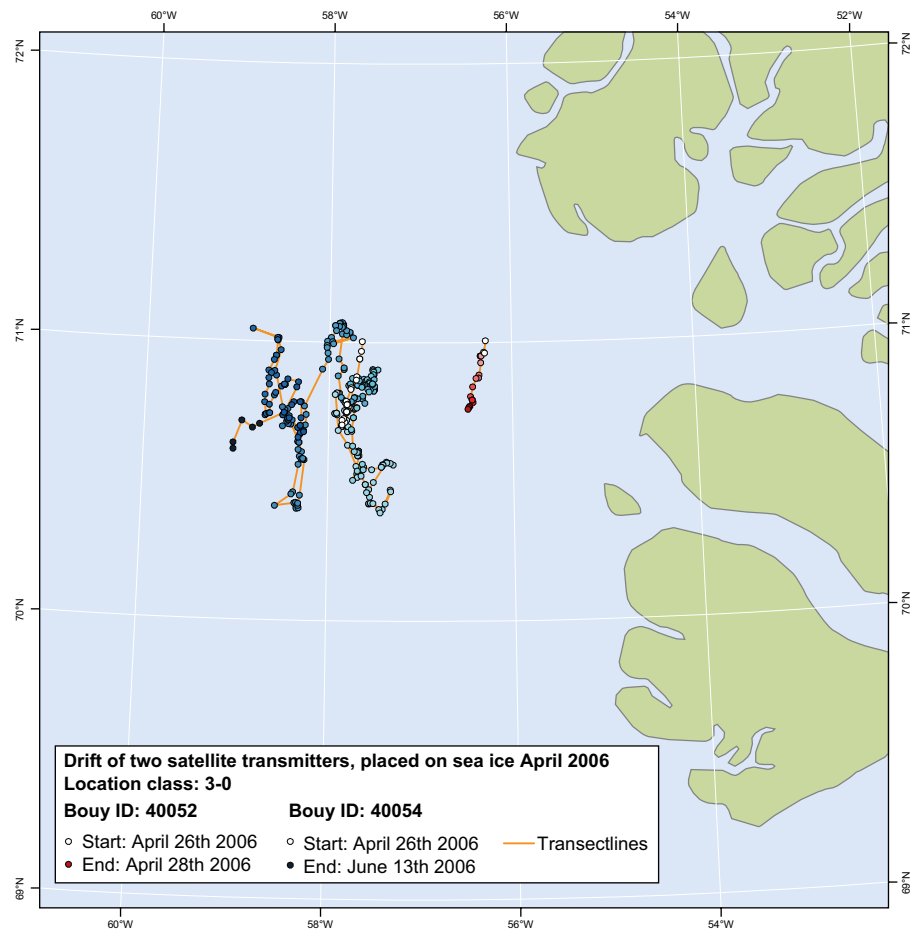
### 3.4.3 Sea ice drift

The drift pattern of the sea ice off West Greenland is not very well known. The local drift is to some extent controlled by the major surface current systems, the West Greenland Current; however, the strength and direction of the surface winds also affect the local drift of sea ice. The drift pattern was studied in the southernmost part of the assessment area in April 2006 (Figure 8) and a later study is presented in the DMI review (Pedersen et al. 2011).

### 3.4.4 Polynyas and shear zone

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

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



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

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

### 3.4.5 Icebergs

Icebergs originate from glaciers calving in the sea, and their size is extremely variable. They are always considered as an intense hazard to navigation and offshore activity.

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

#### Iceberg sources

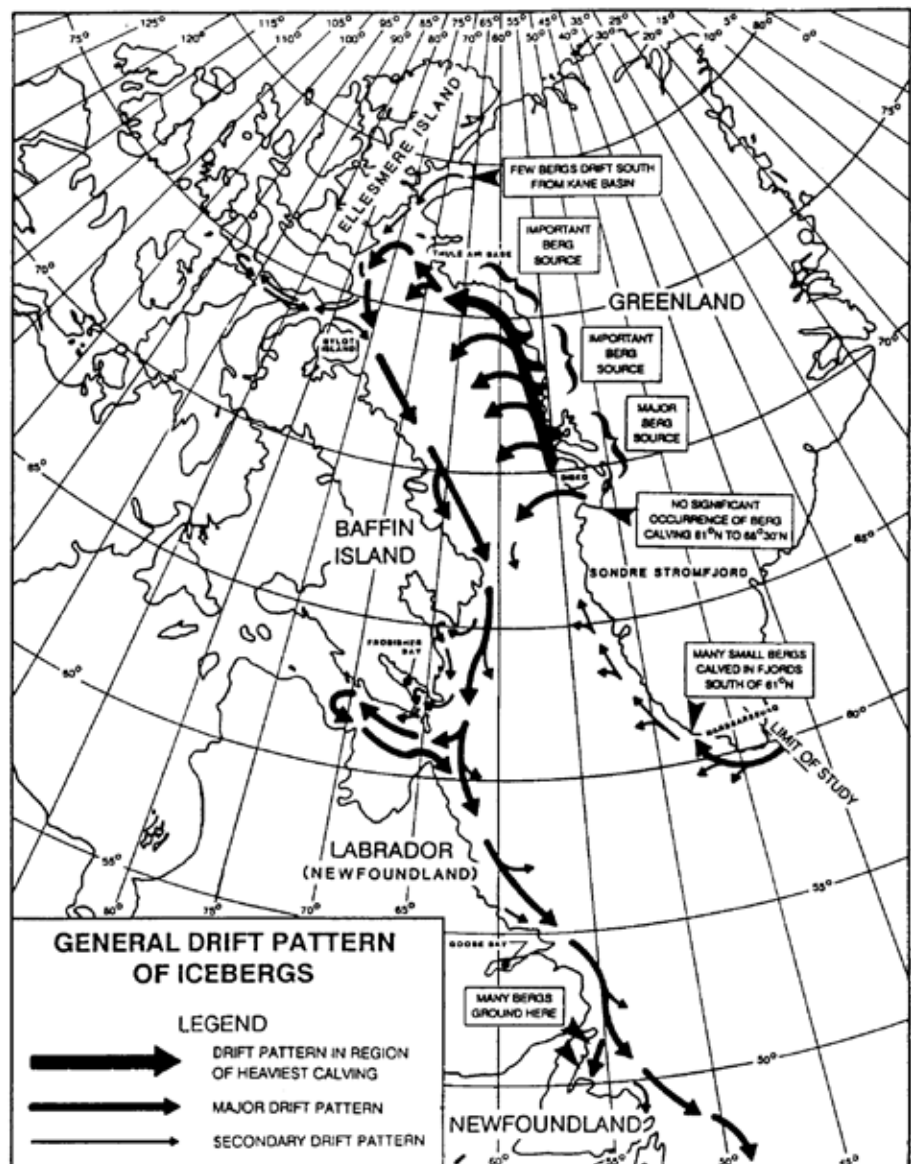
Glaciers are numerous in the coastal parts of the assessment area, and the most productive glaciers in West Greenland are, in fact, concentrated between the Nares Strait and Disko Bay, including the assessment area.

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

### Iceberg drift and distribution

On a large scale, the basic water currents and drift of icebergs in Baffin Bay and the northern Davis Strait are fairly simple (Figure 9). There is a north-flowing current along the Greenland coast and a south-flowing current along Baffin Island and the Labrador coast, giving an anti-clockwise drift pattern. However, branching of the general currents causes variations, and these can have a significant impact on the iceberg population and their residence time. Although the majority of icebergs from Disko Bay are carried northward to northeastern Baffin Bay and Melville Bay before heading southward, icebergs have also been observed to be diverted into one of the west-branching eddies

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



without passing north of 70°N. Most of the icebergs from Baffin Bay drift southward in the western Davis Strait, joining the Labrador Current further south, although some may enter the eastern Davis Strait area west of Disko Island instead. Generally, icebergs produced in Disko Bay or Baffin Bay will never reach the Greenland shores south of 68° N. However, during the 2010-drilling by Capricorn in the Disko West-area, icebergs were tracked and local movements deviated considerably from the overall pattern described above (Section 3.4.3).

### Iceberg dimensions

The characteristics of iceberg masses and dimensions off the west coast of Greenland are poorly investigated, and the following is mainly based on a Danish study in the late 1970s (Valeur et al. 1996, Nazareth & Steensboe 1998).

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

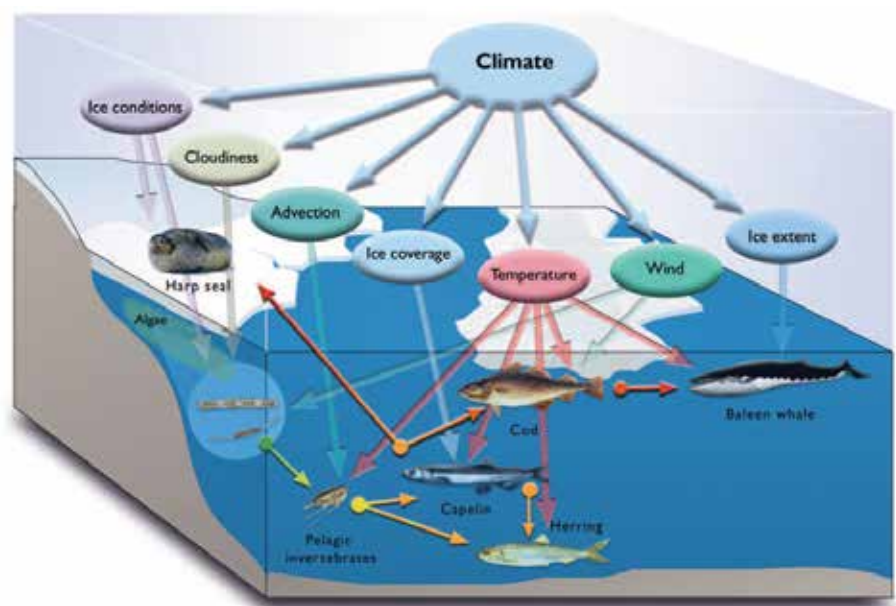
The largest icebergs originating in Baffin Bay are expected to have a maximum draft of about 250-300 m, and the largest iceberg recorded in a study there in 1997 was characterised by a draft of more than 260 m, a mass of up to 90 million tons and a diameter of more than 1,400 m. Icebergs from the highly productive Ilulissat glacier pass a sill, which allows for a maximum draft of 250 m.

### 3.4.6 Climate change

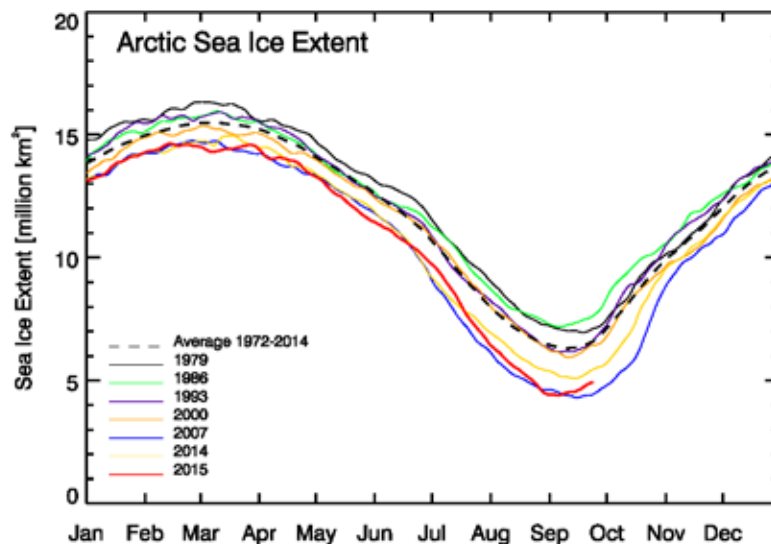
The Arctic marine environment is rapidly changing due to the warming climate (ACIA 2005, CAFF 2013), involving changes in both physical conditions such as water temperatures, sea ice and salinity and biological conditions such as biodiversity, habitats and ecosystems (Figure 10).

Arctic habitats, such as the unique multiyear ice, decrease in extent and species adapted to Arctic conditions are forced northwards, while sub-Arctic species move in from the south.

**Figure 10.** Different climate parameters that may impact the marine food chain, both directly and indirectly. From ACIA (2005).



**Figure 11.** Polar sea-ice extent of selected years 1979 to 2015 with minima in September and maxima in March (data from [http://www.iup.uni-bremen.de:8084/amr2/extent\\_n\\_running\\_mean\\_amr2\\_regular.png](http://www.iup.uni-bremen.de:8084/amr2/extent_n_running_mean_amr2_regular.png)).



Since the publication of the ACIA (2005), several indicators have shown further and extensive changes at rates faster than previously anticipated. Air temperatures are increasing, the sea ice extent has decreased sharply, with record lows in 2007 and 2011 (Jeffries et al. 2015) (Figure 11). In the Baffin Bay region, the winter ice cover has decreased both in extent and duration over the recent decades and the trends continues (Pedersen et al. 2011, Cavalieri & Parkinson 2012).

Ice-free conditions were present in 2008 for the first time in recorded history in both the Northeast and the Northwest Sea Passages (AMAP 2009a). As multi-year ice is replaced by newly formed (first-year) ice, the Arctic sea ice is becoming increasingly vulnerable to melting.

The period 2005-2010 was the warmest ever recorded in the Arctic environment (AMAP 2011a). Since 1980 the increase in annual average temperature has been twice as high in the Arctic region as in other parts of the world. Changes in weather patterns and ocean currents have been observed, including higher inflow of warm water entering the Arctic Ocean from the Pacific.

Based on two different emissions scenarios (A2 and B2) and five global climate models, it has been projected that mean annual surface temperatures north of 60° N will be 2 to 4 °C higher in the mid-2000s and 4 to 7 °C higher toward the end of the 2000s compared with the present (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).

Average autumn-winter temperatures are projected to increase by 3 to 6 °C by 2080, even when using scenarios with lower greenhouse gas emissions than those recorded in the past ten years. It has also been predicted that sea ice thickness and summer sea ice extent will continue to decline, but with considerable variation from year to year. A nearly ice-free summer is now considered likely for the Arctic Ocean by 2050 (AMAP 2011a).

Annual mean temperatures for selected stations in West Greenland, reaching back to 1873, document that there has been a warming period in the first three decades of the twentieth century, followed by cooling until the mid-1970s before temperatures increased again (Stendel et al. 2008, Hansen et al. 2007).



Besides the greenhouse effect of the increased CO<sub>2</sub> concentration, acidification of the oceans will take place. Calcifying organisms, such as coccolithophores, corals, echinoderms, molluscs and crustaceans, will therefore probably be inhibited in forming or maintaining their external calcium carbonate skeletons. Other effects of ocean acidification on marine organisms could include slower growth, decreased reproductive potential or increased susceptibility to disease, with possible implications for ecosystem structure and elemental cycling (for example Orr et al. 2005, Fabry et al. 2008, Kroeker et al. 2010), also in the assessment area.

See also Table 1 from Wassmann et al. 2011 reviewing climate change response of marine organisms.

**Table 1.** Summary of responses of Arctic marine organisms to climate change (Wassmann et al. 2011).

<b>Responses</b>	<b>Nature of changes</b>
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-borne animals
Behaviour and phenology	Anomalous behaviour of ice-bound, ice-associated, or ice-borne animals with earlier spring phenological events and delayed fall events
Community and regime shifts	Changes in community structure due to range shifts of predators resulting in changes in the predator-prey linkages in the trophic network

## 4 Biological environment

### 4.1 Primary productivity

E.F. Møller, M. Frederiksen & K. Johansen

#### 4.1.1 General context

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

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

In addition to the magnitude of total primary production, it is important to know the strength of the pelago-benthic 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 draw. This is partly because primary production varies considerably among the different Arctic regions due to differences in hydrography and thus physical forcing. It has, however, been suggested that areas with pronounced stratification for instance due to melt of sea ice or glaciers, will lead to dominance of smaller phytoplankton cells (Li et al. 2009). These smaller cells are not as readily grazed by mesozooplankton, and at the same time they do not settle to the bottom. Therefore more material may be recycled by the microbial part of the food web.

The assessment area is highly heterogeneous in terms of ice cover and thus primary productivity. The northern part of the area is dominated by the large North Water Polynya, which is one of the most biologically productive marine areas in the Arctic. This area is also relatively well studied. Further south,

the ice-free period in Melville Bay and Baffin Bay is much shorter, but the whole region becomes ice-free during most summers. A number of small polynyas are present along the Greenland coast. The whole region south of the North Water Polynya is very poorly studied. In the following, we review published studies of primary productivity in the assessment area, and supplement this with a series of maps of satellite-derived estimates of surface chlorophyll concentrations.

#### 4.1.2 Primary production in the North Water Polynya (NOW)

The North Water is one of the largest ( $\approx 80,000 \text{ km}^2$ ) and biologically most productive polynyas in the Arctic and is exceptionally important for consumers at higher trophic levels, including humans. Nevertheless, until fairly recently very little was known about the ecology of the area due to logistical constraints. Preliminary data were collected during a brief cruise in 1991 (Lewis et al. 1996). The physical, biological and bio-geochemical processes were studied intensively during the international North Water Polynya Study in 1997-99 (Deming et al. 2002), leading to a better ecological understanding of this productive region than of any other part of the assessment area. However, few more recent *in situ* data are available. Exceptionally for Arctic areas, phytoplankton biomass and primary productivity were high throughout the ice-free period (April-October), although a clear peak was present in early June (Tremblay et al. 2006a). Annual primary production was among the highest recorded in the Arctic (average for the whole polynya:  $251 \text{ g C m}^{-2} \text{ yr}^{-1}$ ), dominated by large producers such as diatoms (Klein et al. 2002), particularly *Thalassiosira* spp. and *Chaetoceros socialis* (Booth et al. 2002). Despite the importance of diatoms, total primary production was most likely limited by nitrate rather than silicate (Tremblay et al. 2002). Most of this production was channelled through the grazing food web, and a relatively small proportion ( $\sim 20\%$ ) was lost through sinking to the benthic system (Tremblay et al. 2006). This implies that most of the local secondary production was available to plankton consumers, including larger zooplankters, fish, marine mammals and planktivorous seabirds. The bloom started in the eastern part of the polynya, where ice break-up and attendant stratification were earliest due to the relatively warm West Greenland Current, and progressed westwards over the season (Odate et al. 2002, Tremblay et al. 2002). The extremely early start of the bloom (April, similar to temperate oceans) was likely due to stratification (shallow mixing) in the eastern part of the polynya (Tremblay et al. 2006b). The prolonged phytoplankton bloom was likely maintained by storm-driven admixture of nutrients (primarily nitrate) from deeper waters (Lovejoy et al. 2002, Tremblay et al. 2002, Tremblay et al. 2006), and it is possible that the bloom would be more short-lived in years with fewer storms during spring and summer. Later freeze-up of the sea ice in autumn may lead to higher production since this will coincide with autumn storms and subsequent upwelling of nutrients (Tremblay et al. 2012). During cruises in late summer and early autumn 2005 and 2006, Martin et al. (2010) found a distinct subsurface chlorophyll maximum at  $\approx 20 \text{ m}$  depth in the North Water, and suggested that this might account for a substantial proportion of total primary production.

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

### 4.1.3 Primary production in Baffin Bay and Melville Bay

This region, constituting most of the assessment area, is poorly studied in terms of primary production, at least partly because of logistical issues due to high ice concentrations and a short open-water season. During summer, a distinct subsurface chlorophyll maximum was found in northern Baffin Bay (Harrison et al. 1982, Herman 1983), and primary production was similar to other Arctic and Antarctic waters (Harrison et al. 1982). Jensen et al. (1999b) measured primary production in the southernmost part of the assessment area during summer and found that it was similar to areas further south along the West Greenland coast (cf. Söderkvist et al. 2006). Recent estimates of the average primary production in the western Baffin Bay vary between 350 and 870 mg C m<sup>-2</sup> d<sup>-1</sup> (Codispoti et al. 2013, Hill et al. 2013, Varela et al. 2013).

### 4.1.4 Satellite-derived maps of estimated surface chlorophyll concentration

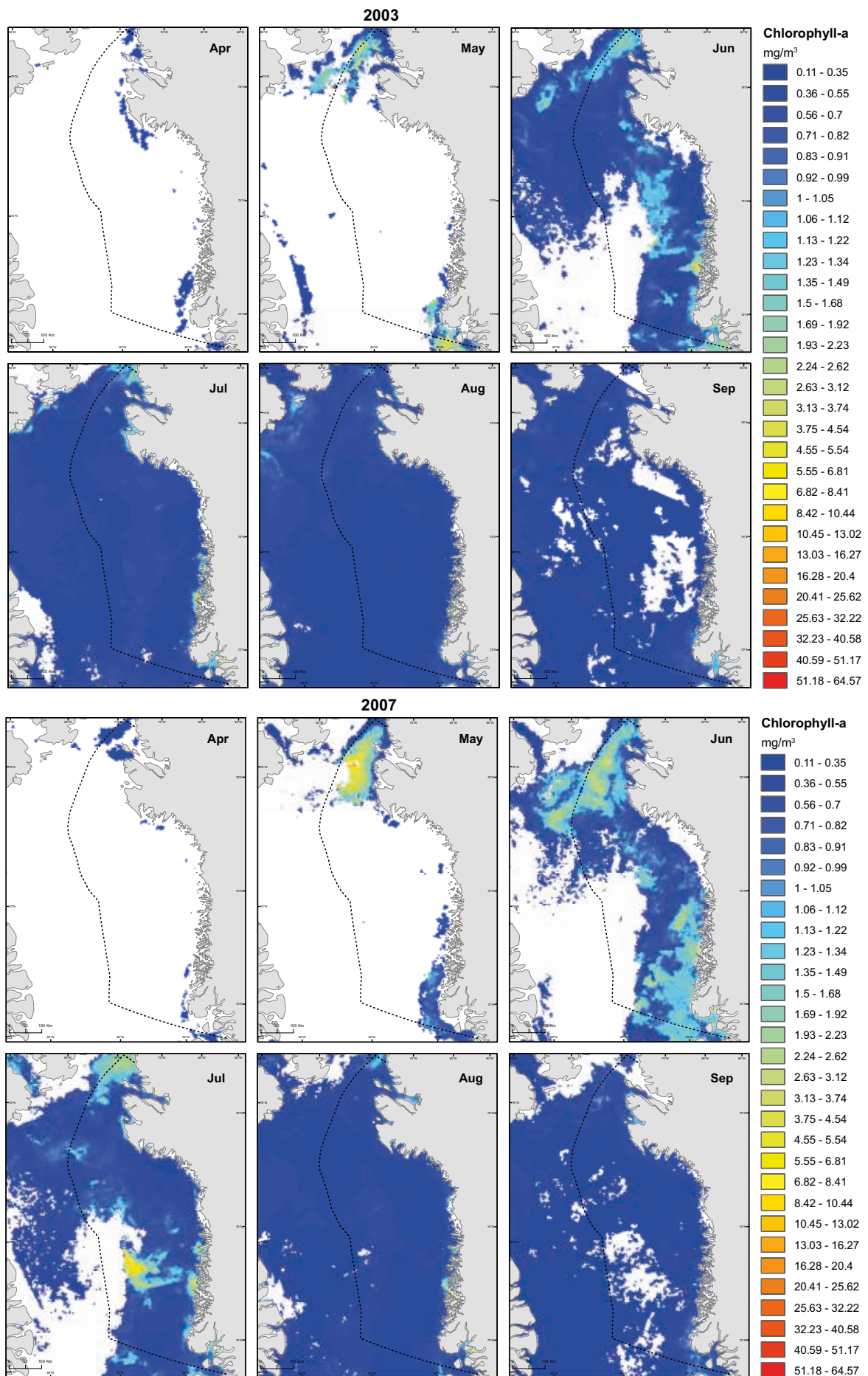
In Figure 12, a series of maps are presented showing estimated monthly (April-September 2003 and 2007) mean surface chlorophyll concentrations, based on data from the MODIS Aqua satellite.

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 concentrations if there is a consistent relationship between surface and total chlorophyll (cf. the subsurface chlorophyll described by Martin et al. 2010). 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 areas on the maps). White areas may represent, for instance sea ice, areas with too little incident light to get proper readings (mainly in northern areas in September), or areas with a very high cloud concentration. In many cases, the ice edge can be reliably detected from these maps, but, for example, the irregular white areas in central Baffin Bay in August-September are more likely to represent persistent cloud concentration. Moreover, a large proportion of the annual primary production may occur while the sea is still ice-covered due both to ice algae and to under ice bloom (see Section 4.5). For instance, a surface phytoplankton bloom began offshore in Amundsen Gulf (arctic Canada) under 90% ice cover reaching maximum biomass under 40% (Forest et al. 2011).

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

### 4.1.5 Primary production and climate change

Changes in the oceanographic conditions caused by climate change affect primary production, including the timing, location and species composition of phytoplankton blooms (for example Jeffries et al. 2015). This may cause a



**Figure 12.** Estimated monthly mean surface chlorophyll concentration in the period April-September 2003 and 2007 in the Baffin Bay area. The map is based on level 3 data from the MODIS Aqua satellite sensor and downloaded from OceanColorWeb (<http://oceancolor.gsfc.nasa.gov>). The spatial resolution used was 4 km, and 16-bit satellite readings were converted to chlorophyll concentrations using the equation:  $\text{Chl (mg/m}^3\text{)} = \exp_{10}((0.00005813776 * \text{scaledreading}) - 2)$ . White areas represent lacking data, due to e.g. sea ice, lack of light or high cloud concentration. The dashed line shows the limit of the assessment area.

mismatch in the timing of phytoplankton and zooplankton production due to early phytoplankton blooms, which may reduce the efficiency of the food web.

Climate change impacts the primary production in several other ways. Lavoie et al. (2010) modelled the impacts of a reduced ice cover and showed that the relative contribution of the ice algal and spring phytoplankton blooms to the annual primary production will be reduced owing to reduction in the length of the ice algal growth season and in the replenishment of nutrients to the mixed layer in winter. The duration of the summer subsurface phytoplankton bloom increased in favour of the main copepod species. This resulted in an increase in export production that is greater than the increase in primary production.

Climate change is also 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), and there is now evidence for earlier chl. *a.* maxima in Greenland waters (Kahru et al. 2011).

#### **4.1.6 Important and critical habitats for primary production**

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

## **4.2 Zooplankton**

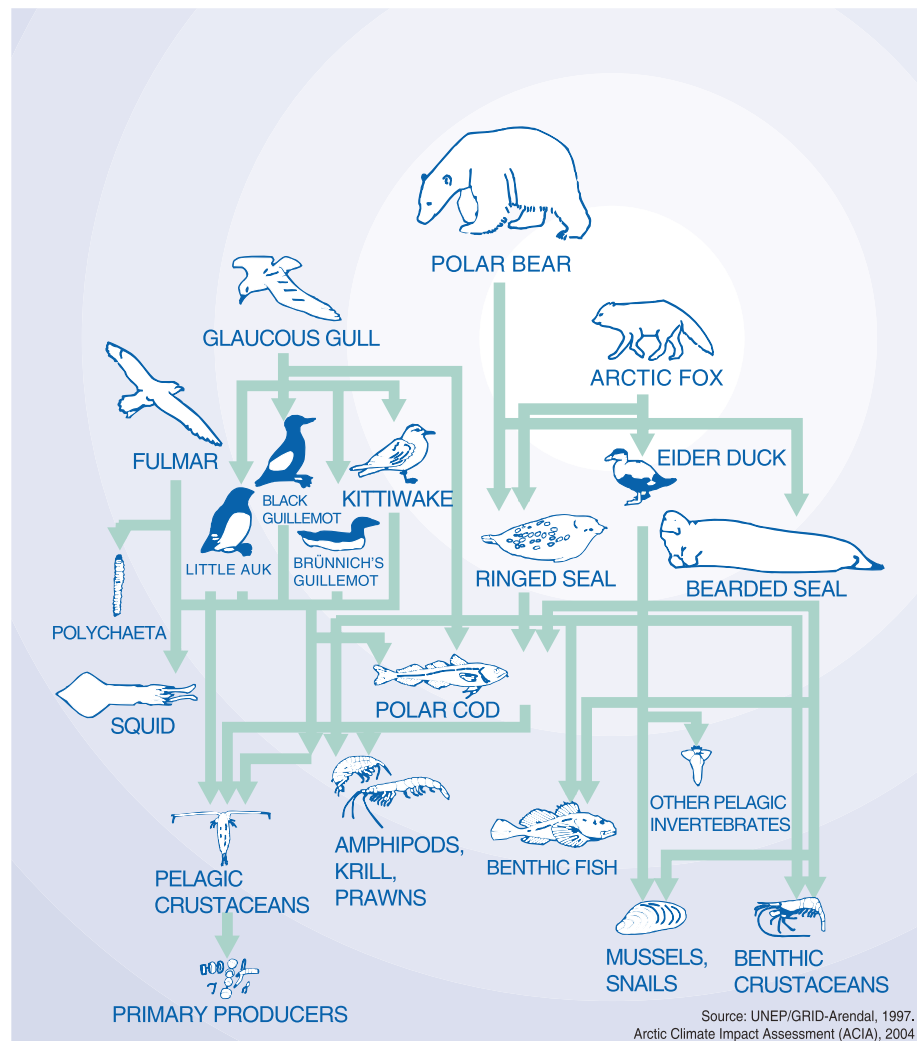
E.F. Møller

### **4.2.1 General considerations**

Zooplankton has an important role within marine food webs (Figure 13), since it constitutes the principal pathway to transfer energy from primary producers (phytoplankton) to consumers at higher trophic levels such as fish and their larvae, marine mammals and seabirds. The little auk (*Alle alle*) and the bowhead whale (*Balaena mysticetus*), for instance, are specialised zooplankton feeders primarily utilising the large copepods of the genus *Calanus* (Karnovsky et al. 2003, Heide-Jørgensen et al. 2016). Most of the higher trophic levels in the Arctic marine ecosystem rely on the lipids that are accumulated in *Calanus* (Falk-Petersen et al. 2009). Consequently, a great deal of the biological activity for instance 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).

In the Arctic, marine zooplankton is not only governed by low temperatures but also by extremes in solar radiation and associated cycles in pelagic primary production. The absence of light during winter, and its nearly continual

**Figure 13.** A schematic description of the interactions in the marine Arctic environment (AMAP).



presence for four summer months per year, has a strong influence on food availability and on the life cycle of the organisms living there. Specific adaptations are required, such as the capacity to store lipids when food is plentiful and to overwinter on these stores. The ability to synthesise and/or store lipids is a critical aspect in the life cycles, since these lipid stores not only provide energy during starvation in winter but also the materials for egg production and larval development (Lee et al. 2006, and references therein, Falk-Petersen et al. 2009).

Earlier studies on the distribution and functional role of zooplankton in the pelagic food-web off Greenland, mainly in relation to fisheries research, have shown the prominent role of the large copepods of the genus *Calanus*. The species of this genus feed on algae and protozoa in the surface layers and accumulate surplus energy in the form of lipids which are used for over-wintering at depth and to fuel reproduction in the following spring. Their life cycles have been estimated to 1-4 years (Madsen et al. 2001, Ashjian et al. 2003).

Two species, *Calanus hyperboreus* and *C. glacialis* are characterised as Arctic species (Falk-Petersen et al. 2007). *C. hyperboreus* undergoes a 2-4 year life cycle, reproducing at depth in winter (November-March). The females release their eggs throughout the winter and some eggs ascend early enough to hatch and moult into the first larval stages before the initiation of the spring phytoplankton bloom.

The other Arctic species, *C. glacialis* probably follows a 2-year life cycle, reproducing during spring and summer in the upper water column and using both stored reserves and available food. During overwintering both species utilise lipid reserves stored during the productive season (Ashjian et al. 2003, Lee et al. 2006 and references therein, Falk-Petersen et al. 2009). The third main copepod species, *Calanus finmarchicus*, 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 assessment area by the inflow of Atlantic water. The last major copepod species, *Metridia longa*, has been classified by several authors as an Arctic deep-water species that overwinters as stage V copepodite and adults (Ashjian et al. 2003).

The vertical distributions of the *Calanus* species differ between seasons. In summer they are found in the upper layers of the water column, while they hibernate at great depth, >200 m, in winter.

The smaller species, such as *Oithona similis*, *Pseudocalanus* spp. and *Microcalanus pygmaeus*, are often found in large numbers. They exhibit a shorter generation time and more sustained reproduction, suggesting that their importance in ecosystem productivity could be greater than implied by their biomass alone, particularly during the periods when *Calanus* hibernate (Hopcroft et al. 2005, Madsen et al. 2008, Darnis et al. 2012).

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 have much higher ingestion rates, faster growth and reproduction than crustaceans (including copepods), 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 groups are chaetognaths, amphipods, ctenophores and cnidarians. Arctic chaetognaths may have considerable biomass and long life cycles (for example two years) and are thought to be important in controlling *Calanus* populations (Falkenhaug 1991). Hyperiid amphipods (for example the genus *Parathemisto* – also known as *Themisto*) can also be abundant in Arctic waters (Mumm 1993, Auel & Werner 2003), with 2- to 3-year life cycles and a similar potential to graze a notable proportion of the *Calanus* population (Auel & Werner 2003). In turn, polar cod (*Boreogadus saida*), seabirds and marine mammals are often feeding on these amphipods. Thus, hyperiid amphipods play a key role in the Arctic pelagic food web (Figure 13) as a major link from mesozooplankton secondary production to higher trophic levels such as seabirds and marine mammals (Auel et al. 2002). A special amphipod, *Apherusa glacialis*, lives in and on sea ice, grazing on ice-associated algae. Also euphausiids (krill), mysids (*Mysidacea*) and pteropods (*Limacina*) can be very numerous and constitute important food for seals, whales and seabirds (Laidre et al. 2010, Agersted & Nielsen 2014).

In general, life cycles of Arctic zooplankton are prolonged compared with populations of closely related species at lower latitudes, and often exceed one year. Zooplankton concentrations are often highest in the upper 500 m. However, as described above, especially the predominant *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 et al. 1990, Dahl et al. 2000). Consequently, many biological activities – such as reproduction and growth of fish and birds – are synchronised with the life cycle of *Calanus*. In larvae of the Greenland halibut (*Reinhardtius hippoglossoides*) and sandeel (*Ammodytes* sp.) from the West Greenland shelf, copepods were the main prey item during the main productive season (May, June and July). They constituted between 88% and 99% of the ingested prey biomass (Simonsen et al. 2006). The little auk is highly dependent on the Arctic *Calanus* species for successful reproduction (Karnovsky et al. 2010, Frandsen et al. 2013).

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

For example in southern Baffin Bay in September zooplankton biomass was much higher in the surface waters of the western parts of the bay, influenced by the cold water from north than in the eastern parts, influenced by warmer water originating from the south. This reflects the differences in the timing of the seasonal cycle (Kjellerup et al. 2014). A particularly high biomass of both zooplankton and polar cod was found in the central part of the basin in association with a local relatively shallow area.

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

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

Anthropogenic impacts, for instance oil pollution, may also have an impact. Estimates of plankton vulnerability to oil pollution tailored for the Baffin Bay assessment area are not available. However, in past years, exposure experiments performed on phytoplankton (Hjorth et al. 2007, Hjorth et al. 2008) and copepods (Hjorth & Dahllöf 2008, Hjorth & Nielsen 2011, Nørregaard et al. 2014) with PAH 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 (see Sections 11.5, 11.6 and 11.7). In Arctic marine habitats, the most severe ecological consequences

of massive anthropogenic impacts (such as oils spills) are to be expected in seasons with high activity of the pelagic food web (i.e. spring and summer). On a horizontal scale the most important areas are the fronts in association with the transition zone between different water masses. Later in the season, when the biological activity is more scattered or concentrated at the pycnocline (> 20 m depth) ecological damage from an oil spill is assumed to be less severe (Söderkvist et al. 2006).

#### 4.2.2 Zooplankton in the Baffin Bay assessment area

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

#### 4.2.3 Zooplankton in the North Water Polynya

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

late primary production was left to sink directly to the bottom (pelago-benthic coupling) to be used by benthic organisms (Tremblay et al. 2006).

#### 4.2.4 Changes in zooplankton occurrence

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 (Li et al. 2009).

Moreover, the influx of Atlantic water masses to the Arctic Ocean has increased during the last decades, but it remains unclear how this flux variability affects the pelagic ecosystem. Plankton species are in general good indicators of 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).

Depending on the species, a warmer climate will cause a shift in the zooplankton community structure towards the smaller less energy rich *C. finmarchicus* as shown experimentally (Kjellerup et al. 2012). This scenario could cause a trophic cascade due to lower energy content per individual (Falk-Petersen et al. 2007). In addition, the share in biomass accounted for by *C. finmarchicus* will increase (Hirche & Kosobokova 2007) due to its higher growth rate and short life cycle (Scott et al. 2000). Thus, a regime shift towards *C. finmarchicus* could influence the little auk populations negatively, as they are specialised on the larger *Calanus* species (Karnovsky et al. 2003), and favour other species like herring (Falk-Petersen et al. 2007).

#### 4.2.5 Important and critical areas for zooplankton

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

### 4.3 Benthic flora

S. Wegeberg

Shorelines with a rich primary production are of high ecological importance. The littoral- and sublittoral canopies of macroalgae are 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 (for example 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 such shorelines will therefore naturally sustain a relatively lower production or may appear as barren grounds. Thus, to identify important or critical areas a robust baseline knowledge of littoral and sublittoral ecology is essential.

Studies of the marine benthic flora in the assessment area are scarce and have mainly been conducted as floristic investigations. Marine macroalgae were collected during different expeditions to West Greenland in the 19<sup>th</sup> century and were identified and described by Rosenvinge (for example 1893, 1898). In addition, two studies of the macroalgal flora have been conducted in the assessment area – Wilce (1964) collected and described the macroalgae at Qaanaaq, and in 2004 macroalgal samples were collected and analysed in connection with an assessment of the environmental impact of the Thule Airbase at North Star Bay (Andersen et al. 2005). Check-lists with indication of distribution of the Greenland marine algae were compiled separately for the east and west coast by Pedersen (1976), supplemented with the data of Andersen et al. (2005) (Appendix 1).

However, the intertidal study reported in Box 2 includes macroalgae.

#### 4.3.1 General context

Marine macroalgae are found along shorelines with hard and stable substratum such as stones, boulders and rocky coast. The vegetation is distinctly divided into zones, most pronouncedly in areas with high tide amplitudes. Some species grow above the high-water mark, the supralittoral zone, where sea water reaches them as dust and spray or by wave action. In the littoral zone, the vegetation is alternately immersed and emersed and characterised by furoid species. The majority of the macroalgal species grow, however, below the low-water mark. The submerged vegetation is restricted to depths with sufficient light conditions. In Greenland, a relatively rich flora can be found until 20-30 m depth, but macroalgae may occur as deep as 50 m.

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

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

The annual production of kelp species in Northeast Greenland and the Beaufort Sea, Alaska, has been estimated, and showed an annual length increase of *Saccharina latissima* of approx. 55-88 cm depending on depth (Borum et al. 2002, Dunton 1985). The kelp production gives an estimate of the amount of kelp-derived carbon available for the next trophic levels in the ecosystems.

The most important environmental conditions for the macroalgal flora in the assessment area are the low temperatures, the strong seasonally changing light regime and ice cover throughout a large part of the year. Adaptions to these conditions are, for example, maintenance of the older generation lamina (together with the new) for up to three summer seasons, whereas in temperate regions the lamina are lost when new are developed in spring. This is seen, for

example, in *Laminaria solidungula* and *Saccharina latissima* in Northeast Greenland (Lund 1959, Borum et al. 2002). As discussed by Borum et al. (2002), the 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 contributes to a positive carbon balance of the individual. For *Saccharina latissima* in Young Sound, Borum et al. (2002) found that the photosynthetic capacity of the lamina from the preceding year was similar to that of the current.

The ability to support a photosynthetic performance comparable to that of macroalgae in temperate regions might be explained by low light compensation points and relatively low respiration rates during periods of poor light conditions which indicates adaptation to constant low temperatures and long periods of low light intensities (Borum et al. 2002). Furthermore, a fast response of photosynthetic performance to changing light conditions is considered to be part of a physiological protection strategy in a highly variable environment as in, for instance, the littoral zone, and it ensures optimal harvest of light when available (Becker et al. 2009, Krause-Jensen et al. 2007). No studies elucidating the specific macroalgal production or photosynthetic strategies have been conducted in the assessment area, but Krause-Jensen et al. (2012) showed that seasonal sea ice cover was the best predictor of spatial and temporal variation in depth extension and the annual production of kelp along a latitudinal gradient from 64° to 78° N in Greenland.

The sea ice has a high physical impact on the macroalgal vegetation. The mechanical scouring of floating ice floes prevents especially perennial furoid species from establishing in the littoral, which is the zone most influenced by the ice dynamics. At such, often quite wind-exposed and ice-scoured localities, communities of opportunistic macroalgae develop quickly during the summer months due to available substratum and because their microstages are not detached by ice. The algae showing this strategy are species of the filamentous genera *Ulothrix* and *Urospora* and the smaller leafy species *Blidingia minima*. This development was observed in the assessment area at North Star Bay by Andersen et al. (2005).

Perennial species from the littoral zone tolerate freezing and may survive in a frozen state in an ice foot if the ice melts gradually without disruption. The macroalgal vegetation then remains intact, which might be the case in more sheltered areas such as the fjord Qaamarujuk, close to Uummannaq, just to the south of the assessment area (Johansen et al. 2001a). In Spitsbergen, *Fucus distichus* was able to halt photosynthetic activities at subzero temperatures and resume them almost fully when unfrozen (Becker et al. 2009).

Fresh water and 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 mixes with fresh and melt water during seasons with high water run-off from land. Low tolerance to hyposaline conditions may result in bleaching (strong loss of pigments) or increased mortality, which suggests that hyposalinity also impacts the photosynthetic apparatus, as shown for kelp species at Spitsbergen (Karsten 2007).

Also substratum characteristics are important for the distribution and abundance of macroalgal vegetation, and only hard and stable substratum can serve as a base for a rich community of marine benthic macroalgae. However, some macroalgal species are commonly found attached to shells or small stones or lie loose in localities with a soft, muddy bottom. In North Star Bay

at Thule Air Base, video records (provided by DHI) show *Saccharina longicruris* on a muddy bottom intermixed with small stones and shells as well as relatively high quantities of *Desmarestia aculeata*. Yet, naturally occurring loose-lying macroalgae tend to be imperfectly developed, 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 in the inner part of fjords, are created and influenced by suspended clay particles from glacier melt water. In such sites, light conditions are impaired due to significantly reduced water transparency, and sedimentation of suspended particles on macroalgal tissue results in shading. This was also the case in North Star Bay where the vegetation was generally covered by a thin layer of fine particles.

Sea urchins (*Strongylocentrotus droebachiensis*) are the most forceful grazers on kelp forests. A high density of sea urchins can result in grazing down of kelp forests leaving 'barren grounds' (also known as the phenomenon 'iso-yake' – Japanese: sea desert) of stones, boulders and rocks covered by coralline red algae only. If barren grounds are created due to grazing by sea urchins, and not by ice scouring, the barren grounds will be found below the intertidal vegetation as the sea urchins do not tolerate desiccation (Christensen 1981). In North Star Bay in the assessment area, underwater video transects showed a relatively high number of sea urchins at patchy stony sea floors. The only presence of macroalgae there was, however, loose-lying green filaments, probably *Chaetomorpha melagonium* (video recordings), suggesting over-grazing of the macroalgal vegetation. In connection with a study on the macroalgal species zonation in the intertidal of the west coast of Disko (immediately south of the assessment area), barren grounds with a relatively high number of sea urchins and grazed kelp forest have been reported (Hansen & Schlütter 1992).

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

There are different reports on the impact of oil contamination on macroalgal vegetation and communities. The macroalgal cover (*Fucus gardneri*) lost in connection with the *Exxon Valdez* oil spill in 1989 in Prince William Sound, has taken several years to fully re-establish as a result of the grazer-macroalgae dynamics as well as intrinsic changes in plant growth and survival (Driskell et al. 2001). Twenty-five years of monitoring, suggest a possible positive correlation between the cover of *F. gardneri* and the cold period of the Pacific Decadal Oscillation (PDO). PDO produces approx. 10-year oscillations between cold and warm periods. Hence, the decreases in *Fucus* cover may be induced by these natural climatic impacts and not necessarily be repercussions from the oil spill in 1989 (Shigenaka 2014). On a short-term basis, no major effects on shallow sublittoral macroalgae were observed in a study on macroalgae and impact of oil spill conducted by Cross et al. (1987). This study suggested that the lack of effect might be due to the observed similar lack of impact on her-

bivores and the vegetative mode of reproduction of 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). See also Section 11.7.3.

#### 4.3.2 The macroalgal vegetation in the assessment area

A checklist with indication of the distribution of the marine macroalgal species in the assessment area is presented in Appendix 1.

According to Pedersen (1976), 183 macroalgal species (excluding bluegreen algae, *Cyanophyta*) are found in Greenland. Due to taxonomic and nomenclatural changes, the present count is 137 species: 37 red, 66 brown and 37 green algal species. Within the assessment area, 32 red, 38 brown and 17 green algae have been recorded, of these only a few at the highest latitudes (78° N), however: 3, 12 and 4, respectively.

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

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

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

Just to the south of the assessment area at Uummannaq, Johansen et al. (2001a) have monitored contaminants from the zinc-lead mine in Maarmorilik and

collected samples of furoid species for analyses, documenting via reports and pictures a rich littoral vegetation of *Fucus* species (*F. distichus*, *F. vesiculosus*, P. Johansen, pers. comm., Johansen et al. 2001a).

In general, knowledge of macroalgal diversity is limited. But studies on macroalgal species composition, biomass and spatial variation have now been carried out in the assessment area (Box 2). The present knowledge of macroalgae diversity and community shows a highly heterogeneous distribution and abundance. This variation is linked with the highly variable physical environment in the assessment area. It is, however, not clear how much of the variation the physical parameters can explain, preventing identification of important or critical shoreline intervals. In addition, no research has yet been conducted into macroalgal community interactions, for instance the biodiversity/abundance of macroalgal-associated fauna or mapping of macroalgal/faunal interactions, including grazing, in the assessment area.

### **4.3.3 Climate change effects on macroalgae**

Climate change will probably affect the macroalgae vegetation due to a prolonged open-water period and thereby a longer growing season, and this coupled with oceanic warming may shift the distribution range of many macroalgae species towards the north (Müller et al. 2009). On the other hand, melting of glaciers leads to increased runoff of freshwater holding suspended material, resulting in lowered salinity and increasing water turbidity (Borum et al. 2002, Rysgaard et al. 2007), with a subsequent negative impact on the local macroalgae vegetation.

## **4.4 Benthic fauna**

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

### **4.4.1 General context**

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

Approximately 20% of the world's shelf areas are located in the Arctic (Menard & Smith 1966). In these areas a high standing stock of benthic macrofauna is found even though the input of food is low and highly seasonal. This is probably due to the fact that large parts of the Arctic consist of relatively shallow shelf areas with a tight pelago-benthic coupling. In addition, the low temperatures prevalent in the Arctic Oceans reduce the energy requirements of benthic organisms. In combination with a high abundance of species that can live for more than 25 years (Blicher et al. 2007, Sejr & Christensen 2007), a high biomass is slowly built up despite a limited annual primary production.

The benthic biodiversity is - in an Arctic context - unusually high. It has been estimated that approximately 90% of the 5000 invertebrate species present in the Arctic Sea live on the sea floor (Bluhm 2010). Given that the majority of the more than 2,000 marine invertebrates (not including meiofauna) expected in Greenland waters (Jensen & Christensen 2003) are benthic species, it can be assumed that the marine benthos could account for at least 75% of all animal species in Greenland or about 25% of all species in Greenland including plants and lichens.



Particularly larger species such as bivalves and gastropods are important prey items for eiders, walruses and some seals. Also a number of commercially important species such as scallops, crabs, and shrimp live on or near the sea floor.

A fundamental conclusion from findings of various benthic surveys conducted in the past years has been that there is not just one typical Arctic benthos community, but a wide variation in communities found in different regions and in distinct depth zones. There is for example, an exponential decline in benthic diversity along a shelf-slope-basin gradient (Piepenburg 2005), but see Section 4.4.3 below. In addition to depth, other factors such as sediment heterogeneity, disturbance, food availability, geographical setting, sea ice cover, particle load from land and hydrographical regimes also influence benthic diversity and species composition. Compared with pelagic organisms, which often display significant seasonal variation in biomass, benthic biomass is much more stable and benthos is thus a predictable food source for the higher trophic levels (Hobson et al. 2002, Born et al. 2003, Richman & Lovvorn 2003).

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

#### **4.4.2 Benthic fauna in the assessment area**

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

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

In order to improve our knowledge and understanding of the benthic fauna in the Baffin Bay assessment area, a larger field study was initiated in 2008, with the aim to obtain information on the species composition and diversity of benthic macro-invertebrates in the eastern part of the Baffin Bay (71° to 78° N). The results from the study presented in Box 1 constitute important baseline information concerning the benthic habitats in the area. Another study, carried out in the intertidal zone, is described in Box 2.

A wide range of physical and biological factors determine the composition and biomass of the benthic community. One of the most important is the composition of the sediment which varies from soft bottom sediments dominated by silt particles (grain diameter < 63 µm) across various types of sand and gravel to hard substrates made of large boulders or solid rock. Distinct benthic assemblages are often found at different substrates. Although soft bottom habitats generally dominate at depths below 100 m, the substrate composition is often highly variable at the meter scale, i.e. between replicate samples at the same station. The variability of the substrate can be related to factors

# Box 1

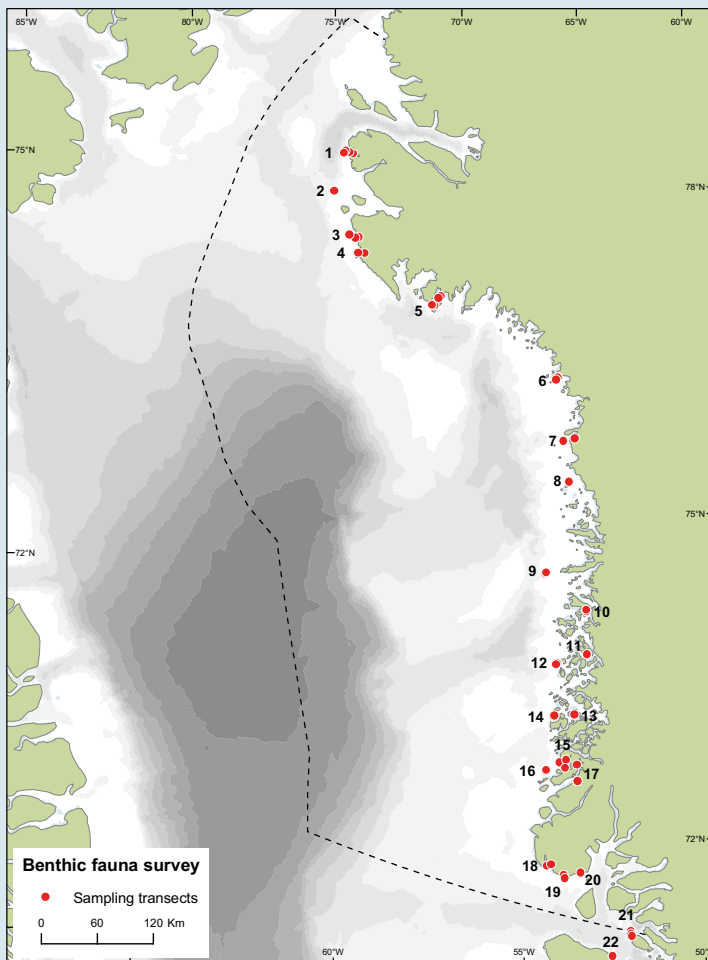
## Benthic fauna studies in Baffin Bay assessment area in 2008

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

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



**Figure 1.** Photos of the seafloor at different stations in the sampling area describing variations in the physical and biological structure. (A) St. 15.3, (B) St. 8.1, (C) St. 9.3, (D) 9.1 and (E) St. 5.2 (Blicher et al. 2008).



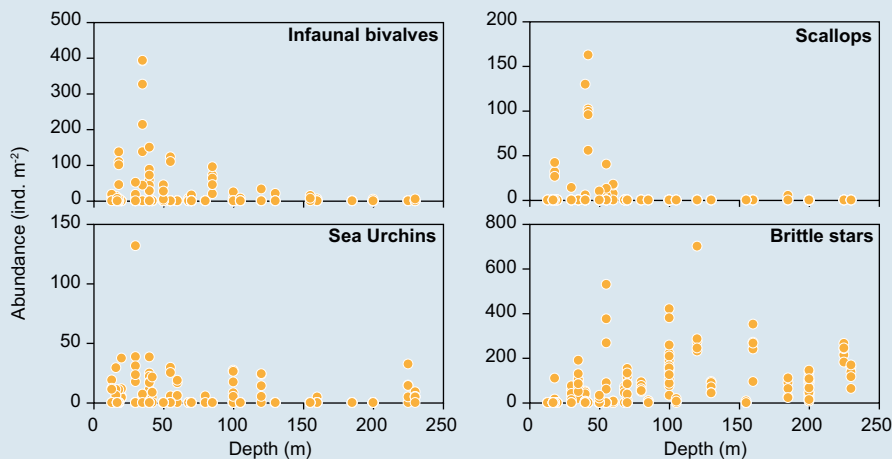
Sampling locations were distributed from north to south in four 50 m depth ranges: 0-50, 50-100, 100-150 and 150-200 m. The shallow part, 0-50m was given highest priority because at these depth range importance of the benthos as food source for higher trophic levels such as seabirds and marine mammals is likely to be highest. Additionally, it is also in the shallow areas that impacts must be expected from potential oil spills. Whenever weather and bottom conditions allowed it, sampling was conducted near sites known to have high densities of seabirds and walrus at different times of the year.

In areas where boulders and rocky substrates were abundant, photos (approximately 0.2 m<sup>2</sup> each) were taken with a benthic drop camera to estimate abundance of large species on soft and hard substrates and the composition of the benthic fauna. The photos are an efficient way of obtaining basic information regarding type of substrate and the abundance of larger, especially epifaunal species. However, photos do not allow detailed taxonomic identification and provide no information on biomass. Examples of typical pictures from soft sediment, gravel and hard sediment are given in Figure 1. Most of the photos taken and analysed in this study are from sampling locations with a water depth less than 100 m and at sites where soft sediments were dominating.

**Figure 2.** Sampling stations (transects along which several samples were made) during the DCE/GINR 2008 survey.

## Abundance and species composition based on photos

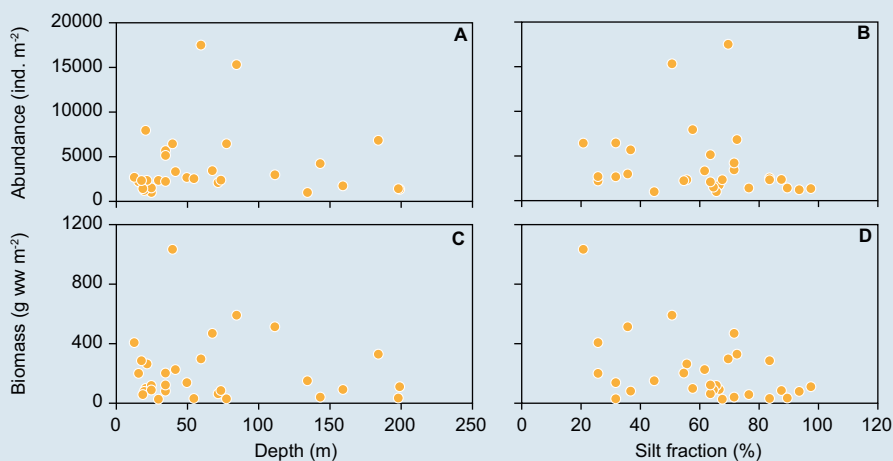
A total of 202 photos were analysed covering approximately 35 m<sup>2</sup>. A total of 38 different taxa were observed in the photos (Table 1); the most abundant being brittle stars (*Ophiura robusta*, *Ophiopolis aculeata* and *Ophiocten sericeum*), infaunal bivalves (*Mya* sp, *Hiatella arctica* and others, scallops (*Chlamys islandica*) and sea urchins (*Strongylocentrosus droebachiensis*) (Figure 3). As observed in Greenland fjords (Sejr et al. 2000), the abundance of large infaunal bivalves was highly variable, but it generally peaked at depths between 10 and 50 m where the sediments consisted of soft sediment mixed with gravel and stones. Scallops were mostly abundant in the same depth segment, but attained highest abundance where the sediment was dominated by gravel. Brittle stars were by far the most abundant group in the photos. High abundances of several 100 individuals m<sup>-2</sup> were encountered in both soft sediments and sediments dominated by gravel and larger stones. This is in line with observation from the Arctic in general, where brittle stars are often the dominant epifaunal species (Piepenburg, 2000, Sejr et al. 2000).



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

## Abundance and biomass based on grab samples

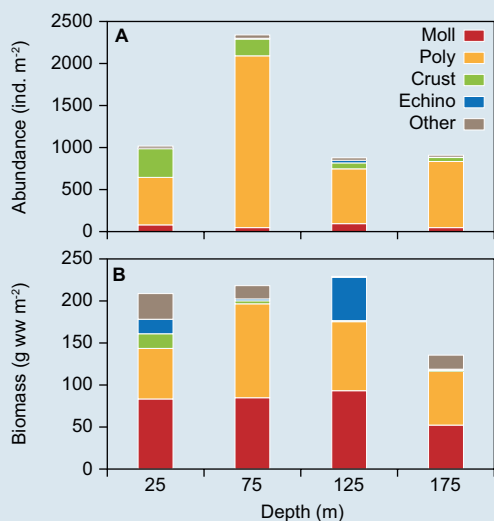
The average benthic biomass showed great variability between sampling stations ranging from 23 to 1030 g wet weight (ww) m<sup>-2</sup> (including shells and skeletons). The biomass did not show any clear correlation with either depth or sediment type (% silt particles, Figure 4). An average biomass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



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

**Table 1.** Taxa identified from the benthic photos.

Phylum	Species
Mollusca	Indet. infaunal bivalves
	<i>Hiatella arctica</i>
	<i>Mya</i> spp.
	<i>Chlamys islandica</i>
	<i>Polyplacophora</i> spp.
	<i>Tectura</i> sp
	<i>Gastropoda</i> indet. 1
Echinodermata	<i>Strongylocentrotus droebachiensis</i>
	<i>Ophiura robusta</i>
	<i>Ophiocten sericeum</i>
	<i>Ophiopolis aculeata</i>
	<i>Opiopleura borealis</i>
	<i>Ophioroidea</i> indet.
	<i>Holothuriodea</i>
	<i>Crossaster</i> sp.
	<i>Asteroidea</i> sp.
	<i>Crinoidea</i> spp.
Cnidaria	Indet. <i>Anemone</i>
	Indet. <i>Alcyonarian</i> 1
	Indet. <i>Alcyonarian</i> 2
	<i>Hydrozoa</i> indet sp. 1
	Crustacea
<i>Mysicacea</i> spp.	
<i>Decapoda</i>	
Indet. <i>Isopoda</i>	
Pycnogonida	
Bryozoa	Indet. <i>Bryozoa</i> 1
	Indet. <i>Bryozoa</i> 2
	Indet. <i>Bryozoa</i> 3
	Indet. <i>Bryozoa</i> 4
	Indet. <i>Bryozoa</i> 5
Brachiopoda	<i>Brachiopoda</i> indet.
Annelida	<i>Polychaeta</i> indet 1
	<i>Polychaeta</i> indet 2
Porifera	<i>Porifera</i> indet.
Hemichordata	<i>Ascidia</i> indet 1
	<i>Ascidia</i> indet 2
Chordata	<i>Pisces</i> spp



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

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

### Species compositions based on grab samples

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

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

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

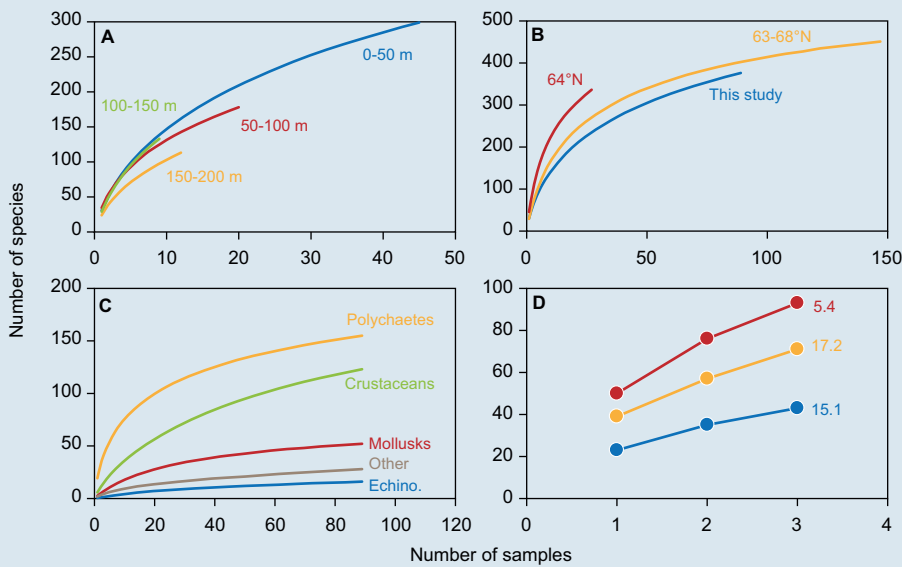
	% contribution			
	0-50 m	50-100 m	100-150 m	150-200 m
<i>Pholoe longa</i>	9.3	0.7	0.2	0.0
<i>Philomedes globosus</i>	8.2	2.8	0.3	0.8
<i>Chaetozone setosa</i>	6.0	5.6	14.8	3.4
<i>Prionospio steenstrupi</i>	4.3	2.2	7.8	9.1
<i>Owenia fusiformis</i>	5.2	33.2	1.2	47.9
<i>Polydora sp.</i>	5.8	18.5	0.0	0.0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

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

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

### Biodiversity

A total of 377 different species were found in the grab samples: 156 polychaetes, 123 crustaceans, 16 echinoderms, 54 molluscs and 28 species belonging to other taxonomic groups. Plots showing the statistical increase in total number of species for each new sample analysed (species-area plots) show no tendency for saturation (Figure 6). Additional sample analysis is, thus, expected to add new species to the total species list. When comparing the different depth segments (Figure 6A) the deepest depth segment (150-200 m) shows the lowest species richness. Species area plots of replicates within stations also show a lack of saturation in species richness. There are two other studies available in West Greenland with which the total species richness can be compared (Figure 6C). One study near Nuuk (64° N) was based on three replicates from each of nine different stations ranging in depth from 47 to 956 m in the Godthåbsfjord and on the shelf (Sejr et al. 2010b). The large difference in depth and substrate at the relatively few stations sampled in the Godthåbsfjord study is part of the reason for the steep increase in number of species identified compared to the present study. Another study was conducted at and around the Store Helle-



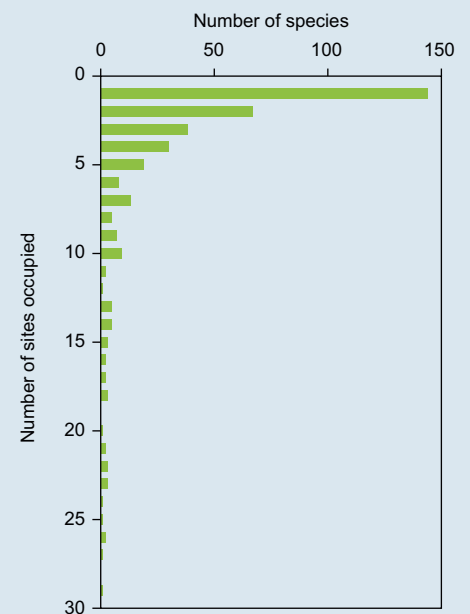
**Figure 6.** Species accumulation curves: (A) for the four different depth segments studied in the eastern Baffin Bay. (B) for major taxonomical groups; (C) from eastern Baffin Bay (this study) compared to two other studies in West Greenland; (D) for three replicates from three different stations sampled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

fiskebanke, located at 63–68° N (Marin ID 1978). Samples were collected at 32 stations ranging in depth from 25 to 550 m. The species richness (excluding Bryozoans) was slightly higher than observed in the current study (Figure 6C). Whether the observed differences between surveys conducted in the sub-Arctic and the present study can be attributed to a difference in the depth, substrate or latitudinal effects is presently unknown. From the data available, the benthic species richness in West Greenland is significantly higher than in North and East Greenland, and West Greenland appears to be a region with high species richness compared to 14 other Arctic regions (Piepenburg et al. 2011). In a comprehensive study on the Norwegian shelf (56–71° N), the total species richness was 809 species based on 101 sites (5 replicates per site), ranging from 65 to 434 m depth (Ellingsen & Gray 2002). No evidence of a latitudinal effect was found on the Norwegian shelf, whereas some aspects of diversity could be related to habitat (sediment) heterogeneity.

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

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

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



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

## Box 2

### Rocky intertidal community structure in West Greenland

M.K. Sejr, S. Wegeberg, M.E. Blicher, S. Høgslund, D. Krause-Jensen, K.N. Mouritsen, B. Olesen & J. Thyrring

#### Introduction

The intertidal zone is one of the best studied marine habitats. Due to its easy access, it has been used as a model habitat to study species interactions and general ecology and is used for monitoring impacts of climate change and environmental conditions in general. However, at present the rocky intertidal zone in Greenland is largely unstudied (but see Høgslund et al. 2014). Here, we present preliminary data from recent efforts to provide baseline data on biomass, diversity and species composition and identification of key factors influencing flora and fauna in the intertidal zone in the assessment area (Figure 1). These efforts are ongoing and have been funded by several independent grants. The field work conducted in the Upernavik region was financed in relation to this impact assessment.

#### Research aim and sampling design

Factors influencing community composition are highly scale-dependent. Thus, a key goal of this project was to compare biomass, diversity and species composition at different scale. The spatial scales we focused on were

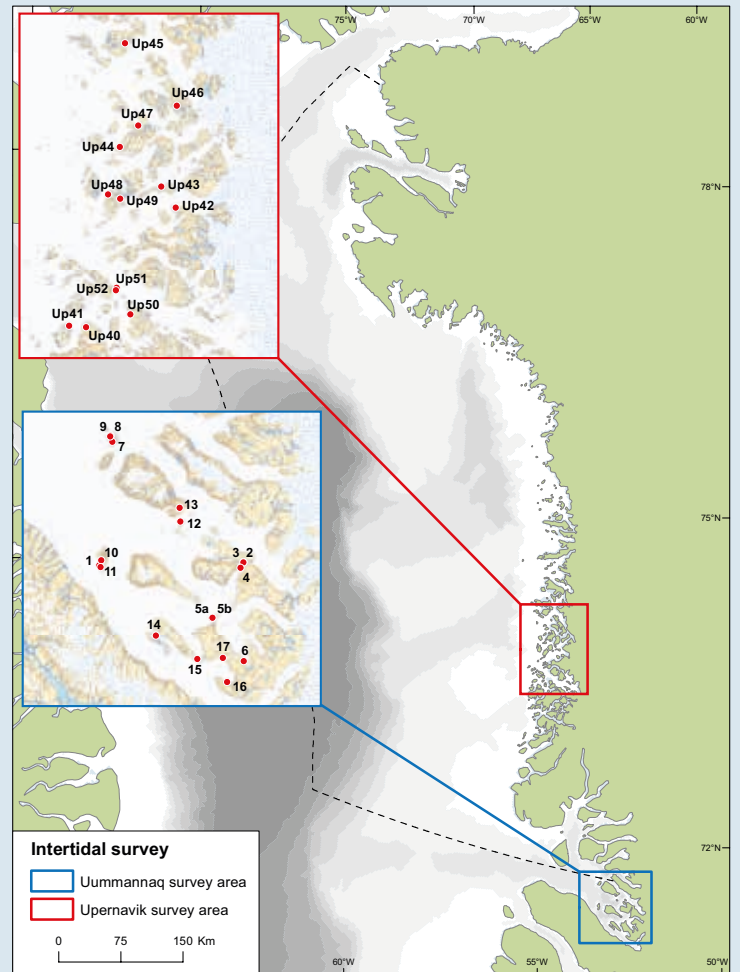
- Large scale (100s km) latitudinal variation along the Greenland coast
- Meso scale (10s km) typically within a fjord
- Small scale (m) vertical variation related to tidal amplitude
- Micro scale (cm) related to surface roughness

In addition to the spatial variation, temporal variation was studied with the aim of identifying re-colonization dynamics after a plot was cleared or partly cleared of organisms (this was followed over a three year period). Also, as part of the marine monitoring program we compared inter-annual variation in population dynamics of flora and fauna at an intertidal site in Nuuk.

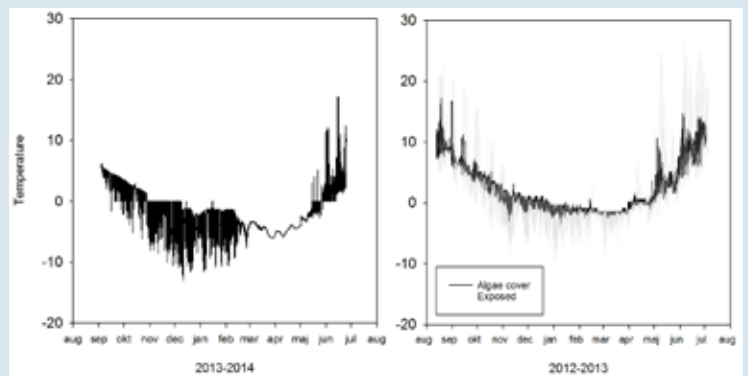
Sampling was usually conducted in the mid-intertidal, sometimes supplemented with sampling at lower and higher elevations. At each site, sampling was done inside a frame measuring 25 by 25 cm and seven replicates were taken. All flora and fauna inside the frame were identified to the lowest taxonomical level. A total of 59 sites were sampled in 6 different regions of West Greenland, resulting in more than 400 samples covering a total of approximately 26 m<sup>2</sup>. In addition to the biological sampling, environmental factors were scored to the extent possible. For example, seasonal temperature variation was measured by mounting temperature loggers. In Figure 2, the seasonal temperatures from two sites are compared. A characteristic feature was the extreme diurnal temperature variation that often exceeds 15°C. On a seasonal scale the total range in temperature experienced by organisms in the intertidal zone often approached 40°C. In Uummannaq, air temperatures dropped below -10 in winter, but around March the diurnal variation disappeared, most likely due to formation of an ice foot around the sensors, which isolates them from low air temperatures. In Nuuk, loggers were placed at an exposed site and at a site with 100% algae cover. Just like the ice foot, a dense cover of macroalgae could modify extreme temperatures during both winter and summer.

#### Large scale variation in Greenland

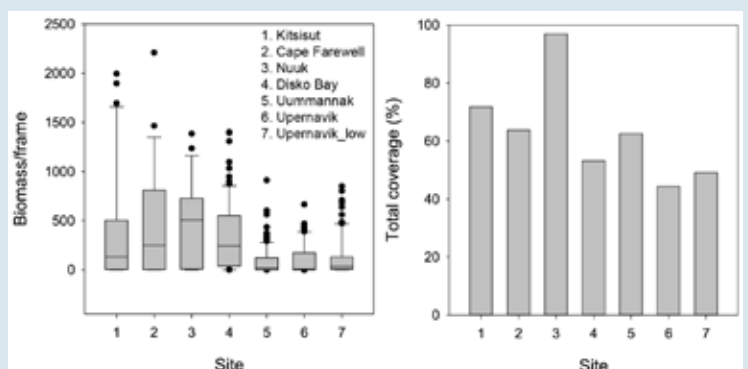
We found a general decrease in maximum biomass values along a south-north gradient (Figure 3). At the four first sites in southern Greenland, we found several observations of biomass of 1000 g or more per frame, equalling more than 15 kg per m<sup>2</sup>. North of Disko Bay, a significant drop was seen. Notice that in Upernavik, we



**Figure 1.** Map of sample sites in the Uummannaq and Upernavik regions.



**Figure 2.** The left panel shows seasonal temperature variation in the mid-intertidal zone near Uummannaq. The right panel shows temperature from two sensors in the mid-intertidal zone in Kobbefjord, Nuuk. One sensor was placed on bare rock and one at 100% cover of algae.

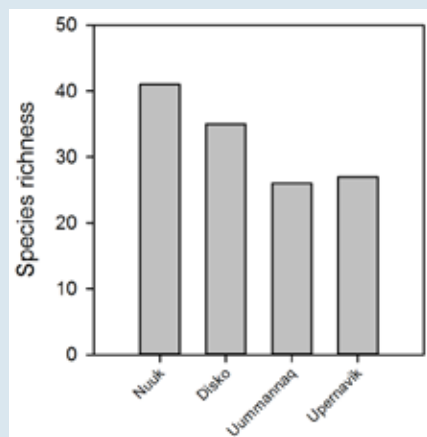


**Figure 3.** Large scale variation in biomass (per 0.0625 m<sup>2</sup> sampling frame) and total cover (%) along the West Greenland coast from approximately 60° to 73° N.

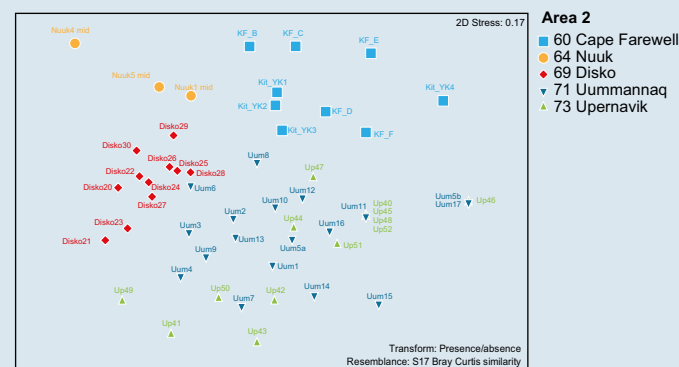
sampled two vertical heights; the mid intertidal and also 30 cm below. The macroalgae *Ascophyllum nodosum* was the primary contributor to sites with very high biomass. A decreasing trend in the total cover from south to north was also observed. However, even in Upernavik under Arctic conditions, approximately half of the rocky intertidal surface zone was covered by flora and fauna, although the total biomass was lower compared to sites further south. The total species richness (Figure 4) decreased going from south to north with the two northern sites Uumannaq and Upernavik being similar. When comparing the species composition along the north to south gradient, samples generally formed clusters with other samples from the same fjord (Figure 5). As for the biomass and species richness, there appeared to be a change north of Disko Bay, where several species disappeared such as the gastropod *Littorina obtusata*, the crustacean *Gammarus oceanicus* and the macroalgae *Ascophyllum nodosum*.

### Meso and small scale variation

To study the local variation within an individual fjord system, four sites were sampled in the Godthåbsfjord (Figure 6). They were selected to represent increasing influence of stress from waves and glacier ice. At each of the sites, samples were collected at three intertidal elevations also representing a stress gradient with the upper elevation experiencing prolonged air exposure and, thus, desiccation. The response of the intertidal community to the different types of stress is shown in Figure 6, which shows the total biomass (A), species richness (B) and total cover (C). In general, it can be seen that increasing stress levels cause a decrease in biomass, richness and cover on both the horizontal scale (between sampling sites) and the vertical scale (within each sampling site). The statistical model including site, tidal elevation and substrate roughness explained the majority of the variance in community parameters (85 to 92%). The importance of surface roughness was especially high at the two sites experiencing significant impact of ice scouring. Here, surface roughness had a statistically significant positive impact on species richness, with crevices allowing development of the tidal community through modification of stress factors.



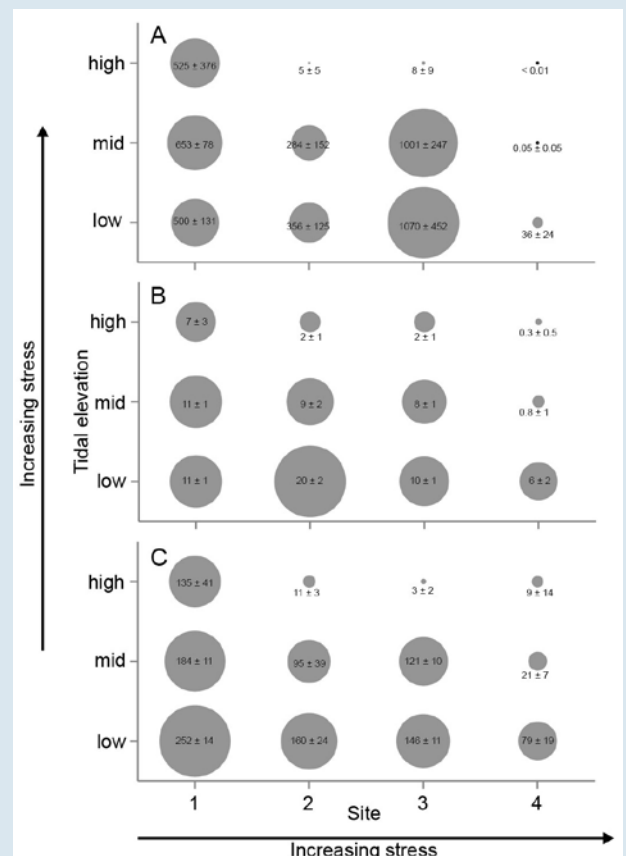
**Figure 4.** Total species richness in the mid intertidal zone in different fjord systems along the West Greenland coast.



**Figure 5.** Plot showing the relative similarity in species composition (based on presence/absence data) at different sampling sites within five different fjord systems in West Greenland

### Community structure driven by physical stress and stress alleviation

Based on our preliminary analysis of the data, it appears that the community structure in the intertidal zone in Greenland is very strongly linked to physical factors resulting in different types of stress for the individual organisms. For some types of stress, such as desiccation and temperature, species display clear differences in their tolerance resulting in vertical zonation or different latitudinal distributions. Other types of stress, such as physical stress from waves and ice scouring, create a more random mosaic of community structure. As a consequence of the importance of physical stress, factors modifying stress have a significant influence. Stress modification can occur from physical factors, such as shore orientation and morphology, which provides shelter from waves, and small crevices that provide shelter from ice scouring. But organisms like macroalgae can also modify stressful temperatures, as exemplified in Figure 1. The combination of factors, inducing stress and those that modify it creates a super variable mosaic pattern where multiple factors working at different scales are involved. As a consequence, one of the big challenges when using intertidal data in monitoring environmental status or change is to accurately describe the physical factors at the relevant spatial and temporal scales. For example, in our studies it is apparent that the community structure we studied during summer is strongly influenced by processes taking place in winter and early spring such as low temperature extremes, ice foot formation and ice scouring. Through the project, we developed a range of techniques to quantify the variation in ice scouring, wave impact, temperatures and surface roughness. Combined with manipulative studies, this allows detailed studies of how climate in a broad sense shape community structure at different scales.



**Figure 6.** Vertical and horizontal variation in (A) biomass, (B) species richness and (C) total cover at 4 sites in the Godthaabsfjord. At each site the mid intertidal zone and low (-75 cm) and high (+75 cm) was sampled

such as depth, distance from glaciers or rivers or input of ice rafted material such as drop stones (stones dropped from icebergs). In shallow coastal areas, scouring icebergs occasionally crush the benthos thereby creating additional variability (Gutt & Starmans 2003). Another challenge is that large boulders and rocky substrates are abundant especially at shallow depths. Such habitats cannot be sampled quantitatively using conventional grab sampling.

Compared with other Arctic regions, the composition of benthic fauna off West Greenland generally shows the highest resemblance to the western part of the Baffin Bay and the Davis Strait and northern Labrador although the pattern differs between different taxonomical groups (Piepenburg et al. 2011). However, in the Piepenburg et al. (2011) study the West Greenland fauna was only quantified based on 45 stations from the sub-Arctic part of the region.

#### **Northern shrimp *Pandalus borealis***

The northern shrimp is the only species from the benthic fauna, that today is utilised on a commercial basis in the assessment area. However, snow crab was utilised until 2004. Although not a true benthos species, the northern shrimp lives on and near the sea bed (epibenthic). It is found on the West Greenland continental shelf and is more or less continuously distributed from Cape Farewell (60° N) to about 74° N, with the highest densities occurring at depths between 150 and 600 m. Within this area, there is little evidence of stock sub-structure, and the population has been assessed as a single stock. During the day, shrimp stay at the bottom, but may perform vertical movements up in the water column during the night. The eggs are laid in summer and carried by the female until the following spring (April-May), when the females seek shallower water on the banks and release the larvae. These are planktonic for three or four months, at which time they drift passively with the currents and subsequently settle on the seafloor far from their release site (Pedersen et al. 2002). Three to six years later they become sexually mature first as males and later, when six to eight years old, as females. Females are larger than males and are therefore the main target for commercial fishery. This took place in the southern part of the assessment area until 2014, but since then fisheries have been tried further north with promising results (Burmeister & Christensen 2016) (Figure 45, p. 187). See also Section 5.1 on the utilisation of the northern shrimp stocks in the assessment area.

#### **Snow crab *Chionoecetes opilio***

The snow crab is another epibenthic species from the assessment area. It is found both offshore and inshore (fjords) (Burmeister 2002), and it predominantly inhabits soft bottom (mud or sand-mud substrate) at depths between 100 and 800 m and at water temperatures ranging from about -1.0 °C to about 4.5 °C.

Similar to other brachyuran crabs, its life cycle features a planktonic larval phase and a benthic phase with separate sexes. The larvae proceed through three planktonic stages before settling on the bottom during autumn, where they feed on fish, clams, polychaetes, brittle stars, shrimp, other crabs (incl. their own species) (Lefebvre & Brêthes 1991, Sainte-Marie et al. 1997).

The early life history of the snow crab, including larval drifts between offshore and inshore sites, nursery grounds, settling and occurrence of benthic stages is unknown or poorly elucidated for the assessment area. The population occurring in the assessment area has an unfavourable conservation status due to years of high fishing pressure. See also Section 5.1 on the utilisation of the snow crabs in the assessment area.



#### 4.4.3 Important and critical areas for benthic fauna

The existing knowledge of distribution, diversity and abundance of the benthos in the assessment area is still too incomplete to identify especially important and or critical habitats except for the shrimp fishing ground (Figure 45).

A special type of benthic community is the cold water coral reefs and sponge gardens. These are particularly sensitive to activities that physically impact the seabed and to sedimentation of particles (Freiwald et al. 2004). A cold water coral reef was recently found in the Davis Strait off Southwest Greenland (Tendal et al. 2013), but neither these nor sponge gardens have so far been located in the assessment area of this SEIA.

In broad terms, the abundance of bivalves is highest in the shallow depth segment (0-50) where also the highest species richness is found. In terms of ecological significance the shallow areas are thus expected to be most important to seabirds and marine mammals. Other studies using underwater video surveys in the area have also documented high abundance of large kelps, sea urchins and crustaceans at depths from 3-25 m (M.K. Sejr *pers. obs.*). Regarding diversity it is important to note, that although the highest species richness has been observed in the shallow segment, species richness has been found to increase from 200 to 2500 m depth in other areas (M.K. Sejr *pers. obs.*), which contradicts the findings of Piepenburg et al. (2005) quoted above. Thus, the region with the potentially highest species richness remains to be studied. Commercial fisheries of scallops and crabs take place within the study area, which can be considered vulnerable to impacts of oil exploration.

#### 4.4.4 Vulnerability

Generally the occurrence of several species with an estimated maximum age of more than 25 years (the bivalves, *Mya* spp., *Hiatella arctica* and *Chlamys islandica* and the sea urchin *Strongylocentrotus droebachiensis*) indicates that the benthic community will be very slow to recover after any type of impact causing mortality of these old individuals that often constitute most of the biomass. From a biodiversity perspective the high prevalence of species found at only one site and of species represented by only single specimens also suggests that mortality from oil spills or exploration activities may result in a significant reduction of total species richness.

#### 4.4.5 Benthic fauna and climate change

Wassmann et al. (2011) presented 12 examples of climate change driven changes in benthic communities including species-specific changes in growth, abundance and distribution ranges as well as changes in species compositions, changes that may also apply to the current assessment area. For example, sub-Arctic and boreal species will become more frequent in the assessment area, creating changes in zoobenthic community structure and probably in functional characteristics as well, especially in coastal areas.

There are already indications of such changes in distribution, including northward range expansion of temperate species, and changes in productivity (Sejr et al. 2009), biomass or communities (Grebmeier et al. 2006). Similar changes have previously been observed during intrusion of unusually warm water along the West Greenland coast and the Barents Sea in the 1920s and 1930s (Jensen 1939, Jensen & Fristrup 1950).

Wesławski et al. (2011) have described and assessed future changes in Arctic benthic communities. In itself, the predicted temperature rise will likely have only minor effects on the coastal benthos, since near-shore living organisms are often adapted to a wide temperature range. More important for the coastal benthos are variables associated with a temperature rise – increase of coastal turbidity and sedimentation, changes in ice cover, increase in storminess, increasing coastal erosion and freshening of surface waters.

#### 4.5 Sea ice communities

S. Wegeberg & D. Boertmann

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

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

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

In the North Water Polynya in the northern part of the assessment area, only < 1-3% of the in-ice community was found to consist of protists (ciliates and dinoflagellates). The microalgal fraction was strongly dominated by pennate diatoms (> 91%) of which the species *Nitzshia frigida* prevailed and constituted to, on average, 85% of total ice algal cell numbers. In the Greenland Sea, the algae were found to contribute to the biomass of the sea ice communities with 43%, bacteria with 31%, heterotrophic flagellates with 20% and meiofauna with 4% (Gradinger et al. 1999). *Melosira arctica*, together with the pennate diatom, *Nitzshia frigida*, tended to be the dominant diatom species off Northeast Greenland/Barents Sea (Gutt 1995, Gosselin et al. 1997, Quillfeldt et al. 2009). However, Irwin (1990) only found *Nitzshia frigida* in the fraction of chain-forming diatoms, constituting 26% of the diatoms, while a large, centric *Cosinodiscus* species was dominant (65%) off Labrador. In the fjord, Kobbefjord in West Greenland (south of the assessment area), Mikkelsen et al. (2008) found that flagellates (prasinophytes, dinoflagellates, cryptophytes) and both centric and pennate diatoms were regular components of the sea ice algal community. Of the diatoms especially *Chaetoceros simplex*, a colonial, centric diatom, was dominant (constituting 75% of total sea ice algal abundance) during its bloom in March. In Davis Strait, Booth (1984) found total dominance of pennate diatom genera.

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

Source	Off Labrador	Arctic Ocean	Kobbefjord	Barents Sea
Irwin (1990)	4.4			
Gosselin et al. (1997)		8.55**		
Quillfeldt et al. (2009)				6.5
Mikkelsen et al. (2008)			0.8*	

The ice-algal production in the Arctic ranges from 5 to  $15 \text{ g C m}^{-2} \text{ year}^{-1}$  depending on sea ice cover (Mikkelsen et al. 2008). Irwin (1989) estimated an annual production of  $4.4 \text{ g C m}^{-2}$  off Labrador, and  $< 1 \text{ g C m}^{-2} \text{ year}^{-1}$  has been reported from Kobbefjord (Mikkelsen et al. 2008) and in Young Sound, Northeast Greenland (Rysgaard et al. 2001).

The ice algal production in the northern part of the Barents Sea is reported to  $5 \text{ g C m}^{-2} \text{ year}^{-1}$ , which corresponds to 16-22% of the total annual primary production (Quillfeldt et al. 2009), and the ice algae in the Arctic Ocean were found to contribute on average 57% of entire primary production ( $15 \text{ g C m}^{-2} \text{ year}^{-1}$ ) (Gosselin et al. 1997). However, in the assessment area, Michel et al. (2002) found that ice algae only represented a small fraction of the total algal biomass,  $< 3\%$ , in the North Water Polynya, and Mikkelsen et al. (2008) and Booth (1984) found that the ice algae only accounted for  $< 1\%$ <sup>1</sup> of the pelagic primary production in Kobbefjord and Davis Strait, respectively. In Young Sound, Rysgaard et al. (2001) reached a similar result over their measuring period.

Estimates of annual primary production of ice algae communities in the Arctic seas are presented in Table 2.

Mikkelsen et al. (2008) tested whether the ice algae acted as primers of the spring bloom of phytoplankton in the water column by algal seeding, but they did not obtain any conclusive results. Michel et al. (2002) concluded that in the North Water Polynya ice algal species released into the water column did not appear to play an important role for the phytoplankton development. The ice algal community was dominated by pennate diatoms species by up to 85% while the phytoplankton bloom was very strongly dominated by pelagic species of centric diatoms not present in the ice algal community. Also Booth (1984) found that species composition in the sea ice differed significantly from that of the phytoplankton.

In the North Water Polynya, the fauna inside the ice was found to be dominated by ciliates and heterotrophic dinoflagellates and the fauna on the underside by nematodes (Nozais et al. 2001, Michel et al. 2002). In other areas also flatworms and crustaceans are among the dominant species of the meiofauna (Gradinger et al. 1999, Arndt et al. 2009). Gradinger et al. (1999) calculated a potential ingestion rate of the meiofauna, which was similar to the estimated annual sea ice primary production, and therefore they assumed that grazing could control biomass accumulation. However, since the biomass of grazers was not exceptionally high, Rysgaard et al. (2001) considered the low ice algal production recorded in Young Sound not to be caused by high grazing

<sup>1</sup> Calculated from an ice algal production of  $0.8 \text{ g C m}^{-2}$  and phytoplankton production of  $94.4 \text{ g C m}^{-2}$  from November to June in Kobbefjord (Mikkelsen et al. 2008).

pressure. In addition, Michel et al. (2002) concluded that only a small amount of ice algal production was channelled through the meio- and microfauna within the ice in the North Water Polynya due to the suboptimal prey size for predators.

The importance of the sea ice algal production compared with the phytoplankton production may vary somewhat according to locality but is almost 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. The production inside the ice could also play a role in ensuring the availability of ice algae for under-ice pelagic and benthic grazers during spring, and grazing is limited inside the ice.

The production of the ice community may be of great importance at times of the year when pelagic and benthic production are relatively low, especially just before the spring bloom of phytoplankton, and it may thus attract crustaceans and fish species such as polar cod and Arctic cod.

In addition, sea ice communities are expected to be very vulnerable to oil spills as the ice may catch and accumulate oil in the interface between ice and sea. Also, the oil may penetrate the ice through brine channels, such interfaces and channels being the spaces occupied by sea ice communities. Especially accumulations of polar cod eggs and larvae will be vulnerable (Section 10.7.1).

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. It should be noted, though that the multi-year sea ice habitat is being rapidly reduced, and in a few decades it may be restricted to small areas 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 Baffin Bay marine ecosystem, including topics such as critical elements dependent on the ice (e.g. polar cod egg development).

## **4.6 Fish**

O.A. Jørgensen, H. Siegstad & R. Nygaard

Present knowledge of the fish fauna in Northwest Greenland (including the assessment area) is mainly based on information obtained during early Danish expeditions and follow-up analyses (Jensen 1926, 1935, 1939), on more recent studies of single fish species, including description of new species (Nielsen & Fosså 1993, Møller & Jørgensen 2000, Møller 2001) and fisheries-related research activities and assessments (Jensen & Frstrup 1950, Pedersen 2005). A checklist to all fish recorded in Greenland waters was recently published (Møller et al. 2010).

### **4.6.1 Fish assemblages**

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

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

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

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

#### 4.6.2 Selected fish species

##### **Greenland halibut *Reinhardtius hippoglossoides***

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

The biology of Greenland halibut in the Baffin Bay is poorly known. Neither spawning nor indications of spawning have been observed, either offshore or inshore, but the offshore area has only been surveyed in late autumn. At present it is believed that Greenland halibut recruits arrive as larvae from a spawning area in the Davis Strait. The larvae drift from the Davis Strait along the coast in the West Greenland Current. At least the southern part of the assessment area is an important nursery area for Greenland halibut. As they grow they gradually migrate back towards the spawning areas in the Davis Strait. Preliminary tagging results support this assumption about the connection between the Greenland halibut population in the Davis Strait and Baffin Bay.

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

The Greenland halibut stock in the area is assessed annually by the Northwest Atlantic Fisheries Organisation (Jørgensen & Treble 2015). Bottom trawl surveys are conducted regularly in the Canadian part of Baffin Bay by Canada, latest in 2012 and 2014 (Treble 2015), and more irregularly by Greenland, most recently in 2004 and 2010 (Jørgensen 2005, 2011).

#### **Polar cod *Boreogadus saida***

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

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

Polar cod is largely a zooplankton-feeder eating copepods and pelagic amphipods (Panasenkov & Sobolova 1980, Ajiad & Gjørseter 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 plays a very important role in the Arctic marine food webs (Figure 13, p. 61) and constitutes an important prey for many marine mammals and seabird species, notably ringed seal, harp seal, white whale, narwhal, thick-billed murre, northern fulmar, black-legged kittiwake, and ivory and Ross's gulls.

#### **Arctic char *Salvelinus alpinus***

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

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

The eggs of the char winter in gravel in deep river pools or in lakes. The fry emerge in April-May and live off their yolk sac for about a month before feeding on small plankton organisms along the margins of rivers or lakes (Muus 1990). The young char called 'parr' remain in fresh water for several years before their first migration to the sea. At a length of 12-15 cm, corresponding to an age of three to six 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 five to seven years.

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

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

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

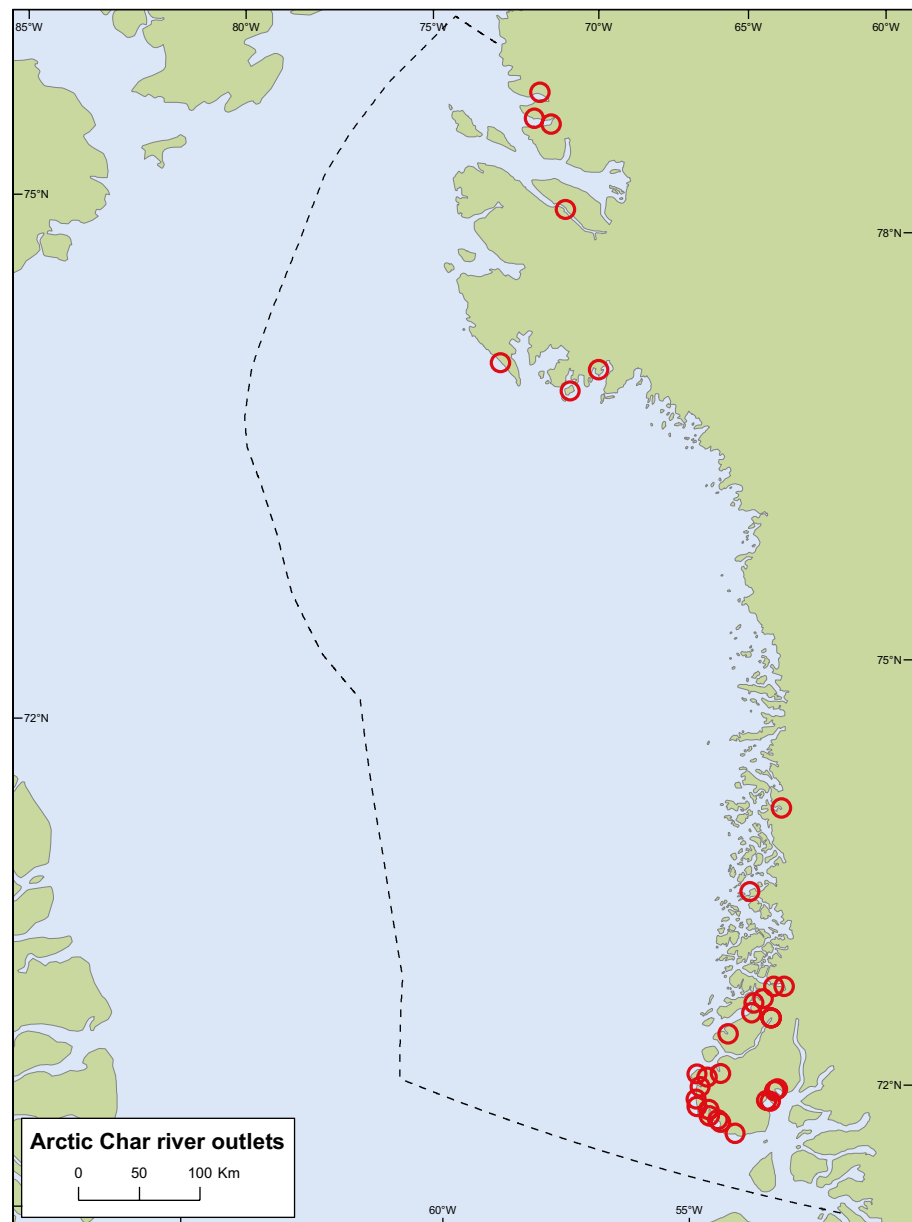
#### **Capelin *Mallotus villosus***

Capelin has a circumpolar distribution and in Greenland it is found from the southern tip up to 73° N on the west and 70° N at the east coast, respectively. In recent years it has moved the range towards north and occurs now regularly in the Qaanaaq area. The population in Greenland is supposed to consist of discrete stocks in individual fjord systems (Sørensen & Simonsen 1988, Hedeholm et al. 2010).

Spawning takes place in shallow water (< 10 m), often close to the beach in the period from April to June. Deep water spawning known from other capelin populations (e.g. Vilhjálmsson 1994) has not been documented in Greenland. Capelin typically spawns at an age of 3-5 years (Hedeholm et al. 2010).

Outside the spawning season capelin is primarily found in the upper pelagic (0-150 m) both in fjords and in offshore waters. However, dense concentra-

**Figure 14.** River outlets with Arctic char. Red circles indicate position of outlets of rivers with anadromous Arctic char. Based on local knowledge (Petersen 1993a, b, Olsvig & Mosbech 2003). The information from northern Upernavik and Qaanaaq municipalities is fragmentary and more rivers with Arctic char probably occur.



tions are sometimes also found in deeper waters down to 600 m (Huse 1998, Friis-Rødel & Kanneworff 2002). Before spawning, capelin migrates to the fjords, where they form dense schools.

Greenland capelin forms a crucial link from lower to higher trophic levels (Hedeholm 2010). From South Greenland it is known that capelin feeds primarily on copepods, krill and *Themisto* spp. (Hedeholm 2010), depending on size. Typical of arctic food webs, feeding on prey with high fat content makes capelin also a high quality prey for various predators such as cod (Hedeholm 2010), harp seals (Kapel 1991), whales and certain seabirds (Friis-Rødel & Kanneworff 2002, Vilhjalmsen 2002). Owing to its importance as food resource for larger fish, seabirds and marine mammals, capelin can be considered as an ecological key species in the southern part of the assessment area.

#### Critical and sensitive habitats

In an oil spill context, the river mouths and their adjacent coastal areas, where migrating char assemble before they move upstream, are the most sensitive habitats. The published knowledge of the occurrence of anadromous populations along the coast of the assessment area is limited. Spawning rivers and



fishing grounds were mapped based on local knowledge during an interview investigation in 2002 covering the former Uummannaq municipality and the southernmost parts of former Upernavik municipality north to 72° 30' N (Olsvig & Mosbech 2003). According to an earlier investigation there are only few char rivers in the northern parts of the former Upernavik municipality and in the former Qaanaaq municipality (Petersen 1993a, b). Figure 14 gives an overview of the known river outlets with spawning Arctic char.

#### 4.6.3 Fish and climate change

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 on 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 and abundance of fish populations will have effects also on fish prey, on predators depending on fish species and on fisheries. For example are yields predicted to increase by approximately 20% for the most important cod and herring stocks in Iceland, and approximately 200% in Greenland over the next 50 years (Arnason 2007). Also, climate-driven fish invasions to the Arctic are also expected to exceed those of any other large marine ecosystem (Cheung et al. 2010).

### 4.7 Seabirds

D. Boertmann

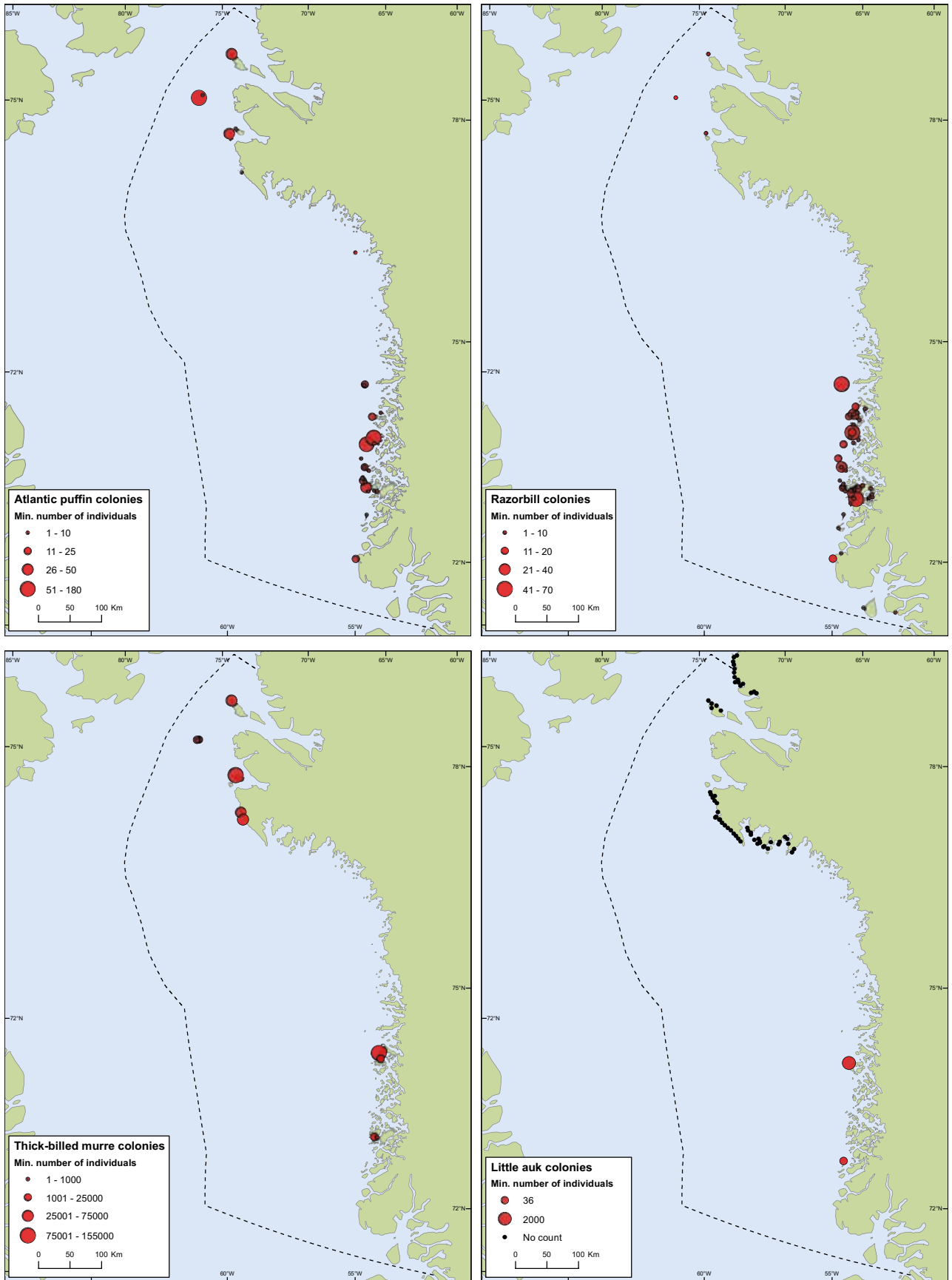
During the ice-free periods, seabirds are very numerous in the assessment area and constitute an important link between the productive marine ecosystem and the relatively low productive terrestrial ecosystem by transporting nutrients from the sea to the breeding colonies on land. Many species are primarily fish eaters consuming schooling species (capelin, sandeel and polar cod). Some species live on or supplement their fish diet with large zooplankton (copepods, *Parathemisto*, krill), and others feed primarily on benthic invertebrates (e.g. bivalves) (Falk & Durinck 1993, Merkel et al. 2007). The species utilise the common resources by means of different feeding methods; for example, some species are deep-diving foragers, while others take their food on the surface. Many seabird species tend to aggregate at breeding or foraging sites where extremely high concentrations may occur (Box 4). For example, 75% of the global population (N = 33 million pairs) of little auks (*Alle alle*) are estimated to breed on a 200 km-long shoreline of the former Qaanaaq Municipality of Northwest Greenland (Egevang et al. 2003). An overview of the seabird species occurring in the assessment area is given in Table 3.

Overall, general knowledge of seabirds in the assessment area is fairly good, and recent studies (Box 4, 5 and 7) have provided new insight into the migration of some of the species.

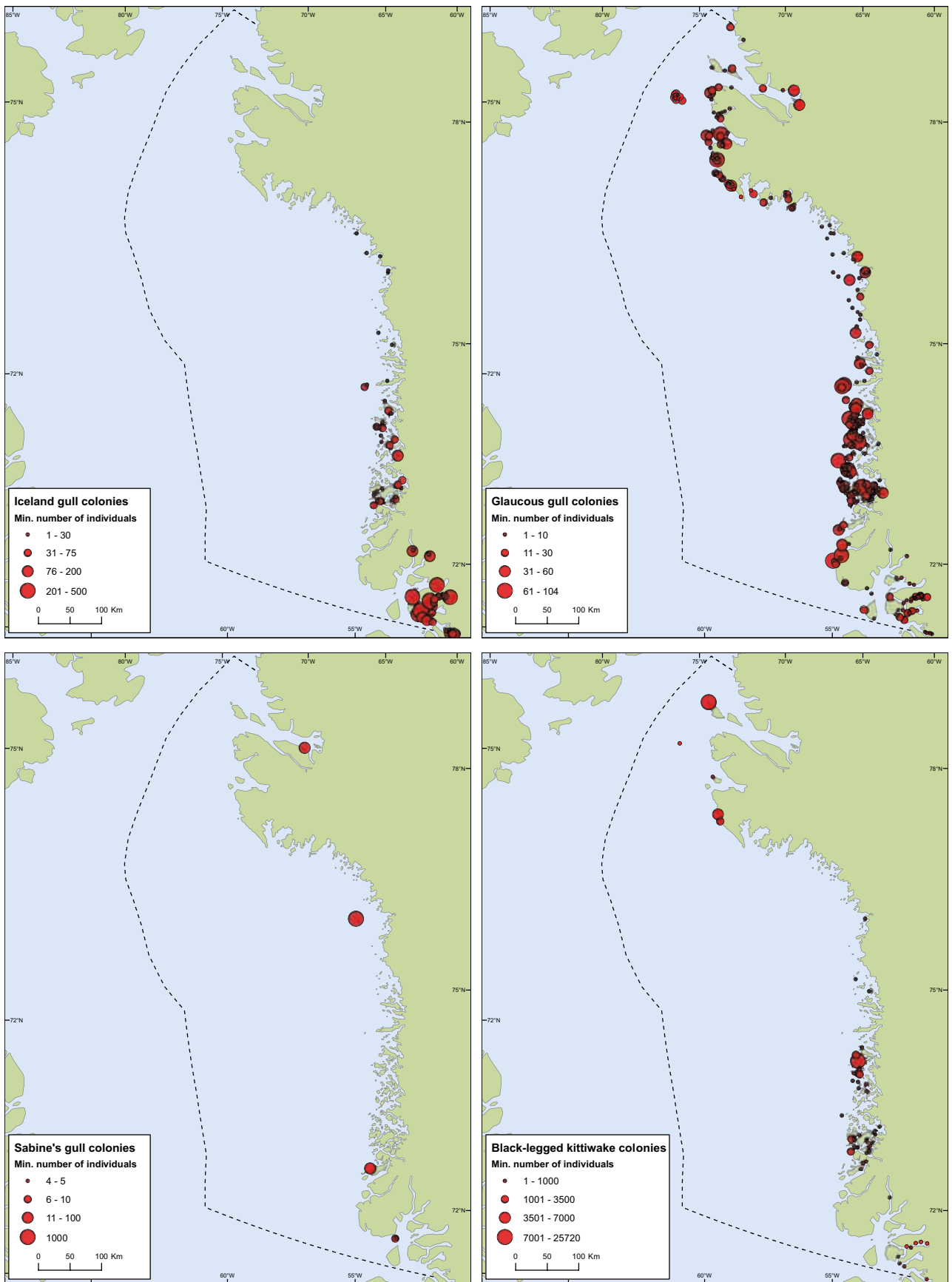
Most seabirds are colonial breeders and numerous breeding colonies are found dispersed along the coast of the assessment area (Figure 15). Colonies vary in size (from a few to millions of pairs) and in composition of species,

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

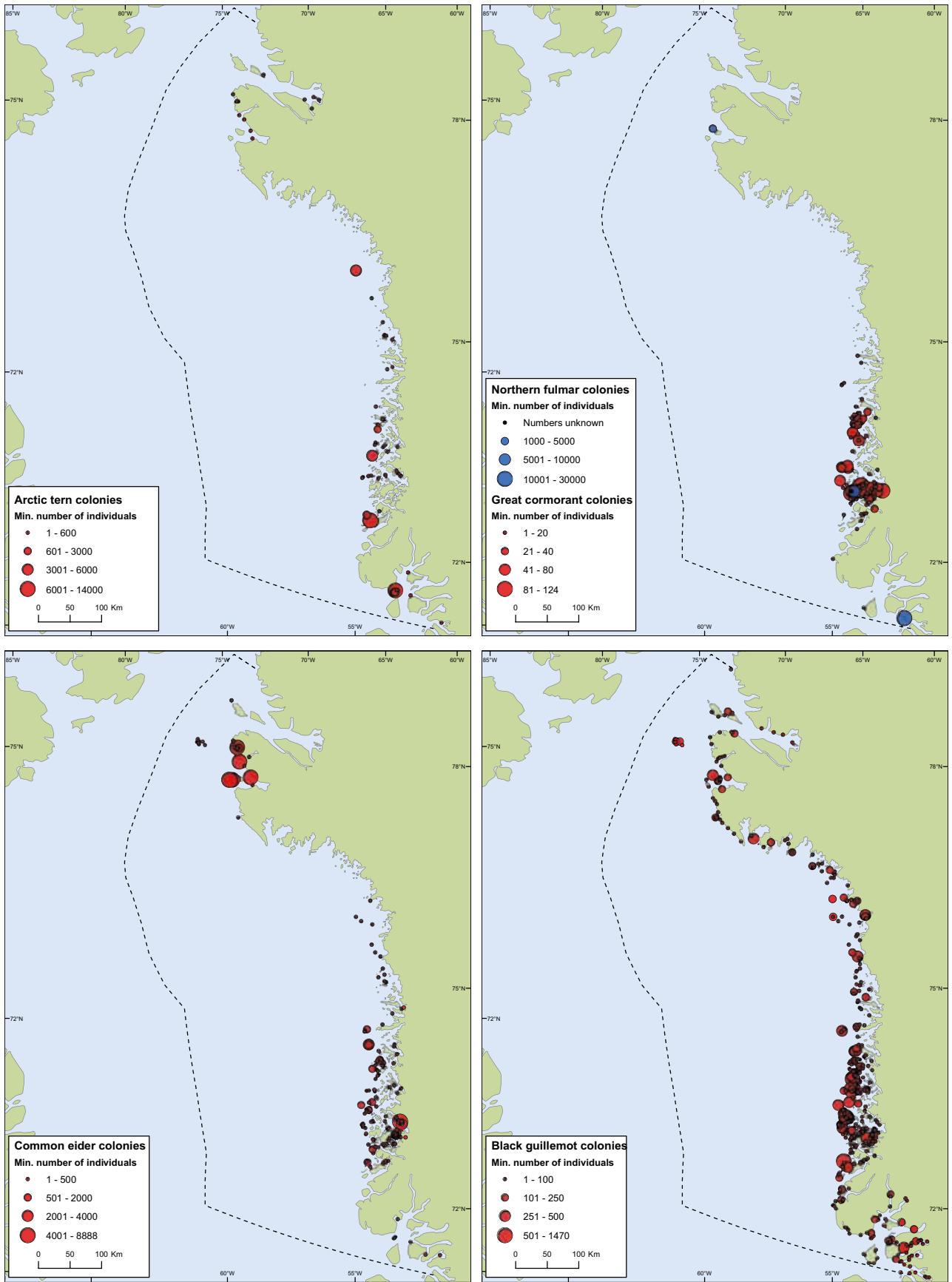
Species	Occurrence	Distribution	Red List status in Greenland	Importance of study area to population	VEC	Significance of population in a conservation context	
Fulmar	b	summer	c & o	Least Concern (LC)	high	+	regional
Great cormorant	b	summer	c	Least Concern (LC)	high	+	national
White-fronted goose	b	May-September	c	Endangered (EN)	medium		international
Snow goose	b	May-September	c	Least Concern (LC)	low		regional
Brent goose	b, mi	May-September international	c	Least Concern (LC)	high		
Common eider	b/s/m	summer	c	Vulnerable (VU)	high	+	national
King eider	s, m, mi,	July-Sept.	c	Least Concern (LC)	high	+	regional
Long-tailed duck	b/m	summer	c	Least Concern (LC)	medium	+	regional
Red-breasted merganser	b/m	summer	c	Least Concern (LC)	low		regional
Red-necked phalarope	mi, (b)	spring and autumn	o	Least Concern (LC)	low		local
Grey phalarope	mi, (b)	spring and autumn	o	Least Concern (LC)	low		regional
Arctic skua	b	summer	c	Least Concern (LC)	low		regional
Black-legged kittiwake	b, mi	summer	c & o	Vulnerable (VU)	high	+	national
Glaucous gull	b	summer	c & o	Least Concern (LC)	medium		international
Iceland gull	b	summer	c & o	Least Concern (LC)	low		regional
Thayers gull	b/mi	summer	c	Not applicable (NA)	low		local
Great black-backed gull	b	summer	c & o	Least Concern (LC)	low		local
Sabines gull	b, mi	May- August	c & o	Near Threatened (NT)	high		national
Ivory gull	mi, s	April-October	c & o	Vulnerable (VU)	medium	+	national
Arctic tern	b, mi	May-September	c & o	Near Threatened (NT)	high	+	regional
Thick-billed murre	b/s, mi	summer	c & o	Vulnerable (VU)	high	+	international
Razorbill	b	summer	c & o	Least Concern (LC)	high		regional
Atlantic puffin	b, mi	summer	c & o	Near Threatened (NT)	high	+	national
Black guillemot	b, mi	summer	c & o	Least Concern (LC)	high		international
Little auk	b, mi	summer	c & o	Least Concern (LC)	high	+	international



**Figure 15A.** Distribution and size of seabird breeding colonies in the assessment area. Thick-billed murre, little auk, razorbill and Atlantic puffin. Note that the size of the huge colonies of little auk in Qaanaaq municipality is unknown. However, the total numbers breeding here has been estimated to more than 30 million pairs.



**Figure 15B.** Distribution and size of seabird breeding colonies in the assessment area. Iceland gull, black-legged kittiwake, glaucous gull and Sabines gull.



**Figure 15C.** Distribution and size of seabird breeding colonies in the assessment area. Black guillemot, northern fulmar, great cormorant, Arctic tern and common eider.

from holding only a single species up to eight different species. In addition to the breeding birds, colonies are also used by many immature birds, which are potential breeders. The breeding seabirds utilise the waters near the breeding site; thick-billed murre (*Uria lomvia*) may fly more than 100 km to find their food, but most feed within a much smaller range (Falk et al. 2000, Box 4). When the breeding season is over all the seabirds (adults + young birds) migrate out of the assessment area to winter in waters primarily Newfoundland (Box 5).

Since the previous edition of this assessment, the distribution of breeding seabirds was mapped in the Melville Bay, from where only very few data were available. This area proved to be relatively poor in breeding seabirds compared with Upernavik and Qaanaaq, and only one site – Sabine Islands – was of national importance (Boertmann 2013, Boertmann & Huffeldt 2013).

Seaducks arrive from breeding sites in Canada and inland Greenland and assemble to moult in remote bays and fjords (Figure 16). The most numerous is the king eider (*Somateria spectabilis*), but also long-tailed ducks (*Clangula hyemalis*) and red-breasted mergansers (*Mergus serrator*) may occur in smaller concentrations in shallow fjords and bays (Mosbech & Boertmann 1999). A few species occur mainly as migrant visitors during spring and autumn, for instance two species of phalaropes and Sabine's gull (*Larus sabini*). The rare and threatened ivory gull (*Pagophila eburnea*) does not breed within the assessment area (as far as known), but occurs as a migrant visitor and it is a frequent summer visitor in the North Water area, perhaps coming from breeding populations on southern Ellesmere Island (Boertmann 1994, Boertmann & Huffeldt 2013, Gilchrist et al. 2008).

In winter, seabirds are generally absent from the assessment area, due to the extensive formation of sea ice. A few black guillemots may occur in cracks and polynyas, especially in the southern part.

Sixteen species of seabirds breed in the assessment area (Boertmann et al. 1996), the most important of which are described below.

Seabirds are also impacted by climate change, and there are concerns for especially species associated with sea ice and species dependent on formation of ice edges and polynyas, particularly ivory gull (Gilg et al. 2009, 2010) and colony breeding species such as thick-billed murre (Laidre et al. 2008b). On the other hand some seabirds are favoured by longer ice free periods, for instance common eiders, which in East Greenland have expanded their breeding range several 100 km to the north in recent years (Boertmann & Nielsen 2010).

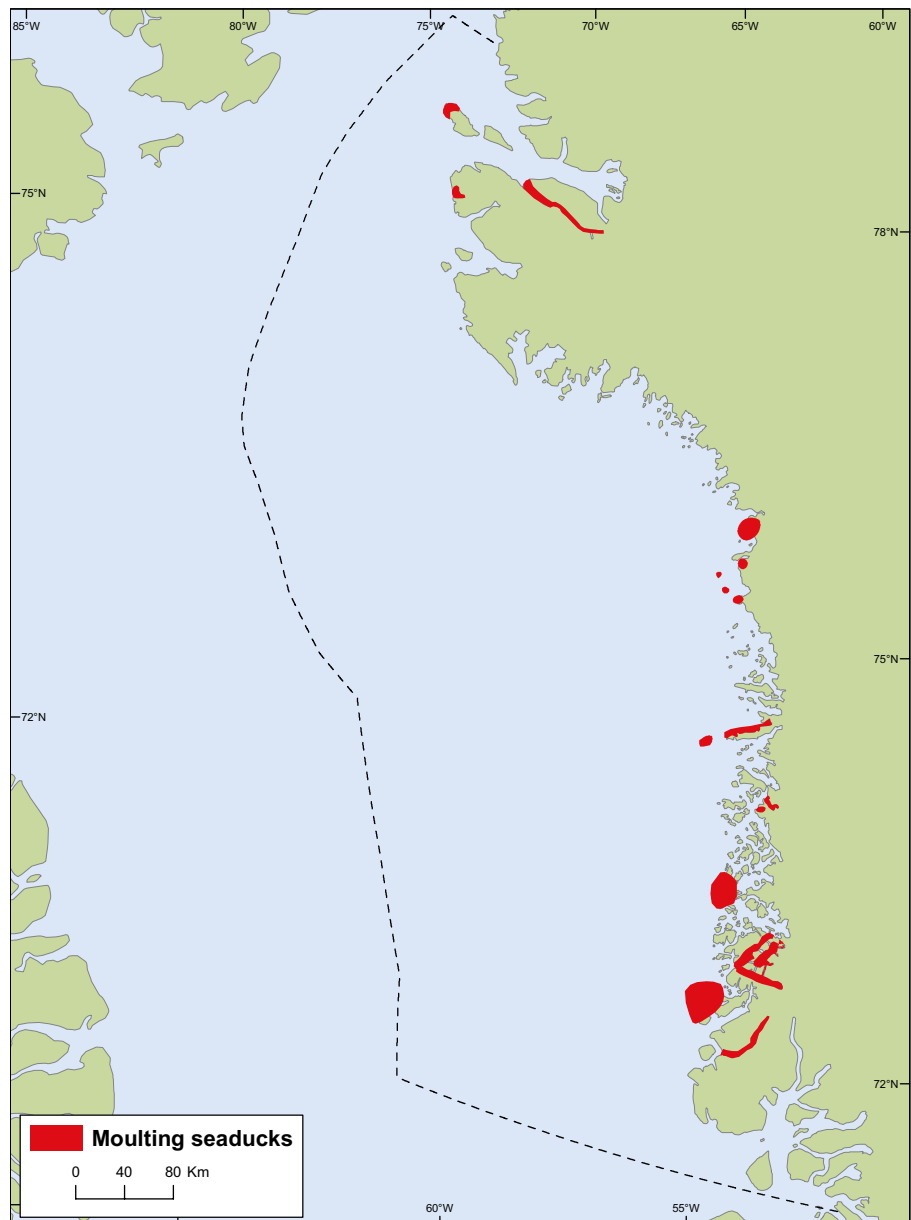
#### **4.7.1 Important bird species occurring in the assessment area**

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

##### **Northern fulmar *Fulmarus glacialis***

*Breeding distribution:* Three breeding colonies are found within the assessment area (Figure 15C), and the major part of the Greenland breeding population is found just to the south of the assessment area, in Uummannaq Fjord and Disko Bay (Boertmann et al. 1996). The breeding numbers in the colonies are unknown, but at least several thousand pairs breed in each.

**Figure 16.** Important areas for moulting seabirds (mainly king eiders) in the assessment area. Moulting takes place in July, August and early September.



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

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

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

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

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

**Great cormorant *Phalacrocorax carbo***

*Distribution and population size:* Cormorants breed in several colonies on the coasts of the southern part of the assessment area (north to about 74° N) (Figure 15C). In 1997, the population was estimated to about 150 pairs. It has increased considerably since then and may include more than 500 pairs today (Boertmann & Mosbech 1997), representing perhaps 10% of the total Greenland breeding population. Moreover, the population may have extended its breeding range further north and the northernmost colony was in 2013 found at Holm Island (74° 30' N) (Boertmann & Huffeldt 2013). Colonies are generally small with fewer than 20 pairs.

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

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

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

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

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

**Common eider *Somateria mollissima***

*Breeding distribution:* This duck is closely associated with the marine environment. It breeds both dispersed and in colonies on low islands and feeds in shallow coastal waters throughout the assessment area. Both in the Upernavik district and in the Qaanaaq-area, numerous colonies are known, while recent surveys show that the breeding population in the Melville Bay is scattered and only numbers a few colonies (Figure 15C).

*Non-breeding concentrations:* Males assemble in moulting concentrations in remote fjords and archipelagos when the females have brooded for some time. Females (failed breeders) follow the males somewhat later and most birds moult within 100 km from the breeding site (Mosbech et al. 2006). The flight feathers are moulted simultaneously, which means that the birds become flightless until new feathers are regrown, i.e. about three weeks. After moulting the eiders migrate to wintering areas in the coastal waters of West Greenland, to the south of Disko Bay (Lyngs 2003, Mosbech et al. 2007c).

*Population size:* The number of breeding pairs in the Qaanaaq District was estimated to 25,000-30,000 in 2009 (Burnham et al. 2012) and approx. 8000 in Upernavik District (Merkel 2010b). The population declined considerably during the 1900s due to non-sustainable harvest. After hunting in spring was prohibited in 2001, populations have recovered throughout the assessment area (Merkel 2010b, Burnham et al. 2012). In Ilulissat and Upernavik active management and monitoring using local stakeholders have been carried out, and an annual population increase of 15% has been estimated (Merkel 2008, 2010b).



*Catch:* The common eider is an important quarry for the hunters of the region. Approx. 3,000 are reported caught by the hunting statistics in the assessment area in recent years (See Figure 46).

*Conservation status:* The common eider population of the assessment area has an unfavourable conservation status due the decline in breeding numbers. It is therefore listed as 'Vulnerable' (VU) on the Greenland Red List (2007). However, this status seems outdated, due to the population recovery.

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

### **Glaucous gull *Larus hyperboreus***

*Breeding distribution:* This is the most common and widespread gull in the assessment area. It breeds along the coasts, both dispersed and in small colonies rarely counting more than 100 pairs (Figure 15B).

*Non-breeding distribution:* Glaucous gulls are present in the region as long as open waters are present. The gulls are usually found in coastal areas, but some also venture far offshore. Significant concentrations occur at breeding sites and in good foraging areas.

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

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

*Sensitivity and critical areas:* The breeding colonies of glaucous gulls are the most sensitive. However, as these colonies are generally small and the population is spread widely along the coasts, the population sensitivity is relatively low compared with other much more concentrated seabirds.

Other large gulls breeding in the assessment area include Iceland gull (*Larus glaucoides*) (Figure 15B) and great black-backed gull (*Larus marinus*) which occur in the southern part of the assessment area. Thayers gull (*Larus thayeri*) is a rare breeder at least in northern Melville Bay (Boertmann & Huffeldt 2013).

### **Black-legged kittiwake *Rissa tridactyla***

*Breeding distribution and population size:* Kittiwakes are strictly colonial breeders that place their nests on vertical cliffs at the sea. At least 40 breeding colonies have been reported from the assessment area, with a total of about 40,000 breeding pairs (Labansen et al. 2010, 2013) (Figure 15B).

*Non-breeding distribution:* Kittiwakes are migratory, leaving the breeding areas in September/October and returning again when open waters appear in April-May (Box 5, Frederiksen et al. 2012). Many non-breeders occur in offshore areas in summer.

*Biology:* Kittiwakes usually feed on the surface when swimming; they can also perform shallow dives. Results of recent studies in the assessment area are presented in Box 3 and 4.

## Box 3

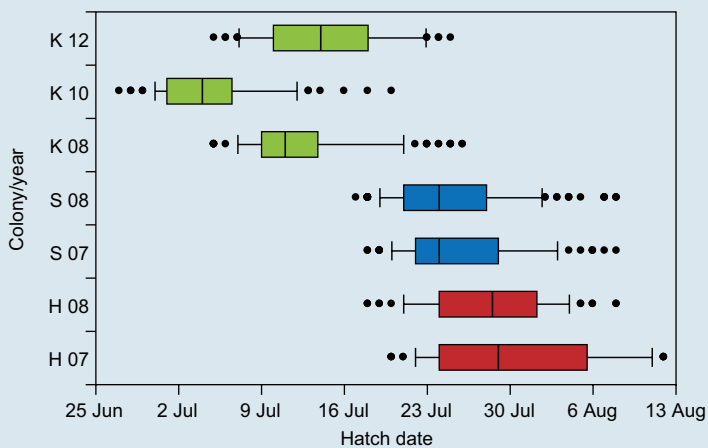
### Breeding biology of thick-billed murres and black-legged kittiwakes in the Eastern Baffin Bay assessment area

M. Frederiksen & F. Merkel

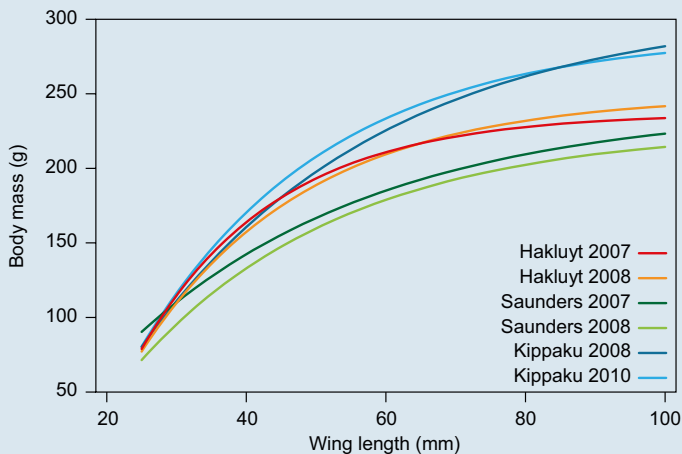
The performance and success of chick-rearing seabirds is generally viewed as a good indicator of the prevailing environmental conditions during summer, specifically the availability of suitable food. Detailed studies of breeding biology were carried out at three colonies in the assessment area in the period 2007-2013. The results shown here illustrate the different conditions prevailing within this large area (Hakluyt Island and Saunders Island are in the former Qaanaaq Municipality and Kippaku is approx. 500 km to the south in Upernavik). Food availability seemed to be higher in the south than in the north: thick-billed murre chicks achieved a better body condition despite being fed less frequently, and breeding success of black-legged kittiwakes was much higher. Unsurprisingly, breeding was also earlier in the south for both thick-billed murres and black-legged kittiwakes. Breeding success was also high for thick-billed murres at Kippaku (results not shown here). Compared to other parts of the Arctic, breeding conditions for both species could be regarded as very good in the Upernavik area, and average in the Qaanaaq area. For more details of studies at Kippaku, see Frederiksen et al. (2014).

Samples of thick-billed murre chicks were aged (based on wing length) at all study colonies, and hatch dates back-calculated ( $n = 50-152$ ) (Figure 1). Breeding was substantially earlier at Kippaku (mean hatch date 2008: 12 July, 2010: 4 July, 2012: 14 July) than at northern colonies (Hakluyt 2007: 30 July, 2008: 28 July; Saunders 2007: 25 July, 2008: 24 July).

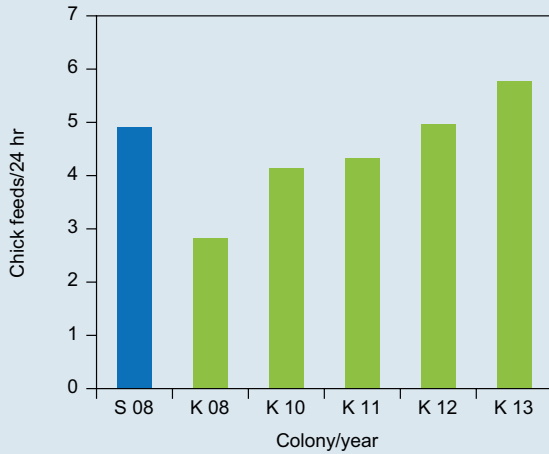
In order to assess feeding conditions, wing length and body mass were measured for samples ( $n = 65-152$ ) of murre chicks at all study colonies (Figure 2). Asymptotic growth curves were then fitted to the data. Results show that chicks at the southern study colony (Kippaku) attained a higher body mass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



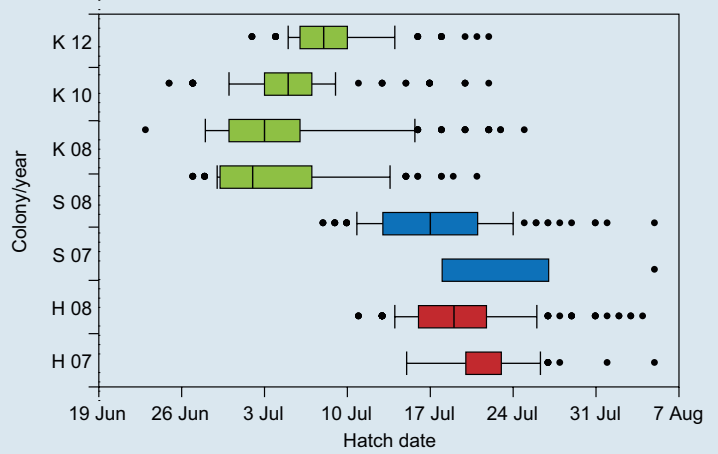
**Figure 1.** Breeding phenology of thick-billed murres. Box plots show the median, 25<sup>th</sup> and 75<sup>th</sup> percentiles, and 10<sup>th</sup> and 90<sup>th</sup> percentiles (whiskers) for each data set. Data sets are identified by letter (H: Hakluyt Island, S: Saunders Island, K: Kippaku) and two-digit year.



**Figure 2.** Body condition of thick-billed murre chicks.



**Figure 3.** Feeding rates of thick-billed murre chicks.

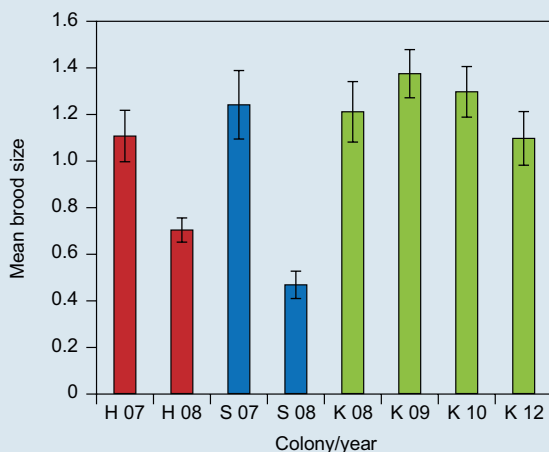


**Figure 4.** Breeding phenology of black-legged kittiwakes. Data sets are identified by letter (H: Hakluyt Island, S: Saunders Island, K: Kippaku) and two-digit year.

Twenty-four hour feeding watches were performed at Kippaku in 2008 and 2010-13 and at Saunders Island in 2008. Mean feeding rate was substantially higher at Saunders Island (4.92 feeds/chick/24 hr) than at Kippaku (2.87 feeds/chick/24 hr) in 2008, but in the following years feeding rate at Kippaku was higher (4.15-5.78 feeds/chick/24 hr) (Figure 3). It is striking that despite the higher feeding rate at Saunders Island, chicks here were in poorer body condition than at Kippaku (Figure 2). The estimate for Kippaku in 2008 may be biased low because of the large number of breeding sites observed.

Samples of black-legged kittiwake chicks were aged at all study colonies ( $n = 54-251$ ), and hatch dates back-calculated. Box plots show the median, 25<sup>th</sup> and 75<sup>th</sup> percentiles, and 10<sup>th</sup> and 90<sup>th</sup> percentiles (whiskers) for each data set (Figure 4). In 2008, mean hatching was about two weeks earlier at Kippaku (mean = 4 July) than at Saunders Island (mean = 17 July) and Hakluyt Island (mean = 19 July). Hatch dates were also very similar at the two northern colonies in 2007 (mean = 20 and 21 July). At Kippaku, mean hatch date was also 4 July in 2009 and 2010, but later (9 July) in 2012.

Breeding success was estimated by counting chicks in active nests and attempting to identify failed nests ( $n = 58-301$ ). Data sets were identified by letter (H: Hakluyt Island, S: Saunders Island, K: Kippaku) and two-digit year (Figure 5). Most chicks were large, and mortality between survey and fledging is likely to have been low. In 2008, mean breeding success was much higher at Kippaku (mean = 1.21 chick/nest) than at Saunders Island (mean = 0.47 chick/nest) or Hakluyt Island (mean = 0.70 chick/nest). Breeding success was lower at the two northern colonies in 2008 than in 2007 (mean = 1.24 and 1.11 chick/nest), although it is uncertain whether data from Saunders Island in 2007 are strictly comparable. At Kippaku, breeding success was also high in 2009, 2010 and 2012.



**Figure 5.** Breeding success of black-legged kittiwakes. Data sets are identified by letter (H: Hakluyt Island, S: Saunders Island, K: Kippaku) and two-digit year.

## Box 4

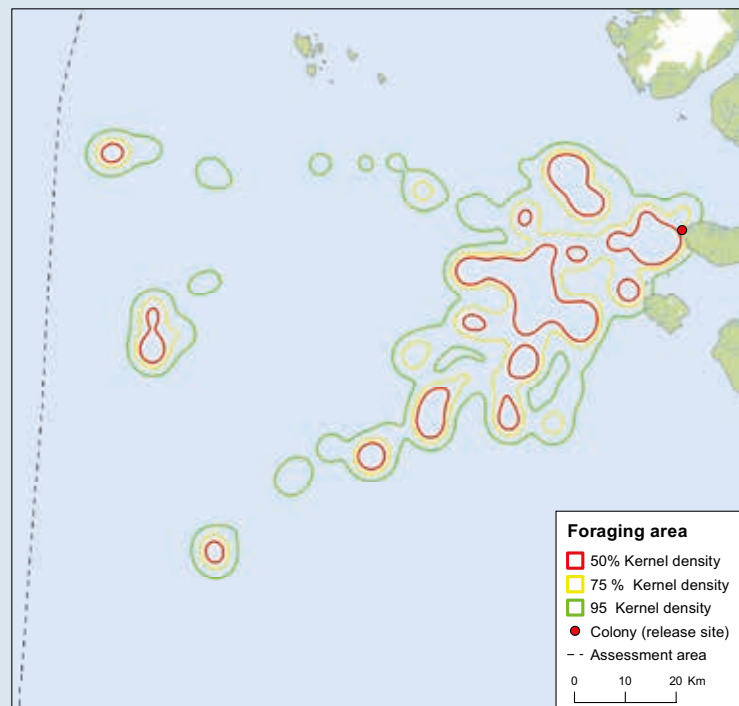
### Foraging areas of thick-billed murres and black-legged kittiwakes

M. Frederiksen, A. Mosbech, F. Merkel, K. L. Johansen & D.S. Clausen

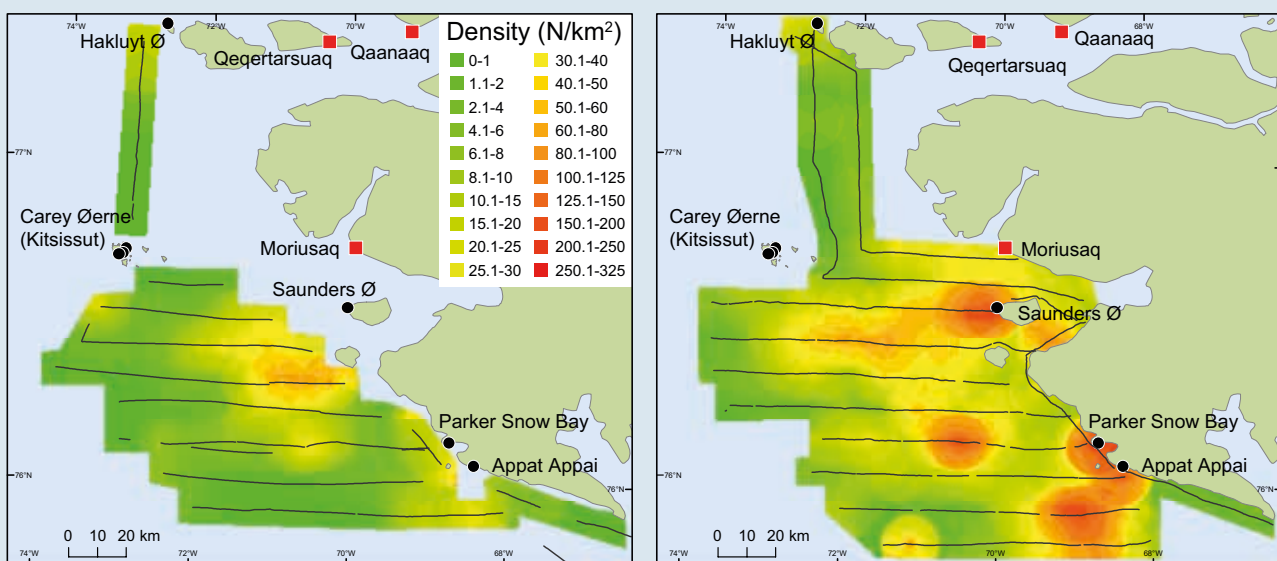
While the locations of the large seabird breeding colonies in West Greenland are well known, until this project little was known about the actual foraging areas used during the breeding season. This is very important information in relation to identification of critical habitats that can be affected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

Ship-based line transect surveys were carried out around Saunders Island in 2007 and 2008 (Figure 2), and around Kippaku in 2008 (Figure 4). Satellite tracking was used at Saunders Island in 2007 and at Kippaku in 2008. To achieve higher temporal and spatial resolution, we deployed GPS loggers at Kippaku in 2009–2013 and at Saunders Island in 2012 and 2014.

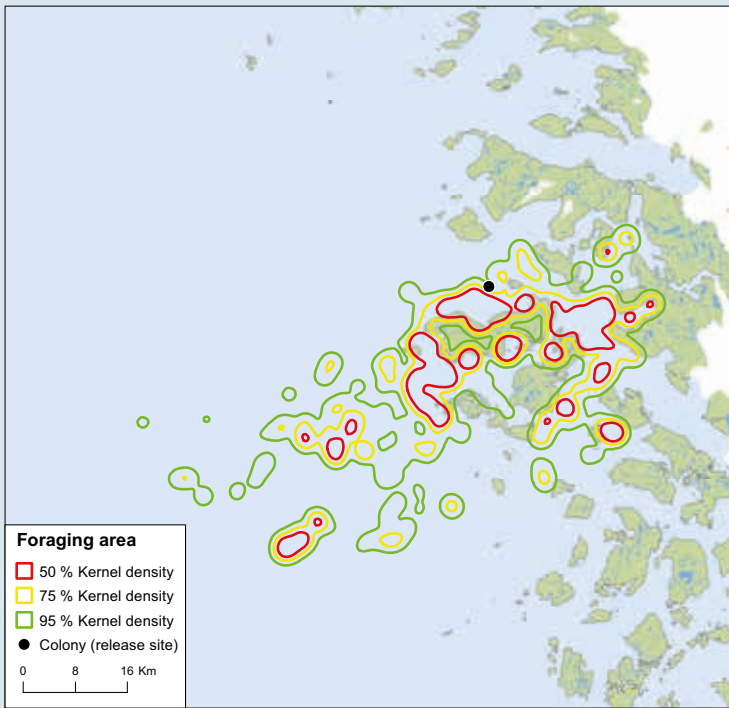
Around Saunders Island and the other colonies in the Qaanaaq area, most murres foraged 30–40 km (up to 100 km) offshore, at a depth of several hundred meters (Figure 1). In contrast, murres at Kippaku foraged either inshore in the archipelago SE of the colony, or offshore to the SW, but at a more shallow depth (around 200 m), and most foraging took place within 30–40 km of the colony (Figure 3). Line transect surveys in 2008 and



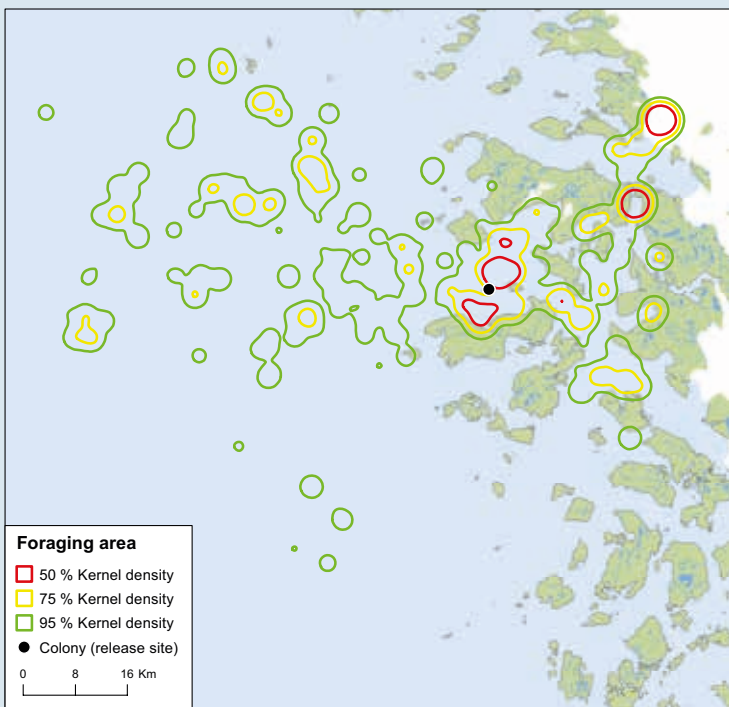
**Figure 1.** Foraging area of thick-billed murres tracked with GPS data loggers while commuting between the colony at Saunders Island and foraging areas. The foraging areas were estimated using kernel analysis (50%, 75% and 95% contours shown), including only locations more than 2 km from the colony and where recorded speed was < 2 km/h. Birds foraged offshore W and SW of the colony, mostly within 30–40 km. However, some trips were up to 100 km, extending nearly to the border of the Greenland EEZ.



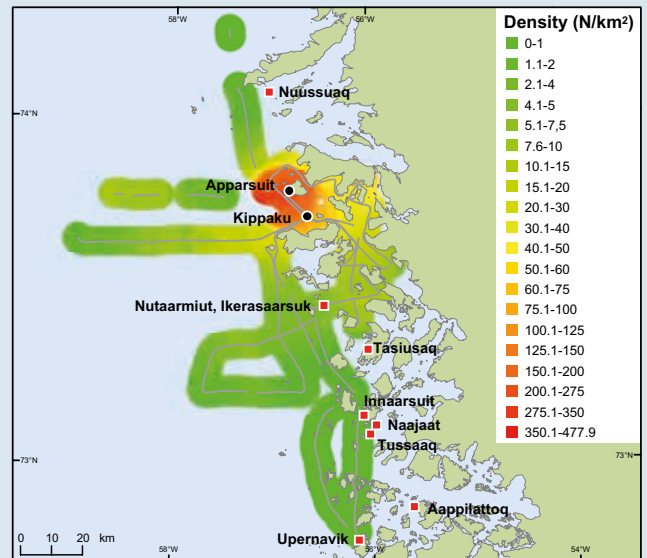
**Figure 2.** Densities of thick-billed murres recorded on ship-based line transect surveys of the North Water area in the breeding seasons 2007 and 2008. The thick-billed murre colonies in the area are indicated with black dots. Significant concentrations were observed west and southwest of three southern colonies. Concentrations within few km of the colonies may not represent foraging birds, while it is most likely that concentrations further offshore represent foraging areas. In both years, foraging concentration areas extended about 40–60 km west and southwest of Saunders Island, and the foraging area of the tracked bird in Box 3, Fig. 1 is within this area. In both years, murre concentrations were low south of the colony at Hakluyt Island in accordance with earlier observations that birds from this colony mainly forage to the north. Colony sizes (pairs): Saunders Island 116,250, Parker Snow Bay 42,000, Appat Appai 33,750, Hakluyt Island 31,500, Carey Islands 7,500 (Merkel et al. 2007b).



**Figure 3.** Foraging areas of GPS-tagged thick-billed murre at Kippaku in 2009-2013. Foraging areas were estimated using kernel analysis (50%, 75% and 95% contours shown), including only locations more than 2 km from the colony and where recorded speed was < 2 km/h. Birds foraged within 45 km of the colony, either within the archipelago or around the shelf break SW of the colony. All birds avoided the vicinity of the much larger thick-billed murre colony Apparsuit 10 km NNW of Kippaku. Most birds repeatedly returned to the same foraging area, although some also shifted to completely different areas. For more details, see Frederiksen et al. (2014).



**Figure 5.** Foraging areas of GPS-tagged black-legged kittiwakes at Kippaku in 2012-2013. Foraging areas were estimated using kernel analysis (50%, 75% and 95% contours shown), including only locations more than 2 km from the colony and where recorded speed was < 8 km/h. Birds foraged within 75 km of the colony, either within the archipelago or offshore W of the colony. Most birds repeatedly returned to the same foraging area, although some also shifted to completely different areas. Note that the northernmost foraging area is placed on the Inland Ice. The map is not updated in relation to glacier retreat and this particular area is now a fjord. For more details, see Frederiksen et al. (2014).



**Figure 4.** Densities of thick-billed murre recorded on ship-based line transect surveys in northern Upernavik in the breeding season 2008. The two thick-billed murre colonies in the area are indicated with black dots. High densities of murre occurred in the archipelago east of the colonies and also west of the colonies, but did not extend far offshore. The density distribution mainly reflects the larger colony Apparsuit, and the data indicate that the main foraging area is within 25 km of the colonies. The murre tracked from Kippaku also to a large extent foraged within the archipelago (Box 3, Figs. 3 and 4). Colony sizes as total numbers of birds present in colonies: Apparsuit 96,400 and Kippaku 19,010 (Labansen et al. 2013).

GPS tracking in 2013 indicated that birds from the very large colony at Apparsuit near Kippaku also mainly foraged within 30-40 km from the colony (Figure 3). Thus, our results indicate that murre foraging behaviour differs substantially between the colonies in the Qaanaaq area, which are associated with the North Water polynya, and the colonies in the Upernavik area, where the topography is more complex and prey diversity presumably higher.

Foraging areas of black-legged kittiwakes at Kippaku were also mapped using GPS tracking in 2012 and 2013 (Figure 5). The results showed great variation between trips, individuals and years. Birds used both offshore areas up to 75 km from the colony, shallow inshore bays, and glacier fronts.

For both species at Kippaku, foraging extended well inside the hydrocarbon license areas in Baffin Bay.

*Conservation status:* The population in West Greenland has an unfavourable conservation status, as it has declined significantly since the mid-1900s, probably due to excessive hunting. However, the large colonies in the former Qaanaaq Municipality, making up more than 80% of the population within the assessment area seem not to have declined (Merkel et al. 2007a, Labansen et al. 2010).

*Catch:* Kittiwakes are a preferred quarry for hunters of the assessment area. Approx. 2,000 birds are reported shot by hunters in the region to the north of Disko Bay in recent years (see Figure 46).

*Sensitivity and critical areas:* Kittiwakes are most vulnerable at breeding colonies where large numbers of birds often assemble on the sea surface. There may also be large concentrations in feeding areas, for example in the marginal ice in spring and early summer.

#### **Arctic tern *Sterna paradisaea***

*Breeding distribution and population size:* Arctic terns are mainly colonial breeders, placing their nests on small and low islands. Colony size ranges from a few pairs to about 20,000 pairs. At least 45 colonies are known from the assessment area, and some in the southern part of the area hold up to 10,500 pairs (Egevang & Boertmann 2012) (Figure 15C).

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

*Conservation status:* In 2008, the West Greenland Arctic tern population was assessed to have an unfavourable conservation status as the population was decreasing, probably due to excessive egg-collecting (which was banned in 2001). However, since then the decrease seems to have decelerated. It is listed as 'Near Threatened' (NT) on the national Red List.

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

#### **Thick-billed murre *Uria lomvia***

*Breeding distribution and population size:* This is one of the most numerous seabirds in the assessment area. By far the major part of the Greenland breeding population is found in colonies on the coasts of the assessment area (Merkel et al. 2014). In the Qaanaaq District there are five large colonies numbering in total 225,000 pairs and in Upernavik there are today three occupied colonies and a number of colonies that are either extinct or on the verge of extinction (Figure 15A). There are approx. 100,000 pairs breeding in Upernavik.

*Biology:* Thick-billed murrelets of the assessment area are migratory, wintering primarily in Newfoundland waters (Lyngs 2003, Boertmann et al. 2004, Frederiksen et al. 2016, Box 5).

Murrelets are pursuit divers, chasing fish and large zooplankton down to more than 100 m depth. They spend very long time on the sea surface, and only come on land in the breeding season. When the chicks are approx. three weeks old and far from fully grown or able to fly, they leave the colony in company

with the male parent and swim/ drift to offshore waters. The male then sheds all flight feathers and becomes flightless for some weeks. The females also moult and become flightless; at least some of them outside the assessment area in Canadian waters. Murres are particularly sensitive to oil spills, and during the period of flightlessness their vulnerability increases.

Recent results of breeding biology studies in the assessment area are presented in Box 3 and 4, and results from tracking studies of the migration pathways are presented in Box 5.

*Catch:* Murres are the most popular seabirds hunted in the assessment area. In recent years, annual catches of approx. 5,000-8,000 murres have been reported (see Figure 46).

*Conservation status:* The West Greenland population is decreasing and therefore has an unfavourable conservation status, except for the colonies in the former Qaanaaq municipality. The decrease has been particularly strong in Uummannaq and the southern part of Upernavik where several colonies have been abandoned, of which some held up to 100,000 pairs before 1950. This decline is mainly ascribed to non-sustainable harvest (Falk & Kampp 1997, Merkel et al. 2014).

*Sensitivity and critical areas:* Murres are very sensitive both to oil spills and disturbance in the breeding colonies, where large proportions of the total population can be impacted by a single incident. Vulnerable offshore concentrations occur at feeding grounds and probably also during the migration periods. The post breeding concentration area discovered from the trackings studies reported in Box 5 is for example such a sensitive area.

### **Black guillemot *Cephus grylle***

*Breeding distribution:* This is probably the most widespread of the breeding colonial seabirds in the assessment area. Colonies are found in most fjords, bays and coasts, and their numbers range from a few to several hundred pairs (Figure 15C). The total breeding population within the assessment area is unknown, but counts at least 10,000 pairs. A few may stay in the assessment area throughout the winter in polynyas and leads (Renaud & Bradstreet 1980).

*Biology:* The nests are placed in caves and cracks in cliffs or below rocks in screes. Black guillemots are more or less migratory, leaving the assessment area when the ice covers the shallow coastal foraging areas. Most of them winter in the offshore drift ice (Mosbech & Johnson 1999) and in the open-water area to the south of the assessment area, but a few have been recovered or tracked to waters west of Baffin Island (Lyngs 2003, Frederiksen et al. 2014).

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

*Catch.* Annually, approximately 2,000-3,000 birds have been reported caught in recent years (see Figure 46).

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

## Box 5

### Identification of migration routes of thick-billed murres and black-legged kittiwakes using satellite telemetry and geolocation

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

#### Migration routes – murres

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

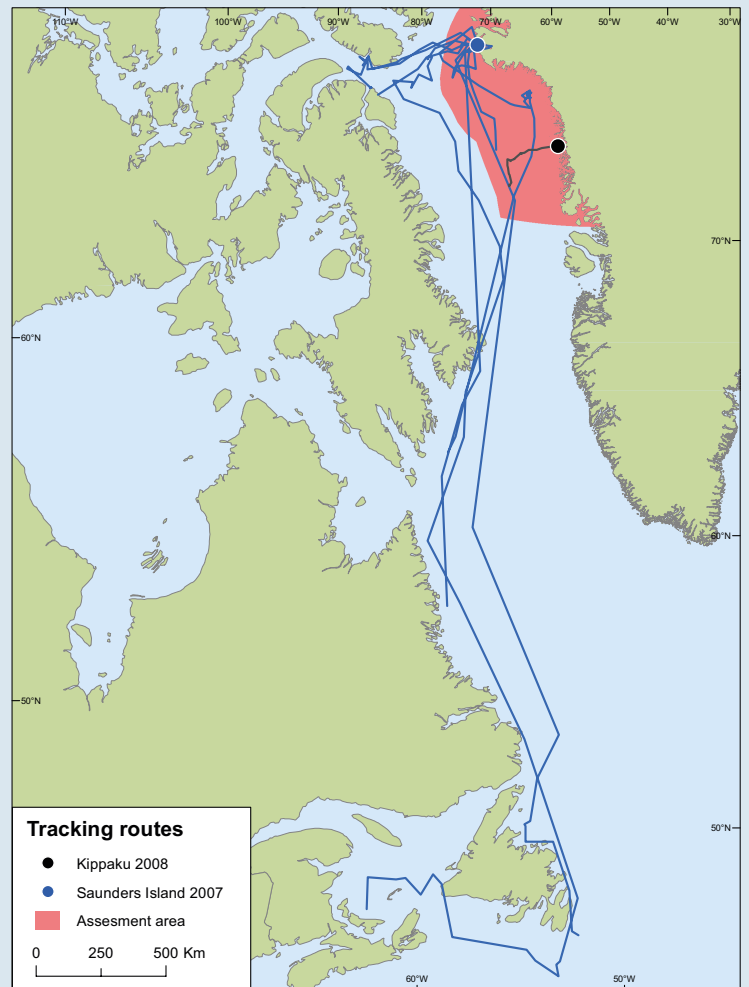
#### Satellite tracking

To track the autumn migration of the murres, we used implanted satellite transmitters with an external antenna (26 g pressure proof implantable Microwave PTT). Murres with chicks were selected. The advantage of the implanted PTT is that it is not shed with the feathers and potentially it can give information on the movements during a full year. The disadvantage is that the surgery typically causes the murre to give up breeding that year, and none have been observed back in the colony in the following years, indicating that either the implanted birds abandon breeding or their mortality is high.

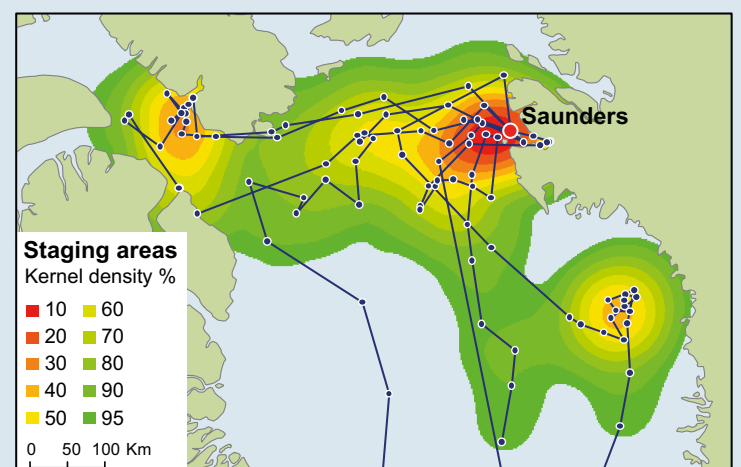
Murres with internal satellite transmitters from Saunders Island were tracked for up to 166 days (median 46 days). Of the ten murres tracked, eight were tracked for some or all of their autumn migration (Figure 1). The routes through northern Baffin Bay varied: four of the eight murres first headed towards Lancaster Sound and staged near the mouth, two staged in the local foraging area (approximately 60 km W-SW of Saunders Island), one staged in Melville Bay and one did not stage en route but flew directly south to western Davis Strait (Figure 2). However, regardless of staging area in northern Baffin Bay, all four murres that were tracked all the way through Baffin Bay followed an offshore route through central Baffin Bay. Four murres were tracked beyond Baffin Bay, and they all went to the western side of the Davis Strait towards the Labrador-Newfoundland wintering area. One murre tracked from Kippaku in northern Upernavik also went west to central Baffin Bay before heading south.

The speed of movement indicated that satellite-tracked murres largely swam south during the first weeks of the autumn migration, despite not accompanying their own chicks. Two of eight birds tracked during the migration appeared to fly part of the way to the moulting area (average speed between locations > 3 km/h).

In conclusion, results from satellite tracking show that murres on autumn migration from Saunders Island tended to stage in northern Baffin Bay before heading south through the central part of Baffin Bay and into the Labrador Current in the western part of the Davis Strait and the Labrador Sea.



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



**Figure 2.** Post-breeding area usage for seven thick-billed murres tracked from the colony at Saunders Island. The figure shows track lines and kernel home range contours for the period from when the birds left the colony (stopped commuting to the colony) to when they headed south.



## Geolocation data loggers

To track the full annual migration of murres, we also used geolocation data loggers, which are small archival tags recording time and light intensity. The data loggers only store the information, and it is therefore necessary to recapture the birds the next year to retrieve the information. Based on the data retrieved from the logger on day-length and time of local noon, the latitude and longitude, respectively, can be calculated. The accuracy of the geolocators is quite coarse, typically within approximately  $\pm 150$  km for individual locations. However, even with this accuracy we have collected very important information on the migration routes and wintering areas of the birds breeding in the colonies at Saunders Island and Kippaku.

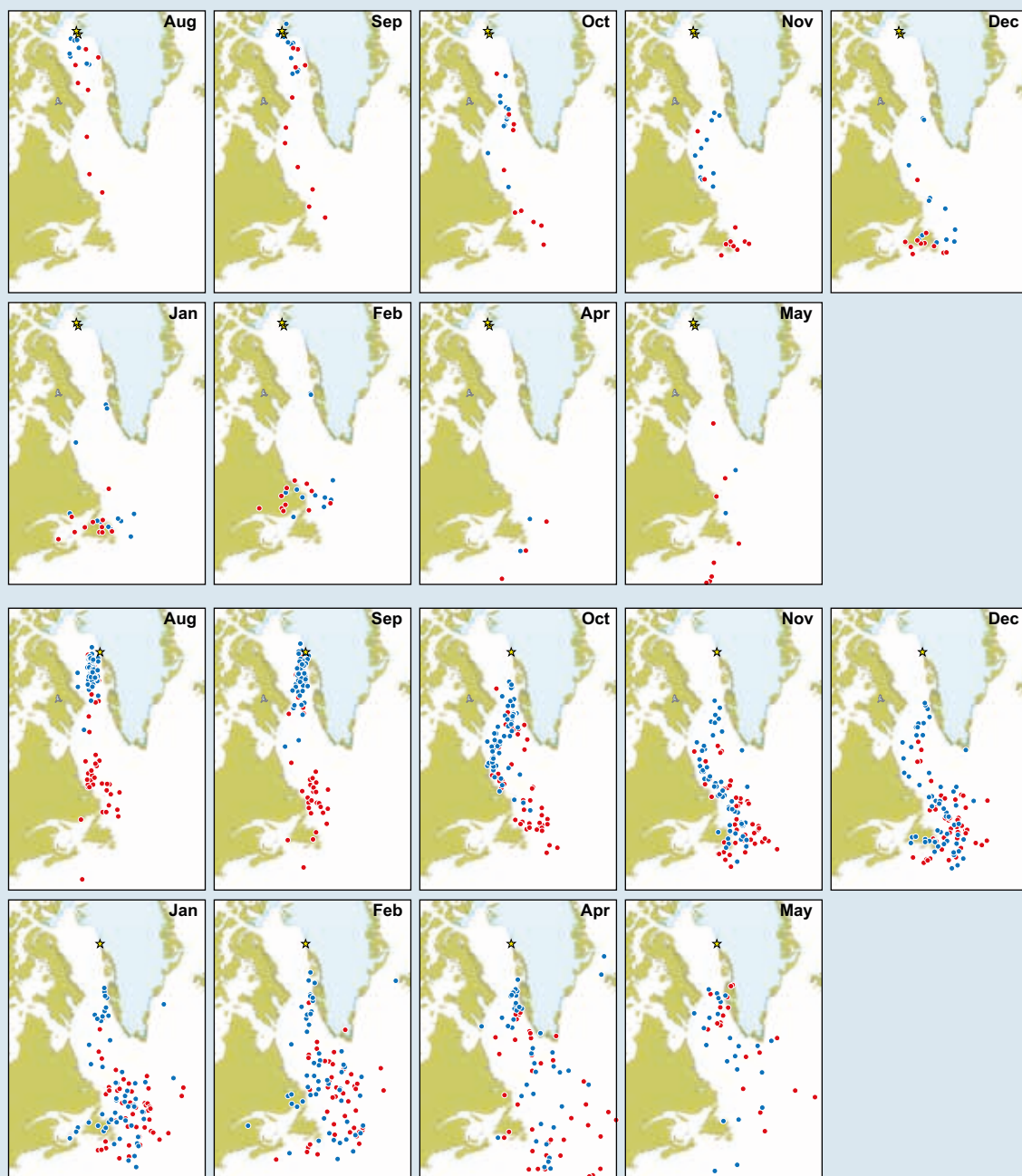
Geolocators were deployed at Saunders Island in 2007 and 2012, at Parker Snow Bay in 2010, and at Kippaku 2008–2013. Details can be found in Frederiksen et al. (2014) and Frederiksen et al. (2016).

Immediately after the breeding season, many female murres from Baffin Bay colonies migrate quickly southwards to the Labrador Shelf. In contrast, nearly all males and some females remain in

the Baffin Bay until at least mid-September. Thus, the geocator results confirm the satellite tracking results that the bay is a very important post-breeding staging (presumably moulting) area for murres, including males accompanying chicks. During winter, most of the population occurs on and east of the Labrador and Newfoundland shelves, although some males spend the entire winter off the West Greenland coast south of the assessment area (approx. 65–68° N). Northward migration starts in April and most individuals return to the colonies during May (Figure 3).

## Migration routes – kittiwakes

Breeding black-legged kittiwakes were also tracked using geolocators at Kippaku in the period 2008–2013. Results are described in Frederiksen et al. (2012) and Frederiksen et al. (2014). After the breeding season, many birds remain in the Baffin Bay for up to several months (until mid-November). During winter, kittiwakes are distributed from the Davis Strait to south of Newfoundland, with a large between-year variation probably linked to ice conditions. Northward migration starts in April, but in most years birds return to the colony in early May.



**Figure 3.** Migration of thick-billed murres tracked with geolocators from Saunders Island and Parker Snow Bay ( $n = 20$  and  $3$ , top set of panels) and Kippaku ( $n = 100$ , bottom set of panels). Each symbol shows the median monthly position of one tracked bird. Males are shown in blue, females in red, and yellow asterisks indicate the location of the study colonies. Note that geolocation does not provide positions during the equinox periods (mid-September to mid-October, and March), and that positions cannot be obtained in Baffin Bay (north of approx. 68° N) in May due to constant daylight.

*Sensitivity:* Vulnerable concentrations occur mainly in summer near the breeding colonies, but also in the migrating period in spring, concentrations may be vulnerable when the birds aggregate in the marginal ice zone or at the edge of the fast ice. However, at population level, due to the wide dispersion of the colonies, the sensitivity of black guillemot is relatively low.

#### **Little auk *Alle alle***

*Breeding distribution and population size:* This small alcid is the most numerous seabird in the North Atlantic. The globally most important breeding area for this species lies in the Qaanaaq area where more than 80% of the total world population is estimated to breed (Nettleship & Evans 1985). This population is estimated to include approx. 33 million pairs, distributed along the shores between northern Melville Bay and Etah in Inglefield Land (Boertmann & Mosbech 1998, Kampp et al. 2000, Egevang et al. 2003, Boertmann 2013), but they do not breed on the Canadian side of the North Water. There are smaller colonies in Upernavik with max. 5,000 pairs (Boertmann et al. 1996) (Figure 15A). Little auks often occur in huge flocks on the water below the colonies and in foraging areas.

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

*Biology:* Little auks are planktivorous, feeding mainly on large planktonic crustaceans such as *Calanus* species and *Parathemisto*, which they catch during pursuit diving (Frandsen et al. 2013). The diving depth of breeding little auks in Qaanaaq has been measured to 35 m (Falk et al. 2000, Pedersen & Falk 2001). In the International North Water Polynya Study, it was estimated that the little auks were responsible for 92-96% of the energy demand of the seabirds in the polynya, indicating their importance in the food web. Their main feeding areas are close to the Greenland coast, which underlines the high production in this part of the polynya (Karnovsky & Hunt 2002), and satellite tracking showed that they flew up to 100 km away from the breeding colonies, which is consistent with observations from ships (Box 8). The breeding colonies are situated in scree where the birds place the nests under rocks and boulders.

Some of the studies of the Eastern Baffin Bay Strategic Environmental Study Program 2011-2014 focused on little auks (Box 6 and 7).

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

Little auks are migratory, wintering in the waters off Newfoundland and Labrador on the edge of the banks (Brown 1986, Lyngs 2003, Fort et al. 2013). They arrive at the breeding colonies in May and leave again in mid- to late August and have probably left the Baffin Bay in late September. After departure from the breeding sites the adult birds perform a simultaneous moult of the flight feathers and become flightless for some weeks (Box 7).

*Conservation status:* The little auk population in the assessment area has a favourable conservation status and the species is listed as of 'Least Concern' (LC) on the Greenland Red List. It is however a national responsibility species (Table 6) because of the very large fraction of the global population breeding within the assessment area (see above).

*Sensitivity:* The large concentrations of little auks on the water will be very sensitive to oil spills, especially when the birds are flightless in September. The tracking studies described in Box 7 revealed a possible moulting area in western Baffin Bay. This presumed moulting area is outside the assessment area, but within the impact zone from an oil spill originating in the Greenland licence blocks.

#### **Atlantic Puffin *Fratercula arctica* and Razorbill *Alca torda***

These two alcid species occur in the assessment area in much lower numbers than the other species of the alcid family. There are probably less than a 1,000 pairs of each species within the area. Their breeding colonies are usually small with less than 50 pairs and they are found on small islands; in the case of the puffin among the outermost islands. The colonies are mainly found in the archipelagos of Upernavik supplemented with a few in Qaanaaq (Figures 15A).

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

Whereas breeding concentrations are known, knowledge is lacking of the concentrations of these two species during their spring and autumn migration.

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

The puffin is listed as Near Threatened (NT) on the Greenland Red List, while the razorbill is considered as Least Concern (LC). Both species was recently up-listed from Least Concern (LC) to, respectively, Vulnerable (VU) and Near Threatened (NT).

#### **Other significant bird species more or less associated to the marine environment**

Sabines gull (*Larus sabini*) is a small gull with a limited breeding distribution within Greenland. Within the assessment area there are four breeding colonies on small islands in Melville Bay, in Inglefield Inlet and in southern Upernavik (Figure 15B). The colony on Sabine Island in Melville Bay (the largest in Greenland) was surveyed in 2012, with a result of more than 500 pairs, which indicates a significant increase since 2007 (200 pairs) (Boertmann & Huffeldt 2013). Sabines gulls are migratory, wintering in the southern hemisphere and occurring in the assessment area from late May to August/September.

Ivory gull (*Pagophila eburnea*) does not breed within the assessment area, but close by, at Ellesmere Island in Canada. It is a common visitor, mainly at the ice edge in the northern part of the assessment area, and most of the birds probably come from the Canadian breeding population, although also birds from the East Greenland population may occur (Lyngs 2003). Summer observations in Melville Bay and in northern Upernavik indicate that breeding may occur in the northern and central parts of the assessment area (Boertmann & Huffeldt 2013, Boertmann 2013).

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

## Box 6

### Development of monitoring methods for little auk colonies based on photo- and videomonitoring

A. Mosbech, P. Lyngs, F. Merkel & K.L. Johansen

With more than 75% of the world population of little auks breeding along some 600 km of coast on the Greenland side of the North Water Polynya, Greenland has a special responsibility for the conservation of the species. As are other seabird populations, the little auk population is very sensitive to oil spills as the birds often occur in high and localized concentrations. The population of little auks are, moreover, very sensitive to changes in the special feeding conditions in the area where the little auks is dependent on the availability of high concentrations of large lipid-rich copepods of the genus *Calanus*. These copepods are High Arctic, and climate change may change their abundance and availability. It is, therefore, a high priority to develop methods and tools to monitor little auk population parameters in the area. Breeding in dense colonies with nests hidden for foxes and gulls deep in boulder scree, the little auk colonies are difficult to census and monitor. However, we have used automated still cameras and video cameras to record parameters such as colony attendance, breeding density, breeding success and feeding rates, and we have started a baseline for monitoring long-term changes.

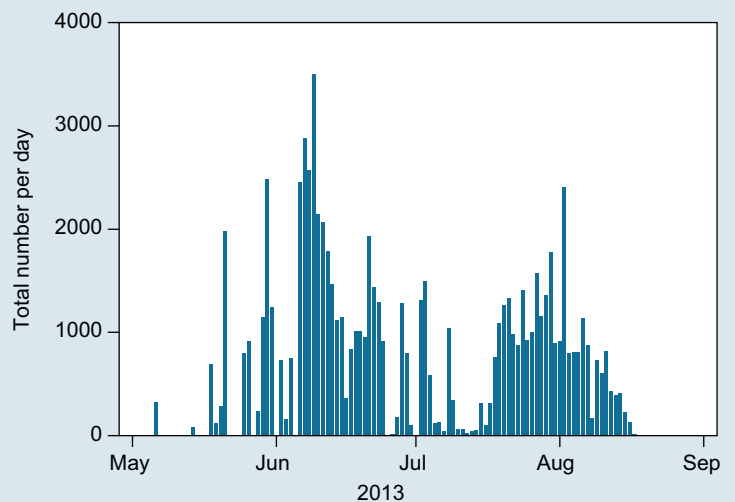
Little auks spend time resting and socializing on top of the boulders near their nest holes. In the study area Paakitsoq, we used two still cameras permanently placed in two different high-density areas of the colony (Figure 1). These cameras took a picture every hour from mid-April to early September, providing information on colony attendance, but also on the occurrence of e.g. muskoxen. While the attendance was very variable from hour to hour depending on weather, foraging conditions and predator disturbances (foxes and gulls), clear patterns emerge when the large amount of photos are analysed (Figure 2 and 3). If the still cameras are run for a longer series of years, the cameras can provide information on long-term changes of the little auk population, phenology and behaviour. Changes in the attendance pattern such as the average and maximum attendance numbers can be used as a proxy for local population changes.

The photo monitoring with still camera can, however, not be used to provide information on e.g. breeding densities and breeding success because the number of attending birds recorded cannot be converted directly to breeding pairs. In addition, the chicks generally cannot be identified on the photos of the large plots, even when they come out of their deep holes to flap their wings just before fledging.

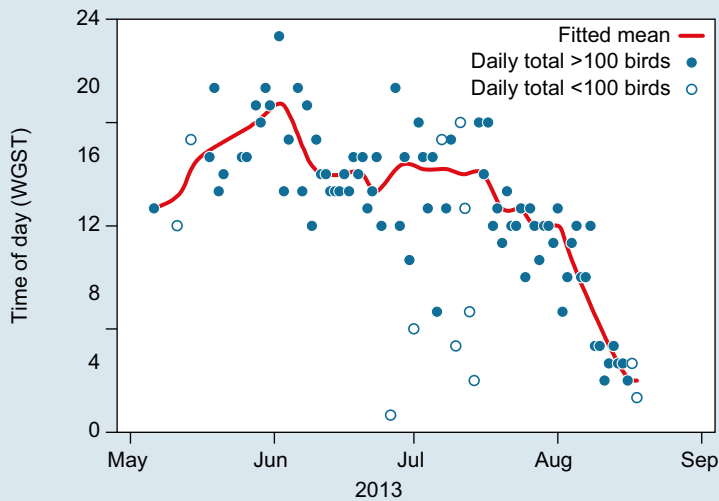
To study breeding density and productivity, we used two video cameras positioned at two selected video-plots in the centre of the colony during the week before fledging. Nearly all the chicks fledged during a few calm nights within a week. The nights before fledging, the chicks emerged for short periods from the holes between the boulders to practise wing flapping (Figure 4). Mostly, the video cameras were recording continuously for 7 hours from midnight and onwards for a week before the little auk chicks fledged, in order to capture and identify all the chicks doing wing flapping in the video plot. Though the recordings are time consuming to analyse, they provide information on the number of chicks produced (breeding productivity), breeding density, feeding rates and other behaviour that otherwise is very difficult to obtain (Figure 5 and 6).



**Figure 1.** Mounting a still camera in a weather proof box on top of a boulder in the Paakitsoq little auk colony. The camera took a picture every hour from mid-April to early September. (Photo P. Lyngs).



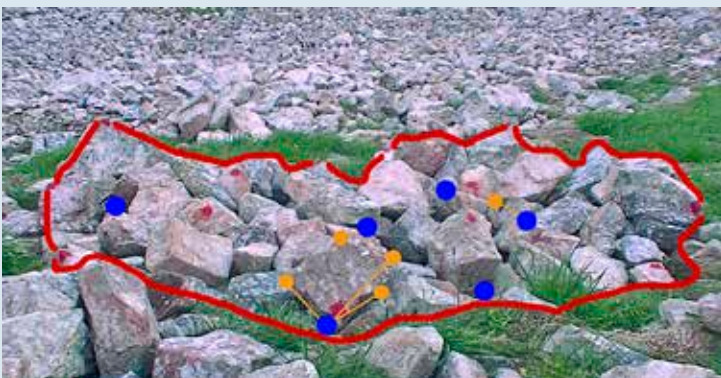
**Figure 2.** Colony attendance of little auks, Paakitsoq, 2013. A still camera positioned at plot V, taking a picture every hour from mid-April to early September 2013, recorded colony attendance of little auks. The total number per day is calculated as the sum of birds counted on the 24 pictures. The first birds were recorded May 6, but attendance did not become regular until late May - early June. Numbers peaked during the mating period around June 10, were lower during the incubation period (late June - mid-July) and increased during the chick-feeding period. Main fledging occurred August 12-16 and the last birds were recorded August 18. On average, little auks were present in the colony at Paakitsoq 17.1 hours/day during June 6-24, 8.6 hours/day during June 25-July 19 and 15.3 hours/day during July 20- August 18.



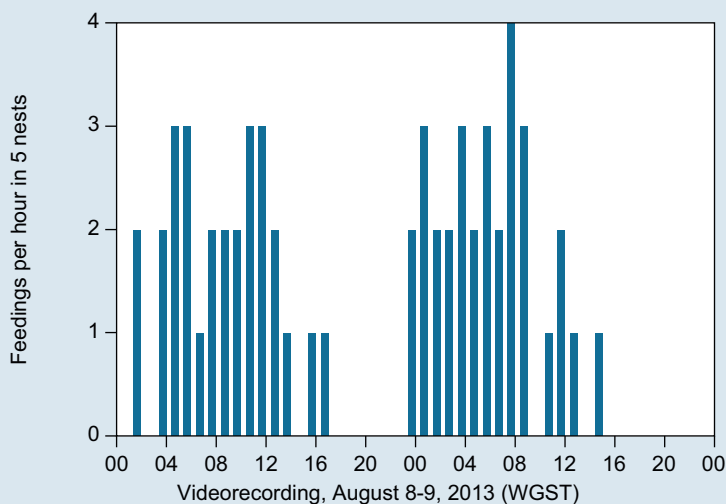
**Figure 3.** Diurnal Timing of little auk colony attendance, Paakitsoq, 2013. Using photos from the same still camera at plot V, we analysed the diurnal timing of colony attendance during the breeding season. By plotting the Median Attendance Hour (MAH, i.e. the time of day when 50 % of the birds were recorded each day) marked changes during the breeding season were obvious. During the mating period in early June, MAH usually fell between 1800 and 2000 hours. During the incubation and early chick-feeding period, MAH fell between 1300 and 1600 hours. Starting in late July, the birds attended the colony even earlier and MAH then fell between 0900 and 1300 hours. When fledging commenced after the first week of August, MAH fell between 0300 and 0500 hours, i.e. when the light intensity is lowest. Thus, MAH changed more than 14 hours over the breeding season.



**Figure 4.** Little auk chick (left) practicing wing flapping before fledging, attended by an adult (right) (Photo P. Lyngs).



**Figure 5.** Breeding density in Plot V, Paakitsoq, 2012. The red line show the border of Plot V, the blue dots the position of the 6 active nests as recorded by video in 2012. Little auks often use alternative entrances to the nest, here indicated by orange dots. Plot V covers an area of 4.71 m<sup>2</sup>. With 6 pairs in 2012 and 5 pairs in 2013, the breeding density ranged from 1.3 to 1.1 pairs per m<sup>2</sup>. In both years and in all nests large chicks ready to fledge were recorded, suggesting a high breeding success.



**Figure 6.** Chick feeding rates in Plot V, Paakitsoq, 8-9 August 2013. Analysing feeding data from a 48-hour continuous video recording in August 2013 at Plot V, we recorded 62 feedings (31 per day) for 5 nests in the plot, all holding large chicks. The chicks fledged during 12-16 August, so the recorded feedings took place 3-7 days before. The feedings were concentrated (87 %) to the first 13 hours of the day, with no feedings between 1700 and 2400 hours. Average feeding rate was 6.2 feeds/nest/24 h. Of the feedings 59 could be designated to a given nest. Daily feeding rates were 3-9 feeds/nest on 8 August and 4-11 feeds/nest on 9 August.

## Box 7

### Tracking of Little auks: migration routes and identification of moulting and wintering areas using geolocation data loggers

Anders Mosbech, Kasper Johansen & Peter Lyngs

When little auks leave the colony after the breeding season the chicks fly away over the sea accompanied by the male parent, and little is known of their migration and potential non-breeding key areas in the region. We used geolocation data loggers to study the year-round movements of little auks from the Paakitsoq colony in the Qaanaaq District. The geolocation data loggers are small, leg-mounted tags recording time and light intensity information from which the latitude and longitude can be calculated. The data loggers only store the information, and it is therefore necessary to recapture the birds the following year to retrieve the information.

In the breeding seasons 2010-2013, we deployed in total 105 geolocators in Paakitsoq and recaptured 46 the following season, and of these 43 gave good data and are used in the following analysis.

The tracking results are summarized on maps in Figure 1 and show a clear pattern for the autumn migration across year and sex. When the little auks left the colony in the first half of August, the southward autumn migration took place in the western Canadian part of the Baffin Bay and the main wintering areas were offshore Newfoundland in the Grand Bank and Flemish Cap region. During the autumn migration, there was a period at least until mid-September where the birds staged offshore Baffin Island in the cold Baffin Island Current. Most likely, this area is the moulting area for little auks where the adults moult their flight feathers and are unable to fly for about 3 weeks. The identification of this moulting area is further substantiated by saltwater immersion data from the leg-mounted data loggers, shown in Figure 2. There was a maximum water immersion ratio during this moulting period and the mid-winter period. Most likely, the moulting area extends somewhat further north than indicated by geolocations in Figure 1, due to data limitations during constant daylight, especially in the northernmost areas.

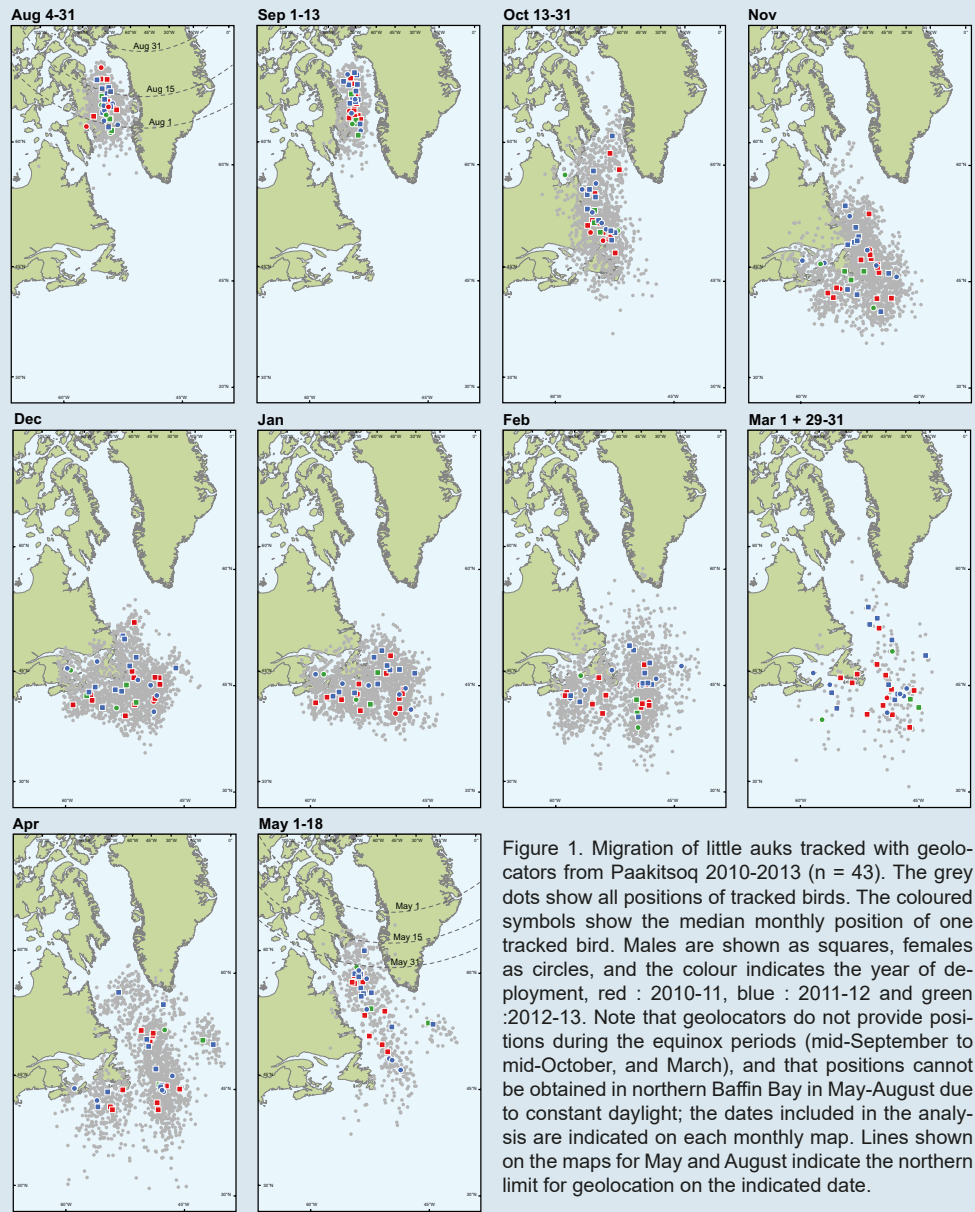


Figure 1. Migration of little auks tracked with geolocators from Paakitsoq 2010-2013 ( $n = 43$ ). The grey dots show all positions of tracked birds. The coloured symbols show the median monthly position of one tracked bird. Males are shown as squares, females as circles, and the colour indicates the year of deployment, red : 2010-11, blue : 2011-12 and green : 2012-13. Note that geolocators do not provide positions during the equinox periods (mid-September to mid-October, and March), and that positions cannot be obtained in northern Baffin Bay in May-August due to constant daylight; the dates included in the analysis are indicated on each monthly map. Lines shown on the maps for May and August indicate the northern limit for geolocation on the indicated date.

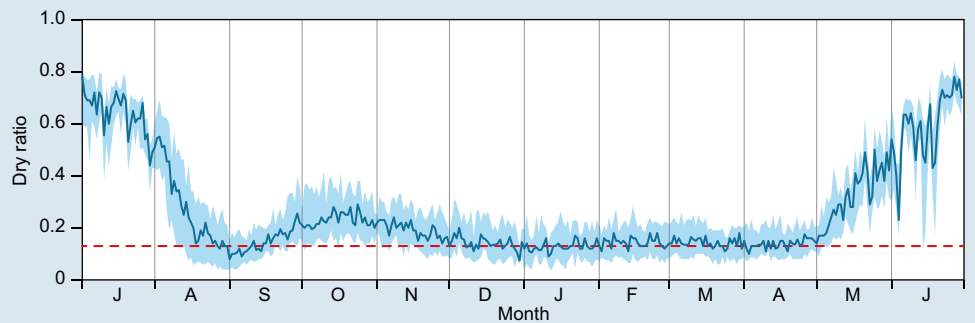


Figure 2. The daily proportion of dry recordings from saltwater immersion sensors on the leg-mounted little auk geolocation data loggers ( $n=43$  individuals). The red line is the median value for December-January where the birds are rather stationary in the wintering areas. High values indicate the bird is spending considerable time flying or sitting on land, so that the logger is out of the water. The end of the breeding season can be identified by a clear decline in the proportion of dry recordings. During the non-breeding season, little auks are exclusively at sea. Here, low proportions of dry recordings reflect much contact with sea water (i.e. diving or resting on the surface), whereas high proportions would suggest more flying activity. However, dry recordings may arise from activities other than flying (birds lifting their legs out of the water, birds sitting on sea ice), and the proportion of dry recordings is therefore not necessarily zero when the birds do not fly. The low proportions in late August and early September when birds are staging off Baffin Island thus indicate little or no flying activity, followed by an increase in flying activity in October when birds move south to the winter area.

Geese use salt marshes and other nearshore habitats for feeding. These salt marshes often become inundated at high water levels. Geese occur in the assessment area when breeding, moulting and staging during migration. Significant concentrations of moulting snow geese (*Anser caerulescens*) occur at the coasts of Qaanaaq district; and internationally important concentrations of pale bellied brent geese (*Branta bernicla*) may appear throughout the assessment area during migration periods in May-June and again in August/September when the entire flyway population moves through the area. It is therefore a national responsibility population (Table 6). The endemic and red-listed Greenland white-fronted goose (*Anser albifrons flavirostris*) breeds in low numbers in inland areas of the southern part of the assessment area and Canada geese (*Branta canadensis*) commonly occur as breeding and moulting birds throughout the terrestrial part of the assessment area (Boertmann & Glahder 1999, Boertmann & Huffeldt 2013).

The brent geese come from a small discrete population breeding in high-Arctic Canada and on a few islands in Qaanaaq District (Burnham & Burnham 2010, Egevang 2015). They winter in northwest Europe. The snow geese belong to a very large population, with the major part breeding in Arctic Canada and with winter quarters in northeast USA. The white-fronted geese belongs to a small decreasing population which breeds exclusively in West Greenland and winters in the British Isles. The numbers of Canada geese on the other hand are increasing and the birds belong to a population which has its main distribution in eastern Canada, with winter quarters in northeastern USA.

King eiders (*Somateria spectabilis*) may breed in low numbers in the northernmost part of the assessment area. However, large numbers, primarily males, assemble from July in fjords, bays and straits to perform moult, and they become flightless for a period of three weeks (Salomonsen 1968, Mosbech & Boertmann 1999). Within the assessment area, particularly the fjords in southern Upernavik are important for moulting king eiders (Figure 16), but large flocks have also been recorded in Qaanaaq District and in Melville Bay (Boertmann & Huffeldt 2013).

Phalaropes (*Phalaropus* spp.) are small shorebirds (waders) associated with the marine environment during the non-breeding period. The grey phalarope (*Phalaropus fulicarius*) breeds on small islands together with Arctic terns, for instance in Melville Bay (Egevang et al. 2004, Egevang & Boertmann 2012, Boertmann & Huffeldt 2013), while the red-necked phalarope (*Phalaropus lobatus*) breeds at ponds and small lakes on the tundra.

#### **4.7.2 Seabird migration pathways in the Baffin Bay area**

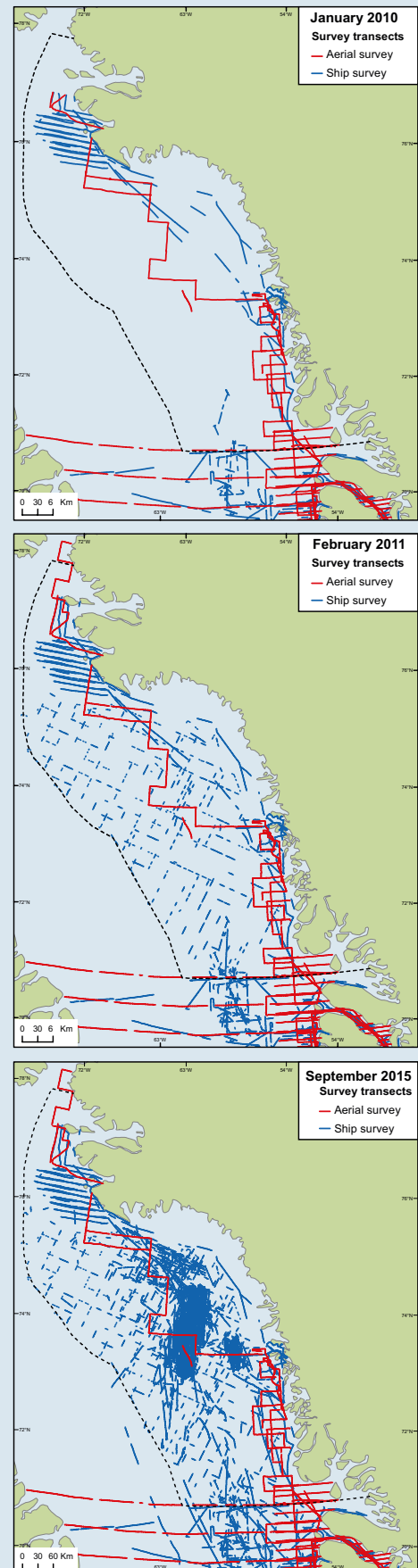
Besides the large breeding populations of alcids (thick-billed murres and little auks) on the Greenland side of the Baffin Bay at least 650,000 pairs of thick-billed murres breed on the Canadian side (Nettleship & Birkhead 1985). All breeding birds from Canada and Greenland, their offspring and populations of other seabird species move southwards through Baffin Bay towards their winter quarters primarily off Newfoundland/Labrador (Box 5 and 7). This is documented from recoveries of birds banded in the breeding colonies (Lyngs 2003) and by the recent studies carried out in relation to this SEIA (Box 5 and 7). Besides the very numerous species other species move through the Baffin Bay in spring and autumn, for example black-legged kittiwakes, ivory gulls (especially important in a conservation context) and black guillemots.

## Box 8

### Offshore densities of seabirds in the Baffin Bay assessment area

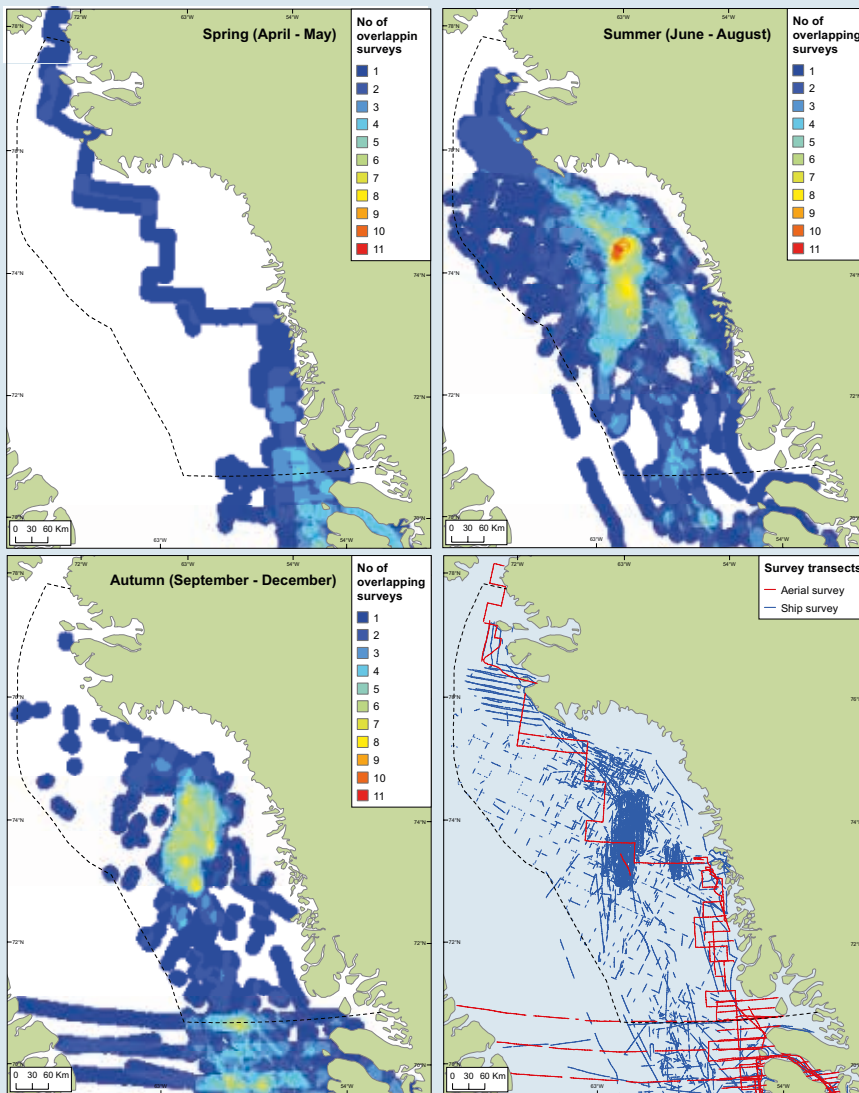
D. Boertmann, A. Mosbech, F. Merkel, M. Frederiksen & K. L. Johansen

Since the beginning of the 1990s, DCE (former NERI) has collected data on seabirds in the off-shore areas of Greenland. Both ships and aircrafts have been used as platforms, and the sampling methods (Distance Sampling, Buckland et al. 2001) allow for calculation of densities (individuals/km<sup>2</sup>) of the different species. The surveys have been carried out by DCE, both on dedicated seabird surveys and on ships of opportunity, and also and with increasing intensity by the Marine Mammal and Seabird Observers (MMSO) on board ships carrying out seismic surveys in Greenland waters. These MMSOs are instructed to sample seabird data in the same way as DCE do, so the data acquired can be incorporated into the database kept by DCE. These seismic surveys have, in many cases, covered waters, where no previous information on seabirds was available. The information from the DCE seabird-at-sea database is available for companies preparing Environmental Impact Assessments in the Greenland waters. Figures 1 and 2 (lower right) show the seabird-at-sea survey effort in the Baffin Bay assessment area, and the following figures (2-7) show the bird densities distributed over seasons (except winter).

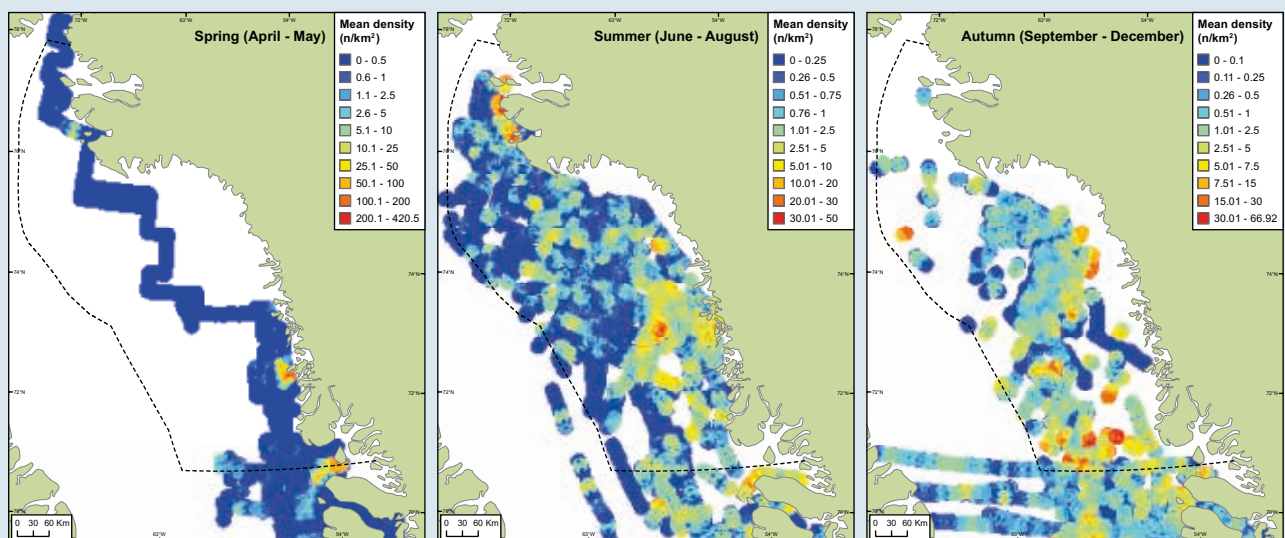


**Figure 1.** Shows the increase in data (survey lines) since 2010. The increase between 2011 and 2015 is mainly due to the MMSO data sampled during seismic surveys.

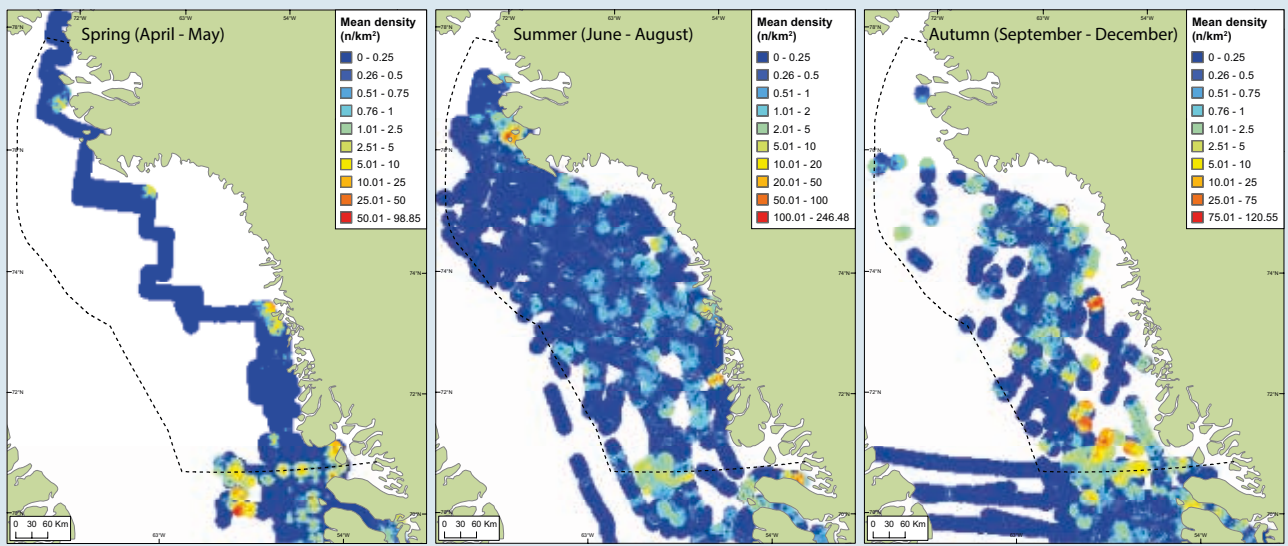




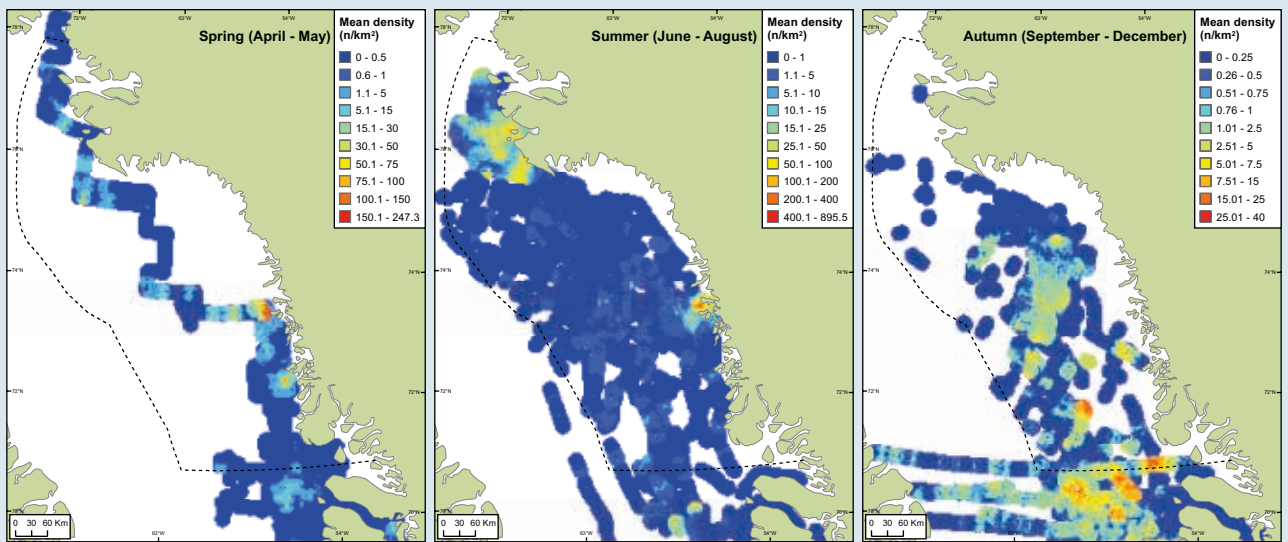
**Figure 2.** Effort (no. of surveys) of seabird-at-sea surveys in the Baffin Bay assessment area. Ship and aircraft based surveys combined, and shown for the three seasons with sufficient daylight to survey and with open waters present (in spring only open waters in the southern part and in the shear zone). Map lower right shows all survey lines included so far.



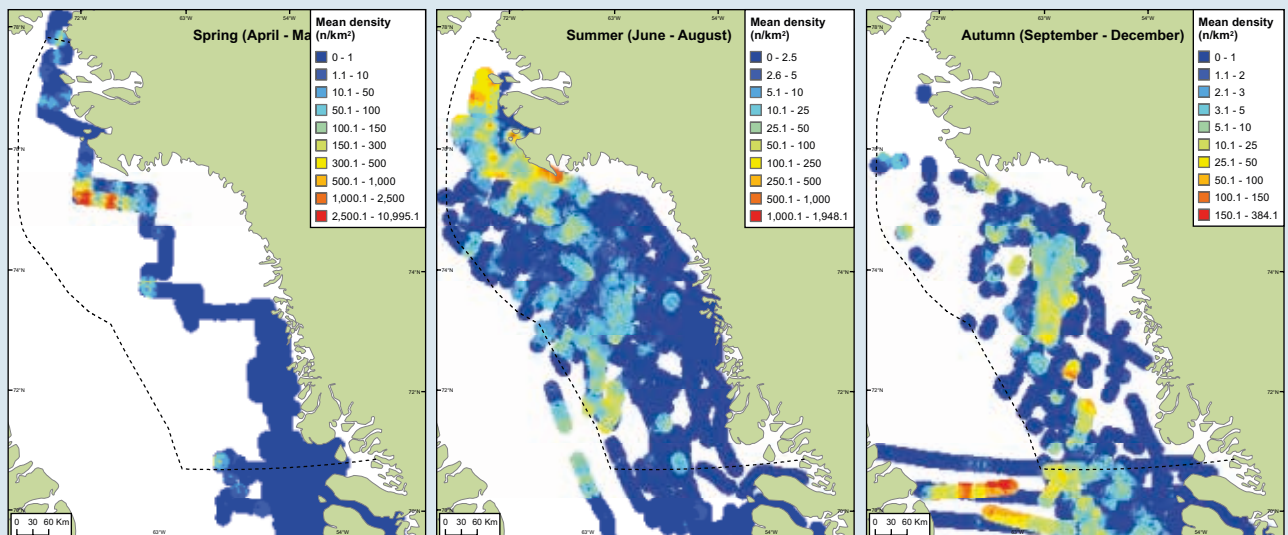
**Figure 3.** Off-shore densities of northern fulmar in three seasons as recorded on the surveys in the DCE/GINR seabird-at-sea database. In spring, when ice is still present generally very low densities were recorded. The few high-density spots are near large breeding colonies. In summer the fulmars are much more widespread, and high density spots were found at several sites – both near large breeding colonies and off-shore at feeding areas – often where shrimp trawlers operate. In the autumn season fulmars have been recorded widespread in the surveyed area, and the high densities are most likely at feeding sites, for example where shrimp-trawlers operate.



**Figure 4.** Off-shore densities of black-legged kittiwake in three seasons as recorded on the surveys in the DCE/GINR seabird-at-sea database. In spring high densities occur in some coastal sites, near large breeding colonies, and also in off-shore areas particularly in the southern part or just to the south of the assessment area. These are migrating birds on their way towards north and staging in feeding areas. In summer off-shore densities are generally low, except for an area in the southern part. This concentration probably represents non-breeding birds assembled at a feeding area. There are some high-density spots, which are close to large breeding colonies. In autumn high densities occur in large areas in the southern part, where also northern fulmars and thick-billed murres show high densities in autumn.



**Figure 5.** Off-shore densities of thick-billed murre in three seasons as recorded on the surveys in the DCE/GINR seabird-at-sea database. In spring low densities have been recorded in the leads and crack along the shear zone, while high densities have only been recorded near the large breeding colonies in northern Upernavik. Many birds are probably still to the south of the assessment area on the way north from the winter grounds. In summer the large breeding colonies in Thule and Upernavik are visible as high-density areas. In autumn, thick-billed murres occur widespread in the southern part and central of the assessment area, with very high densities in and near the southernmost previous licence block. Cf. the maps of kittiwake and fulmar densities in autumn, which also show high densities in this region.



**Figure 6.** Off-shore densities of little auk in three seasons as recorded on the surveys in the DCE/GINR seabird-at-sea database. In spring there are very few records in the southern and central parts of the assessment area, but in the northern part very high pre-breeding densities occurred in the northern part in the shear zone to the south of the huge breeding colonies in Thule. In summer the huge breeding colonies in Thule also reflect the high densities recorded in the northern part for the assessment area. In autumn, the birds have left the breeding areas and congregate now in the deep off-shore parts of Baffin Bay especially on the Canadian side

In total, it is estimated that at least one hundred million seabirds (adults and juveniles combined) move through Baffin Bay during September and October. Migration routes and critical areas (for example staging areas or important feeding areas) for these migrating seabirds have until recently been largely unknown.

Since 2007, Department of Bioscience, Aarhus University, has focused on the migration of thick-billed murres and little auks, by tracking birds by means of satellite telemetry and geo-dataloggers, and results of this tracking are presented in Box 5 and 7. The studies show that immediately after the breeding season, many female murres from Baffin Bay colonies migrate quickly southwards to the Labrador Shelf. In contrast, nearly all males and some females remain in Baffin Bay until at least mid-September, which has been confirmed by ship surveys (Box 8). The bay is thus a very important post-breeding staging (presumably moulting) area for murres, including males accompanying chicks (Box 5, Frederiksen et al. 2016). During winter, most of the population occurs on and east of the Labrador and Newfoundland shelves, although some males spend the entire winter off the West Greenland coast south of the assessment area (approx. 65-68° N). Northward migration starts in April and most individuals return to the colonies during May.

The little auks leave the breeding colonies when the chicks are able to fly in early to mid-August, and they move quickly to the Canadian side of Baffin Bay (Box 7, 8) where the *Calanus* copepods probably have not yet descended to their deep winter habitats. Later descent of *Calanus* in the colder waters off western Baffin Island was demonstrated in a survey in September 2009 in the Davis Strait in relation to the background studies in the Disko West licence area (Kjellerup et al. 2014).

#### **4.7.3 Important seabird habitats**

Besides the breeding colonies and their associated feeding areas where large concentrations of seabirds can occur on the water, significant concentrations of seabirds may occur elsewhere in the assessment area. These areas are however, difficult to identify (Fauchald et al. 2002). Exceptions are the polynyas (see Section 3.4.3), which act as very important staging and feeding areas when the birds arrive from the south and other areas of Baffin Bay still are ice-covered. Other areas with early ice break-up, such as the coastal shear zone, may also create open waters to the benefit of early arriving breeding seabirds. This seems to be the case especially in Upernavik, where the concentration of seabird breeding colonies is much higher than further south in West Greenland, despite the extensive ice cover until late May (Laidre et al. 2008b).

Little is known about important recurrent seabird concentration regions in the offshore areas. The studies conducted in 2011-2014 revealed two important post breeding areas: One for the thick-billed murres and one for the little auks. Here they assemble and most likely moult and are flightless for some weeks (Box 5 and 7). Some of the ship-based surveys also indicate thick-billed murres may occur in concentration areas (Box 8).

Although not seabirds, geese should be mentioned in this context as they often utilise saltmarshes within the assessment area (see above). Particularly the Greenland white-fronted goose (*Anser albifrons flavirostris*) is vulnerable due to the serious decrease of the population. Brent geese (*Branta bernicla*) on migration between breeding sites in Arctic Canada and wintering grounds in northwest Europe also utilise these salt marshes during stopovers (Boertmann et al. 1997, Egevang & Boertmann 2001b). However, no information on such is available from the assessment area.

## 4.8 Marine mammals

Marine mammals are another important component of the ecosystem in the Baffin Bay assessment area. Besides polar bear and walrus, at least 14 species of whales and five species of seals occur regularly in the area (Table 4).

Some of the marine mammals listed in Table 4 have been studied more intensively during the past years within the assessment area thus allowing a more detailed description.

The impacts of climate change on marine mammals and seabirds are likely profound, but not easy to estimate since patterns of changes are non-uniform and highly complex (ACIA 2005). If the loss of sea ice becomes as dramatic (temporally and spatially) as projected by the ACIA-designed models, negative consequences for Arctic mammals depending 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 with regard to habitat requirements and evidence for biological

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

Species	Period of occurrence	Main habitat	Distribution and abundance in assessment area	Protection/exploitation	Greenland Red List status	Importance of assessment area to population	VEC
Polar bear	Whole year	Drift ice and ice edges	Relatively common and mainly when ice is present	Catch regulated	Vulnerable (VU)	High	+
Walrus	Autumn, winter, spring	Polynyas, MIZ, shallow water	Mainly migrants in southern part. In NOW whole year	Catch regulated	Critical Endangered (CR)	High	+
Hooded seal	Jun.-Oct.	Mainly deep waters	Numerous	Catch unregulated	Least Concern (LC)	Medium	
Bearded seal	Whole year	Waters with ice	Widespread and abundant	Catch unregulated	Data Deficient (DD)	Medium	+
Harp seal	Jun.-Oct.	Whole area	Numerous	Catch unregulated	Least Concern (LC)	Medium	
Ringed seal	Whole year	Waters with ice	Common and widespread	Catch unregulated	Least Concern (LC)	High	+
Bowhead whale	Winter, Spring (Feb.-Jun.)	Pack ice/ marginal ice zone	Locally abundant migrant and winter visitor	Catch regulated	Near Threatened (NT)	Medium	+
Minke whale	Summer (Ap.-Nov.)	Coastal waters and banks	Rather common mainly in southern part	Catch regulated	Least Concern (LC)	Low	
Blue whale	Jul.-Oct.	Edge of banks	Few, and in southern part	Protected	Data Deficient (DD)	Low	
Fin whale	Summer (Jun.-Oct.)	Edge of banks, coastal waters	Abundant mainly in southern part	Catch regulated	Least Concern (LC)	Low	
Humpback whale	Summer (Jun.-Nov.)	Edge of banks, coastal waters	Rather abundant mainly in southern part	Catch regulated	Least Concern (LC)	Low	
Killer whale	Jun.-Aug.	Ubiquitous	Irregular	Catch unregulated	Not Applicable (NA)	Low	
White whale	Autumn, Winter, Spring (Oct.-May)	Banks	Abundant migrant and in winter also in NOW	Catch regulated	Critical Endangered (CR)	High	+
Narwhal	Whole year	Winter: edge of banks, deep waters. Summer: glacier fjords	Abundant summer, winter and migrant visitor	Catch regulated	Critical Endangered (CR)	High	+

and demographic responses to climate change. They found that hooded seal, polar bear, and narwhal are the three most sensitive Arctic marine mammal species, primarily due to their reliance on sea ice and their specialised feeding behaviour. The least sensitive species were ringed seal and bearded seal, primarily due to large circumpolar distribution, large population sizes and flexible habitat requirements.

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 to habitat loss (sea ice) and change in food sources will differ depending on whether they are ice-obligate (for example polar bear, ringed seals), ice-associated (certain seals, white whale, narwhal, bowhead whale and walrus) or seasonally migrant species (i.e. fin and minke whales).

#### **4.8.1 Polar bear *Ursus maritimus***

E.W. Born and K.L. Laidre

An update on polar bears and polar bear studies in Baffin Bay per September 2015 is provided below. The update includes a summary of polar bear field research activities in 2011 in relation to the “*Eastern Baffin Bay*” SEIA-program.

Currently, the Scientific Working Group of the Canada-Greenland Commission on Polar Bears in Baffin Bay and Kane Basin is analysing results of a joint Greenland-Canadian large-scale study covering the period from 2011 to 2014. The purpose of this study is to determine the size of the polar bear subpopulation in Baffin Bay (and the neighbouring Kane Basin subpopulation) by use of genetic mark-recapture and to understand the ongoing behavioural and ecological changes that are due to loss of sea ice. An integrated part of this study is analyses of polar bear movement and habitat preferences based on satellite telemetry. Data from 12 satellite radio collars deployed on adult females in 2011 in Baffin Bay (Northwest Greenland) under the “*Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014*” are included in this large multi-year analysis of movement and habitat choice.

The analysis includes 38 adult female polar bears that were tracked during spring 2009 to spring 2015, 20 adult female polar bears tracked between spring 2012 and 2015 and 40 males (30 adult and 10 subadult) that were tracked during 2009-2013.

Data collected from 43 adult female polar bears tracked in Baffin Bay during 1991-1996 will be used as a historical baseline to determine changes in movement and habitat choice over time in comparison with the 2009-2015 data.

##### **General distribution**

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

The overall distribution of polar bears in Baffin Bay is governed by the presence of mountainous coasts on each side of the ‘bay’, seasonal changes in ice conditions and current ice patterns in the region (Born 1995, Taylor et al. 2001). The annual land-fast ice along the coast and fjords of Baffin Island and northwestern Greenland is usually formed during October and remains until July (Teilmann et al. 1999, Born et al. 2002, 2004). This ice is used extensively by polar bears (Taylor et al. 2001). The offshore pack ice in Baffin Bay con-

sists mainly of annual ice that usually forms in October-November and disintegrates and disappears in June-July (Ferguson et al. 1999, 2000, Stirling & Parkinson 2006, Amstrup et al. 2007). During 1979-2013 autumn formation of sea ice in Baffin Bay was delayed by ca. five days per decade whereas spring break up of sea ice has advanced ca. seven days per decade (Laidre et al. 2015). As a consequence, the extension of the spring habitat for polar bears in Baffin Bay has significantly declined, most notably so since the mid-1990s (Peacock et al. 2012).

When the central Baffin Bay field of consolidated pack ice disappears during spring and summer the polar bears are faced with the choice of either using eastern Baffin Island or the Melville Bay area in Greenland as a summer retreat. Satellite telemetry during 1991-1997 indicated that the majority of polar bears followed the spring retreat of the pack ice towards the west to spend the open-water season on Bylot and Baffin Islands (Taylor et al. 2001, Figures 17, 18). This was confirmed by a new study in 2009-2010 (see Box 9). However, in some years, the ice remains during summer in the Melville Bay area and polar bears can be encountered on this ice (Figure 18). Observations by researchers from GINR and interviews with subsistence hunters living in Northwest Greenland indicated that polar bears can be met along the coasts of Northwest Greenland during summer, when some bears choose to spend the open-water season on or by the glaciers in Melville Bay (Born et al. 2011a).

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

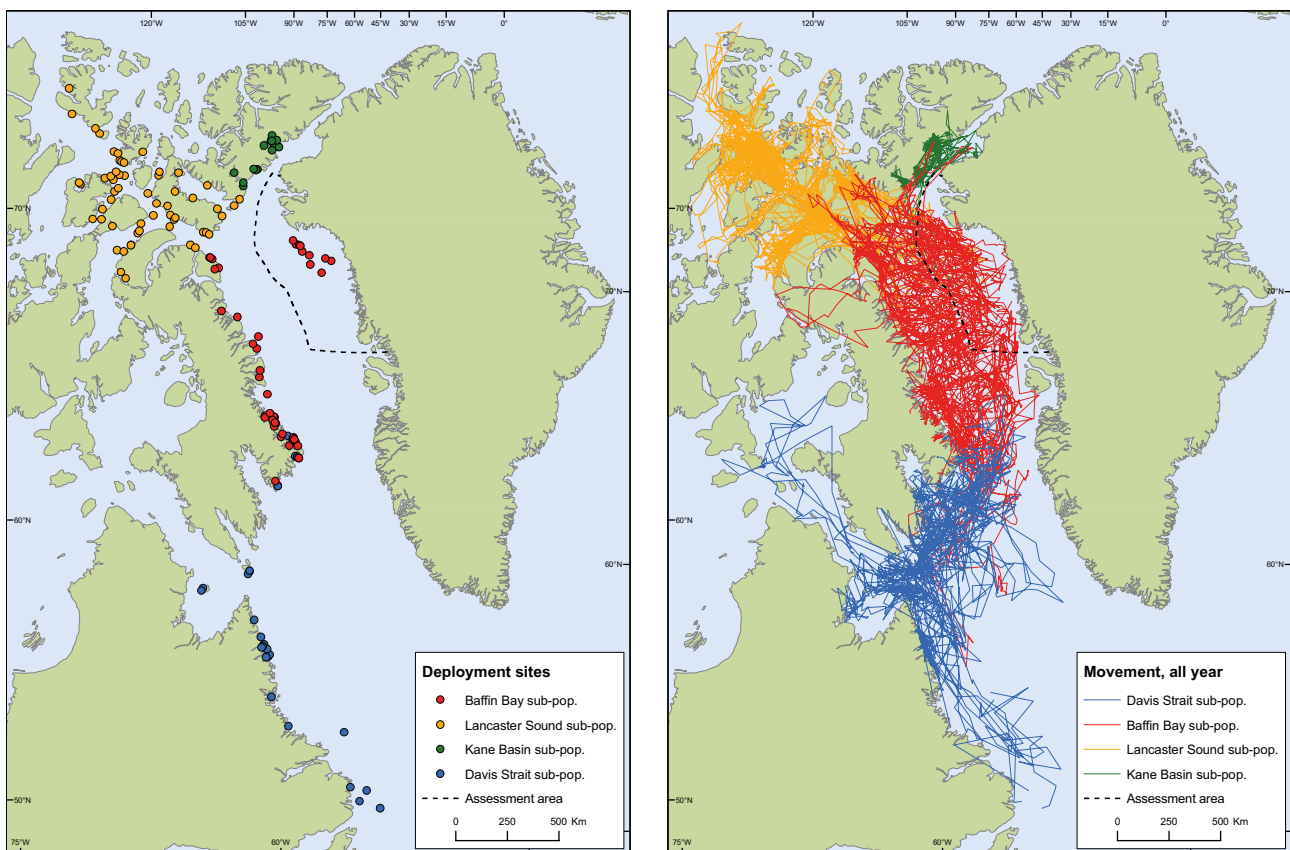
In the shear zone between the land-fast ice in the Melville Bay and the Baffin Bay pack ice, there is a lead running between Holm Island and Cape York. Each winter, this lead, which has a more or less fixed position, attracts polar bears because it is used by ringed seals (Rosing-Asvid & Born 1990, Born et al. 2011a) and is a migration route for other marine mammals during spring. During winter and spring, some polar bears occur at this shear zone as indicated by satellite telemetry (Taylor et al. 2001, Figure 18, Box 9) and information from the subsistence hunters living in Northwest Greenland (Born et al. 2011a). The polar bear hunters often move along the edge of the land-fast ice at this lead during their sled hunting trips in spring (ibid.).

Forty-three adult female polar bears tracked by use of satellite telemetry in Baffin Bay during 1991-1996 only entered maternity dens in the Baffin Island-Bylot Island areas (M.K. Taylor & E.W. Born unpublished data). This was also the case for the two females entering dens in the 2009-2010 study (Box 9). The central parts of the Melville Bay were established as a nature reserve in June 1980 (Anonymous 1980), allegedly because female polar bears have maternity dens in this area (Vibe 1971). However, interviews with experienced polar bear hunters living in the former municipalities of Upernavik and Qaanaaq in 1989-1990 (Rosing-Asvid & Born 1990) and 2006 (Born et al. 2011a) indicated that maternity dens are only rarely found in Northwest Greenland.

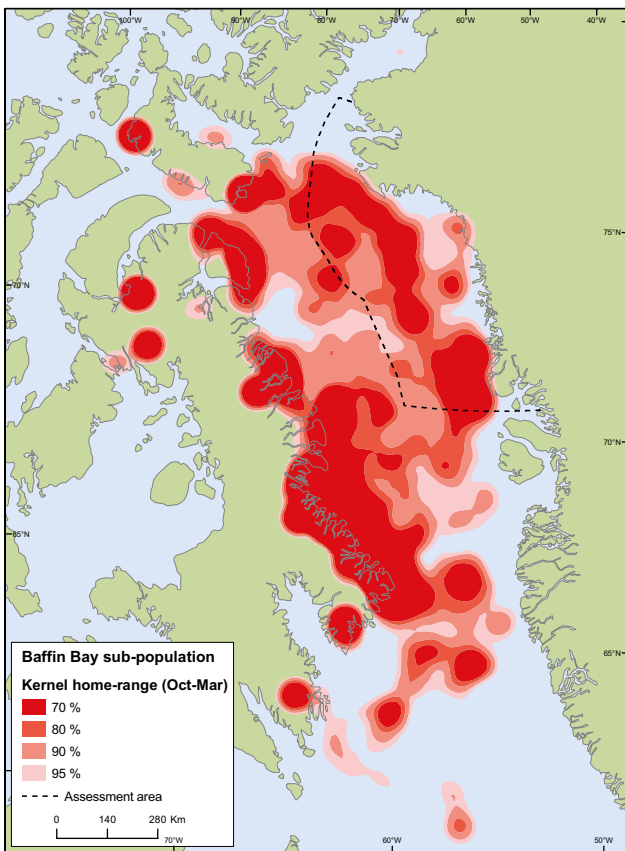
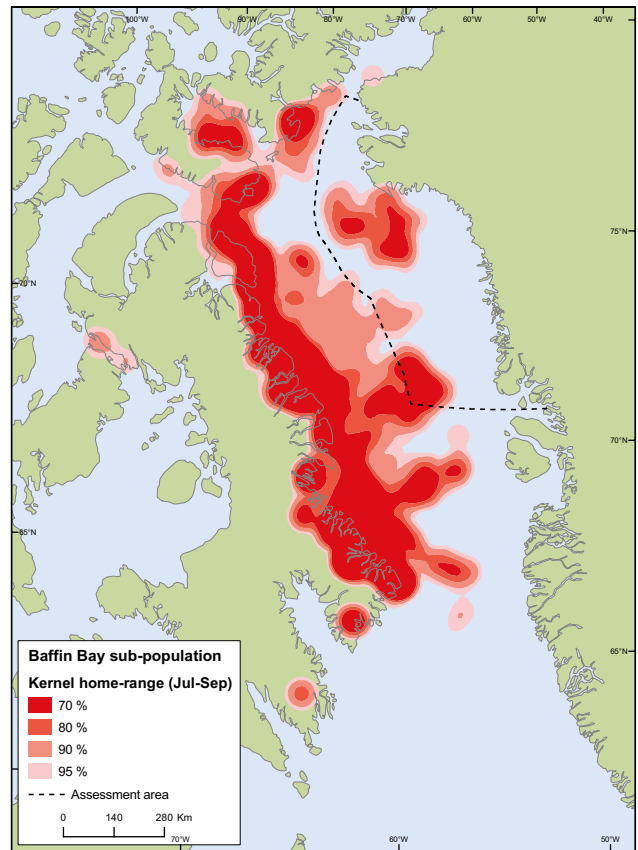
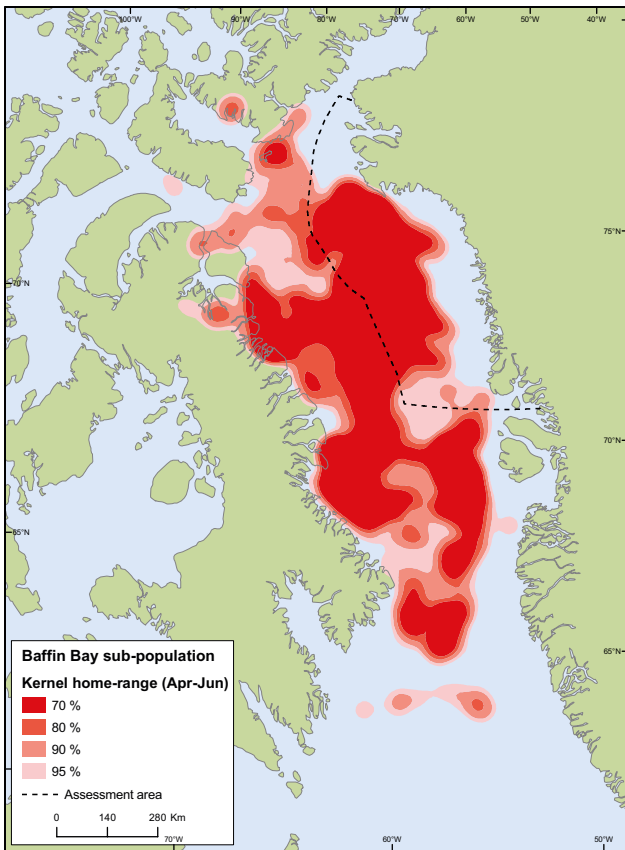
Since the beginning of the 1990s, the polar bear hunters living in Northwest Greenland have observed increased occurrence of polar bears in their hunting areas between approx. 72° N and approx. 80° N - i.e. the assessment area

(Born et al. 2011a). During an interview survey in 2005, a similar increased 'coastal' occurrence of bears was reported by Inuit living on the eastern coast of Baffin Island (Dowsley & Taylor 2006). In Northwest Greenland this enhanced occurrence was reflected in a significant increase in the catch of polar bears in the former Upernavik municipality during 1993-2005 (Born & Sonne 2006). The majority of the interviewees in Northwest Greenland and on Baffin Island were of the opinion that the increase reflected an actual increase in the Baffin Bay subpopulation. However, in both areas the informants reported marked changes in the sea ice and several suggested that the apparent increase in bears within the hunting areas could also reflect a change in distribution due to the reduction in sea ice (Dowsley & Taylor 2006, Born et al. 2011a). Since 1979 the spring break-up of the sea ice in Baffin Bay has occurred significantly earlier in the season and the total amount of sea ice has decreased since ca. 2000 (Stirling & Parkinson 2006, Peacock et al. 2012, Laidre et al. 2015). This decrease has been most pronounced in northeastern Baffin Bay (Born 2005), which is used intensively for polar bear hunting (Born et al. 2008).

An analysis of the relationship between sea ice cover and polar bear body condition during 1977-2010 indicated that polar bears in Baffin Bay exhibited positive relationships between body condition and summertime sea ice cover. The study suggested that declining body condition in polar bears in Baffin Bay was a result of recent declines in sea ice habitat (Rode et al. 2012).



**Figure 17.** Left map: Locations where adult female polar bears were instrumented with satellite transmitters (1991-1995) given by sub-population. A total of 41 bears were instrumented in the Baffin Bay sub-population (9 in NW Greenland and 32 along eastern Baffin Island) and their movements were tracked during 1991-1997. The identification and delineation of the various sub-populations based on hierarchical cluster analyses is described in Taylor et al. (2001). Unpublished data: Greenland Institute of Natural Resources, Nunavut Wildlife Management Division, University of Saskatchewan. Right map: Track lines showing the overall movement during 1991-1997 of 41 polar bears instrumented with satellite transmitters. A certain degree of overlap between the different sub-populations is apparent. The instrumented polar bears made little use of the fast ice and North Water Polynya area in the Baffin Bay assessment area in NW Greenland (i.e. the Melville Bay area). This was thought to be an avoidance response due to a relatively high hunting pressure in the area (Taylor et al. 2001). Unpublished data: Greenland Institute of Natural Resources, Nunavut Wildlife Management Division, University of Saskatchewan.



**Figure 18.** Home ranges (calculated as Kernel home range contours) of the Baffin Bay sub-population of polar bears based on satellite-telemetry tracking of 41 female polar bears 1991-1997. October-March (winter). April-June (spring). July-September (summer, or open water season). The definition of seasons relevant to polar bear ecology follows Born et al. (1997) and Wiig et al. (2003). Sources: Taylor et al. (2001), unpublished data from GINR, Nunavut Wildlife Management Division, University of Saskatchewan. This information on polar bear area use obtained from satellite-telemetry may no longer be representative, given the fact that sea ice conditions and polar bear occurrence have changed in Northwest Greenland.

With analogy to the situation in southwestern Hudson Bay, Stirling & Parkinson (2006) and Born et al. (2008) suggested that the apparent increase in nearshore observations of polar bears reflects a change in distribution due to reduced sea ice.



Based on a population estimate of approx. 2,100 bears for the Baffin Bay subpopulation in 1997 (Taylor et al. 2005) and the reported combined Canadian and Greenlandic catches, modelling (Population Viability Analysis, PVA) indicated that the population was subject to over-exploitation and had declined until 2004 (Aars et al. 2007, Anonymous 2007, Obbard et al. 2010).

Due to the current uncertainty of the status of the Baffin Bay polar bear population and the out of date data, the Scientific Working Group (SWG) of the Canada-Greenland Joint Committee on Polar Bears in Baffin Bay and Kane Basin recommended that new studies should be conducted to estimate abundance, subpopulation delineation and vital rates of the Baffin Bay subpopulation of polar bears (SWG 2010). Accordingly, during 2011-2015, Canadian research institutes and GINR conducted a large-scale study to estimate the abundance of Baffin Bay polar bears using genetic mark-recapture. The data from 2011 collected under the SEIA were included in this study.

### **Conservation status**

The population occurring in the assessment area has an unfavourable conservation status, mainly due to the expected reduction in the habitat but also to the catch. Therefore the polar bear is listed as 'Vulnerable' (VU) on both the global Red List (IUCN 2015) and the Greenland red List (Boertmann 2008).

Population and habitat modelling have projected substantial future declines in the distribution and abundance of polar bears as a consequence of habitat reduction (Derocher et al. 2004, Durner et al. 2009, Lunn et al. 2010).

### **Delineation of populations**

The Baffin Bay subpopulation is essentially closed to the east and west because of Greenland and Baffin Island, although movements across Baffin Island and into neighbouring subpopulations have been recorded (Taylor et al. 2001, Figure 17).

Recoveries from the subsistence hunt in Northwest Greenland of polar bears that have been tagged in Canada indicate that polar bears from other subpopulations occasionally enter the Baffin Bay assessment area (Born 1995, GINR unpublished data, Figure 17). Between 1977 and 2004, a total of 55 tags (family groups counted as one recovery) have been delivered in Greenland from the Baffin Bay subpopulation. Of these, nine (approx. 16%) were from bears that had been tagged in other management zones than Baffin Bay (i.e. the Davis Strait, Lancaster Sound, Viscount Melville Sound and Kane Basin; GINR unpublished data). Information obtained during the interview survey in 2006 indicates that only about half of the recovered tags are being delivered to the authorities (Born unpublished data). Some movement out of Baffin Bay has also been demonstrated. Of 306 polar bears that originally were tagged in Baffin Bay about 18% were recovered during 1979-2009 outside Baffin Bay (i.e. in Lancaster Sound, the Davis Strait, Kane Basin, Foxe Basin, M'Clintock Channel and East Greenland; one individual) (Peacock et al. 2012).

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

The southern boundary runs from Cape Dyer, Baffin Island to Qeqertarsuaq/Disko Island, Greenland (Figure 17) where there is a submarine ridge influ-

encing ice and current conditions in Baffin Bay and the Davis Strait (Taylor et al. 2001). Satellite telemetry during 1991-1997 indicated that this boundary was surprisingly strong given that Baffin Bay and the Davis Strait are covered with pack ice from December until July. The ice platform presents no difficulties for polar bears that are capable of making unidirectional long-distance movements in active pack ice against both wind and current drift (for example Wiig et al. 2003).

Genetic analyses showed that polar bears in Baffin Bay differ significantly from those in the Davis Strait and Lancaster Sound, whereas no difference was found between the Baffin Bay and Kane Basin subpopulations (Paetkau et al. 1999, Peacock et al. 2015). It was suggested that this lack of difference was caused by a 'source-sink' relationship, meaning that the larger Baffin Bay subpopulation has supplied Kane Basin with polar bears as a result of long-term over-exploitation of the Kane Basin subpopulation (Paetkau et al. 1999, Taylor et al. 2007).

### **Movements**

In the 1990s, female polar bears instrumented with satellite radios made remarkably few excursions onto the fast ice of Melville Bay (Taylor et al. 2001, Figure 17, Box 9) despite the fact that the land-fast ice in the Melville Bay is a good habitat for ringed seals (Born et al. 1999). It was suggested that this space use pattern is an avoidance response (Taylor et al. 2001). The fast ice and the adjacent offshore pack ice are used intensively by the Greenlanders for hunting of polar bears during late winter and spring (Rosing-Asvid & Born 1990, Born et al. 2011a).

Studies of the movement of 17 adult male and 20 adult female polar bears instrumented with satellite transmitters during 2009-2011 (i.e. including some transmitters deployed in 2011) between the West Greenland coast and up to 150 km offshore between ca. 70° and ca. 76° N showed that during the spring breeding period (April-May) the bears mainly occupy the eastern part of Baffin Bay over the West Greenland continental shelf between ca. 68° 30' N and ca. 76° N including the Melville Bay area (Laidre et al. 2012). There were no differences in movement rate or sea ice habitat selection for the two sexes. However, in all years, adult females had significantly more linear movements and significantly larger breeding range sizes than males (*Ibid.*).

Non-denning bears return to the sea ice at Baffin and Bylot Islands in November (Ferguson et al. 1999), and many proceed across Baffin Bay to Greenland waters (Taylor et al. 2001). Of a total of 32 polar bears fitted with satellite transmitter on eastern Baffin Island during autumn, 17 (approx. 53%) occurred inside the Baffin Bay assessment area for periods of variable duration. Fifteen (approx. 47%) entered the assessment area during winter, 12 (approx. 38%) during spring and six (approx. 19%) during summer (for periods see Figures 17, 18). By comparison, of nine polar bears instrumented in the Melville Bay during spring, all used the assessment area at some point during the year. Six (approx. 66%) occurred there during winter, five (approx. 56%) in summer and all during spring (Born unpublished data). This indicates the importance of these parts of the Baffin Bay to polar bears.

The general movement pattern is that bears instrumented with satellite radios during spring in Northwest Greenland occurred over the Greenland continental shelf during spring. As the Baffin Bay ice gradually melts and recedes towards west in late spring, most polar bears follow the sea ice to summer on Baffin Island. However, some individuals choose to summer in the Melville

Bay area (Born et al. 2013a, b; Laidre and Born unpublished data). Recent satellite telemetry has demonstrated that some bears spend all year in the Melville Bay area (Laidre & Born unpublished data). During winter, the polar bears roam widely in Baffin Bay with a tendency to concentrate over the continental shelves along Baffin Island and Northwest Greenland (Born et al. 2013a, b; Laidre & Born unpublished data).

Most Baffin Bay individuals do not move south of ca. 66° 30' N (Taylor et al. 2001; Laidre and Born unpublished data). However, when the sea ice conditions permit, some Baffin Bay individuals may move as far south as the offshore hooded seal whelping areas that vary in position between years from Southeast Baffin Island to Nuuk, Greenland (Bowen et al. 1987, Stirling & Parkinson 2006).

The polar bears in Baffin Bay move considerable distances during the year. The home range size of polar bears exploiting Baffin Bay averaged 192,000 km<sup>2</sup>, which is considerably larger than the home ranges of bears inhabiting areas with more consolidated ice (Ferguson et al. 1999). A suggested explanation for the large home ranges of bears in Baffin Bay was that these bears explore a habitat with large seasonal flux of annual ice in which the distribution of various prey, in particular ringed seals, is variable and patchy. In addition, 'offshore' polar bears have access to other food sources (narwhals, white whales (belugas), bearded seals, hooded seals and harp seals), the distribution of which changes seasonally and between years. Furthermore, the overall movement rates of polar bears exploiting the Baffin Bay pack ice are higher than those of polar bears inhabiting the land-fast ice (Ferguson et al. 2001).

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

The majority of satellite transmitters in the study by Taylor et al. (2001) were deployed during autumn along the western shores of Baffin Bay (Taylor et al. 2001, Figure 17). Due to logistical constraints, satellite radios were not deployed offshore (i.e. in the western parts of the assessment area). This geographical bias in deployment sites and the fact that the sea ice conditions in the polar bear habitat inside the assessment area have changed markedly since the mid-1990s call for caution when interpreting previously collected satellite data in relation to current and future polar bear habitat choice and oil activities.

### **Size of the Baffin Bay subpopulations**

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

However, after having reconsidered the status of the Baffin Bay subpopulation the Scientific Working Group (SWG) of the Canada-Greenland Commission on

## Box 9

### The 2011 polar bear study

E.W. Born & K.L. Laidre

In spring 2011, polar bears were immobilized and tagged in the Melville Bay as part of the *Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014*. (Figure 1). The purpose of the study was to study area occupancy and habitat choice in relation to the assessment area.

The field work occurred from 2-16 April 2011 during which a total of 34 polar bears were immobilized. Satellite radio collars were deployed on 12 adult females. Furthermore, small ear satellite radios were fitted on 10 adult males, two sub-adult males and three dependent 2-year-old cubs (Table 1).

The ear radios transmitted for an average of 62 days (SD=18.1 d, range: 28-91 d, n=15) before they were shed.

The satellite radio collars transmitted for an average of 546 days (SD=379.5 d, range: 24-1173 d, n=12). However, bear number 7314 (Table 1) captured in 2011 was a re-capture of a bear previously captured in Melville Bay in April 2010. Therefore in 2011 her still-active satellite radio collar was replaced with a new satellite radio collar. Hence this bear was tracked for a total of 1126 days (2010-2011 transmission not included in previous summary statistics).

### General movement

#### Movement of adult males and subadults

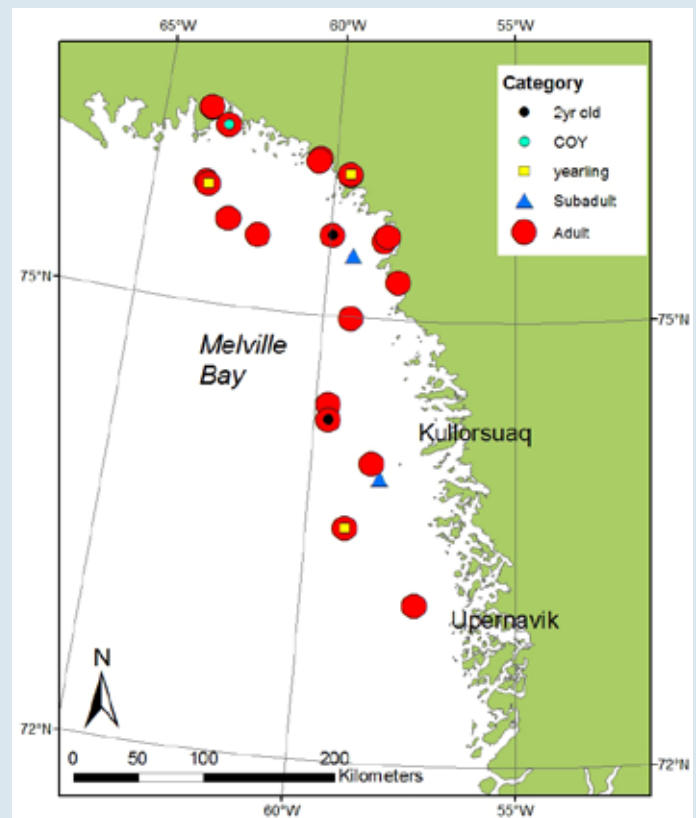
Between deployment and final transmission stop on 9 July 2012, 12 of the polar bears (80%) fitted with ear satellite radios remained in the assessment area, whereas three bears moved towards Canada. One of these three (an adult male) stopped transmitting close to the entrance to Jones Sound. Another adult male moved into Jones Sound and a subadult male reached ca. 80 km off the coast of Baffin Island before the transmissions stopped.

The tracking with ear satellite radios demonstrates the general importance of the NW Greenland spring feeding and mating areas to adult males, and previously work has shown that adult male and female polar bears generally use the same sea ice habitat in NW Greenland during spring (Laidre et al. 2012). The movements of males also indicated that there is some connection between polar bears in Baffin Bay and polar bears in other subpopulations (in this case the Kane Basin subpopulation).

#### Movement of adult females

The satellite collars allowed for tracking of adult females for up to several years.

In 2011, adult female bears collared in Melville Bay moved extensively around the Baffin Bay region. Generally there was high use of the assessment area in Baffin Bay in spring and summer (Figure 2) with bears making localized movements in the optimal habitats. Two of the bears moved into the area of the Kane Basin subpopulation where the transmissions ended. One bear (D7334) moved into Lancaster Sound, where it was shot. One bear also moved into Davis



**Figure 1.** Location of tagging sites (sex and age category) of 34 polar bears that were tagged in the Melville Bay area during 2-16 April 2011 in connection with the “Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014”. COY = Cub of the year.

Strait, but subsequently returned to the Baffin Bay subpopulation area.

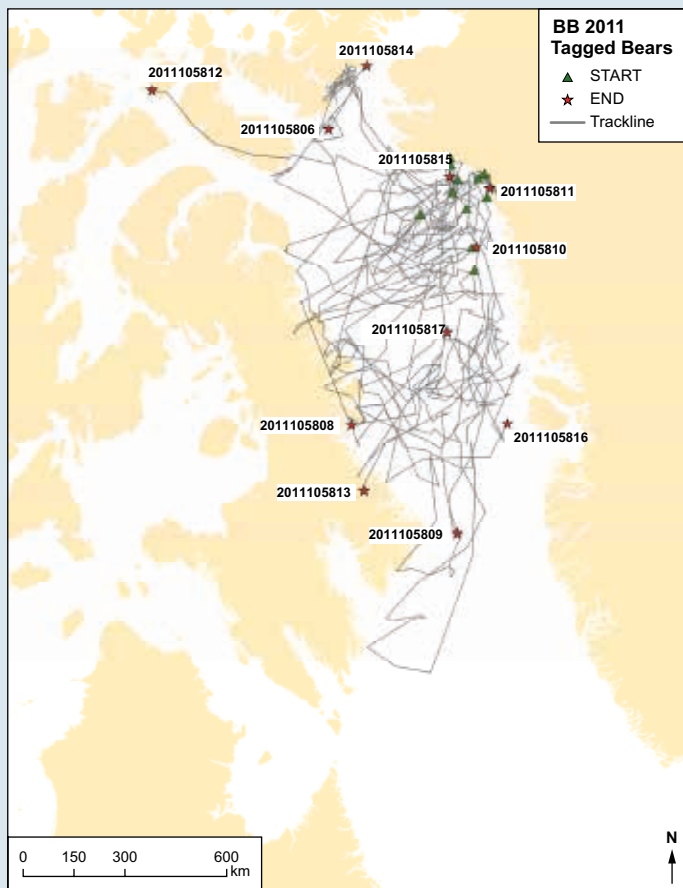
The general movement pattern of the adult female polar bears in the Melville Bay area in 2011 was representative of the general area use by all 38 adult female polar bears which were instrumented with satellite radios in W and NW Greenland during 2009-2013 (SWG 2016).

The data confirmed that polar bears occurring in eastern Nunavut and in NW Greenland belong to a single subpopulation that roams the entire Baffin Bay, as several bears that were originally tagged in Canada were recaptured in NW Greenland. A total of seven adult polar bears (five females and two males) aged 13-24 years were recaptured during 2009, 2010, 2011 and 2013 within the assessment area (Born and Laidre unpublished data).

### Spring fidelity to the assessment area

In general, polar bears show a high degree of site fidelity to spring feeding areas (Lone et al. 2013 and references therein). This is also the case for NW Greenland. Fidelity to NW Greenland during spring was demonstrated by recapture of individuals over multiple years in the same areas, harvest by subsistent hunters of previously tagged (marked) bears, and by tracking individual adult female polar bears via satellite telemetry.

During spring 2009-2013 (5 seasons) the Greenland Institute of Natural Resources (GINR) handled and tagged a total of 139 polar bears in NW Greenland between 70° 14'N and 76° 20'N (i.e. between Qeqertarsuaq/Hare Ø and NE of Savissivik) and between the Greenland coast and ca. 150 km offshore. Ninety-four (53 females; 41 males) of these in-



**Figure 2.** Movements of 11 adult females tracked via satellite telemetry during 2011-2014. A 12th adult female (7314, Table 1) was captured on 6 April 2011 in Melville Bay and was fitted by a new satellite radio collar. On 9 April 2010 the same bear had been captured about 75 km from the 2011-capture location and fitted with a satellite radio. This allowed for tracking her for a total of 1126 days during which period she roamed widely in Baffin Bay. However, she returned to NW Greenland over four consecutive springs showing high fidelity to the assessment area.

dividuals were independent (i.e.  $\geq 2$  years of age) and the remainder were dependent cubs (0, 1 and 2 year old) accompanying their mothers (Born and Laidre, unpublished data). Eight of these individuals were recaptured by GINR during spring in subsequent years (2011-2013) in NW Greenland.

Furthermore, some bears tagged in NW Greenland during 2009-2013 were recovered in NW Greenland by subsistence hunters in subsequent years. During 2010-2014 six tagged polar bears (independent 3+ year olds) were shot by subsistence hunters during their spring hunt for polar.

Of the adult females instrumented with satellite radio collars in April 2011 which transmitted  $\geq 1$  year ( $N=9$ ; Table 1), seven (ca. 78%) returned to the assessment area in subsequent springs. Four of these bears (ID 105806, 105809, 105811, 105814) occurred in NW Greenland in two consecutive springs (i.e. 2011 and 2012) until transmission stopped and one (ID 105813) in three springs (2011-2013). However, two females (74774/105807 and 105817) occurred there in four consecutive springs (i.e. 2010-2013 and 2011-2014, respectively). The remaining two adult female bears that transmitted  $\geq 1$  year (105808, 105816) moved to eastern Baffin Island during the spring and early summer of 2012.

Of the adult female polar bears instrumented in 2011 and transmitting  $< 1$  year, two (105810, 105815) remained in the tagging area in Melville Bay and one (105816) moved toward Baffin Island before transmission stop.

This information indicates a strong fidelity of some polar bears to the assessment area during spring.

### Summer fidelity to the assessment area

The occurrence of polar bears in NW Greenland during summer (i.e. during the open water season) was verified through visual observations in September 2012 and 2013 (Born et al. 2012, 2013c) and via satellite telemetry (SWG 2016).

During September 2012 and 2013 systematical helicopter-based search for polar bears was conducted in the Melville Bay area. During 4-11 September 2012 the coast and offshore between  $74^{\circ} 20' N$  (i.e. a little south of Kullorsuaq) and  $76^{\circ} 33' N$  (Thule Air Base) were searched. The operation was repeated during 8-15 September 2013 when the coastal areas between  $74^{\circ} 34' N$  (Kullorsuaq) and  $76^{\circ} 46' N$  (abandoned settlement Moriussaq) were covered. In 2012, a total of 13 polar bears were observed between  $75^{\circ} 35' N$  and  $76^{\circ} 05' N$ , and in 2013 a total of 17 polar bears were observed between  $75^{\circ} 33' N$  and  $76^{\circ} 23' N$ . Observations included both sexes and all age classes (i.e. adults, subadults and dependent cubs including cub-of-the-year, COYs).

Satellite telemetry revealed that some individuals are resident during the entire year in the Melville Bay area. Of 38 adult females furnished with satellite collars in NW Greenland, seven remained in the Melville Bay area for the entire tracking season (i.e. 1-2+ years) (SWG 2016). This is the first time this has been documented for the area and suggests that a local or resident fraction of unknown size is present.

### Maternity denning in the Melville Bay area

According to the polar bear hunters living in NW Greenland adult female polar bears are denning in Melville Bay (Rosing-Asvid & Born 1990, Born et al. 2011). During the spring operation to tag polar bears in NW Greenland two maternity dens were observed in Melville Bay (13 April 2012:  $75^{\circ} 35' N 58^{\circ} 24' W$ ; 11 April 2013:  $75^{\circ} 48' N 60^{\circ} 01' W$ ) On 7 September 2012 a bear that had entered a presumed maternity den was observed at  $76^{\circ} 16' N 67^{\circ} 01' W$  (Born et al. 2012, 2013c).

Maternity denning activity in NW Greenland was also indicated through live capturing a total of eight adult female polar bears accompanied by newborn (COYs = cubs of the year) during April 2010-2013 (Born & Laidre unpublished data). Furthermore, maternity denning in Melville bay was demonstrated through satellite telemetry (SWG 2016).

## Conclusions

The 2011-operations taken together with information collected during polar bears studies (some of which serving other purposes than this SEIA) in 2009-2014 indicate that the NW Greenland is an important habitat for polar bears belonging to the Baffin Bay subpopulation. The Melville Bay area and in particular the Melville Bay Nature Reserve is an important spring feeding area and maternity denning area. Polar bears occur in Melville Bay all year round and some fraction of the subpopulation appears to be resident in the Melville Bay area. Compared to observations made during polar bear studies in Melville Bay in 1992 and 1993 the new information indicates an increased use by polar bears in this area.

## Future studies

Additional information would be valuable for quantifying and identifying the importance and the potential impacts to polar bears in the assessment area and particularly in the Melville Bay region. First,

given that the data documented a resident (local) population in the area (e.g., bears that remain in the area year-round and do not move to Baffin Island in summer) it would be necessary to deploy a larger number of satellite collars on adult female to determine if the fraction of bears staying in the area is 18% in all years. This is also recommended, in light of rapidly changing ice conditions in Baffin Bay, because polar bear habitat is deteriorating and bears may move to a local glacial front strategy. Furthermore, it would be necessary to quantify the number of polar bears using Melville Bay year round. This would involve focused helicopter flying in the assessment area to obtain skin biopsies from as many bears as possible sampled using biopsy darting. This would facilitate quantifying (1) site tenacity of polar bears in Melville Bay if repeated over several years, and (2) numbers of polar bears in the Melville Bay assessment area based on repeated sampling during spring and fall. This information can be related to real time observations of sea ice conditions and satellite data on ice cover to quantify the risk to the fractional portion of the Baffin Bay subpopulation from oil spills in West Greenland.

**Table 1.** Number (sex and age category) of 34 polar bears that were tagged in the Melville Bay area during 2-16 April 2011 in connection with the "Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014". The type of satellite radio (PTT) fitted on some individuals is shown with days of transmission (per mid-April 2015).

ID	Original ID	Sex	Field age category	Tooth age (years)	Day (Apr 2011)	Location on tagging				Together with	Transmitter (PTT) Type	PTT ID	Duration(days)		Body mass estim. (kg)
						Deg N	Min	Deg W	Min				Collars	Ear radios	
7316		M	Subadult	3	2	75	25	59	20		Wild. Comp. SPOT5 ear satellite radio	105781		35	226
7275	D7275	M	Adult	10	3	74	24	59	41		Wild. Comp. SPOT5 ear satellite radio	105783		78	438
7319	X13178	F	Adult	13	3	74	18	59	39	D7320, D7321	Telonics TAW-4610H satellite collar	105806	551		205
7320		M	2 yr old	2	3	74	18	59	39	D7319, D7321	Wild. Comp. SPOT5 ear satellite radio	105784		58	(160)
7321		F	2 yr old	2	3	74	18	59	39	D7319, D7320	Wild. Comp. SPOT5 ear satellite radio	105785		46	116
7314	X14224	F	Adult	15	6	74	59	59	18		Telonics TAW-4610H satellite collar	105807	780		228
7322		M	Adult	10	6	75	30	61	58		Wild. Comp. SPOT5 ear satellite radio	105786		71	334
7323		M	Adult	12	6	75	49	63	33		Wild. Comp. SPOT5 ear satellite radio	105787		75	439
7324		F	Adult	13	6	75	48	63	29	D7325	Telonics TAW-4610H satellite collar	105808	576		218
7325		M	Yearling	1	6	75	48	63	29	D7324	-	-		86	225
7326		M	Subadult	5	7	73	55	58	18		Wild. Comp. SPOT5 ear satellite radio	105788		86	225
7327		F	Adult	15	9	75	32	58	32		Telonics TAW-4610H satellite collar	105809	797		214
7328		M	Adult	4	9	75	33	58	26		Wild. Comp. SPOT5 ear satellite radio	105789		72	248
7331		M	Adult	15	9	75	33	58	26		Wild. Comp. SPOT5 ear satellite radio	105790		28	(360)
7330		F	Adult	5	10	75	32	59	57	D7332	Telonics TAW-4610H satellite collar	105810	24		196
7332		M	2 yr old	2	10	75	32	59	57	D7330	Wild. Comp. SPOT5 ear satellite radio	105791		91	183
7333		F	Adult	5	10	75	57	59	36		Telonics TAW-4610H satellite collar	105811	370		196
7334		F	Adult	9	10	75	58	59	35	D7339	Telonics TAW-4610H satellite collar	105812	108		205
7339		F	Yearling	1	10	75	58	59	35	D7334	-	-			94
7335		F	Adult	10	11	73	34	59	4	D7336	Telonics TAW-4610H satellite collar	105813	1079		218
7336		F	2 yr old	2	11	73	34	59	4	D7335	-	-			123
7337		M	Adult	5	11	74	1	58	31		Wild. Comp. SPOT5 ear satellite radio	105792		62	271
7342		F	Adult	10	12	76	19	63	40	D7343, D7344	Telonics TAW-4610H satellite collar	105814	670		226
7343		M	Yearling	1	12	76	19	63	40	D7342, D7344	-	-			105
7344		F	Yearling	1	12	76	19	63	40	D7342, D7343	-	-			76
7345		M	Adult	9	12	76	19	63	41		Wild. Comp. SPOT5 ear satellite radio	105793		45	383
7346		F	Adult	7	12	76	13	63	8	D7347	Telonics TAW-4610H satellite collar	105815	50		209
7347		F	Cub of the year	0	12	76	13	63	8	D7346	-	-			22
7348		M	Adult	11	12	75	35	62	48	D7349	Wild. Comp. SPOT5 ear satellite radio	105794		53	417
7349		F	Adult	5	12	75	35	62	48	D7348	Telonics TAW-4610H satellite collar	105816	369		173
7370		M	Adult	4	13	75	15	58	6		Wild. Comp. SPOT5 ear satellite radio	105795		64	314
7371		F	Subadult	3	13	76	3	60	27		-	-			139
7372		F	Adult	4	13	76	2	60	29		Telonics TAW-4610H satellite collar	105817	1173		145
7305	X14148	M	Adult	24	16	73	5	57	20		Wild. Comp. SPOT5 ear satellite radio	105782		69	396

Polar Bears in Baffin Bay and Kane Basin cautioned that given the large-scale environmental changes in Baffin Bay since the early 1990s and that vital parameters in the subpopulation may therefore have changed, modelling of the population size beyond 2004 was not feasible. Consequently the SWG recommended that a new population census should be conducted (SWG 2010).

During 2011-2014, the Greenland Institute of Natural Resources and the Department of Environment (Government of Nunavut) conducted a large-scale genetic mark-recapture study with the purpose of determining the size of the Baffin Bay and Kane Basin subpopulations. Analyses were made during 2015, and the results of the study including results of analyses of movement and habitat choice of bears in these areas will be presented in 2016.

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

### **The catch**

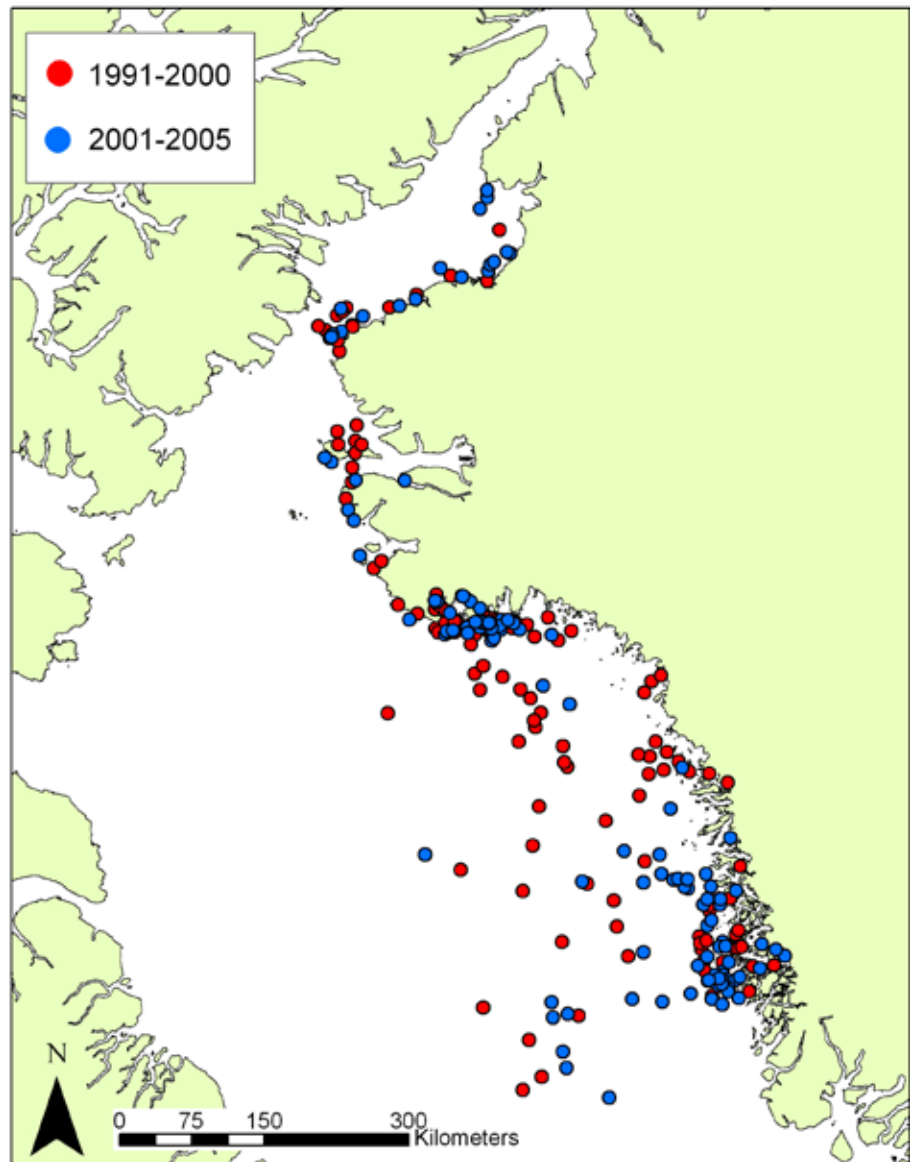
Traditionally the hunt of polar bears is of great cultural and economic importance to the subsistence hunting communities in Northwest Greenland (Born & Rosing-Asvid 1989, Rosing-Asvid & Born 1990, Rosing-Asvid 2002, Born et al. 2008). The Melville Bay area and adjacent pack ice in northeastern Baffin Bay (i.e. within the assessment area) are important areas for the hunting of polar bears from the Baffin Bay subpopulation, whereas polar bears from the Kane Basin subpopulation are taken in the former Qaanaaq municipality north of Savissivik (Rosing-Asvid & Born 1990, Rosing-Asvid 2002, Born et al. 2011a, Figure 19). Typically, the catches during spring when dog sleds are used were concentrated at a shallow water bank about 100 km from the coast in Melville Bay ('Qoorfiit') and at offshore shallow water banks in the former Upernavik municipality. Polar bears are still taken offshore on the ice during spring, but due to the reduced extent of sea ice more bears are now taken during boat trips (Born et al. 2008).

During 1993-2005 (i.e. since the introduction of a new catch reporting system and until introduction of quotas in 2006), the catch of polar bears in Greenland from the Baffin Bay population averaged 101/year (range: 60 (1994)-206 (2003) bears/year). Of these, on average 84 bears/year (range: 60 (1994)-188 (2003)) were taken inside the assessment area (i.e. reported for the former municipalities of Ummannaq, Upernavik and Qaanaaq (only north to Savissivik)). On average 69% of this catch was reported from the former Upernavik municipality (Born 2007). The Greenland take from the Baffin Bay population during the 5-year period 2010-2014 averaged 69 bears/year (SD=5.6, range: 63-75 polar bears (Born 2015)). Nunavut raised its quota for its take from the same population for the 2005/2006 hunting season from 64 to 105 polar bears. During the 5-year period 2005-2009 the annual take in Nunavut from the Baffin Bay population averaged 99 polar bears (SD=2.0, range: 97-103 bears/year) (SWG 2010).

### **Critical and important areas**

Polar bears may occur almost everywhere in the assessment area when ice is present. Some areas seem however, to be more important than others, for example the recurrent shear zone system south of Cape York and probably also the edges of the North Water Polynya. The Melville Bay area, including both fast ice up to glacial fronts and pack ice, is also important for Baffin Bay polar bears.

**Figure 19.** The distribution of 293 polar bear catches in the Qaanaaq and Upernavik municipalities shown for two periods (1991-2000: n=145; 2001-2005: n=148). Source: Born et al. (2008).



### Sensitivity

While moving on pack ice, the polar bears enter the water to swim from one ice floe to another (Aars et al. 2007) thereby increasing their risk of becoming fouled in case of an oil spill. Polar bears also show a preference for the ice edges where potential oil spills would accumulate. In Svalbard, three polar bears monitored for between 12 and 24 months with satellite-linked dive recorders had an average monthly percentage time in water ranging between 0.9 and 13.2%. The maximum duration of swimming events ranged between 4.3 and 10.7 h, and dives reached 11.3 m depth (Aars et al. 2007). Polar bears are very sensitive to oiling as they are dependent on the insulation properties of their fur and also because they will ingest the toxic oil as part of their grooming behaviour (Øritsland et al. 1981, Geraci & St Aubin 1990). Polar bears have been shown to be especially sensitive to ingesting oil, so polar bears getting in contact with oil are likely to succumb.

Based on the studies described above, a considerable proportion of the Baffin Bay subpopulation could be detrimentally affected by a large oil spill in the assessment area, in particular during winter and spring. Even bears from neighbouring populations could be affected as some individuals tend to move into the assessment area.



#### 4.8.2 Walrus *Odobenus rosmarus*

E.W. Born

Walrus winter in leads and cracks between the land-fast ice and the moving pack ice in the assessment area between the peninsula Nuussuaq in the Uummannaq area and Cape York. The number of walrus wintering in this area is unknown but is thought to be relatively low. An unknown number of walrus also use the assessment area as a migration corridor during spring and autumn. Walrus from the Baffin Bay stock regularly winter in the Cape York and Wolstenholme Island/Saunders Island areas (i.e. in the northern part of the assessment area).

##### **Recent information on walrus in West and Northwest Greenland**

Information on the occurrence of Atlantic walrus in West and Northwest Greenland was summarised by Born (1990) and Born et al. (1994a, 1995, 2015). The following review of distribution and abundance in the assessment area between Illorsuit/Ubekendt Ejland (approx. 71° 10' N) in the Uummannaq area and Granville Fjord (approx. 76° 47' N) in the Wolstenholme Fjord is based mainly on these sources. The movements of walrus in central western Greenland (south of the assessment area) were studied during spring 2005, 2006, 2007 and 2008 (Mosbech et al. 2007a, Dietz et al. 2014). Furthermore, the distribution and abundance of walrus between approx. 65° 30' N and approx. 74° N were determined during aerial surveys conducted in the spring of 2006 (Heide-Jørgensen et al. 2006a, Mosbech et al. 2007a), 2008 and 2012 (Heide-Jørgensen et al. 2014). The summer abundance of walrus in the North Water Polynya (NOW) area was estimated based on aerial surveys conducted in spring 2009 and 2010 (Heide-Jørgensen et al. 2013a) and summer 2009 (Stewart et al. 2014a). The winter abundance in the eastern part (Greenland part) was estimated based on a survey in April 2014 (Heide-Jørgensen et al. 2016).

The status of the walrus subpopulation in West and Northwest Greenland (i.e. to the south and north of the assessment area) was evaluated by the North Atlantic Marine Mammal Commission in 2009 and 2013 (NAMMCO 2009, 2013) and by Witting and Born (2014). A comprehensive interview survey was conducted in 2010 where a total of 76 experienced walrus hunters living north of Maniitsoq in West and Northwest Greenland were interviewed about walrus and the catch of walrus. Twenty of these interviewees lived inside the assessment area (i.e. in settlements and towns situated between the peninsula of Nuussuaq in the Uummannaq area and Cape York (Born et al. 2015).

##### **Biology**

The following life history traits are relevant to the evaluation of the potential effects on walrus by oil-related activities. One important characteristic of walrus is that they are gregarious year round (Fay 1982, 1985), which means that impacts will concern groups rather than single individuals (Wiig et al. 1996). Walrus are benthic feeders that usually forage where water depths are less than approx. 100 m (Vibe 1950, Fay 1982, Born et al. 2003), although they occasionally make dives to at least 200-250+ m depth, both inshore and offshore (Born et al. 2005, Acquarone et al. 2006). They generally have affinity for shallow water areas with suitable benthic food, traditionally used terrestrial haul-outs ('ullit', singular 'ulli') in the vicinity of these banks and wintering areas without solid ice but with floes for hauling out and access to food (Born et al. 1995 and references therein). In western and northwestern Greenland, such habitats are mainly found between approx. 66° 30' N and approx. 70° 30' N and between approx. 76° N and approx. 78° 30' N (Born et al. 1994a,

1995, Born 2005), which means that the main foraging grounds of walrus in West Greenland are mainly outside the eastern Baffin Bay assessment area.

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

### **Walrus food**

The shallow water benthic community in the assessment area was studied at a few stations in 1936 (Vibe 1939, 1950) and in 2008 on 41 stations (Box 1, Sejr et al. 2010a). In 2008, *infauna* including walrus food items (*Mya* sp. and *Hiattella arctica*) was found in variable abundance, but generally peaked between 10 and 50 m depth. Biomass decreased with increasing depth. According to Sejr et al. (2010a) the average biomass of 200 g ww m<sup>-2</sup> (including shells and skeletons) for depths < 150 m was comparable to that reported by Vibe (1939, 1950, see Section 4.4.2).

Hence, locally there is suitable walrus foraging habitat in the assessment area and not at least north of 76° N, where walrus winter (Vibe 1950). However, given the fact that the relatively narrow strip of shallow water areas along the coast between ca. 72° and ca. 76° N is generally covered with fast ice during winter, wintering conditions for walrus seem unsuitable here. However, extensive walrus feeding banks are found in the Wolstenholme Island- Saunders Island area (Vibe 1950) in the northern part of the assessment area where walrus regularly occur from autumn to spring (Born et al. 2015).

According to the walrus hunters living in the assessment area bivalves (*Mya* and *Serripes*) are the main food items of walrus. Other food items such as scallops, snails, bottom-dwelling worms and shrimps are also taken. In addition, parts of seals are often found in the stomachs of walrus that are killed (Born et al. 2015).

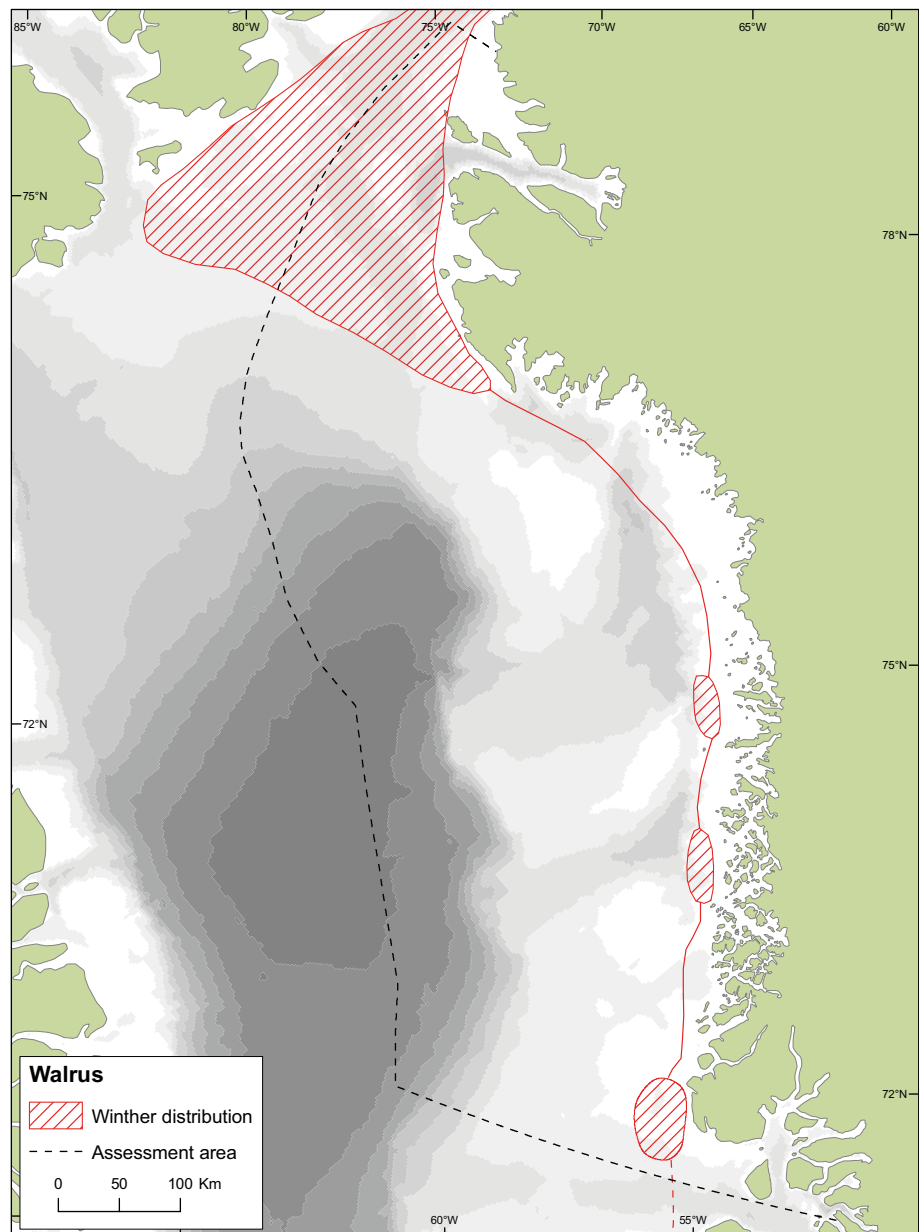
### **Distribution and population size**

It has not been determined whether walrus occurring in the southern and central part of the assessment area belong to the West Greenland wintering stock or to the Baffin Bay stock (formerly referred to as “The North Water stock”) or whether they represent a mixture from both of these subpopulations (Born 2005; Dietz et al. 2014). Walrus in the assessment area south of Cape York are basically transient (Born et al. 1994a, 1995, 2015); therefore, the situation north and south of the assessment area where the transient animals may have their origin is also briefly described.

Generally, the historical and present distribution of walrus in the Uummanaq and Upernavik areas appear to be similar (Born et al. 1994a, 2015). Judging from catch statistics and an interview survey in 2010 walrus are not numerous in these areas and they appear to be mainly transient (Born et al. 2015) (Figure 20). However, a limited number can occur during winter in cracks and leads in the shear zone between the fast ice and the Baffin Bay pack ice (Born et al. 2015).

The general scarcity of walrus between the Nuussuaq peninsula and Kulorsuaq and their more southerly distribution during early spring was corroborated by aerial surveys conducted in March-April 2009-2013 when a helicopter-based search for polar bears on the fast ice, the shear zone and the offshore pack ice covered the area between 70° 22' N and 76° 15' N (i.e. between Vaigat and Savissivik). During a total of 245 hours “on effort” flying

**Figure 20.** The general distribution of walrus in the assessment area.



during 2009-2013, only eight walrus were observed. These walrus were all seen in shallow waters south of 72° N (i.e. between Upernavik Kujalleq and the Nuussuaq Peninsula in the Uummannaq area) in 2009 and 2012 (Born et al. 2015 and references therein).

According to the hunters, walrus occur in certain relatively small shallow water areas (polynyas) close to the coast south of Melville Bay. For example the tips of the peninsulas Nuussuaq and Svartenhuk in the Uummannaq area and the Kraulshavn peninsula further north are areas where walrus may occur regularly during spring. However, during this time of the year walrus are also seen 75-100 km offshore among the pack ice in the Upernavik town area. Walrus are observed travelling north in spring and south in the autumn and some (probably few) walrus may winter in the assessment area.

Walrus can occur in May near some islands at the leads at Kitsissorsuit (Ederfugleøer, 74° 02' N and 57° 46' W) and they may also be seen in the shallow water areas at the Nuussuaq peninsula. At this time of the year the walrus are travelling north. However, when the light disappears in November they are in the shallow waters between Kiatassuaq (Holm Island, 74° 29' N and

57° 30' W) and Kraulshavn. According to informants from Kullorsuaq, walrus are travelling north at the edge of the fast ice west of Kiatassuaq and farther north during April-June. In fall they are seen migrating south at the western islands west of Kullorsuaq. Single walrus may be encountered in the Melville Bay during the narwhal hunt in July (Born et al. 2015).

Generally, walrus are transient in the Savissivik area where they migrate north along the edge of the fast ice in late April-June. In this area, there is a less conspicuous southward migration in autumn. The walrus arrive to the eastern parts of the North Water Polynya (including the Wolstenholme Island/Saunders Island area in the northern part of the assessment area) usually in October and winter there until next May-June when they migrate north to summer along eastern Ellesmere Island. During autumn, winter and spring there is a segregation of the two sexes: adult males stay in the Wolstenholme Island/Saunders Island area and in the Northumberland Island area and females and young further north. Walrus are also known to winter in the polynya at Cape York (Born et al. 2015).

Walrus were once reported to have hauled out occasionally near Eqqorleq and Tussaaq in the southern part of the Upernavik area. However, walrus no longer regularly haul out on land in the assessment area and none of the interviewees in the assessment area had seen walrus on land (Born et al. 2015).

To the south of the assessment area, walrus from the Southeast Baffin Island-West Greenland stock (cf. Andersen et al. 2014) occur during winter (Born et al. 2015). Aerial surveys in late March and April-May 2006 revealed that walrus most likely from this stock occurred within the assessment area at approx. 71° 10' N (Mosbech et al. 2007a) and approx. 73° N (Heide-Jørgensen et al. 2006a).

Walrus winter in the eastern parts of the NOW area between Wolstenholme Island and Cape Inglefield (Freuchen 1921, Vibe 1950, Born et al. 1995, 2015) i.e. inside the northernmost part of the assessment area. The population occurring in the NOW area is referred to as the "Baffin Bay" population (NAMMCO 2009). The thin ice there is frequently broken up by storms, giving the walrus access to shallow feeding banks (Vibe 1950). During winter walrus are hunted on the thin ice or from the edge of the fast ice, including the Savissivik and Wolstenholme Island areas (Born et al. 1995). In recent years, the thin ice hunt has been impeded by worsening of sea ice conditions (less ice and frequent unseasonal ice break-ups) due to global warming (Born et al. 2010, 2015). Walrus in the eastern parts of the NOW area are segregated on the basis of sex and age class, with females and subadults generally occurring farther north than adult males (Vibe 1950, Born et al. 1995, 2015).

In the past, walrus arrived in the eastern parts of the North Water area from the south during spring (Freuchen 1921, Vibe 1950). These migrants joined the animals that had overwintered there. Although information from local people indicates that some walrus still do come from the south during spring (Born et al. 2008, 2015), it appears that the pronounced influx during June and July described by Freuchen (1921) and Vibe (1950) no longer takes place.

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

references therein). They previously also occurred farther east in Wolstenholme Sound and also penetrated McCormick Fjord (Vibe 1950). Most likely, these changes have been caused by an increase in hunting pressure (Born et al. 1995). However, apparently walrus stragglers have again begun to occur farther inshore in the Inglefield Inlet area in recent years (Born et al. 2015).

Aerial surveys conducted in late May 2009 and 2010 in northern Baffin Bay to estimate the abundance of marine mammals in the NOW area resulted in estimates of total abundance (i.e. the estimate was corrected for walrus submerged and out of sight) of 1,238 walrus (cv=0.19) in 2009 and 1,759 (cv=0.29) in 2010 (Heide-Jørgensen et al. 2014). The winter abundance of walrus in the Greenland part of the North Water Polynya was assessed in an aerial survey in April 2014, and a fully corrected estimate of 2,544 walrus (95% CI: 1,513-4,279) was achieved (Heide-Jørgensen et al. 2016).

During summer the walrus are found along the coast and in the fjords of eastern Ellesmere Island, in Jones Sound and along the northern coast of Lancaster Sound (Canada) (Stewart et al. 2014a, Born et al. 2015). Aerial surveys conducted on 9 and 20 August 2009 along eastern Ellesmere Island resulted in a corrected estimate of abundance of the Baffin Bay population in the NOW area during the open water season 2009 of 1,249 walrus (95% CI: 1,370, Stewart et al. 2014a). Not all summering areas of the Baffin Bay population were covered and this estimate therefore is considered a minimum (NAMMCO 2009, Stewart et al. 2014a).

There are no historical estimates of abundance of walrus in western and northwestern Greenland. Catches over several decades of many hundreds of animals indicate, however, that perhaps the Central West Greenland and the Baffin Bay population numbered several thousand walrus at the beginning of the 20<sup>th</sup> century (Born et al. 1994a, 1995, Witting & Born 2005, 2014).

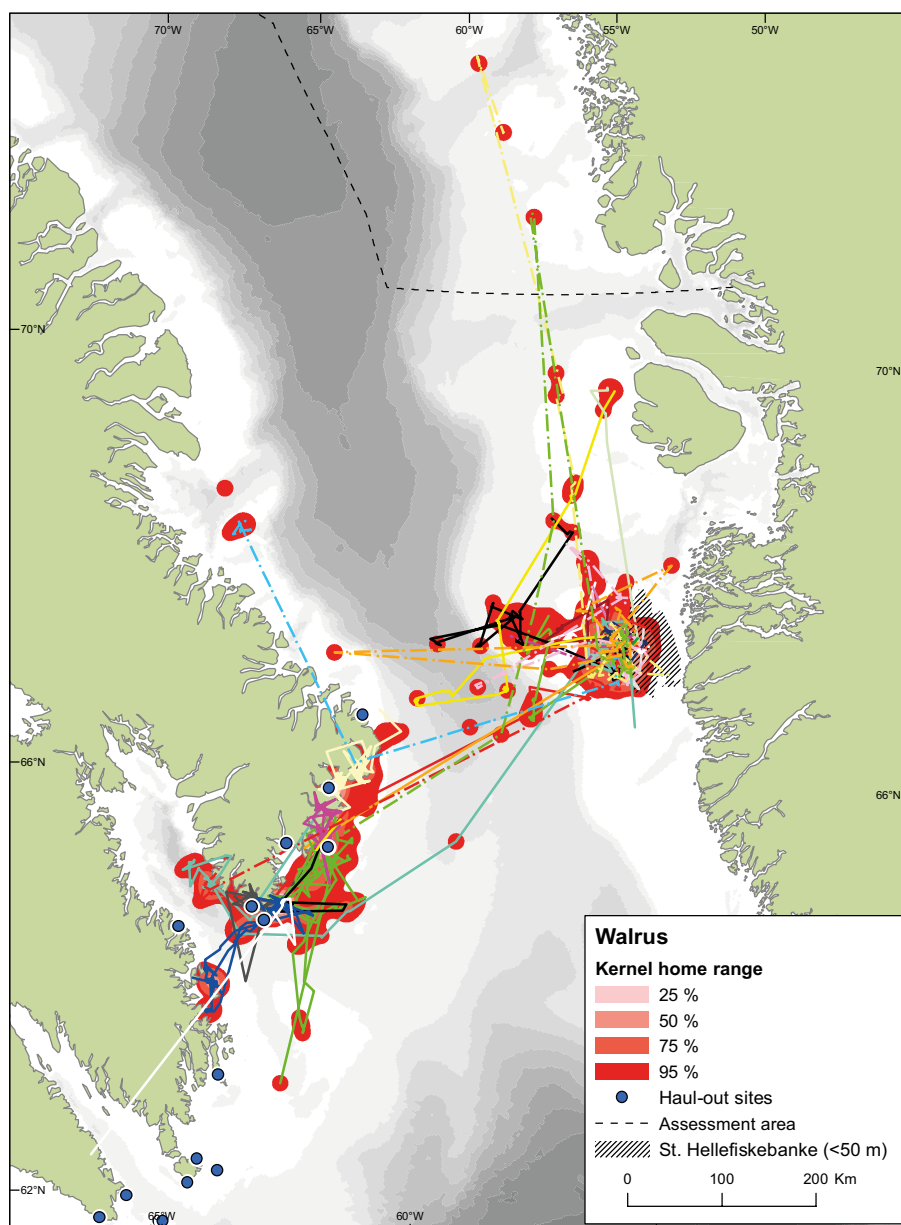
### **Delineation of populations**

Genetic analyses (Cronin et al. 1994, Andersen et al. 1998, Andersen & Born 2000, Born et al. 2001, Andersen et al. 2009a, Andersen et al. 2014) indicate that three subpopulations exist in the Baffin Bay-Davis Strait region: Eastern Hudson Bay-Hudson Strait, West Greenland and the Baffin Bay ("North Water") population. Results indicated that (1) walrus in West Greenland and the Baffin Bay populations differ (i.e. north and south of the assessment area) genetically with some likely limited male mediated gene flow between these populations, (2) walrus at southeastern Baffin Island and West Greenland do not differ genetically, (3) walrus from Hudson Strait have some genetic input to the Southeast Baffin Island-West Greenland stock.

The satellite telemetry study during 2005-2008 supported the genetic study (Andersen et al. 2014) and historical information (Born et al. 1994a) that walrus in West Greenland and at southeastern Baffin Island constitute the same population, which is hunted in both Greenland and Nunavut (NAMMCO 2009, Dietz et al. 2014). Surveys conducted in 2005-2007 along eastern Baffin Island indicated that a minimum of 2,500 walrus from the Southeast Baffin Island-West Greenland stock summer along the coast of Southeast Baffin Island (Stewart et al. 2014b).

Samples of walrus tissues for genetic analysis are not available from the central assessment area (i.e. between Uummannaq and Savissivik) and therefore the genetic affinity of walrus occurring in this area has not been determined. Overall, the scarcity of information prevents a firm conclusion concerning the

**Figure 21.** Track lines and home range (calculated as kernel home range polygons, KHR) of 31 walrus instrumented with satellite transmitters by the GINR and DCE at Store Hellefiskebanke during March-April 2005-2008 and at South East Baffin Island August-September 2007 (source: NAMMCO 2009, Dietz et al. 2014). Note that some of walrus make excursions to the norths and into the assessment area.



demographic affinities of the likely relatively few walrus occurring in the southern and central assessment area. Those occurring in the northern part of the assessment area (i.e. north of ca. 76° N) undoubtedly belong to the Baffin Bay population.

### Movements

According to Freuchen (1921) and Vibe (1950) the walrus crossed Melville Bay far offshore during their spring migration north into the Smith Sound region. Although there are indications that some walrus move north in the shear zone between the land-fast ice and the Baffin Bay pack ice during spring (Born et al. 2015), a 'large-scale' spring migration north along the western coast of Greenland as indicated in Freuchen (1921) is not recorded today (Born et al. 2015).

During spring 2005-2008, 23 walrus were fitted with satellite transmitters at their wintering grounds at Store Hellefiskebanke, Central West Greenland in order to study movements and habitat choice (NAMMCO 2009, Dietz et al. 2014). Eight of the tags lasted long enough to document the migration from the wintering grounds in the northern Davis Strait to southeastern Baffin Is-

land. The westward migration occurred between 7 April and 25 May along quite similar routes across the most shallow and narrowest part (ca. 400 km) of the Davis Strait. Hence, although the walrus birth season is protracted (Born 2001), the walruses leave their West Greenland wintering grounds prior to the peak of the calving season in late June (Born 2001).

However, during 2008 two instrumented walruses first migrated north from Store Hellefiskebanke along the West Greenland coast 50-100 km offshore as far north as ca. 73° 27' N (Nutaarmiut) before turning south again (Figure 21). One of these walruses stopped transmitting on its way south along the coast whereas the other migrated to Baffin Island. This demonstrates that an unknown proportion of the West Greenland wintering stock of walruses may occur within the assessment area for an unknown period of time during spring (NAMMCO 2009, Dietz et al. 2014).

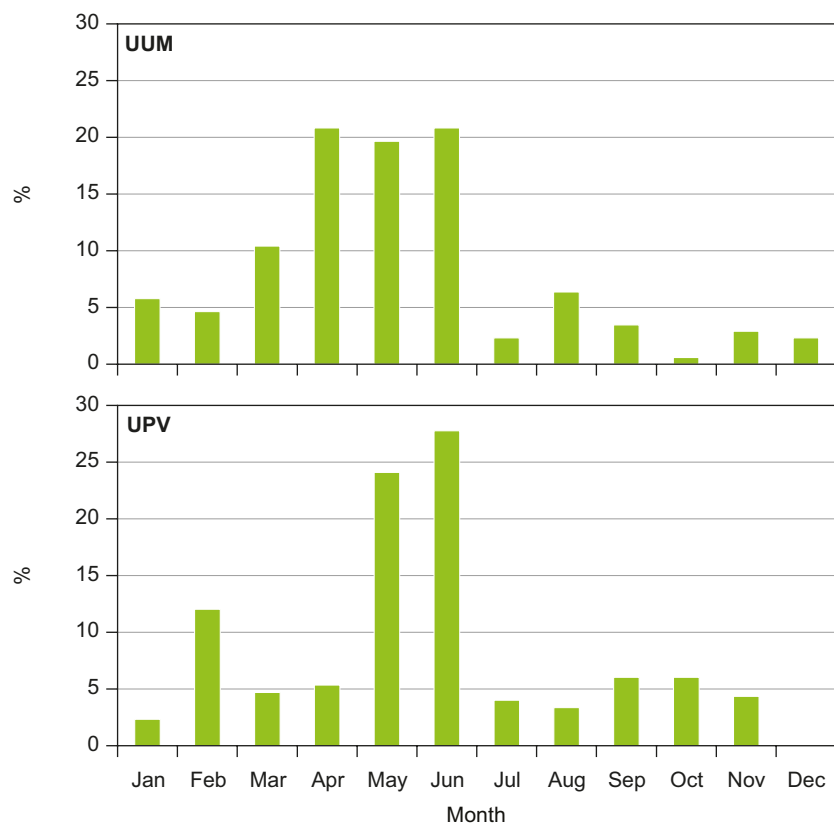
Heide-Jørgensen et al. (in prep.) tagged 60 walruses in 2010-2015 with satellite-linked transmitters on the Greenland side of Smith Sound. These walruses were present in the assessment area from October to June/July, and spend the rest of the year in the Canadian High Arctic to the north of Lancaster Sound.

### Catch

The catch statistics indicate that the take of walruses in the Uummannaq area peaks in March-June and in Upernavik in May-June (Figure 22). This is in accordance with information obtained during an interview survey in 2010 (Born et al. 2010). This seasonality may reflect the timing of a northward migration of walruses along the coast during spring but it may also to some extent be explained by different hunting patterns governed for instance by weather and light conditions (Figure 22).

In the Uummannaq and Upernavik areas, walruses are either caught when they winter in the shear zone between the fast ice and the Baffin Bay pack ice, or when they move along the ice edge in spring (Born et al. 2015).

**Figure 22.** Seasonal distribution of the catch of walruses in the Uummannaq area (UUM, N=177) and the Upernavik area (UPV, N=300) during 1993-2006 (Source: APNN).



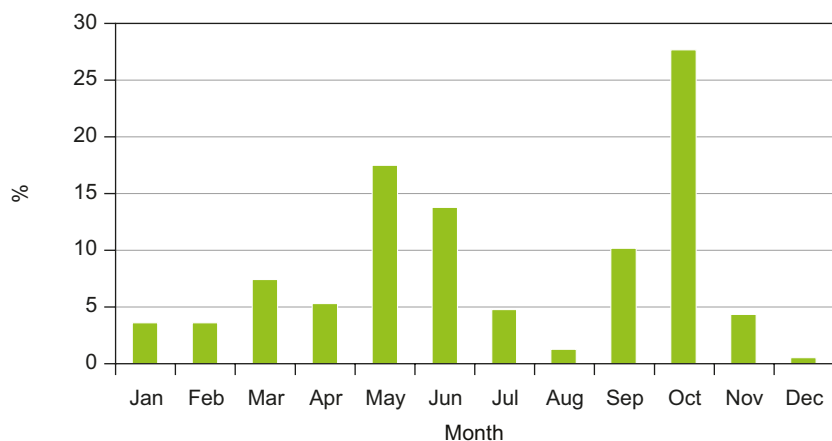
According to former, official game records, the annual catch of walrus in the Uummannaq and Upernavik areas decreased between 1940 and 1987. The average annual catch in the period 1940-1959 in these two areas combined was around 22 walrus and between 1960 and 1987 the catch averaged 11 walrus per year. Over the entire period, the catch in the Uummannaq area comprised about 20% of the total catch of walrus in these two regions (Born et al. 1995). It must, however, be noted that for many years the catch records during the periods mentioned were insufficient. A new system of reporting catches (the '*Piniarneq*',) was introduced in 1993. During 1993-2006, the reported catch of walrus in the Uummannaq area averaged 12.6 per year (SD = 12.5, range: 0-38 animals (APNN), Nuuk). The corresponding figures for the Upernavik area were 21.4 walrus per year (SD = 15.5, range: 7-58 walrus). The seasonal distribution of the hunt reported in *Piniarneq* in the two municipalities is shown in Figure 22.

Annual quotas for the catch of walrus from the West Greenland population were 61, 61, 61, 69 and 69 for 2011, 2012, 2013, 2014 and 2015, respectively. The increase in quotas in 2014 was a result of a more favourable assessment of the number of walrus wintering in West Greenland. The annual quota for Uummannaq-Upernavik alone (i.e. inside the assessment area) was 27 during 2011-2013. ([Link to quotas in 2013](#); [Link to quotas in 2015](#)).

Due to the more predictable and abundant occurrence in the eastern parts of the North Water area, the catch of walrus has always been of great importance in the former Qaanaaq municipality. The catch of walrus provided the local people with food for themselves and their sled dogs and the trade of walrus ivory was also a source of cash income (Vibe 1950, Born 1987, Born et al. 1995), and this is still the case (Born et al. 2015). Basically the walrus are caught during three types of hunt (Born 1987, Born et al. 1995, Born et al. 2015): (1) Ice edge and thin ice hunt during winter and particularly spring. This hunting activity is mainly conducted from February to April at western Wolstenholme Island and off Neqe at the northern entrance to Murchison Sound; (2) 'summer' boat hunting (May-August) using skiffs. After an intense hunting activity from mid-May through June the walrus leave the area and go to eastern Ellesmere Island; (3) boat hunt (September-November) when the walrus reappear in the Qaanaaq area in the autumn when they are hunted by boat until formation of fast ice. These hunting patterns are reflected in the seasonal distribution of catches in the former Qaanaaq municipality (Figure 23).

Historically, the catch reports from Qaanaaq were inadequate. However, an estimated 100-300 walrus were landed annually between the 1940s and the late 1980s (Witting & Born 2005, 2014 and references therein). Quotas were introduced in 2006 (Wiig et al. 2014). During 1993-2006 the reported catch of

**Figure 23.** Seasonal distribution of the catch of walrus in the former Qaanaaq municipality (QAA, N=1,753) 1993-2006 (Source: APNN).





walrus in the entire Qaanaaq area averaged 125.2 per year (SD = 53.7, range: 67-265 walrus, source: APNN). In the southern part of the Qaanaaq area (i.e. the northern part of the assessment area), the catch reported from the two settlements Savissivik and Moriussaq averaged 15.8 walrus per year (SD=14.3, range: 4-43 walrus) during the same period. An interview survey indicated that nowadays 2-4 walrus are landed annually in Savissivik (the settlement Moriussaq was officially abandoned in 2010 but became depopulated before that; Born et al. 2015).

Hence nowadays, the total annual catch of walrus in the assessment area is ca. 30.

The Greenland walrus quotas for the Baffin Bay stock for the five-year period 2011-2015 were 64, 64, 64, 83 and 86, respectively (Anonymous 2006a). For 2014 and 2015, the quota for the Greenland take of walrus from the Baffin Bay population (from which the catch in Savissivik is assumed to be taken) was raised from 64/year to 86/year also due to more optimistic population estimates obtained in 2009 and 2010.

### **Trends in the catch of walrus**

During the Born et al. (2015) interview survey in 2010 the majority of interviewees reported a general decrease in the catch of walrus in their settlement/town and only few expressed that the catch had increased. The answers indicated that the catch of walrus has decreased and several reasons for this trend were given: (1) the introduction of a quota on walrus (and also quotas for white whale and narwhal in case of hunting trips mainly targeting these species with walrus as a "secondary" species), (2) decrease in market demands, (3) a general decrease in the number of hunters, (4) climate changes resulting in walrus spending less time on the traditional hunting grounds and bad ice and weather conditions influencing the ability to access the walrus.

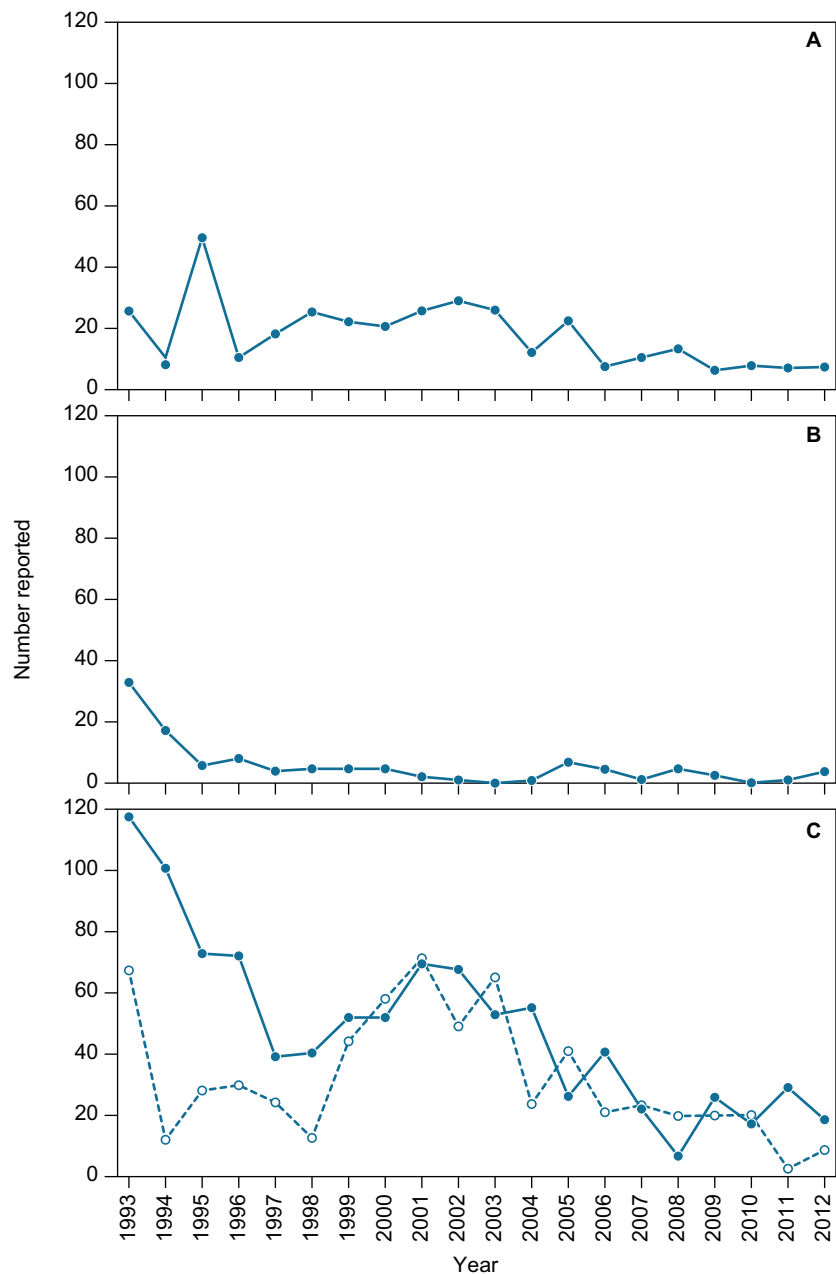
In all areas (i.e. from Maniitsoq to Siorapaluk), catches of walrus reported officially by the *Piniarneq* system have shown a negative trend with a gradual decrease during 1993-2012 (tests for correlation catch/year were all statistically significant,  $P \leq 0.01$ , data not shown) with no marked decrease in catches after the introduction of quotas in 2006 (Born et al. 2015) (Figures 24A, B, C).

Apparently factors other than quotas have led to a general decrease in the catch of walrus. Since the early to mid-1990s, the sea ice in West Greenland has decreased markedly with earlier spring break-up and later autumn formation. The interview survey clearly showed that the climate changes with worse sea ice conditions and unpredictable weather have made walrus hunting more difficult in all subareas. Not least this has been the case in the Qaanaaq area with the traditionally important "*thin ice hunt*", which nowadays is only rarely practiced because the thin ice does not form or is broken up unexpectedly due to strong winds from the south (Born et al. 2010, 2015). Born et al. (2015) concluded that climate change has been a major factor responsible for a general decrease in the catch of walrus during the last two decades.

### **Important and critical areas**

The preferred habitat for walrus is shallow waters with high densities of bivalves. The generally sedentary nature of walrus 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.

**Figure 24.** (A) Trend in the catch of walrus (1993-2012) reported to the Piniarneq catch reporting system from nine towns and settlements between Niaqornat and Kullorsuaq that were visited during an interview survey in 2010 (Born et al. 2015). (B) Trend in the catch of walrus (1993-2012) reported to the Piniarneq catch reporting system from Savissisivik and Qeqertat in NW Greenland (Born et al. 2015). (C) Trends in the catch of walrus (1993-2012) reported to the Piniarneq catch reporting system the town Qaanaaq (solid line) and the settlement Siorapaluk (dashed line) in NW Greenland (Born et al. 2015).



As the major part of the walrus in the assessment area are probably migrants or wintering at a number of places in the dynamic shear zone, it is not possible to designate important or critical areas. An exception is the Cape York area and the mollusc banks at Qeqertarsuaq/Wolstenholme Island and Saunders Island in the former Qaanaaq municipality where walrus are known to occur during autumn, winter and spring (Born et al. 2015). Other critical habitats are the shallow waters at Northumberland Island and the shallow water areas at the entrance to Murchison Sound.

#### Conservation status

The walrus populations occurring in the assessment area have an unfavourable conservation status, probably due to depleted status of the populations. The West Greenland population is red-listed as 'Endangered' (EN) and the North Water population as 'Critically Endangered' (CR). However, these assessments should be renewed, as new information is available.

### **Sensitivity**

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

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

Wiig et al. (1996) speculated that if walrus do not avoid oil on the water, they may suffer if their habitats are affected by oil, like other marine mammals, they may be harmed by both short-term and long-term exposure. Wiig et al. (1996) also pointed out that walrus feeding areas could be impacted resulting in the ingestion of toxic bivalves or a reduction of the available food supply. This latter effect could be critical for walrus wintering in limited open-water areas. The high level of gregariousness may also make walrus especially sensitive to oil spills – many individuals will be affected by oil spills hitting an assemblage and oil may be transferred between individuals.

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

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

### **4.8.3 Seals**

A. Rosing-Asvid & R. Dietz

Four species of seals occur regularly in the assessment area; two species (harp- and hooded seals) are migrants occurring only during the open water season, whereas ringed seals maintain breathing holes in the area throughout the winter. Bearded seals can also make breathing holes, but will mainly do so in relatively thin ice. They can be found in the assessment area throughout the year, but their numbers increase significantly during spring and summer.

### **Sensitivity**

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

## Hooded seal *Cystophora cristata*

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

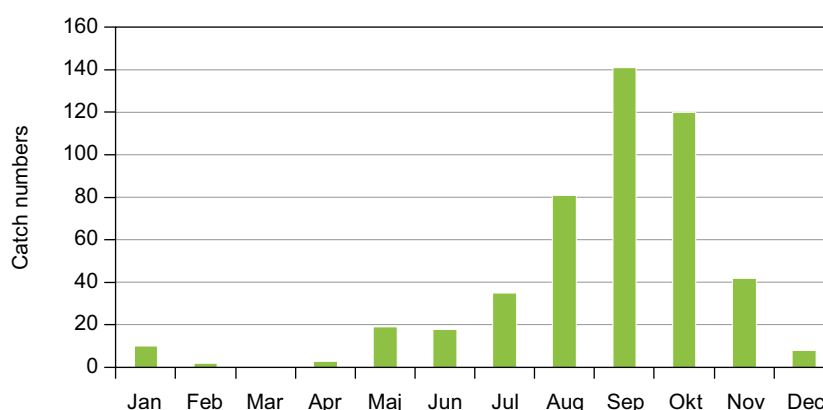
*The catch:* The annual catch in the assessment area is about 500/yr. The catch statistics show that some seals arrive in the assessment area when sea ice starts to break up in May, and a few will stay there throughout the open-water period in May-November. Most hooded seals will, however, follow the migratory pattern described above, a fact that is also reflected in the seasonal distribution of the catches. The annual catch distributed by month is shown in Figure 25.

*Conservation status:* The hooded seal is listed as 'Vulnerable' (VU) on the international Red List, since the population in the northeast Atlantic is decreasing (IUCN 2015). However, the subpopulation occurring in the assessment area is stable or slightly increasing (IUCN 2015) and it is managed internationally through a working group under ICES and NAFO. The catch of hooded seals from this subpopulation is considered sustainable (ICES 2006). The hooded seal is assessed as a species of 'Least Concern' (LC) on the Greenland Red List.

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

*Critical and important habitats:* No particularly important areas are known for hooded seals within the assessment area.

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



## Bearded seal *Erignathus barbatus*

Distribution: Bearded seals can make breathing holes, but only in relatively thin ice, and they therefore avoid regions with thick shore-fast ice and are rare in regions with unbroken, heavy drift ice (Burns and Frost 1979; Kingsley et al. 1985). However, the study of ringed and bearded seals (Rosing Asvid et al. 2015) found a small stationary population of bearded seals in the inner part of Melville Bay, defying the belief that all bearded seals avoid heavy ice conditions during winter (see Box 10). Some bearded seals are known to be stationary in areas with light ice conditions or recurring leads or polynyas during winter, whereas strong fluctuations in abundance in other areas indicate that a large fraction of the bearded seals move around. These distribution changes are mainly governed by the sea ice conditions and many bearded seals follow the pulse of the expanding and shrinking sea ice in the Baffin Bay and Davis Strait region. They concentrate mainly along the ice edge and in the shear zone. The passive acoustic monitoring in southern Baffin Bay (Boye et al. 2015) showed that bearded seals were present in late winter and spring when ice covered the areas (Box 12).

Bearded seals give birth in April-May and the lactation period is around 24 days (Gjertz et al. 2000). In the assessment area, pups have been recorded born around 1 May. The number of bearded seals whelping and lactating in the assessment area is unknown.

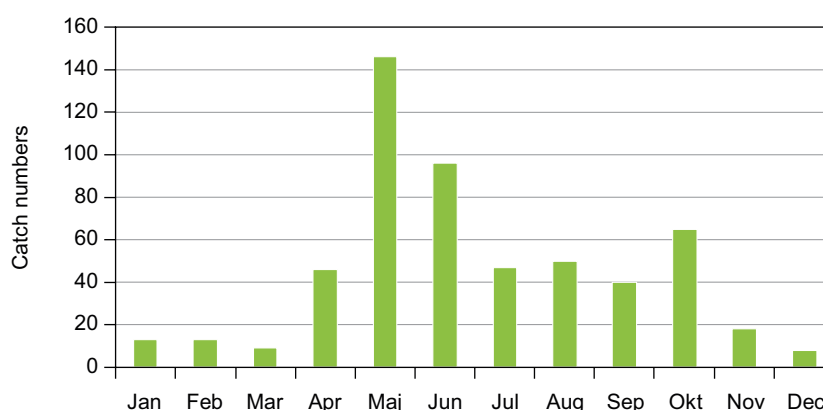
Bearded seals feed mainly on fish and benthic invertebrates found in waters down to 100 m depth (Burns 1981, Gjertz et al. 2000). Ongoing studies show that bearded seals in South Greenland spend considerable time at much deeper water (> 300m) and shrimps are found to be the most important prey in the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

Bearded seals were surveyed in the Greenland part of the North Water in April 2014, and the resulting estimate was 6005 individuals (95% CI: 4070-8858) (Heide-Jørgensen et al. 2016).

*The catch:* Annual catches in the assessment area is about 5-600 seals/year, of which < 100 are caught during winter (December-March). The annual catch distributed on months is shown in Figure 26.

*Conservation status:* The bearded seal has a favourable conservation status. It is listed as 'Data Deficient' on the Greenland red List due to lack of knowledge about population boundaries and numbers, but at global scale it is listed as a species of 'least concern' (LC) (IUCN 2015).

**Figure 26.** The number of bearded seals caught in the subsistence hunt in the assessment area by month in 2007.



## Box 10

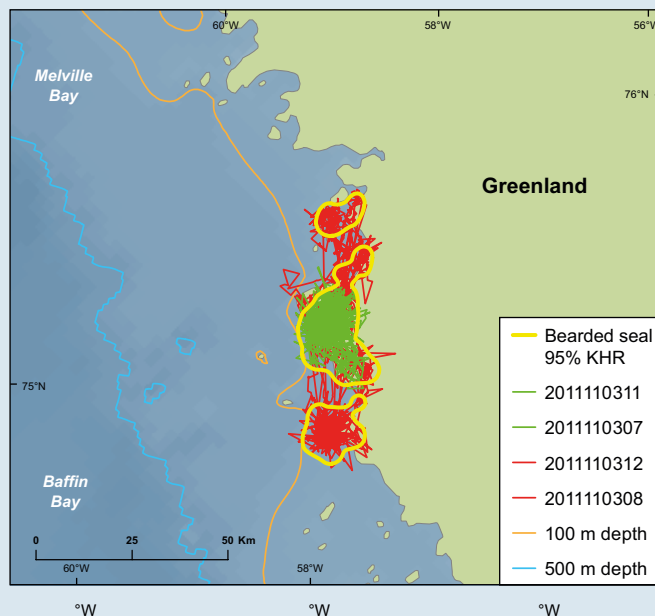
### Seal studies in Melville Bay

A. Rosing-Asvid & R. Dietz

#### Bearded seal

The seal study of the Eastern Baffin Bay Environmental Studies Program 2011-2014 was mainly focused on ringed seals, but when a small concentration of bearded seals was encountered in the inner part of Melville Bay, two of them (a male and a female) were captured and tagged with satellite linked data-loggers. These are the first bearded seals tagged in the Baffin Bay area. Contact with the seals was kept for 358 and 312 days, respectively, and 4.363 positions were obtained. Both seals showed a very high degree of site fidelity to the area where they were tagged (Figure 1). Seasonal migration was expected, as studies from other areas indicate that bearded seals only maintain breathing holes in relatively thin ice and normally avoid heavy ice-conditions such as those of the inner part of Melville Bay. Two hunters from the closest settlements (Kullorsuaq) participated in the tagging, and they reported that they had seen bearded seals maintaining breathing holes in up to 1 m thick ice in the tagging area.

Both seals stayed within the 100 m contour for most of the year, but the female would stray more often than the male, and her deepest dive was 448 m vs. 264 m for the male. In addition to detailed dive data the loggers also provided diurnal / seasonal haul-out data, which are important when adjusting sighting surveys for submerged animals.



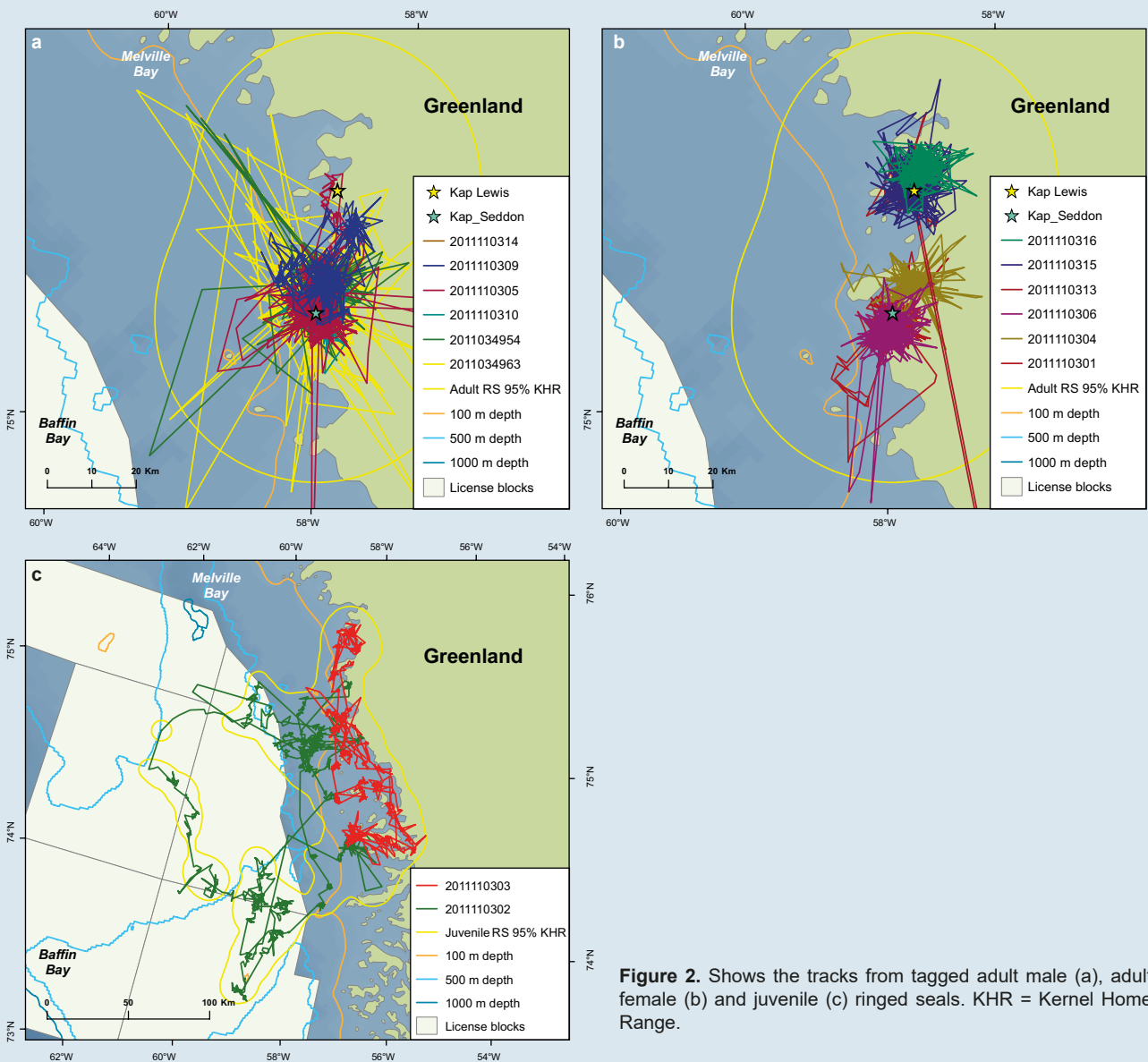
**Figure 1.** Track from a male (green) and a female (red) bearded seal, tracked for 358 and 312 days respectively. The yellow lines show the Kernel Home Ranges (95 %).

## Ringed seal

The seal study provided the first tracking of ringed seals from the Melville Bay sanctuary. Different types of satellite linked data-loggers were used. Two juvenile seals were tagged a little south of the sanctuary, and 10 adult seals (five males and five females) were tagged within the sanctuary in the period 6-9 September, 2011. Only adult seals were seen in the sanctuary. Contact with the tagged seals lasted on average 266 days and 20,310 positions were obtained. Tags were glued on the fur and dropped off during the following moult. In addition to the glued-on tag, three seals were also instrumented with a small tag attached to a flipper. These small tags gave contact for 286, 533 and 648 days.

Eleven of the twelve adult seals stayed very close to the area in which they had been tagged (Figure 2 a and 2b). Only one female left the sanctuary and moved about 130 km south along the coast to become stationary there. Both the adult males and adult females spent most of their time within the 100 m contour, but the males generally strayed more often out into deeper waters. Detailed diving patterns were recorded for 3 males and 3 females. Deepest dives for the three males were 211 m, 280 m and 355 m, and deepest dives for the 3 females were 136 m, 136 m and 224 m.

The two juvenile seals (a male and a female) tagged a little south of the sanctuary lacked the site fidelity shown by the adult seals (Figure 2c). Their movements were more random. The female mainly moved along the coast both northward into the sanctuary and south along the coast. The young male explored more offshore areas with deeper waters, and its deepest recorded dive was 584 m.



**Figure 2.** Shows the tracks from tagged adult male (a), adult female (b) and juvenile (c) ringed seals. KHR = Kernel Home Range.

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

*Critical and important habitats:* The wide distribution of bearded seals indicates that they adapt to several habitats. However, most bearded seals prefer light ice conditions during winter and in the assessment area such conditions are mainly found in the Nort Water Polynya and the dynamic shear zone (mainly in the southern part of the assessment area).

### Harp seal *Pagophilus groenlandicus*

*Distribution:* Harp seals are migratory seals. The vast majority of the seals from the West Atlantic population concentrate around the whelping areas off Newfoundland in February-April. They give birth on the drift ice in March and they moult in April (Sergeant 1991). After the moult they spread out in the waters between Greenland and Canada and some seals move up along the Greenland east coast. In the assessment area, they occur throughout the open water period.

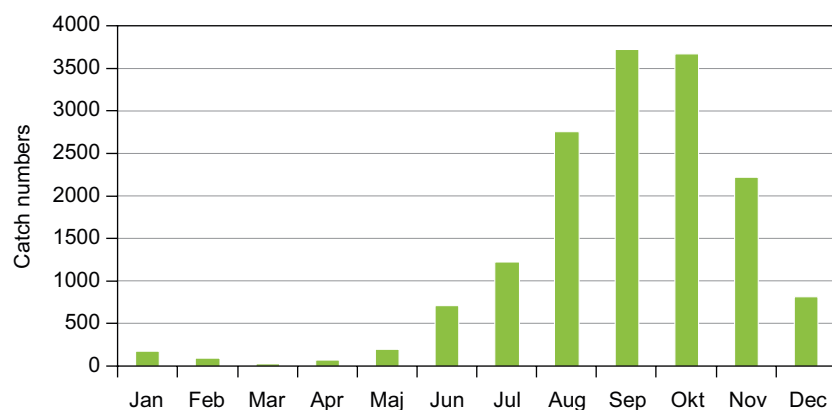
The number of harp seals in the assessment area increases throughout the summer and early autumn, but when the sea ice starts to form they initiate their migration back toward the whelping areas off Newfoundland. During summer, most adult harp seals will forage in pods that typically consist of 5-20 individuals, while juvenile seals forage alone. All age classes feed mainly on capelin, polar cod, amphipods (*Parathemisto libellula*) and krill (*Thysanoessa spp.*) (Kapel 1995).

The West Atlantic population whelping on the ice off Newfoundland in early March is estimated to have increased from around 1.8 million in the early 1970s to about 7.8 million individuals in 2008, and the current (2014) estimate is around 7.4 million (ICES 2014). The proportion of seals entering the assessment area is unknown and probably also variable, but it might be in the region of 10% of the population.

*The catch:* The catch in the assessment area has been steadily increasing from around 2,000/year in the early 1970s to around 14,000-16,000/year in recent years. Annual catch distributed by month is shown in Figure 27.

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

**Figure 27.** The number of harp seals caught in the subsistence hunt in the assessment area by month in 2007.





mal in the northern hemisphere, and the West Atlantic population is probably close reaching its highest level in history. It is listed as a species of 'Least Concern' on the Greenland Red List.

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

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

### **Ringed seal *Pusa hispida***

*Distribution:* Ringed seals are present in the assessment area in high numbers throughout the year. They make breathing holes in the new ice, and adult seals establish territories and maintain breathing holes throughout the winter in areas that later in the winter become fast ice or consolidated pack ice. Juvenile seals are generally less sessile and most of them spend the winter in areas with loose unconsolidated sea ice.

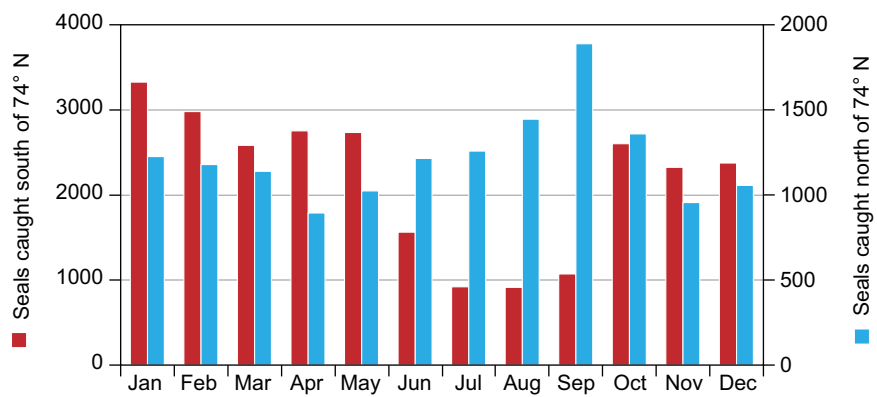
Aerial surveys in the 1980s revealed large concentrations of ringed seal in the Baffin Bay pack ice (Finley et al. 1983). These and other surveys found average densities of ringed seals on fast ice as well as on consolidated pack ice in the Baffin Bay area to vary between 1.3 to 2 seals/km<sup>2</sup>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

Ringed seals give birth in March-April in lairs dug out in a snowdrift covering a breathing hole, and many thousands of pups are likely to be born in the assessment area each year. The pups lactate for up to seven weeks (Hammill et al. 1991). Birth lairs are mainly found on stable sea ice with snowdrifts. Such conditions are often formed around pressure ridges and in fjords with glaciers where the advancing glaciers often create ideal breeding conditions for ringed seals. The many glaciers running out into the Melville Bay create such conditions and the inner parts of the bay has been recognised as an important breeding area for ringed seals and, hence, an important area for polar bears. A nature reserve was therefore established in this part of the bay in 1980. The seal background study (Rosing Asvid et al. 2015) provided the first insight into the movement and diving behaviour of ringed seals in this area (see Box 10).

The seals start moulting their fur in May and this period overlaps with the breeding and nursing period. The re-growth of new hairs is facilitated by increased blood supply to the skin and the seals will therefore spend most of the day basking in the sun on the ice during June. They need sea ice to haul-out on in this period and their numbers therefore decline in some of the coastal open water areas in the southern part of the assessment area. Some move into ice-filled glacier fjords and others follow the retreating sea ice north and westward to the high Arctic areas. When the sea ice expands again during early winter, they spread out again.

Ringed seals mainly prey on polar cod, Arctic cod, *Liparis* spp. and amphipods (*Parathemisto* spp.) in near-shore waters in the assessment area (Siegstad et al. 1998). Prey selection is unknown for offshore areas, but likely include the same species.

**Figure 28.** The number of ringed seals caught in the subsistence hunt in the assessment area by month in 2007 (shown separately for areas north and south of 74° N).



*Catch:* Ringed seals are caught in high numbers in the assessment area by hunters from the Qaanaaq and Upernavik districts. The catches decrease in the southern part and increase in the northern part when the sea ice disappears in the south around June and *vice versa* when the sea ice spread out again in autumn. Less than 10% of the seals caught are adults (Christiansen 1983). The sale of ringed seal skins is important for the local hunters and the meat is of high importance in the household economy. In recent years, the annual catch of ringed seals in the assessment area has been around 40,000. The number of juvenile seals caught in the assessment area and further south along the Greenland west coast is higher than what can be produced locally, reflecting an influx from extra-limital populations to the north or west of the assessment area (Christiansen 1983). The overall catch along the west coast has been relatively stable for many years and is therefore considered to be sustainable. The annual catch distributed by month is shown in Figure 28.

*Conservation status:* The ringed seal has a favourable conservation status, because of its relatively uniform and widespread circumpolar distribution, which generally prevents overexploitation. Ringed seals are listed as of 'Least Concern' (LC) on the Greenland Red List.

*Sensitivity:* Breeding ringed seals depend on stable sea ice during the two months when they give birth and nurse their pups. This stationary behaviour makes them vulnerable to disturbance and particularly to activities disrupting the stable ice. However, ringed seals were found not to be particularly impacted by seismic operations in Arctic Canada and Alaska, where they showed only little avoidance of the sound source (Harris et al. 2001). Ringed seals can be affected by oil spills in the same way as all other seals (see the above introduction to seals).

*Critical and important habitats:* Stable ice during the whelping and nursing period is a critical factor for ringed seal pup survival. Such ice conditions are widespread within the assessment area (both offshore and in fjords and along the coast). The establishment of the nature protection area in the inner parts of Melville Bay was a recognition of the importance of this area to polar bears and their primary food, the ringed seal.

#### 4.8.4 Baleen whales

F. Ugarte & M.P. Heide-Jørgensen

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

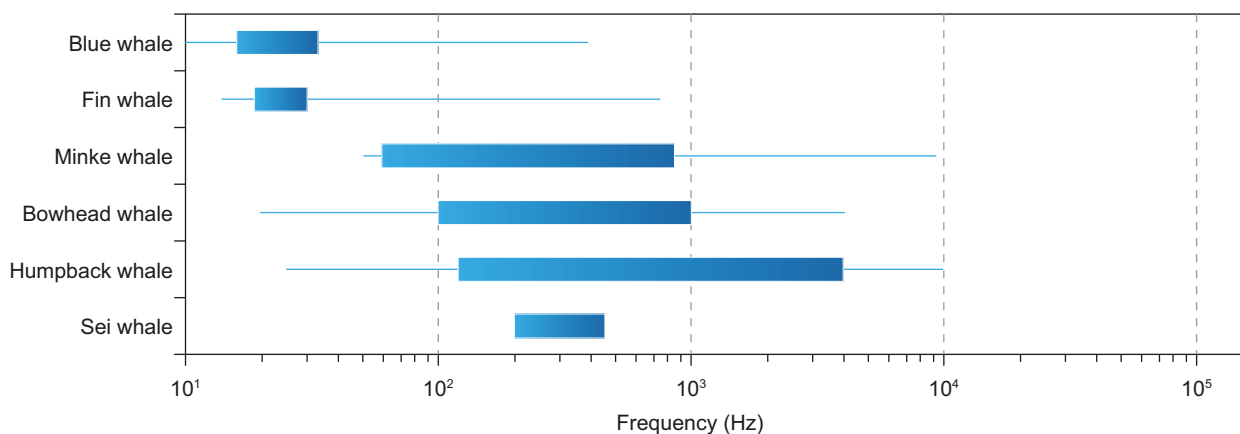
Generally, limited information exists on the rorqual species in the assessment area. They all migrate between calving and mating grounds in southern areas and their northern summer feeding grounds, which are widespread in the northern Atlantic, including the waters off West and Northwest Greenland. However, the Passive Acoustic Monitoring in southern Baffin Bay in 2011-2012 (part of the Eastern Baffin Bay Environmental Studies Program 2011-2014; Boye et al. (2015)) showed that fin whales were present throughout the winter (Box 12). Climate change will likely influence these migratory species in terms of distribution changes due to geographic shifts in the locations of the frontal and upwelling areas that concentrate their food. Such large-scale oceanographic changes are likely to affect most marine mammals, but they are currently very difficult to predict (Kovacs & Lydersen 2008). In the assessment area, new habitats for these migratory whales may open if the location of the ice-edge retreats during the spring months, as predicted by most models. This may result in an increased importance of the Baffin Bay assessment area to these large whales.

### Baleen whale sensitivity to oil activities

Oil activities potentially impacting 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, aircrafts and vessel supply activities (Tervo et al. 2012, see also Chapter 10).

Drilling and offshore construction activities, such as blasting, have the potential to produce behavioural disturbance and physical damage (Ketten 1995, Nowacek et al. 2007). Off Newfoundland, Ketten et al. (1993, quoted from Gordon et al. 2003) found damage consistent with blast injury in the ears of humpback whales trapped in fishing gear after blasting operations in the area. Two of the humpback whales with damaged ears had been observed shortly before by scientists in an area where blasting was occurring (Lien et al. 1993). In this case, the blasting did not provoke obvious changes in behaviour among the whales, even though it may have caused serious injury. This suggests that whales may not be aware of the danger posed by loud sound.



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

## Box 11

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

M.P. Heide-Jørgensen & K. Laidre

A total of 78 bowhead whales were instrumented with satellite-linked radio transmitters in Disko Bay in 2009 ( $n = 28$ ) and 2010 ( $n = 50$ ). Three types of transmitter configurations were used: cylindrical implantable SPOT 5 tags that provide only positions of the whales ( $n = 33$ ), cylindrical implantable Mk10 tags that collect and transmit compressed and binned dive data ( $n = 16$ ) and external SWING SPLASH tags secured with a spear with barbs that also collect dive data ( $n = 29$ ). All tags were deployed in Disko Bay between 15 February and 5 June with most deployments in April. Data from the tags were collected for as long as 14 months (Figure 1, 2, 3, 4 5) and seven tags are still transmitting at the time of the completion of this report.

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

#### Winter: January – March

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

#### Spring: April – May

Most of the tagging effort on bowhead whales took place in April–May in Disko Bay. Generally, the bowhead whales are concentrated in the western part of Disko Bay in April–May, but the northbound migration was initiated in early May and bowhead whales can be found all along

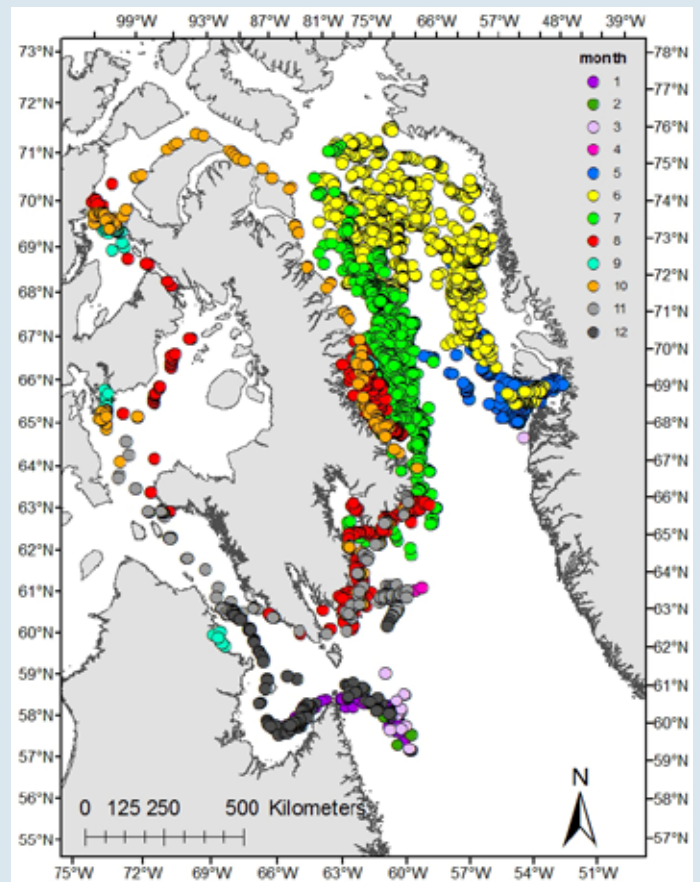


Figure 1. Locations of all bowhead whales tagged in 2009 in Disko Bay and tracked through December 2009 ( $n = 28$ ).

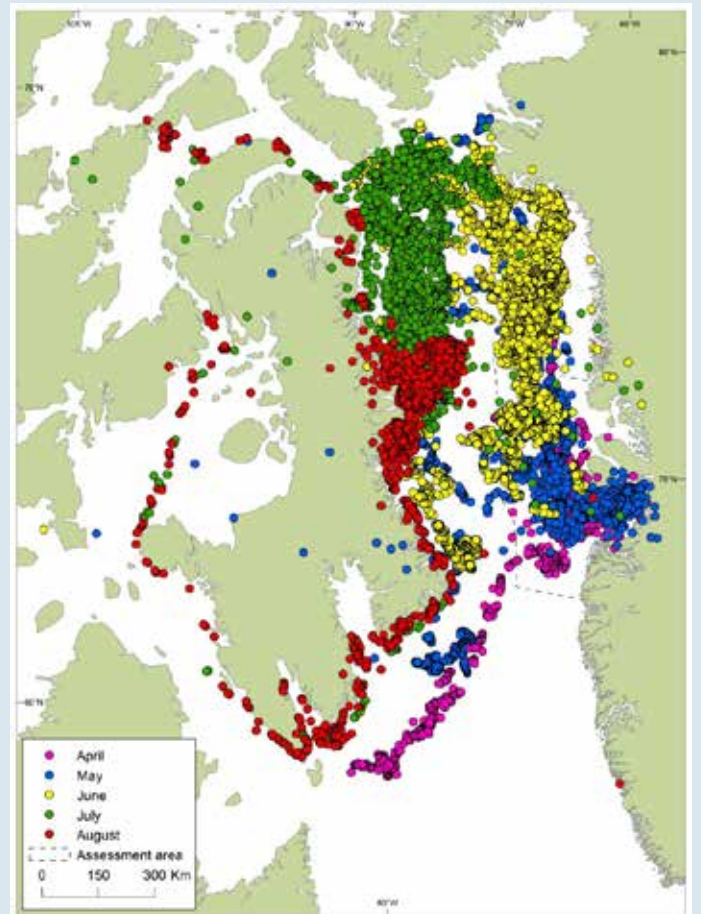
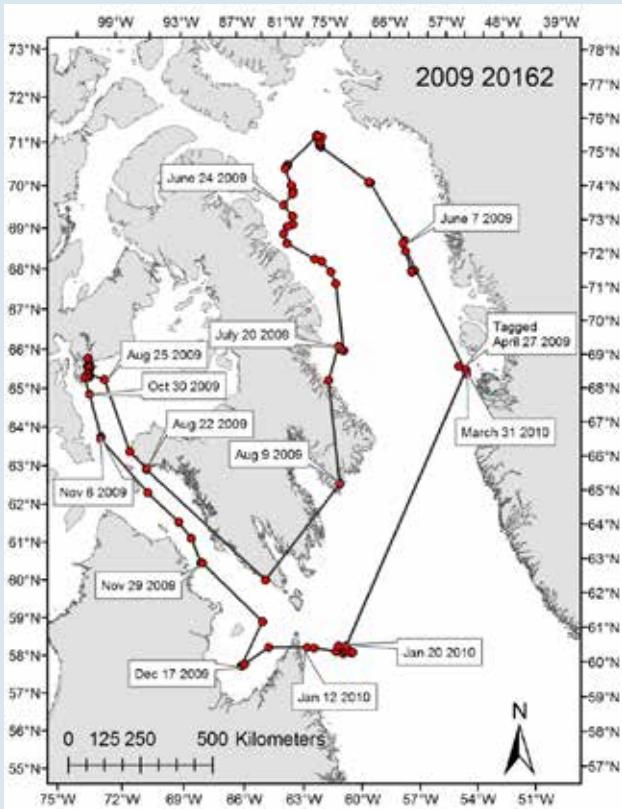
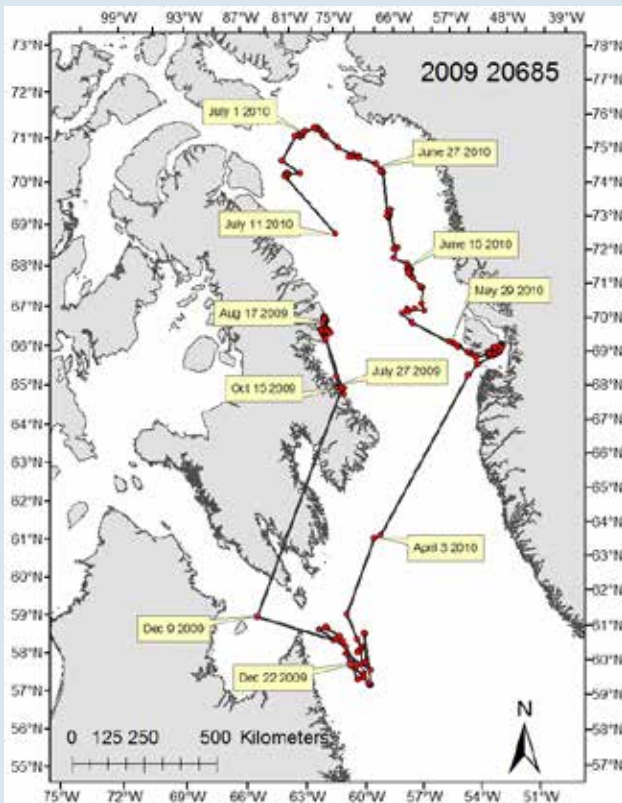


Figure 2. Locations of all bowhead whales tagged in Disko Bay in 2010 and tracked through August 2010 ( $n = 50$ ).



**Figure 3.** Track of a female bowhead whale (Id. no. 20162) tagged on 27 April 2009 in Disko Bay and tracked through March 2010.



**Figure 4.** Track of a female bowhead whale (Id. no. 20167) tagged 17 May 2009 in Disko Bay and tracked through 11 July 2010.

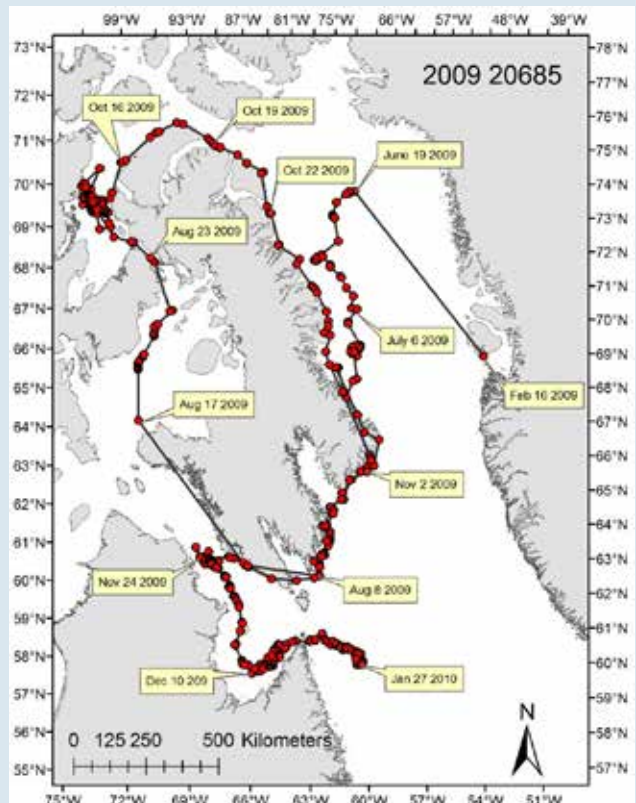
the West Greenland coast as far north as Melville Bay and the North Water, and they are also found in the eastern part of Disko Bay and in Vaigat.

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

### Summer: June – August

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

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



**Figure 5.** Track of a bowhead whale (sex unknown, Id. no. 20685) tagged 27 April 2009 in Disko Bay and tracked through 27 January 2010.

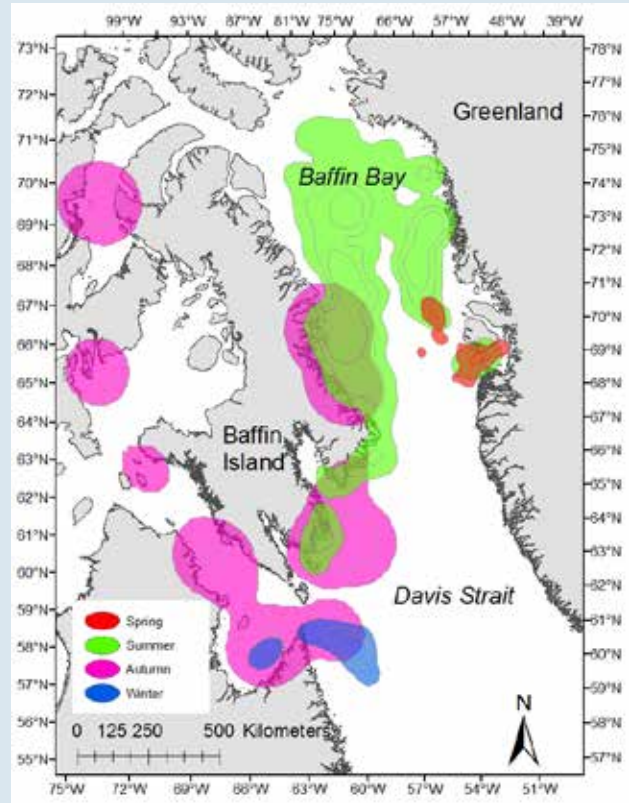
August is typically spent in coastal areas in the Canadian high Arctic archipelago and in northern Hudson Bay and Foxe Basin. Some bowhead whales circumnavigate Baffin Island in August, but the largest concentrations of whales have been found in Prince Regent Inlet in late August.

The summer home range demonstrated the vast area over which the bowhead whales range during these months (Figure 6, 7 and 8).

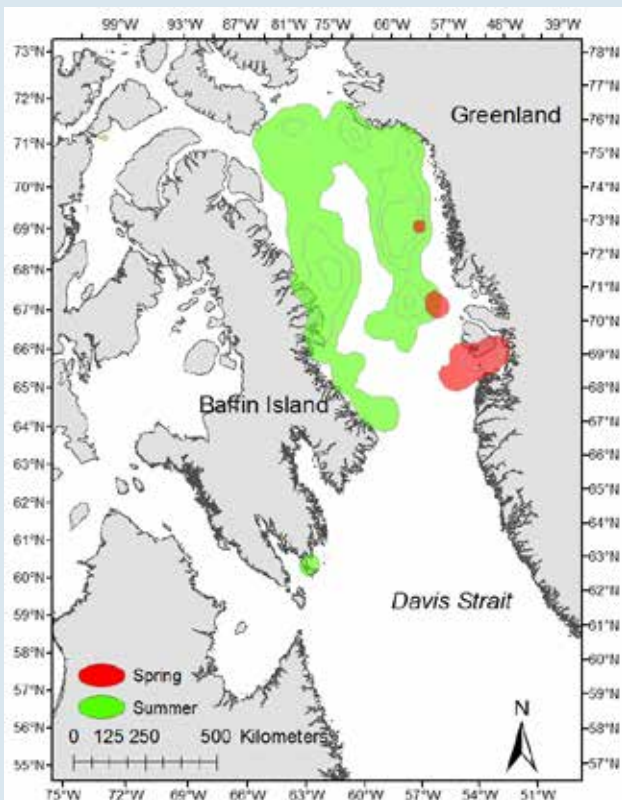
**Autumn: September - December**

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

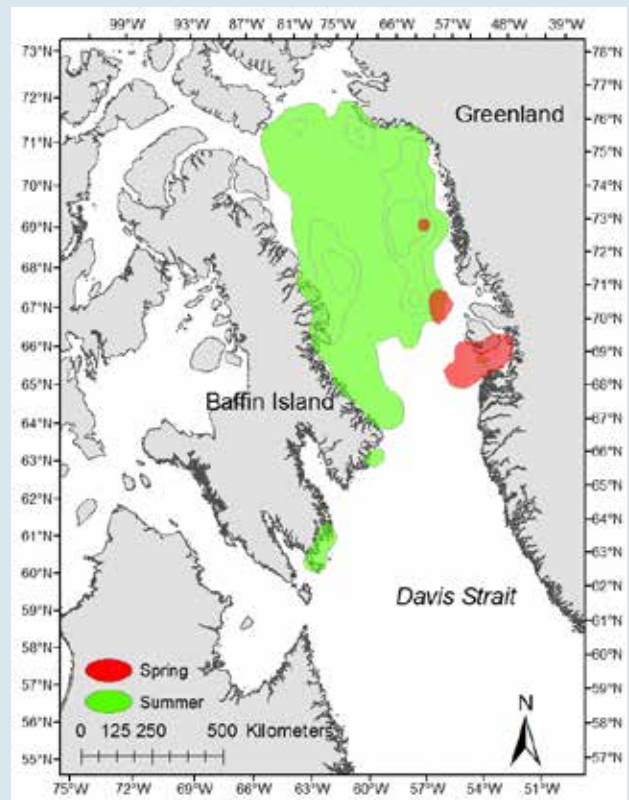
The 95, 75, and 50% autumn kernel home range was concentrated in multiple smaller focal areas which included the east coast of Baffin Island (Isabella Bay and offshore from Cumberland Sound), Prince Recent Inlet, Repulse Bay, and multiple areas within Hudson Strait (Figure 6).



**Figure 6.** Seasonal home range distributions of bowhead whales from 2009 (n = 28). The coloured area is the 95% kernel home range and the contours indicate 30% and 60% home ranges.



**Figure 7.** Seasonal home range distributions of bowhead whales from 2010 (n = 50). The coloured area is the 95% kernel home range and the contours indicate 30% and 60% home ranges.



**Figure 8.** Combined spring and summer home ranges for bowhead whales tracked in 2009 and 2010 (n = 78). The coloured area is the 95% kernel home range and the contours indicate 75% and 50% home ranges.

Nowacek et al. (2007) reported that only one study (Patenaude et al. 2002) has documented responses of whales to aircrafts. 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.

The whales seem not able to detect oil as, they do not avoid oil-contaminated waters (Harvey & Dalheim (1994), Goodale (1981), quoted in Anonymous 2003b). Immediate contact with the oil in water will be through the skin and perhaps the eyes. If oil is swallowed, the baleen and the gastrointestinal tract are likely to be injured. 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 and with 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 may affect filtration, but this issue has not been studied. The effect on the baleen will likely depend on factors such as the quality of the oil and the water temperature (Werth 2001). Whales may also be particularly sensitive to inhaling oil vapours (see further in Section 10.2.9).

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

### **Bowhead whale *Balaena mysticetus***

The bowhead whale is the only baleen whale that remains year round in Arctic and sub-Arctic waters. Four populations of bowhead (Okhotsk Sea, Bering/Chukchi/Beaufort Sea, Foxe Basin/Hudson Bay/Baffin Bay/Davis Strait and Spitsbergen) are currently recognised.

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

The bowhead whales occurring in the Baffin Bay assessment area primarily utilise the area for feeding and migration between spring concentrations areas in the Disko Bay region and summer grounds in the Canadian Arctic archipelago.

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

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

## Box 12

### Passive acoustic monitoring of marine mammals

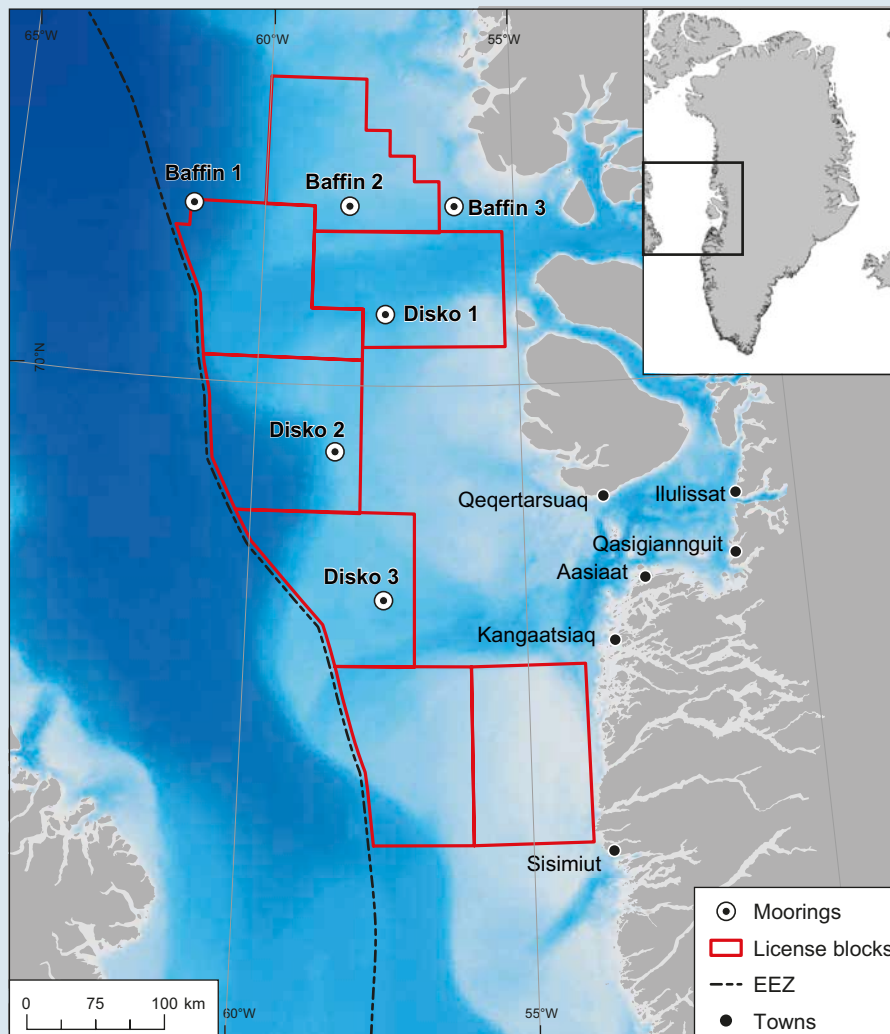
T. Boye & M. Simon

The Disko West and the Baffin Bay areas constitute critical feeding habitats and migration corridors for various marine mammals found at the top of the food chain. To obtain knowledge on their distribution and seasonal occurrence, we recorded vocalizing marine mammals in the period from October 2011 to September 2012. Three recorders were moored to the sea floor in the Disko West assessment area and three within the Baffin Bay assessment area (Figure 1). Four of these instruments recorded continuously for one year, and only data from these are reported here.

The focal species were bowhead whales, fin whales, humpback whales, blue whales and bearded seals. To a lesser extent, we also reviewed the presence of sei whales, killer whales and echolocating toothed whales.

The recordings revealed that the timing of when different marine mammal species vocalize within the assessment areas varied but all sites were more or less used by different species throughout the year (Figure 2).

Fin whales were recorded at all four sites, whereas humpback whales and blue whales were only detected on one buoy in the Disko West Area (Figure 2). Sei whale's songs were not registered on any of the buoys. All four species are, however, found in West Greenland waters, and additional years of recording will be analyzed for detections of the four rorqual species along with social calls of humpback whales. The concentration of sea ice seemed to have a large impact on the presence of fin whales, blue whales and humpback whales, and when sea ice concentrations were most extensive almost no calls were registered. However, fin whale singing was also detected during periods of extensive sea ice concentrations (Figure 2).



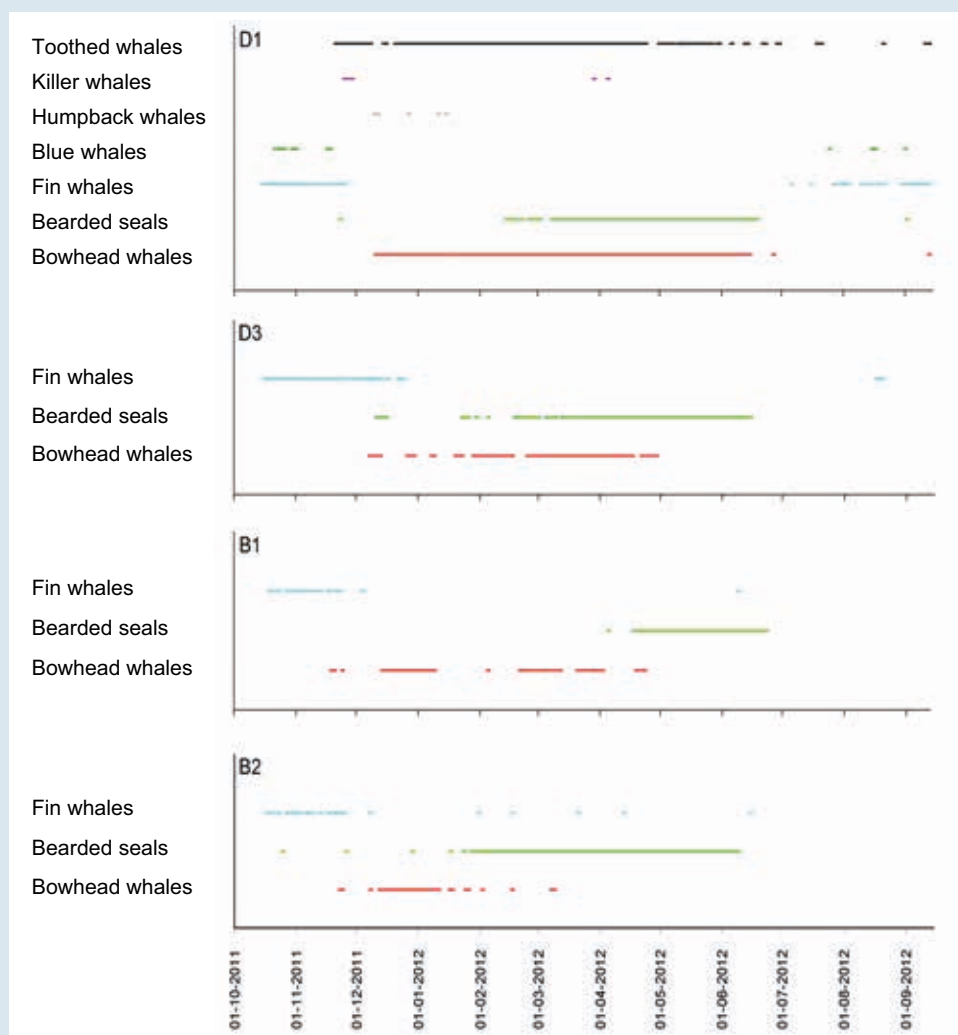
**Figure 1.** Map of the six moorings deployed in Disko West and South Baffin Bay assessment area. Bathymetry from IBCAO 3.0.



Bowhead whale singing was registered earlier (November) in the Disko West and Baffin Bay assessment areas than visual sightings in previous years (February) have registered them. The first registrations were made on the northwestern most buoys. Last calls were registered by mid-June in Disko West, coinciding with the northwestern migration. No vocal detections of bowheads were made after April in Baffin Bay (Figure 2).

Bearded seals were registered as early as October but we found a clear seasonal peak from mid-March to mid-June, followed by an abrupt termination in detections at all four buoys (Figure 2). At three out of four sites, the last detections of calls coincided with a complete drop in the mean sea ice concentration by early to mid-June, whereas at the fourth site, in Baffin Bay, the final detections of calls were recorded a little later and still during a period with 60% sea ice cover. Except for a single outlier in September, no bearded seal calls were detected in any of the instruments from July onwards. Time of year (breeding season) and the degree of sea ice concentration (bearded seals depend on ice for breeding) likely influence the presence of vocalizing bearded seals. The presence of bearded seals in the assessment areas during periods adjacent to calling cannot be excluded, but most bearded seals in these areas likely follow the pulse of the expanding and retreating pack ice.

Calls of killer whales were recorded in late November and again in late March and early April but they were very few (Figure 2). Echolocation clicks of toothed whales were more or less spread out covering the entire period from November 2011 to September 2012. Most clicks were recorded from mid-December until mid-April. The recorders were not set for a full bandwidth analysis of echolocation and therefore it was not possible to identify the clicks to a species level. However, the majority of clicks during winter and spring were most likely foraging narwhals that winter off West Greenland. They migrate to foraging areas in the south central Baffin Bay, central Davis Strait and Disko Bay and stay there from November through April.



**Figure 2.** The seasonality of different marine mammal species within the four recording sites D1, D3, B1 and B2.

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

### Current distribution of bowhead whales

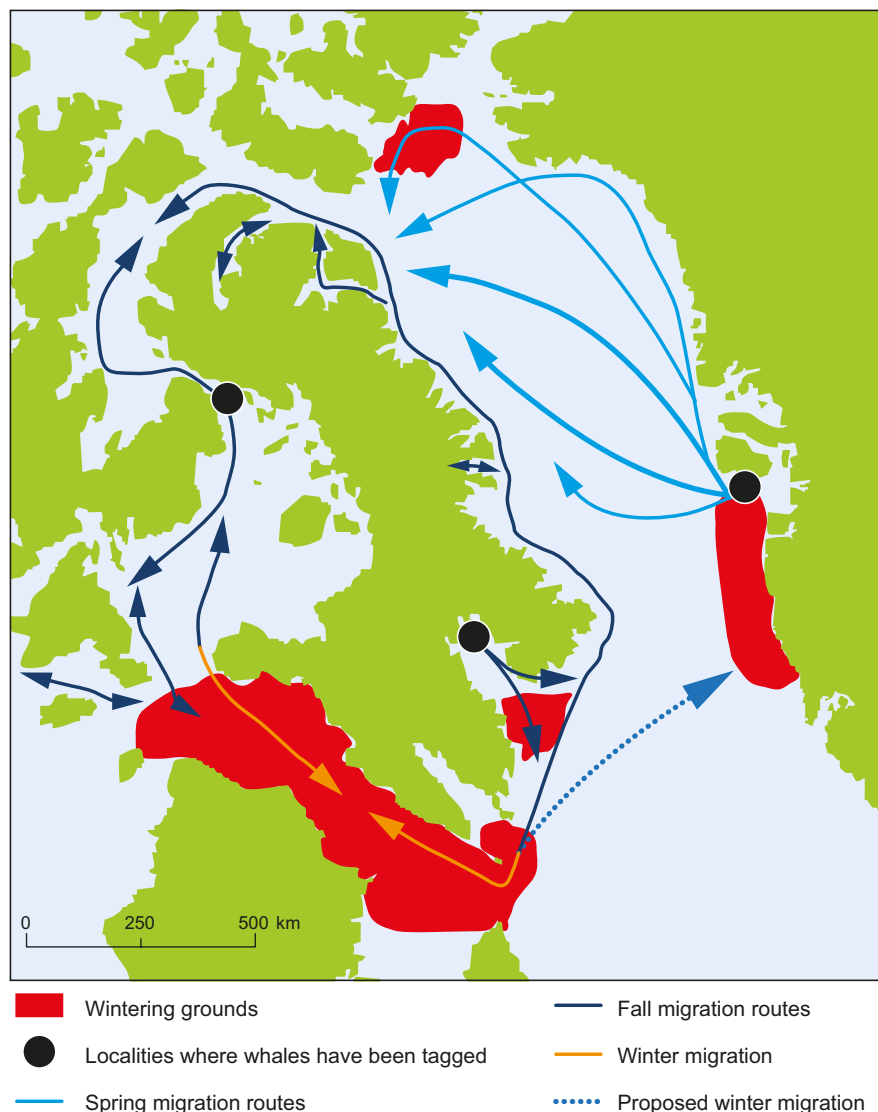
Today, bowhead whales are primarily spring and summer visitors along the west coast between Nordre Strømfjord and the southern part of Qaanaaq (Box 11), and their core areas are Disko Bay and offshore waters in Baffin Bay north of Disko Island.

A few bowhead whales winter in the North Water Polynya or visit the polynya in early summer (Heide-Jørgensen et al. 2013a, Figure 30) and, depending on ice conditions, occur within the northern part of the assessment area until at least July when they move westwards.

### Migrations

The whales arrive from the southwest to Disko Bay in February. Here they remain until June when they move northwards and northwestwards through the assessment area towards summering grounds in Canada. The migration is probably facilitated by leads and cracks in the pack ice (Heide-Jørgensen et al. 2003d, Heide-Jørgensen et al. 2006b, Nielsen et al. 2015) (Box 11).

**Figure 30.** Wintering grounds, spring and autumn movements of bowhead whales in Baffin Bay. The assessment area is indicated with a black line.



However, the results of the Passive Acoustic Monitoring in southern Baffin Bay in 2011-2012 (part of the Eastern Baffin Bay Environmental Studies Program 2011-2014; Boye et al. (2015)) indicate that bowhead whales may be present throughout the winter, at least in the southern part of the assessment area (Box 12).

### **Stock identity**

Satellite tracking studies in Canada and Greenland (Box 11) shows that bowhead whales occurring in West Greenland are part of a population that extends from Foxe Basin through the Canadian high-Arctic archipelago in the west to West Greenland waters in the east, including Hudson Bay, Hudson Strait and the east coast of Baffin Island (Heide-Jørgensen et al. 2006b).

### **Population segregation**

Even though the bowhead whales in West Greenland are shared with those in Hudson Bay and Foxe Basin, there is evidence of considerable age and sex segregation between the two areas. Females with calves and young immature whales are primarily found in Foxe Basin, whereas in Disko Bay (and the Baffin Bay assessment area) the population consists mostly of adult whales (Heide-Jørgensen et al. 2011). Skin biopsy samples of bowhead whales collected in Disko Bay between 2000 and 2010 showed that 78% (n=448) of the whales sampled were females based on genetic sex determination (Palsbøll et al. 1997), and length estimates exceeding 12-14 m suggest all were mature (Heide-Jørgensen et al. 2010b). Very few calves have been seen in West Greenland; thus, the large proportion of females must be either pregnant, resting or in oestrous (post-lactating). Acoustic studies in Disko Bay indicate that the bay is also a mating ground. Mating is believed to occur in March and April (Reese et al. 2001). Intensive singing activity of bowhead whales was recorded in April 2007 (Stafford et al. 2008, Tervo et al. 2009).

### **Current abundance in West Greenland**

The abundance of bowhead whales in West Greenland was assessed from an aerial survey conducted in March and April 2006. The surveyed area included the region between Sisimiut and Upernavik and up to approximately 100 km offshore and resulted in an estimated abundance of 1,229 (95% CI: 495-2939) bowhead whales for the surveyed area (Heide-Jørgensen et al. 2007a). A similar aerial survey conducted in 2012 gave an abundance estimate of 744 whales (CV = 0.34, 95% CI: 357-1,461; Rekdal et al. 2015). The difference is assumed to be due to a variable fraction of bowhead whales present in the surveyed area in the two years. The bowhead whales wintering off West Greenland constitute a fraction of the total population moving through Baffin Bay to the Canadian summer grounds where the population in 2001-02 was estimated to 6,344 (exceeding 12-14 m: 3,119-12,906) (IWC 2008).

Another approach to estimate the abundance in West Greenland is genetic mark-recapture analyses of biopsies collected from free ranging whales in Disko Bay. A mark-recapture estimate of whales identified in 2010 compared with all identifications between 2000 and 2009 resulted in an estimate of 1,410 bowhead whales (95% CI: 783-2038) representing the size of the population that supplies the spring aggregation in Disko Bay and also the individuals moving through the assessment area (Wiig et al. 2011). Based on samples from a total of 427 individuals (2000-2013), with 11 recaptures from previous years, another mark-recapture yielded an estimate of 1,538 whales in 2013 (95% CI: 827-2,249, Rekdal et al. 2015). While the aerial survey is considered a snapshot of the local spring aggregation in Disko Bay, the genetic approach estimates the abundance of the source of this aggregation and of the whales

moving through the assessment area. As the whales in Disko Bay primarily are adult females that do not visit the bay annually, the genetic method would presumably yield higher estimates. The studies indicate that the increase in abundance observed between 1998 and 2006 has levelled off and that despite the recovery, numbers of bowhead whales in Baffin Bay are still much lower than the original population size (Allen & Keay 2006).

#### **Diving and foraging ecology**

Feeding habits of bowhead whales in Disko Bay have been studied through examination of the stomach contents of whales captured in the subsistence harvest of whales. Four stomach samples were collected in 2009 and 2010 and in all stomachs the prey items were > 99% calanoid copepods > 3 mm long (Heide-Jørgensen et al. 2012b). In one stomach, where species determination was possible, primarily *Calanus hyperboreus* was found. The stomach contents of the bowhead whales from Disko Bay indicate that they feed almost exclusively on calanoid copepods and that no other prey items contribute substantially to their diet. This is in agreement with observations of diving behaviour and area utilisation by whales instrumented with time-depth-recorders and satellite transmitters (Laidre et al. 2007, Heide-Jørgensen et al. 2013b). The stomach contents of three whales (of the same stock) taken by the subsistence hunt in the Canadian archipelago in the period 1996-2008 surprised by containing high numbers of benthic and epibenthic organisms, especially mysids (Pomerleau et al. 2011).

#### **Critical and important areas**

The assessment area is extensively used by bowhead whales during their spring migration between Disko Bay and Arctic Canada, from late May through June. Just to the south of the assessment area, Disko Bay and the waters to the southwest of Disko must be classified as one of the most important bowhead whale habitats worldwide; it is used extensively for foraging by mature whales and mating also takes place (Rekdal et al. 2015).

The North Water Polynya is a winter and spring/early summer habitat, but only few whales have been seen in this area during surveys in May 2009 and 2010 and April 2014 (Heide-Jørgensen et al. 2013a, 2016).

#### **Conservation status and catch**

The population occurring in the assessment area now has a favourable conservation status as it is increasing and is more numerous than previously believed. It is listed as 'Near Threatened' (NT) on the Greenland Red List and as 'Least Concern' (LC) on the international Red List (IUCN 2015).

The Baffin Bay stock has been protected since 1910. In recent years a few individuals have been taken in Canada and Greenland as part of the subsistence hunt. The IWC permitted Greenland to take two per year in the period 2008-2015.

#### **Minke whale *Balaenoptera acutorostrata***

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

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

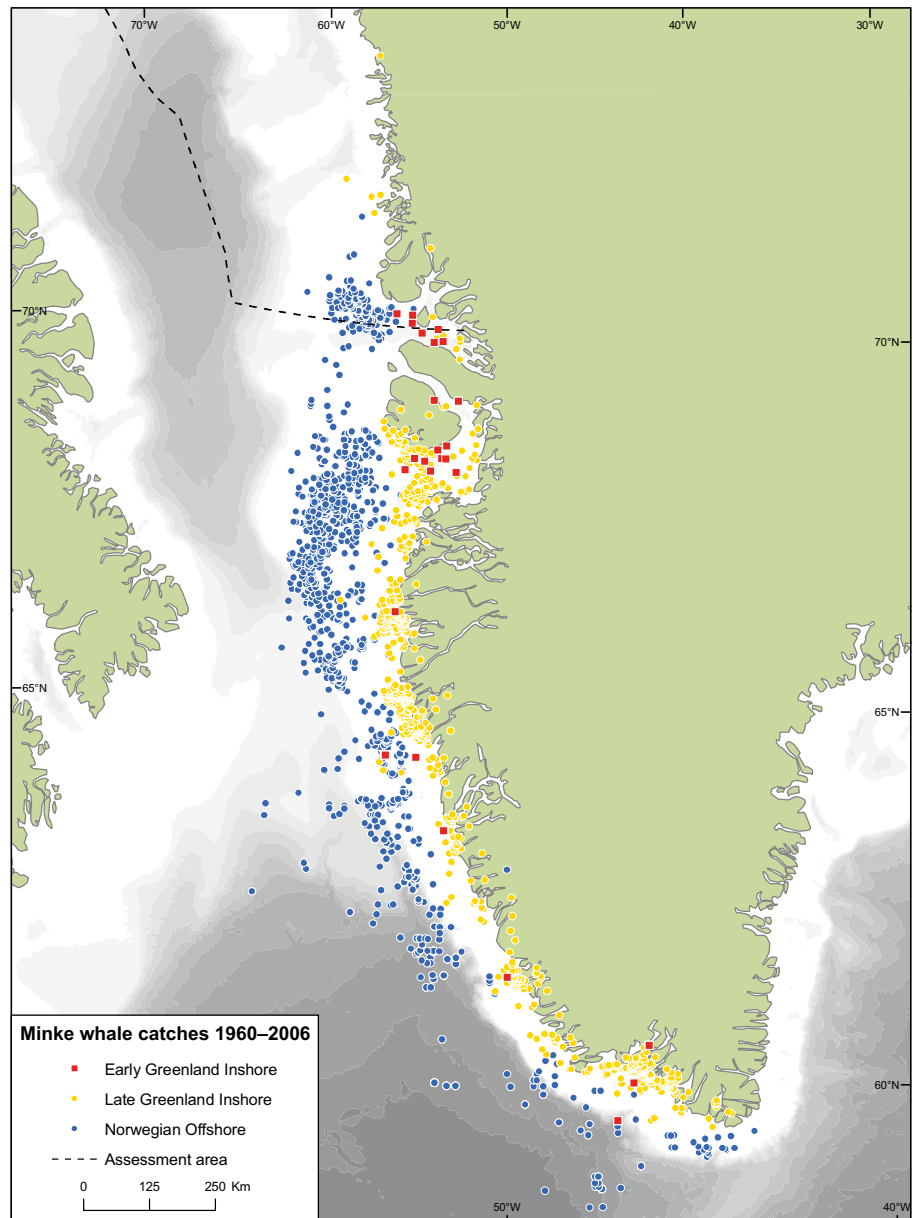
### Distribution

Minke whales occur as summer visitors mainly in the southern part of the assessment area (Figure 31). In recent years, minke whales have been reported as far north as Siorapaluk in the former Qaanaaq Municipality, most likely as an effect of climate change. There is no knowledge of specific important areas to minke whales within the assessment area.

### Conservation

The population occurring in the assessment area has a favourable conservation status. Both the global Red List (IUCN 2015) and the Greenland Red List categorise the minke whale as of 'Least Concern' (LC).

**Figure 31.** The distribution of minke whales in the assessment area (and West Greenland) shown by the reported catches in the period 1960 to 2006, distributed on three different hunting regimes (see text). Only about 18% of the minke whales taken by the collective hunt (from small boats) have been reported with accurate positions (Ugarte 2007). Therefore, catches from the assessment area are under-represented in this figure.



### Stocks

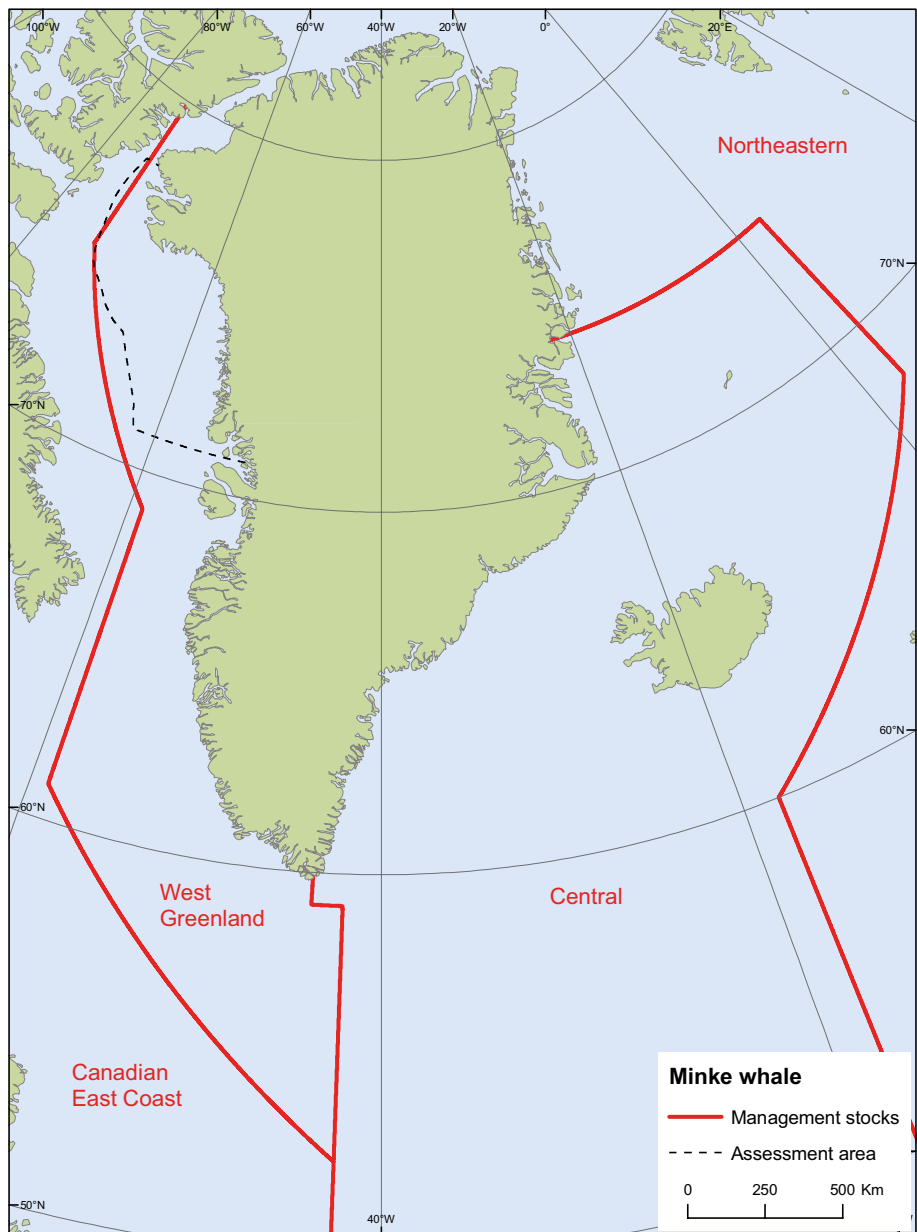
For management purposes, the International Whaling Commission (IWC) recognises four different stocks of minke whales in the North Atlantic (Figure 32). These management regions were established based on studies of catch statistics, biological characteristics and tagging. Newer molecular studies tend to confirm the established subdivisions (Andersen et al. 2003, Born et al. 2007).

### Catch

Minke whales have been hunted in West Greenland since the middle of the 20<sup>th</sup> century. Quotas for West Greenland are set by the IWC and the minke whale quota in 2015 was 164 whales. The Greenland government divides the quota among the towns. Most of the minke whales are taken south of Disko Island where there are boats equipped with harpoon canons. Further north in the assessment area, minke whales are taken from dinghies with outboard engines, and several dinghies work as team, using hand held harpoons and high-powered rifles. This type of hunt is called the 'collective hunt'

From 1968 to 1986, small-type whaling boats from Norway caught minke whales in the waters off West Greenland. During the early and mid-1970s,

**Figure 32.** The management stocks of minke whale in the North Atlantic. Only one stock occurs within the assessment area.



Norwegian catches off West Greenland averaged 175 minke whales annually. After 1977, following recommendations by the IWC, the Norwegian catches were reduced to 75 minke whales annually (Kapel & Petersen 1982). The Norwegian boats stopped catching minke whales in Greenland in 1986.

The Norwegians recorded data on each whale caught, including size, sex, reproductive status and the location where the whale was caught. From this dataset, we can see that several minke whales were caught within the southern part of the assessment area (Figure 31).

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

Several surveys of large whales in West Greenland, south of the Baffin Bay assessment area, have been carried out since 1984, the most recent in 2015. Based on the fluctuations in abundance estimates from eight different years, Heide-Jørgensen & Laidre (2008) concluded that a varying proportion of North Atlantic minke whales uses the West Greenland banks as summer feeding grounds.

The 2007 survey resulted in a minke whale abundance estimate for West Greenland of 16,609 whales (95% CI: 7,172-38,461; Heide-Jørgensen et al. 2010d). The actual number of minke whales in West Greenland is assumed to be higher because this survey did not cover the northernmost part of West Greenland (i.e. the assessment area), where minke whales also occur. Results from the survey from 2015 will be ready in 2016.

### **Sensitivity**

Minke whales produce a variety of vocalisations using frequencies that vary from a few kHz down to 60 Hz (review in Rankin & Barlow 2005). Anthropogenic noise in these frequencies may impact on minke whale behavior and communication.

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

### **Sei whale *Balaenoptera borealis***

Sei whales are on average 14 m long and weigh 20-25 tons. They feed on small fish, krill, squid and copepods. Their distribution is worldwide, from subtropical or tropical waters to high latitudes of the sub-Arctic or sub-Antarctic. It is assumed that most populations move seasonally between high latitudes in summer to tropical waters in winter (IWC 2008). In the North Atlantic, they are usually associated with high concentrations of krill (*Meganyctiphanes* spp. and *Thysanoessa* spp.) which is their main prey.

The distribution of sei whales is poorly understood. They occur in apparently unpredictable patterns. Although they occur in polar areas, sei whales seem to be more restricted to mid-latitude temperate zones than other rorquals (Jefferson et al. 2008).

### **Distribution**

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

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

### **Conservation**

The population occurring in the assessment area probably has an unfavourable conservation status as commercial whaling in the 20<sup>th</sup> 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) on the global Red List (IUCN 2015) and as 'Data Deficient (DD)' on the Greenland Red List.

Surveys of cetaceans in West Greenland have been carried out at regular intervals since 1984. Sei whales were rarely observed in the earlier surveys, but appear relatively abundant in the most recent surveys of 2005 and 2007. Numbers of sei whales off West Greenland, calculated from a ship survey in 2005, were 1,529 (95% CI: 660-3,540) (Heide-Jørgensen et al. 2007b). This is an underestimation of the actual numbers because the survey did not cover all the potential habitats of sei whales off West Greenland and because animals under water at the time of the survey and animals missed by observers were not accounted for.

### **Sensitivity**

See the introduction to baleen whales.

### **Blue whale *Balaenoptera musculus***

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

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

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

### **Distribution**

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



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

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

#### **Conservation status**

The population occurring in the assessment area has an unfavourable conservation status due to heavy exploitation by commercial whaling during the first half of the 20<sup>th</sup> century. The population shows some signs of recovery since global protection was initiated in 1966, but the population size remains low (IUCN 2015). Blue whales are categorised as 'Data Deficient' on the Greenland Red List. In the global Red List, blue whales are classified as 'Endangered' (IUCN 2015).

#### **Sensitivity**

Due to their low densities and their ability to communicate acoustically over long distances, blue whales are probably especially sensitive to acoustic pollution. Blue whales synchronise their call sequences and display very fine pitch discrimination and control over their calling frequency (McDonald et al. 2009). The physical characteristics 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 42-90 km from operating airguns and, at these relatively large distances they were unable to detect changes in the behaviour of the whales.

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

#### **Fin whale *Balaenoptera physalus***

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

Fin whales favour prey items such as krill and small schooling fish, for example herring (*Clupea harengus*) and capelin. 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) and catch statistics (Simon et al. 2007a) indicate that at least some individuals re-

main at high latitudes all year round. Passive acoustic monitoring in the Davis Strait indicated that fin whales may mate during winter in West Greenland, and that fin whales remain in the Davis Strait until the advance of the sea ice (Simon et al. 2010). Recently, results of passive acoustic monitoring in southern Baffin Bay in 2011-2012 (part of the Eastern Baffin Bay Environmental Studies Program 2011-2014; Boye et al. (2015)) have revealed that fin whales occur there throughout the winter (Box 12). Moreover, fin whales are regularly observed in the Uummannaq district in November (GINR unpublished).

### **Distribution**

Fin whales occur regularly during summer in fjords of the southern part of the assessment area, and may occur further north in offshore areas. However, the offshore waters in Baffin Bay are poorly surveyed for cetaceans, and there are no data on the distribution or numbers of fin whales in the assessment area.

### **Conservation**

Fin whales have an unfavourable conservation status on a global scale, and are categorised as 'Endangered' (EN) on the global Red List (IUCN 2015). This listing is based on the population decrease recorded in the southern hemisphere due to whaling. However, in the North Atlantic fin whales are abundant and the population here has a favourable conservation status, and the species is listed as of 'Least Concern' (LC) on the Greenland Red List.

Fin whales are genetically similar in widely separated areas of the North Atlantic. Current genetic research (Pampoulie et al. 2008) contemplates two likely scenarios: 1/ separate populations have split from a common ancestry in a not too distant past (i.e. after the most recent glaciation) or 2/ a single population may exist comprised of individuals moving over very long distances and to different areas.

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

### **Catch**

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

Greenlanders started catching fin whales from fishing boats equipped with harpoon cannons in 1948, but as early as 1924 a steam ship was officially designated to catch large whales in West Greenland. Until the 1970s, this catch took 0-13 fin whales per year. The IWC aboriginal subsistence quotas have regulated fin whale takes in West Greenland since 1977. The quotas have ranged from six to 23 whales annually and remained stable at 19 whales from 1995 to 2009. The quota for 2010 and 2011 was reduced to 10 whales, and from 2012 it was raised again to 19. The total quota is seldom used and the catches are usually around 10 fin whales per year (Kapel & Petersen 1982, Caulfield 1997, Witting 2008).

Due to the lack of boats equipped with harpoon cannons in the northernmost parts of West Greenland, most fin whales are taken south of the assessment area. However, a few individuals have been caught off Uummannaq, in the

southernmost part of the region, by boats travelling from the towns of the Disko Bay area (Simon et al. 2007a).

Due to their economic importance, considerable effort has been dedicated to estimate the numbers and the abundance trends of large whales, including fin whales in West Greenland, south of Disko Island. The estimate from an aerial survey in September 2007 was 4,468 (95% CI: 1,343-14,871) fin whales, and the population may be increasing (Heide-Jørgensen et al. 2010e, Witting 2008). The actual number of fin whales in West Greenland must be larger because the survey did not cover the northernmost parts of the fin whale's range, including the assessment area. A new survey for large whales was carried out in 2015 and an abundance estimate is expected to be presented in 2016.

### **Sensitivity**

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

A 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). Furthermore, bearings to singing whales indicated that whales moved away from the air-gun 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 may even leave an area for an extended period (Castellote et al. 2010).

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

### **Humpback whale *Megaptera novaeangliae***

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

### **Distribution**

Due to poor survey efforts, the distribution patterns and numbers of humpback whales in the assessment area are unknown. For West Greenland south of the assessment area, a series of eight surveys carried out between 1984 and 2007 was used to estimate a rate of increase of 9.4% per year (Heide-Jørgensen et al. 2012a). This high rate of increase is consistent with the observed rate of increase at other feeding grounds in the North Atlantic. The abundance estimate for 2007 was 3,272 (95% CI: 1,300-8,233). The actual abundance of humpback whales in West Greenland may be larger since the survey did not cover important humpback whale habitats in the far north (including the assessment area) or offshore areas with depths exceeding 200 m. A new survey was carried out by GINR in 2015 and the results are expected during 2016.

It is likely that the range of humpback whales in West Greenland will expand as the population continues to increase. In recent years, humpback whales are found to be more widely distributed in West Greenland and records of ob-

servations further north, inside the assessment area, are now frequent. Thus, Uummannaq fjord may become an important feeding ground for humpback whales.

Humpback whales can be individually identified by the pattern on the fluke, which they often raise above the surface at the start of a deep dive. Movement patterns of thousands of humpbacks photographed across the North Atlantic show high levels of site fidelity with occasional long-distance movements between four main feeding aggregations (Figure 33): Gulf of Maine, eastern Canada, West Greenland and the eastern North Atlantic (Stevick et al. 2006).

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

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

**Figure 33.** Feeding aggregations of humpback whales in the North Atlantic: Gulf of Maine, Eastern Canada, West Greenland and Eastern North Atlantic. There are also feeding aggregations off Southeast Greenland.



### **Conservation**

The population occurring in the assessment area has a favourable conservation status as it is abundant and increasing. Whaling has seriously depleted all humpback whale stocks, and humpback whales received worldwide protection in the 1980s. Most populations have increased substantially since the cessation of commercial whaling, and in 2008 the status of humpback whale was changed from 'Vulnerable' (VU) to 'Least Concern' (LC) on the global Red List (IUCN 2015). Their classification on the Greenland Red List is also 'Least Concern' (LC).

### **Catch**

Until their protection in 1986, humpback whales were an important source of whale meat for the people in West Greenland, who caught on average 14 animals annually, yielding approximately 112 tons of whale meat (IWC 1991). In 2008, the Scientific Committee of the IWC advised that a catch of ten humpback whales per year would be sustainable (IWC 2008). On the basis of this advice, a quota of nine humpback whales per year was granted by the IWC to Greenland for 2010-2012. The quota was increased to 10 whales per year in 2013-2017. All the humpback whales are caught south of the assessment area.

### **Vocalisation**

Humpback whales are well known for the long and complex songs produced by males on the breeding grounds (Parsons et al. 2008). Most knowledge about the sound produced by humpback whales on their feeding grounds comes from a few studies in the North Pacific Ocean (D'vincent et al. 1985, Thompson et al. 1986) and the Gulf of Maine (Stimpert et al. 2007), where cooperative feeding calls, as well as click-like sounds have been described. In West Greenland, humpback whales seem to be mostly silent during summer (Simon 2010). Humpback whale sounds are low to mid-frequency, usually 30 Hz to 8 kHz, although up to 24 kHz may be reached (Figure 29). Peak frequencies tend to be around 315 Hz and 630 Hz (Parsons et al. 2008).

### **Oil spill and noise vulnerability**

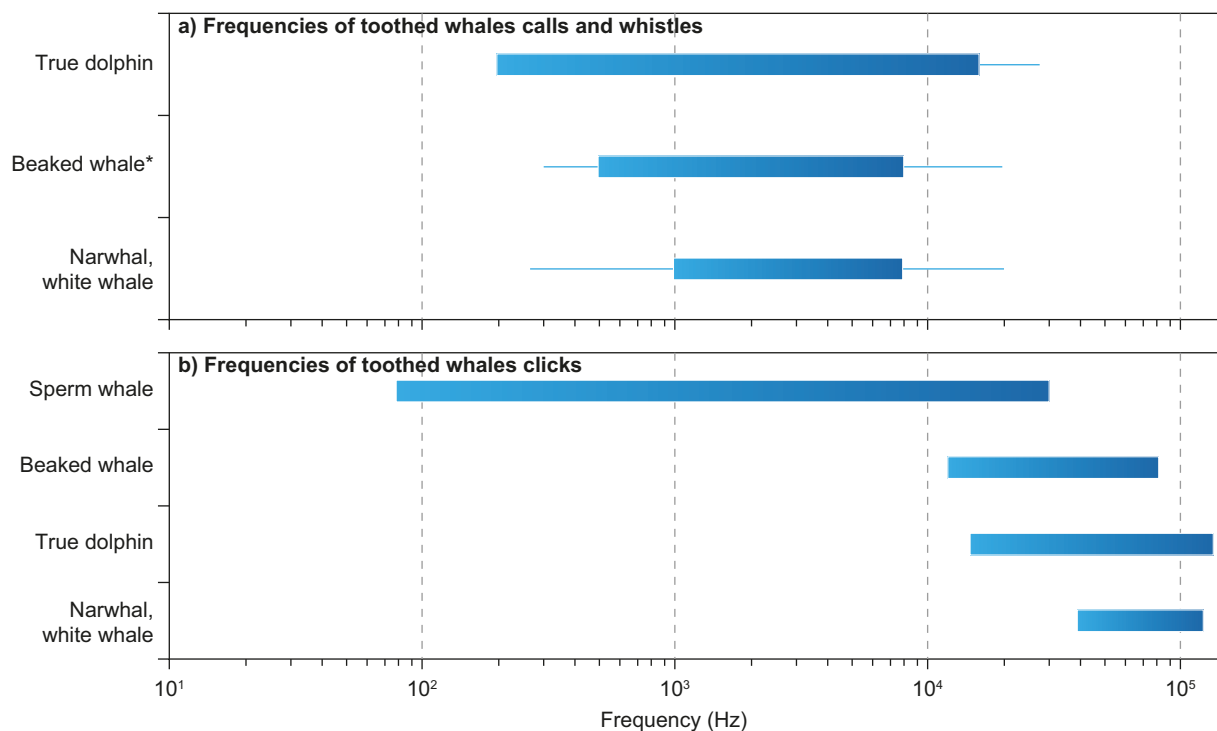
See the introduction to baleen whales.

#### **4.8.5 Toothed whales**

F. Ugarte & M.P. Heide-Jørgensen

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

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



**Figure 34.** Known frequency ranges of pulsed calls and whistles (a) and echolocation clicks (b) made by toothed whales in the Baffin Bay assessment area. True dolphins (family Delphininae) include killer whale, pilot whale and white beaked dolphin. Beaked whales (family Ziiphidae) include bottlenose whale. Figure modified from Mellinger et al. (2007).

### Toothed whale sensitivity to acoustic pollution

Toothed whales produce clicks for echolocation<sup>2</sup> and communication. In addition, killer whales produce pulsed calls made of clicks in very rapid succession. Narwhals, white whales, white-beaked dolphins, pilot whales and killer whales produce whistle-like sounds. Pulsed calls serve several purposes, including long-range communication and transmission of information about kinship and group cohesion. Whistles are important during short-range social contacts and may include information about the identity of the whistler. Figure 34 shows the frequency ranges of echolocation clicks, calls and whistles produced by toothed whales in the assessment area.

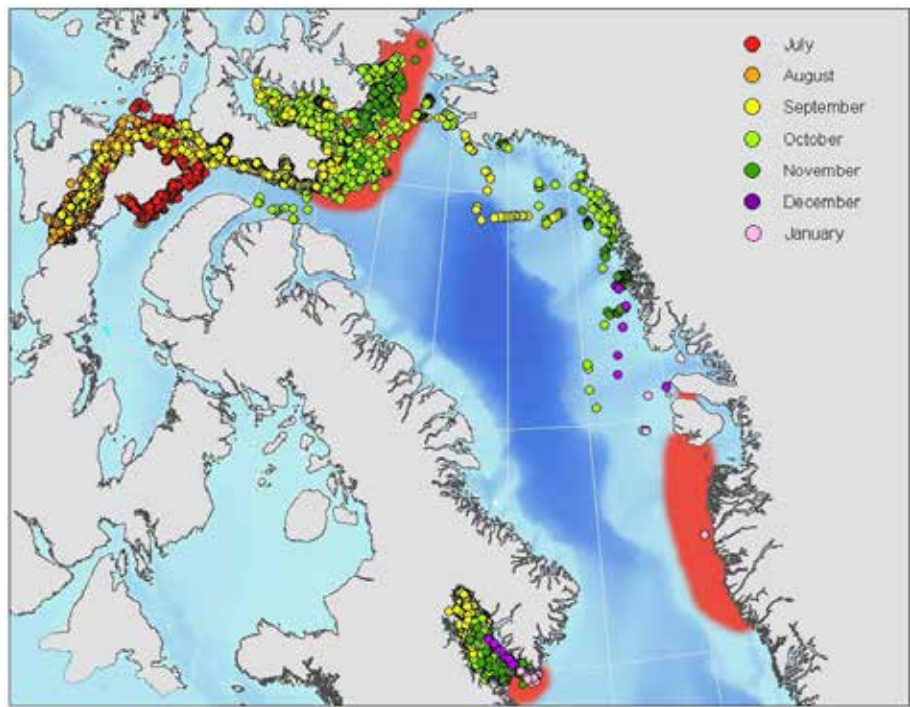
Masking by anthropogenic sounds, including noise from ships, oil exploration and development, can reduce the active space of sounds produced by toothed whales. Whales can also be displaced from noisy areas, and extremely loud sounds may physically damage their hearing organs (review in Nowacek et al.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

### Toothed whale sensitivity to oil spills

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

<sup>2</sup> Echolocation is the ability of finding (i.e. locating) objects by listening to the reflections (echoes) of echolocation clicks.

**Figure 35.** Positions of satellite-tracked white whales distributed according to month. Red areas indicate winter quarters (GINR unpublished).



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

This was also observed in the oil spill from the *Deepwater Horizon* incident, and several papers describe increased mortality and serious effects on bottlenose dolphins in the areas affected by the spill (see Section 11.7.8).

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

#### Distribution

The long-finned pilot whale occurs in temperate and sub-polar zones and, according to most literature, ranges from Disko Bay and Ungava Bay in the north-west, from 68° N in eastern Greenland across Iceland and the Faroe Islands to mid-Norway, and south to North Carolina, the Azores, Madeira and Mauritania (for example Jefferson et al. 2008). Greenlandic catch statistics (Ministry of Fishery, Hunting and Agriculture APNN, unpublished data) show, however, that pilot whales occasionally occur as far north as Uummannaq and Upernavik in the southern part of the assessment area in late summer or early autumn.

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

The diet of pilot whales consists primarily of squid, but they also eat small to medium-sized fishes, such as cod and herring.

#### Catch

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

### **Population**

Pilot whales occurring in the assessment area (and the rest of Greenland) probably represent vagrants from a single large North Atlantic population. Abundance of pilot whales on the banks of West Greenland was estimated in 2007 to be 7,440 (95% CI: 3,014-18,376) (Hansen & Heide-Jørgensen 2013a). The surveys only covered part of the range of pilot whales in West Greenland and it must therefore be considered a minimum estimate.

### **Conservation**

Long-finned pilot whale is listed as 'Data Deficient' (LC) on both the global Red List (IUCN 2015) and the Greenland Red List.

### **Sensitivity**

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

### **White-beaked dolphin *Lagenorhynchus albirostris***

White-beaked dolphins inhabit the North Atlantic Ocean in the cold temperate zone and the southern part of the Arctic. According to several published sources, Disko Bay is the northern limit of their distribution in West Greenland (for example Reeves et al. 1999, Kinze 2002). However, unpublished and unverified catch statistics indicate that white-beaked dolphins occur as far north as Upernavik, well into the assessment area.

The primary habitat of white beaked dolphins are waters less than 200 m deep, especially along the edges of continental shelves.

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

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

### **Catch**

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

The abundance of white-beaked dolphins on the banks of West Greenland was estimated in 2007 to be 11,801 (95% CI: 7,562-18,416) (Hansen & Heide-Jørgensen 2013a). The surveys only covered part of the range of white-beaked dolphins in West Greenland and it must be considered a minimum estimate.

### **Conservation**

The global status of the white-beaked dolphin is 'Least concern' (LC) (IUCN 2015). On the Greenland Red List, the white-beaked dolphin is listed as 'Data Deficient'.

### **Sensitivity**

See the introduction to toothed whales.



## **Killer whale *Orcinus orca***

Killer whales are top predators occurring in all oceans, and they tend to concentrate in colder regions with high productivity. They feed on prey varying in size from herring to adult blue whales. Different killer whale populations tend to specialise and feed on locally abundant prey species. Across populations the movements and behaviour of the prey influence killer whale behaviour, movements and social organisation. As a result of these specialisations, there are different ecotypes of killer whales. Examples of such ecotypes include killer whales that feed seasonally on sea lion and elephant seal pups in Patagonia (Lopez & Lopez 1985), herring in Norway and Iceland (Simon et al. 2007b), sharks in New Zealand (Visser 2005) and tuna in the Gibraltar Strait (Guinet et al. 2007). In some cases, up to three different ecotypes are known to overlap in one area, such as in the northeastern Pacific where the ecotypes called 'residents', 'transients' and 'offshores' feed on salmon, marine mammals and sharks, respectively (Ford & Ellis 2002 Baird & Dill 1995, Herman et al. 2005). In Antarctica, three ecotypes are feeding on tooth-fish, seals or large whales, respectively (Pitman & Ensor 2003). Sympatric ecotypes (i.e. with overlapping ranges) seldom interact and do not interbreed.

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

Killer whale populations tend to be small, often numbering in the hundreds, rather than thousands (for example Bigg et al. 1990, Similä & Ugarte 1997, Ford & Ellis 2002, Visser 2001). Based on genetic analyses of killer whales from several locations in the North Pacific, Hoelzel et al. (2007) suggested that killer whale populations in the North Pacific had small effective sizes and that there was ongoing low-level genetic exchange between populations.

Killer whales produce calls and whistle-like sounds for communication and clicks for echolocation (Simon et al. 2007a). Calls serve several purposes and group-specific call repertoires play a fundamental role in the social organisation and mating system of killer whales (Barrett-Lennard 2000). Whistles are important during short-range social contact (Thomsen et al. 2001).

### **Distribution**

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

Heide-Jørgensen (1988) reviewed published and unpublished information available on killer whales in Greenland and carried out a questionnaire-based investigation of sightings of killer whales. Observations occurred in all areas of West Greenland, and sightings were most frequent in Qaanaaq, Disko, Nuuk and Qaqortoq.

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

### **Catch**

Norwegian small-type whalers caught 13 killer whales at four locations in Southwest Greenland from 1968 to 1972 (Øien 1988). Norwegian catches of kill-

er whales in Greenland stopped when the market for meat from toothed whales for pets and fur animals was much reduced (Jonsgård 1977 in Øien 1988).

Killer whales are hunted in Greenland, partly for human subsistence and partly to feed dogs, but also because they are considered as a pest (i.e. as competitors to seal and whale hunters).

Before the current reporting system was established in 2008, three catches of killer whales were reported from the assessment area after 1996. In 2008 six killer whales were landed

### **Conservation**

Killer whales are listed as 'Data Deficient' (DD) on the global IUCN Red List (IUCN 2015) and as 'Data Deficient' (DD) on the Greenland Red List (Boertmann 2008).

### **White whale (beluga) *Delphinapterus leucas***

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

### **Distribution**

White whales migrate through the assessment area, where they occur in October-November and again in April-June. They may also occur in winter as one population spends the winter in the North Water and as the central West Greenland wintering grounds occasionally range as far north as the southern assessment area (Figures 35, 36). In recent years they seem to winter and migrate further out from the coast than previously, probably due to the reduced amount of sea ice (Heide-Jørgensen et al. 2010a).

The summer grounds of white whales are in the Canadian Arctic archipelago, where they often occur in extensive estuaries.

### **Movements**

White whale migration in Greenland waters has been documented by two white whales equipped with satellite transmitters in Canada and tracked to the winter quarters south of Disko Bay (Heide-Jørgensen et al. 2003b).

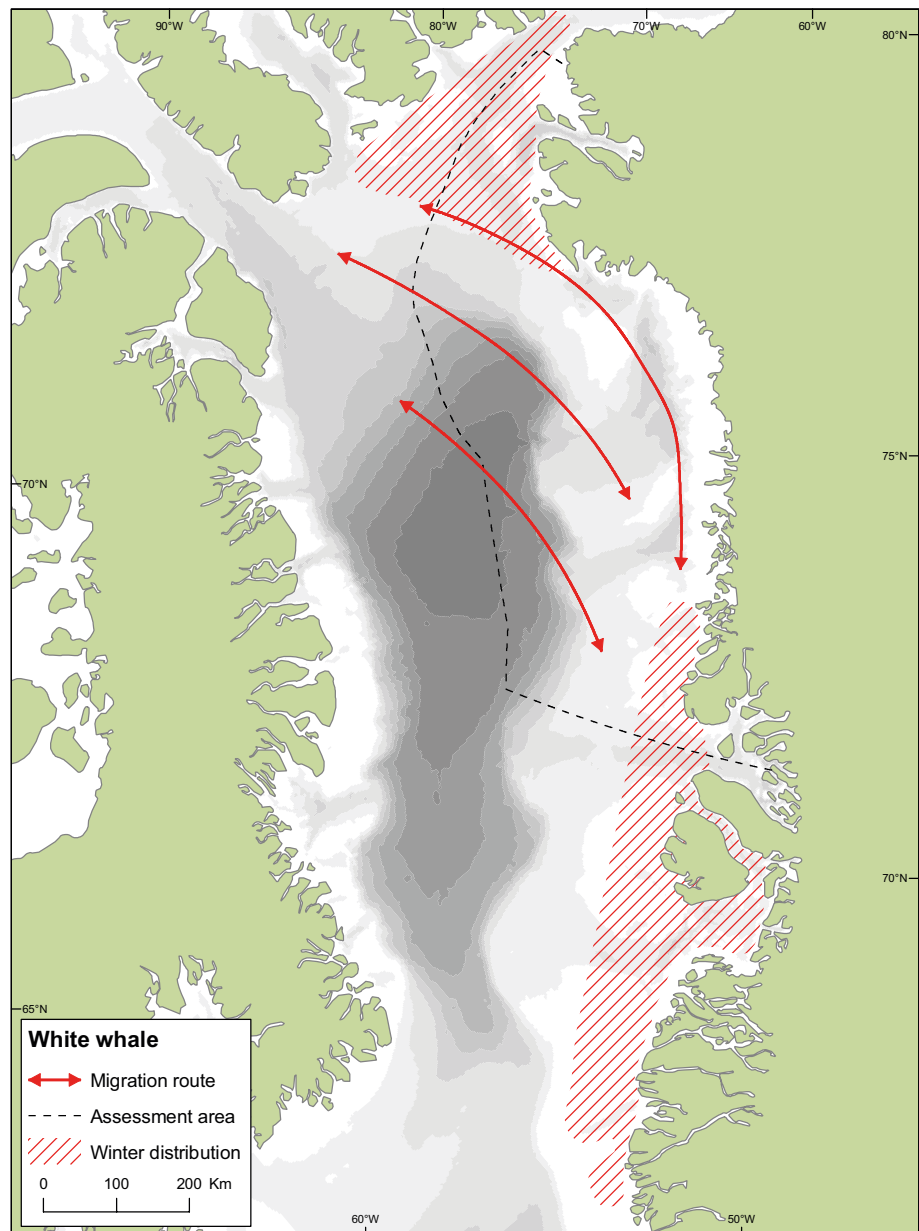
White whales are expected to acquire the major part of their annual food intake in their winter quarters in West Greenland and in the North Water.

### **Abundance**

Aerial surveys conducted in West Greenland between 1981 and 1994 found a decrease of 62% in the number of white whales, a decrease, which is the result of overharvesting (Heide-Jørgensen & Reeves 1996).

Further surveys in 1998 and 1999 confirmed the decline and found 7,941 (95% CI: 3650-17,278) white whales in West Greenland, corrected for whales missed by the observers and whales that were submerged during the survey (Heide-Jørgensen & Acquarone 2002).

**Figure 36.** White whale winter grounds and migration routes.



In 2006, the total abundance of white whales in West Greenland was estimated to 10,595 (95% CI: 4,904-24,650), again corrected for missed and submerged animals. The greatest abundance of white whales in 2006 was found in the areas south of Disko Bay at the northern part of Store Hellefiskebanke, a pattern similar to that found in surveys of white whales conducted since 1981. The whales were mainly observed at the eastern edge of the pack ice covering Baffin Bay and the Davis Strait. The survey from 2006 suggested that the population is increasing after a period with severely reduced catches (Heide-Jørgensen et al. 2010a).

A new survey in 2012 estimated the abundance in West Greenland to 9,072 whales (95% CI: 4,895; 16,815) and confirmed that the population was recovering (Heide-Jørgensen et al. in prep.).

In April 2014, the numbers of white whales in the Greenland part of the North Water Polynya were estimated to 2324 (95%CI: 968-5575) as a result of an aerial survey (Heide-Jørgensen et al. 2016).

### **Catch and population trends**

Commercial harvesting of white whale in West Greenland and Baffin Bay began in the late-19<sup>th</sup> century (NAMMCO 2008). After a period with large catches in Nuuk (from 1906-22) and in Maniitsoq (1915-29), white whales disappeared from the area south of 66° N (Heide-Jørgensen & Acquarone 2002). Between 1927 and 1951, large catches were reported in the southern part of the former municipality of Upernavik, and since 1970 in the northern part. In the 1990s catches, in this area were about 700 whales per year.

The total number of white whales caught by hunters in West Greenland, averaged 550 in the period 1993-2003, and annual catches between 500 and 1,000 white whales often exceeded the catch of all other whale species combined (Heide-Jørgensen & Rosing-Asvid 2002).

As the number of white whale wintering off West Greenland has declined since 1981, the Canada/Greenland 'Joint Commission on Conservation and Management of Narwhal and Beluga' (JCNB) concluded that the West Greenland stock was substantially depleted and advised that a delay in reducing the catch to approximately 100 animals per year would result in a further population decline and further postpone the recovery of this stock (NAMMCO 2001). In 2004, a quota of 320 white whales per year was established for West Greenland. This quota has been gradually reduced and in the 2007/2008 season it was 160. In accordance with the new biological advice from JCNB, the quota increased to 310 in 2009.

### **Conservation status**

The population occurring in the assessment area has an unfavourable conservation status, because it is still considered reduced due to excessive catches in the 1980s and 1990s. It is therefore listed as 'Critically Endangered' (CR) on the Greenland Red List. In Canada it is listed as 'Threatened/Special Concern' depending on the stocks. On the global Red List, the white whale was moved from 'Vulnerable' (VU) to 'Near Threatened' (NT) in 2008 (IUCN 2015), but with the note that the white whale is "unquestionably a conservation dependent species".

### **Critical and important habitats**

As white whales mainly are transient in the assessment area, no specific important or critical areas are known. The migration corridor is a critical habitat, but no particularly important summering or wintering areas are known in the assessment area, other than the NOW polynya. There are, however, traditional hunting grounds especially in Qaanaaq, at Savissivik, along Upernavik and in Disko Bay.

### **Sensitivity**

White whales are generally believed to be sensitive to noise from seismic surveys and drilling (Lawson 2005). In Arctic Canada white whales have been observed to avoid seismic operations by 10-20 km (Lee et al. 2005). See also the introduction to toothed whales.

### **Narwhal *Monodon monoceros***

Narwhals have high site fidelity to migration routes and summering and wintering grounds, and they generally use the same areas year after year (Heide-Jørgensen et al. 2003a, 2013d). In the summer months, narwhals visit inshore bays and fjords in the Canadian Arctic archipelago and Greenland (Figure 38). In the autumn, upon the formation of fast ice, narwhals are forced to

move east and south out of these regions and spend the winter in areas covered by dense offshore pack ice (Dietz & Heide-Jørgensen 1995, Dietz et al. 2001, Heide-Jørgensen et al. 2002, Heide-Jørgensen et al. 2003a, Dietz et al. 2008). During winter, narwhals are widely dispersed in Baffin Bay and the Davis Strait with high concentrations between 55°-64° W and 68°-71° N and off Disko Bay (Koski & Davis 1994, Heide-Jørgensen et al. 1993, Dietz et al. 2001, Heide-Jørgensen & Acquarone 2002, Dietz et al. 2008, Laidre & Heide-Jørgensen 2011). During spring, concentrations of narwhals are seen along ice edges on the east coast of Baffin Island, at the entrances of Lancaster and Jones Sound, and in Smith Sound (for example Bradstreet 1982, Koski & Davis 1994). Narwhals are also known to move along the ice edges off West Greenland and to concentrate in the North Water Polynya in spring before entering Inglefield Inlet (Born et al. 1994b, Heide-Jørgensen 2004, GINR unpubl. data).

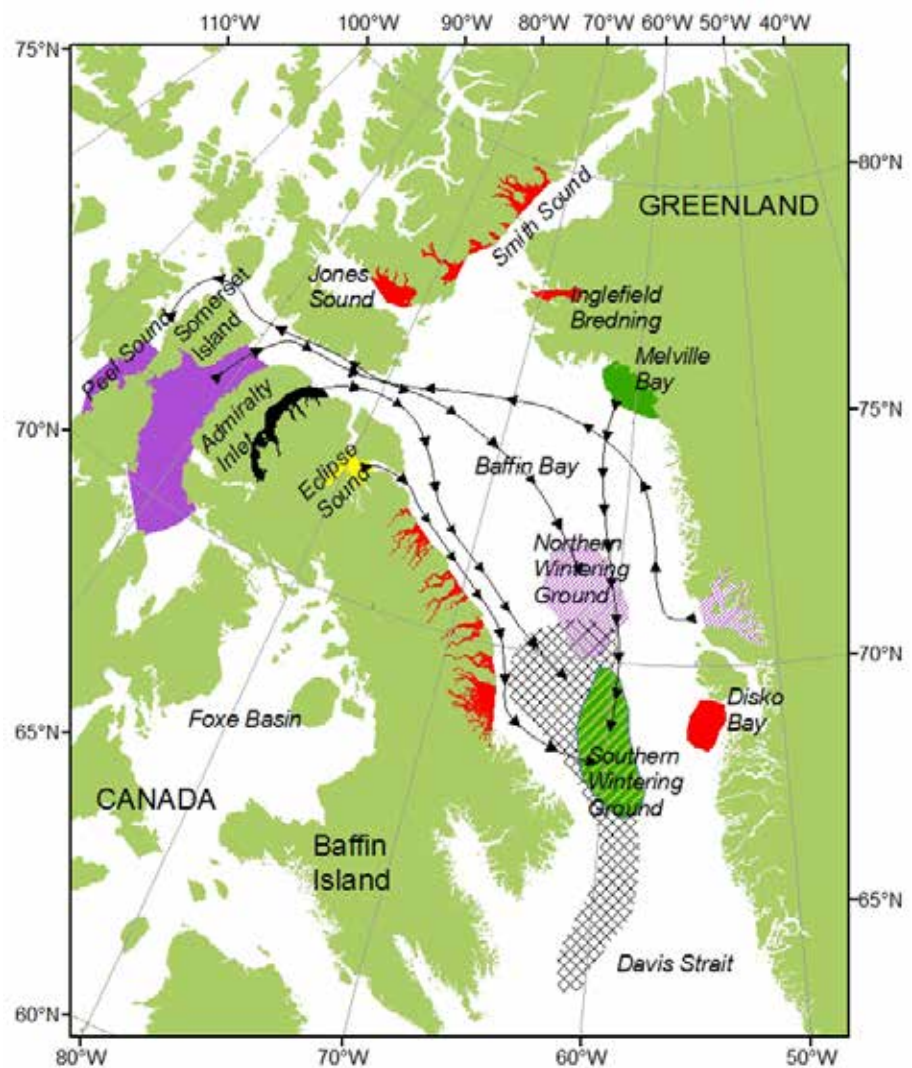
### Current distribution of narwhals

Figure 37 shows the global distributing range of the narwhals. In Greenland, narwhals occur at two summer concentration sites in the Baffin Bay assessment area – Melville Bay and Inglefield Inlet. Both are visited by significant numbers of narwhals from June through October.

**Figure 37.** Overall distribution of narwhals, with indication of important summer grounds. The assessment area is indicated with hatched line.



**Figure 38.** Population units of narwhals in West Greenland and the Eastern Canadian Arctic with migration routes and main wintering grounds indicated (black, purple and green). Red areas inshore Canada and NW Greenland indicate areas where important summer concentrations occur, but their relationships to other concentrations areas are not known. The red area at Disko Bay in Greenland indicates an important winter concentration area, where the stock identities of the whales have not been established.



Narwhals are regularly seen and caught along the coasts of the assessment area from October through May. Aerial surveys conducted in 1981 and 1982 demonstrated that narwhals are widespread in the offshore in the pack-ice in central Baffin Bay in winter, and an important winter (late November through March) concentration area, 'the Northern Wintering Ground', is located in the southern part of the assessment area (Figure 38).

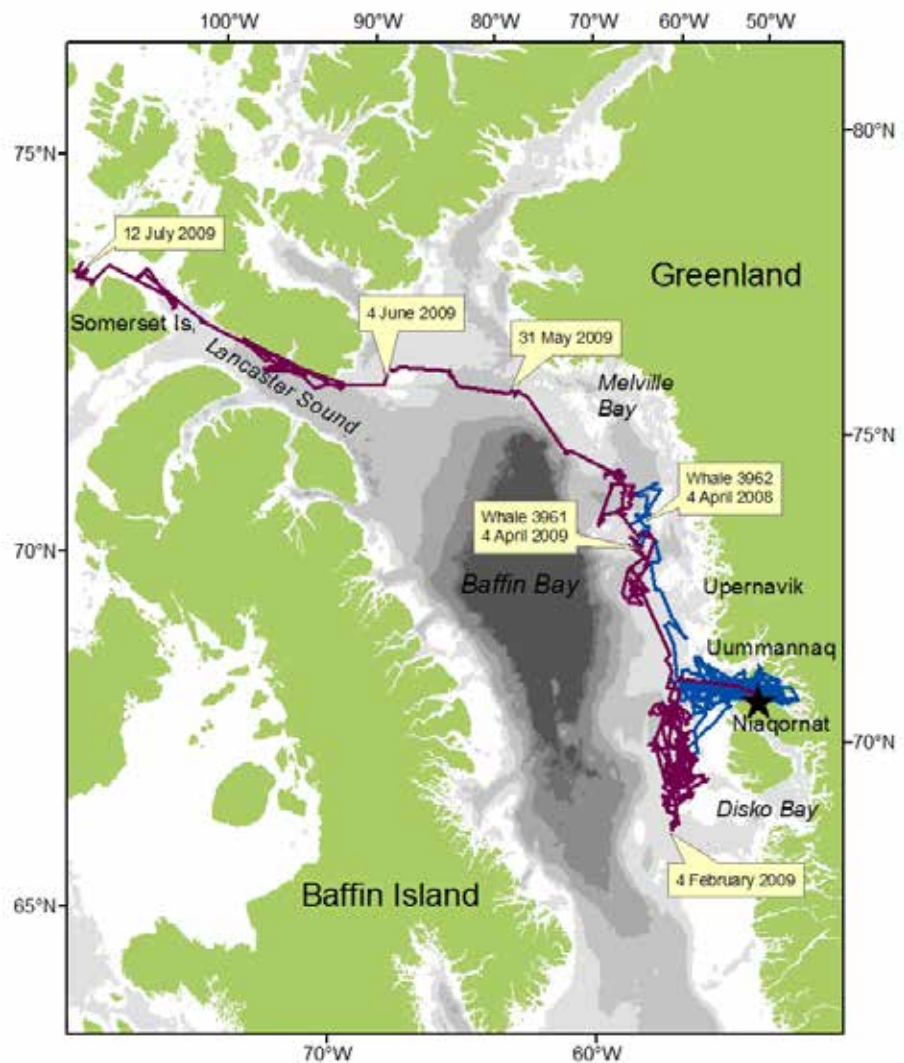
### Stock identity

Narwhal stocks or management units of narwhals are traditionally identified based on the summer aggregations (Dietz & Heide-Jørgensen 1995, Dietz et al. 2001, Heide-Jørgensen et al. 2002, Heide-Jørgensen et al. 2003a, 2013, Dietz et al. 2008).

Judging from the satellite tracking data, the three summer stocks in the Canadian high Arctic: Eclipse Sound (including Pond Inlet and Navy Board Inlet with adjacent fjords), Admiralty Inlet and Somerset Island (including Prince Regent Inlet and Peel Sound) have limited exchange during summer (Figure 38). Other Canadian summer aggregations exist along the east coast of Baffin Island and their stock identity is unknown (Figure 38). Jones Sound and Smith Sound also have smaller aggregations that likely constitute stocks.

In November, an aggregation occurs in Uummannaq, West Greenland. This is not a wintering ground because the whales are forced to leave the fjord in late

**Figure 39.** Tracks of two narwhals tagged in Uummannaq in 2007 and 2008.



December to winter offshore once the fast ice forms. These narwhals essentially winter in the eastern part of Baffin Bay in the same general area where whales from other stocks are found. Two whales tagged in Uummannaq in November departed at the same time and took a similar route north into the Baffin Bay assessment area (Figure 39); a more detailed account of this is given below (Heide-Jørgensen et al. 2013c).

The winter aggregation in Disko Bay has been visited by whales from both Melville Bay, Tremblay Sound and Admiralty Inlet (Figures 40, 42), (Heide-Jørgensen et al. 2013c), many of which pass through the Baffin Bay assessment area in autumn and again in spring. Apparently, Disko Bay is a mixing ground for narwhals from several summering stocks.

#### **Current abundance in West Greenland**

The abundance of narwhals off West Greenland was assessed from an aerial survey conducted in March and April 2006. The surveyed area included the region between Sisimiut and Upernavik and up to approximately 100 km offshore, and the resulting abundance estimate was 7,819 (95% CI: 4,358-14,029) narwhals for the surveyed area (Heide-Jørgensen et al. 2010c).

Another aerial survey covered the eastern part of the Davis Strait and Baffin Bay in March-April 2012 and sampled approximately 7,800 km of the total survey area of ca. 243,000 km<sup>2</sup>. A fully corrected estimate of abundance was 18,583 narwhals (95% CI: 7,308-47,254) (Hansen et al. 2015a).

Abundances of narwhals at the summering grounds in Inglefield Inlet and Melville Bay were estimated in 2007 and were 8,368 (95% CI: 5,209-13,442) and 6,024 (95% CI: 1,403-25,860) respectively.

Surveys in 2012 and 2014 in Melville Bay specifically addressed the effects of seismic exploration on the abundance and distribution of narwhals in the Bay (Box 13). The peak abundance estimates in 2012 and 2014 were 2,983 narwhals (95% CI: 1,452-6,127) and 3,091 (cv = 0.50; 95% CI: 1,228-7,783) narwhals, respectively (Heide-Jørgensen et al. 2013c, Hansen et al 2015b).

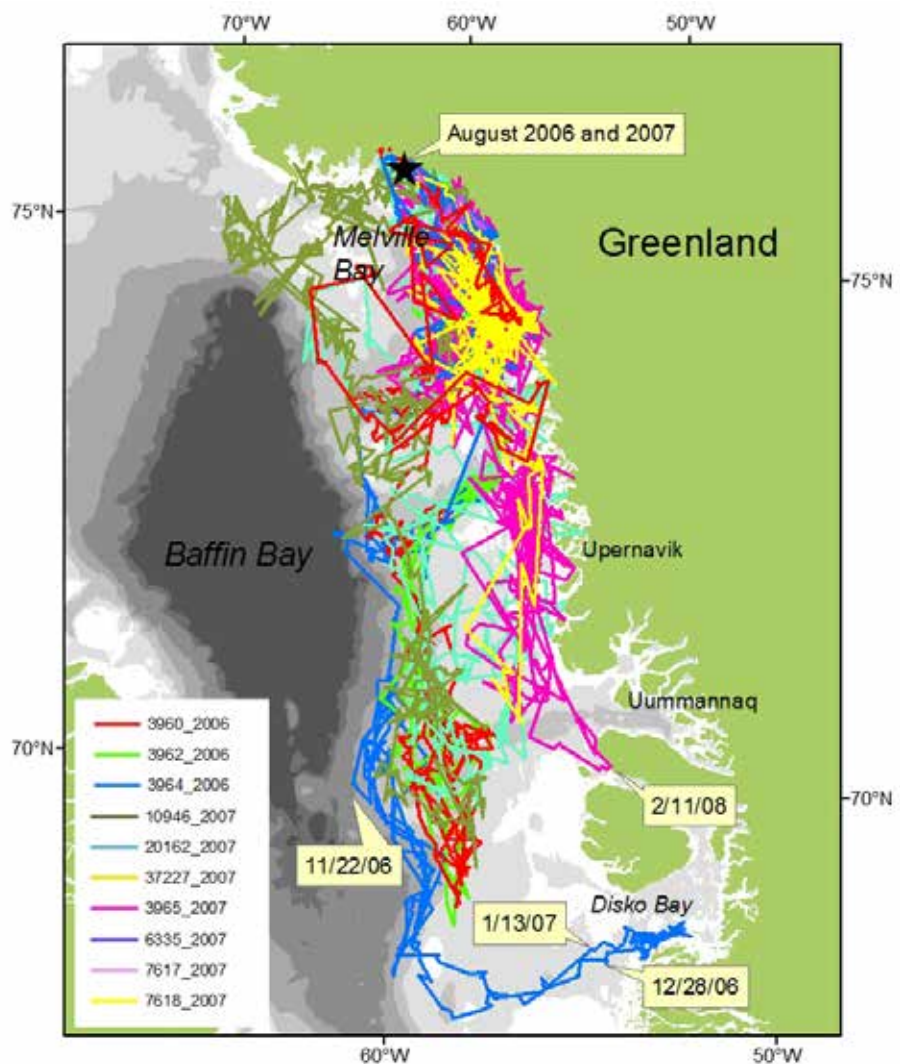
In April 2014, the numbers of narwhals in the Greenland part of the North Water Polynya were estimated to 3059 (95% CI: 1750-5316) as a result of an aerial survey (Heide-Jørgensen et al. 2016).

### Migrations

Narwhals leave their summering grounds at about the same time each year and they follow similar routes during their autumn migration. Narwhals also use the same general areas for wintering and they are somewhat stationary on their wintering grounds from late November through March. Whales from different stocks have similar timing for abandoning their wintering grounds and initiating the spring migration.

Data on migrations are available from satellite tracking of 85 individual narwhals from five different coastal localities in Arctic Canada (n=3) and West

**Figure 40.** Tracks of narwhals tagged in Melville Bay in 2006 and 2007.



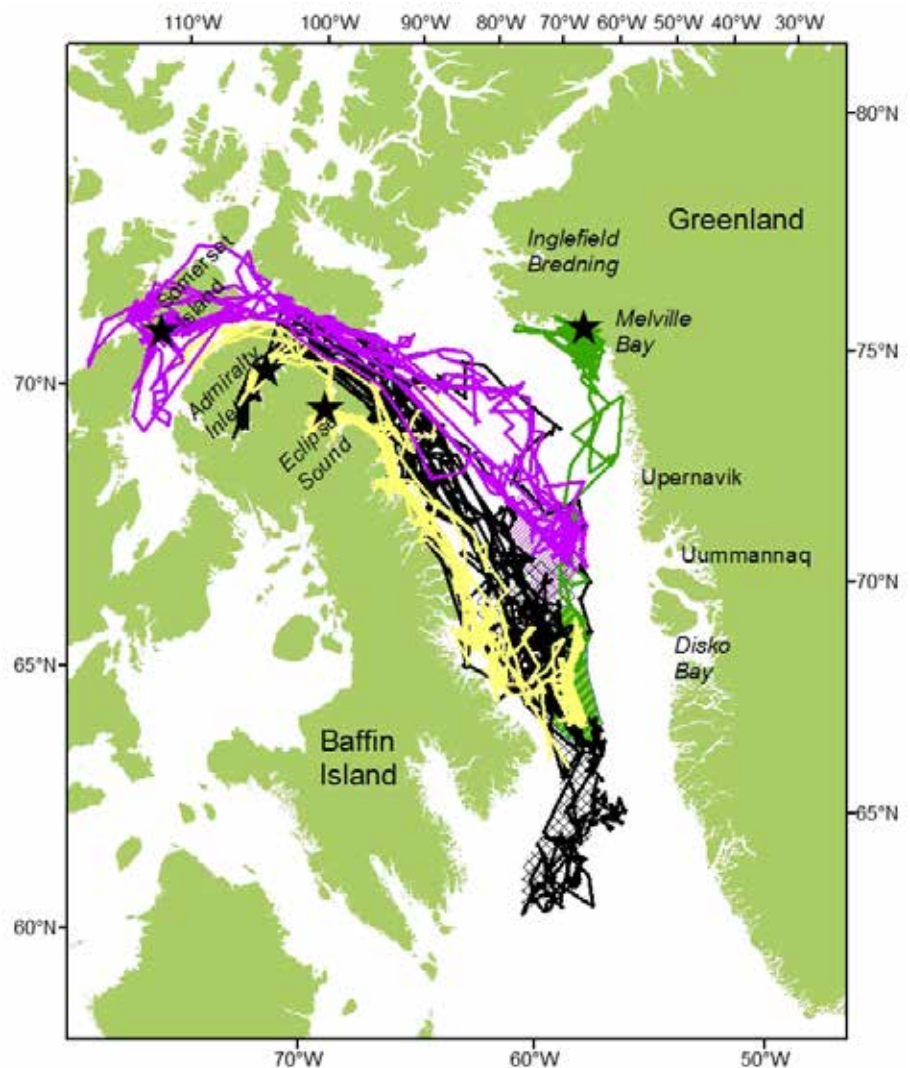


Greenland (n=2). Published results from tagging before 2005 are summarised in Figure 41, whereas tracking results from 2005-2008 are presented in Figures 39, 40 and 42 (see also Heide-Jørgensen et al. 2013c).

1) *Eclipse Sound*. Tagging data from Eclipse Sound in 1997-1999 demonstrated how narwhals from Eclipse Sound departed on their autumn migration and moved east through Pond Inlet and south along the east coast of Baffin Island and visited some of the fjords. In November, they arrived on the wintering grounds in the central Davis Strait which were in the same general vicinity as the wintering grounds of narwhals from Melville Bay. This 'Southern Wintering Ground' is centred on 69° N and 60° W. In 2010 one male narwhal from Eclipse Sound entered the southern part of Disko Bay in December.

2) *Somerset Island*. In September and October narwhals from Peel Sound and Prince Regent Inlet moved east along the southern and the northern coast of Lancaster Sound. The whales moved toward West Greenland across or on the northern side of the deep basin in Baffin Bay and continued south to the 'Northern Wintering Ground' centred on 71° N and 62° W, a wintering area distinct from that used by whales from the Eclipse Sound and Melville Bay stocks and within the Baffin Bay assessment area. The Somerset Island whales remained stationary on the 'Northern Wintering Ground' through March when they started the return migration through Lancaster Sound along the southern shoreline of Devon to the Somerset Island summering ground (Heide-Jørgensen et al. 2003a, Dietz et al. 2008).

**Figure 41.** Tracks of narwhal from Canada and Greenland tagged before 2005. Asterisks indicate tagging sites. Each whale indicated by a colour.



## Box 13

### Environmental studies designed to assess the effects of seismic exploration in the Baffin Bay 2012 on narwhals

M.P. Heide-Jørgensen, J. Tougaard, A. Mosbech & J. Nyman

#### Background

In 2012, Shell, Maersk and ConocoPhillips obtained permissions to carry out four major seismic surveys in connection with oil exploration in four license areas in northern Baffin Bay. A seismic exploration programme of this magnitude was unprecedented in Greenlandic waters, and this caused concern for the possible impacts on marine life in Baffin Bay and, in particular, on narwhals in the Melville Bay, which are also subject to a local subsistence hunt.

One of the two narwhal populations in West Greenland spends the summer in Melville Bay, a marine environment with a designated protection area for narwhals in relation to seismic activities. However, low-frequency sounds, such as seismic pulses, travel long distances and could potentially ensonify the protected area in Melville Bay. It was therefore decided to carry out three studies in 2012 and two follow-up studies in 2014 to examine possible effects of seismic noise on narwhals and narwhal hunting in Melville Bay, and to acquire baseline information for use in future regulation of activities in the area. The three studies in 2012 were:

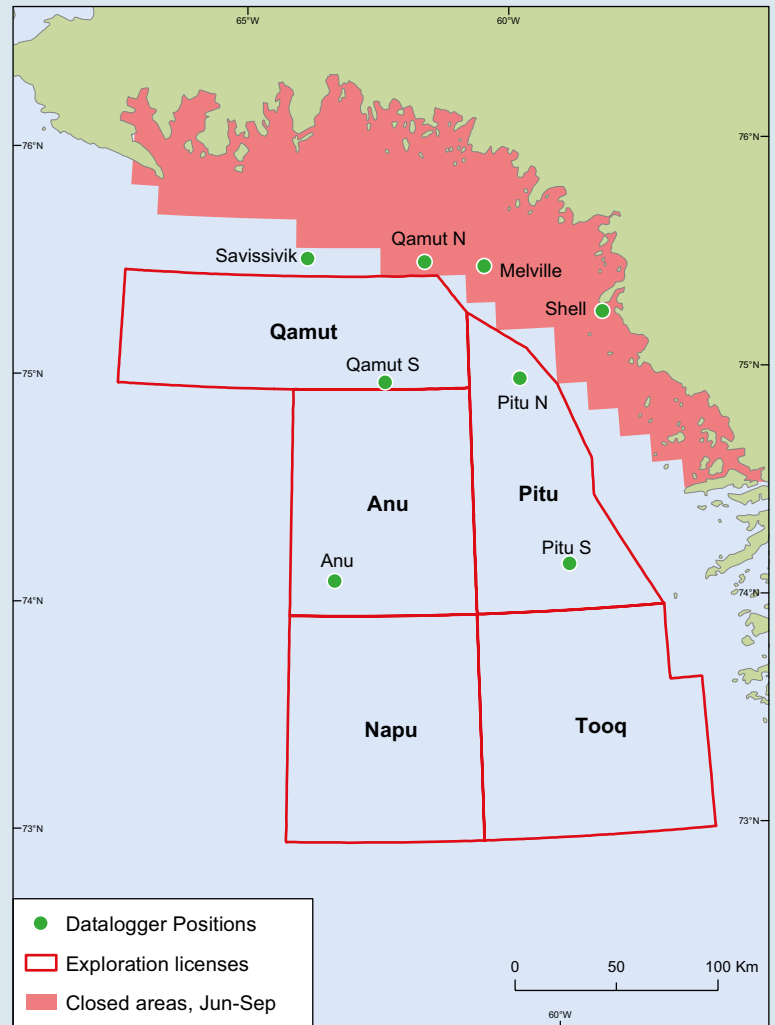
**Study 1:** Propagation of airgun pulses from seismic surveys.

**Study 2:** Monitoring abundance and distribution of the narwhal population in Melville Bay before and during the seismic programme.

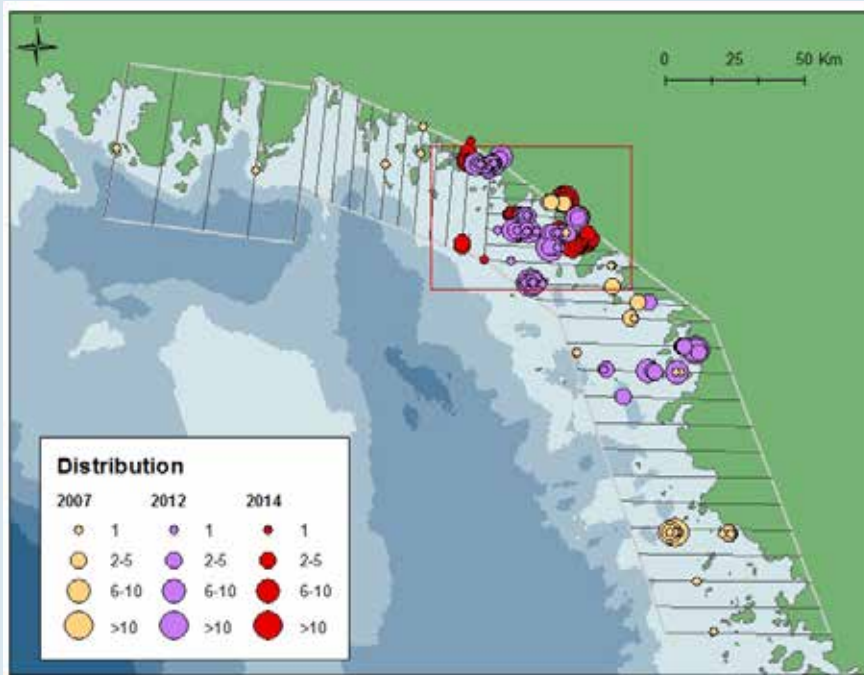
**Study 3:** Hunting and occurrence of narwhals in Melville Bay.

The purpose of the first study was to investigate the propagation of seismic pulses from the industrial scale seismic vessels operating in the area, and to assess whether the noise modelling used in the Environmental Impact Assessment (EIA) was adequate (the modelling had been prepared in advance for the EIAs). The study included collection of data for calibrating a 3D noise propagation model developed by the Woods Hole Oceanographic Institution in the USA.

The seismic investigations were carried out in the offshore part of Baffin Bay, and the study took place in the same part of the bay. Twenty-one data loggers located at three different depths at seven stations were used to collect the acoustic data in addition to salinity and temperature data that were required to calibrate the 3D model (Figure 1). The final project report was submitted in October 2014 (Wisniewska et al. 2014). For logistical reasons all loggers were deployed in offshore areas where potential conflicts with drifting icebergs would be minimized; however, Shell provided one data logger that was located close to the coast in Melville Bay.



**Figure 1.** Section of the west coast of Greenland with a focus on Baffin Bay and Melville Bay. The red area marks the narwhal protection zone that is closed for seismic explorations during 1 June to 30 September. The data logger stations are indicated by name, and there were three data loggers at three different depths at each station. One of the four data loggers (BB4) deployed by Shell is shown as 'Shell' on the map.



**Figure 2.** The inner part of Melville Bay, indicating the transect lines that were flown to document the distribution of narwhals before and during the seismic activities (upper panel). The dots show observations of narwhals in 2007 (yellow), 2012 (turquoise) and 2014 (red). From (Heide-Jørgensen et al. 2014b).

The purpose of the second study was to use three systematic visual aerial surveys to monitor short-term changes in the distribution and number of narwhals in their summer habitat before and during the seismic surveys (Figure 2). The study was designed to provide data on distribution and abundance that were directly comparable to a previous narwhal survey in Melville Bay conducted in 2007. A project report (Study 2) was submitted in January 2013 (Heide-Jørgensen et al. 2013e).

The purpose of the third study was to observe and monitor whether opportunities for hunters to catch narwhals changed during the period when the seismic surveys were conducted. The study involved on-site interviews with hunters and participation in hunting activities in Melville Bay as well as a questionnaire survey among hunters in the two settlements adjacent to Melville Bay. A project report (Study 3) was submitted in January 2013 (Heide-Jørgensen et al. 2013).

In 2014, it was decided to expand the background studies with studies that would address the long-term effects on the narwhal population and the hunters' utilization of the Melville Bay.

**Study 4:** Monitoring occurrence of narwhals in Melville Bay after seismic survey activities in 2012.

**Study 5:** An interdisciplinary study of possible effects of oil and gas exploration on the narwhal hunt in Melville Bay, Northwest Greenland.

The continued monitoring of narwhals in 2014 involved an aerial survey of Melville Bay (Study 4) applying the same methods as in previous surveys in the bay. A report on this subproject was submitted in December 2014 (Heide-Jørgensen et al. 2014b).

The interdisciplinary study in 2014 (Study 5) used hunter interviews and catch reports to gain insight on the behavioural changes of the narwhals. A project report was submitted in May 2015 (Nuttall et al. 2015).

## Results and discussion

Three aerial surveys were carried out in 2012: One partly before the seismic program began, and two surveys during the seismic program. The intention was to carry out the first survey before the seismic program commenced, however, due to weather conditions the first aerial survey took place during a period in which Shell (Napu and Anu licence areas) began its surveys first, followed by Maersk (Tooq licence area) three days later. The first survey therefore covered three days without and four days with seismic activities. The two subsequent aerial surveys were carried out four and nine weeks after Shell and Maersk began, and therefore three days and approximately one month, respectively, after ConocoPhillips commenced seismic surveys in the area closest to the narwhal protection zone (Qamut licence area; Figure 1).

The three aerial surveys showed that the narwhals stayed closer to the coast during the period with seismic investigations (survey 2 and 3) than prior to the seismic investigations (survey 1). It is, however, part of the natural behaviour of the narwhals to approach the coastal areas in July-August following the recession of sea ice in the bay, and the coastal affinity in August cannot be ascribed to seismic activities.

Compared to the results of an aerial survey conducted in the same area in mid-August 2007, the narwhal observations from surveys 2 and 3 were significantly closer to the coast. The distribution of narwhals from the 2007-survey was, in comparison with the two first surveys in 2012, intermediate in relation to the distance to the coast. In terms of timing, the 2007 survey was also intermediate between survey 1 and 2 in 2012.

Generally, the narwhals were more dispersed in a north-south direction in 2007, while they were distributed in a narrow part of the central area of Melville Bay in 2012. In 2012, the distance between the different narwhal groups was significantly shorter during all three surveys than during the 2007-survey. In conclusion, the distribution of narwhals in

2012 was more clumped and concentrated in a smaller section of the coast than in 2007.

The interview survey of the hunters showed that 58% of the 79 narwhals caught in northern Baffin Bay in 2012 were caught before the seismic surveys began, while the rest were caught during the period with seismic activities. The hunters reported no changes in catch locations or difficulties compared with other years. However, when compared with catches reported in 2007–2009, the catches in 2012 were more concentrated in the central and protected part of the Melville Bay, consistent with the distribution of narwhals observed in the aerial surveys. The catch survey also showed that most of the narwhals were caught from kayaks.

It is possible that the clumped distribution of narwhals in the central part of Melville Bay in front of active glaciers was due to avoidance or disturbance from seismic noise. However, other sources of disturbances cannot be excluded. The fronts at active glaciers, like the central part of Melville Bay, provide an acoustic environment very different from other coastal areas because noise from boats and air-gun pulses may be masked by the background noise from the glaciers and offshore air-gun pulses may be deflected by the silt topography in front of the glaciers.

The density of narwhals changed between the three aerial surveys, as their autumn migration began during the third survey, but the total abundance of narwhals did not seem to be affected by the seismic survey activities.

The acoustic data logger located closest to the area favoured by the narwhals in 2012 was placed approximately 40 km from the Melville coast (Melville Station). The highest noise levels recorded here were approximately 110–124 dB re 1  $\mu$ Pa (rms) (Wisniewska et al. 2014). Another data logger located further north in Melville Bay, about 125 km from the coast (Savissivik Station) had the highest noise levels of approximately 130–155 dB re 1  $\mu$ Pa (rms). Both data loggers were deployed outside the strata included in the aerial surveys, but within the area shown by satellite telemetry to be visited by narwhals in August–September (Heide-Jørgensen et al. 2013e). Another data logger (BB4) located inside the Melville Bay also recorded air-gun pulses, but at lower levels. This reflects both the greater distance from the seismic sources, but also the complex conditions for sound propagation with melting ice, moving icebergs and uneven bathymetry near the coast.

Behavioural changes have been observed in narwhals at levels from 94 to 105 dB re 1  $\mu$ Pa (rms) (between 20 and 1000 Hz) from both passive and actively ice-breaking vessels, i.e. at frequency ranges and noise levels similar to the seismic noise encountered in Baffin Bay in 2012 (Wisniewska et al. 2014). This means that air gun pulses travelling from the seismic areas to the offshore acoustic loggers closest to the narwhal area in Melville Bay were potentially loud enough to cause behavioural changes if narwhals were present in offshore areas. The coastal logger demonstrated masking of air gun pulses and a reduced likelihood of effects on the narwhals.

The aerial survey of narwhals in Melville Bay in 2014 (Study 4) demonstrated a continued contraction of the area used by the whales and that they were even more clumped in the inner part of the bay than apparent from the comparison of 2007 and 2012 surveys. The central area of the bay seemed increasingly important, but it remains uncertain whether this reduction in area usage is part of a long-term contraction from before 2007 or whether it is a recent phenomenon. Nothing suggests that it is caused by a general population decline or by changes in prey concentrations, and it seems more likely a result of external disturbance.

The results of in-depth analysis of the aerial surveys have, in combination with catch history and biological parameters, been used to provide advice on future sustainable harvest levels in the bay (Hansen et al. 2015b, Witting 2015).

Interviews of hunters in 2014 (Study 5) re-iterated their concern about the impact of seismic investigations and their observations of altered migration routes and more nervous swimming among the narwhals. Quantification of the hunter's observations remains, however, difficult.

### Assessment and perspectives

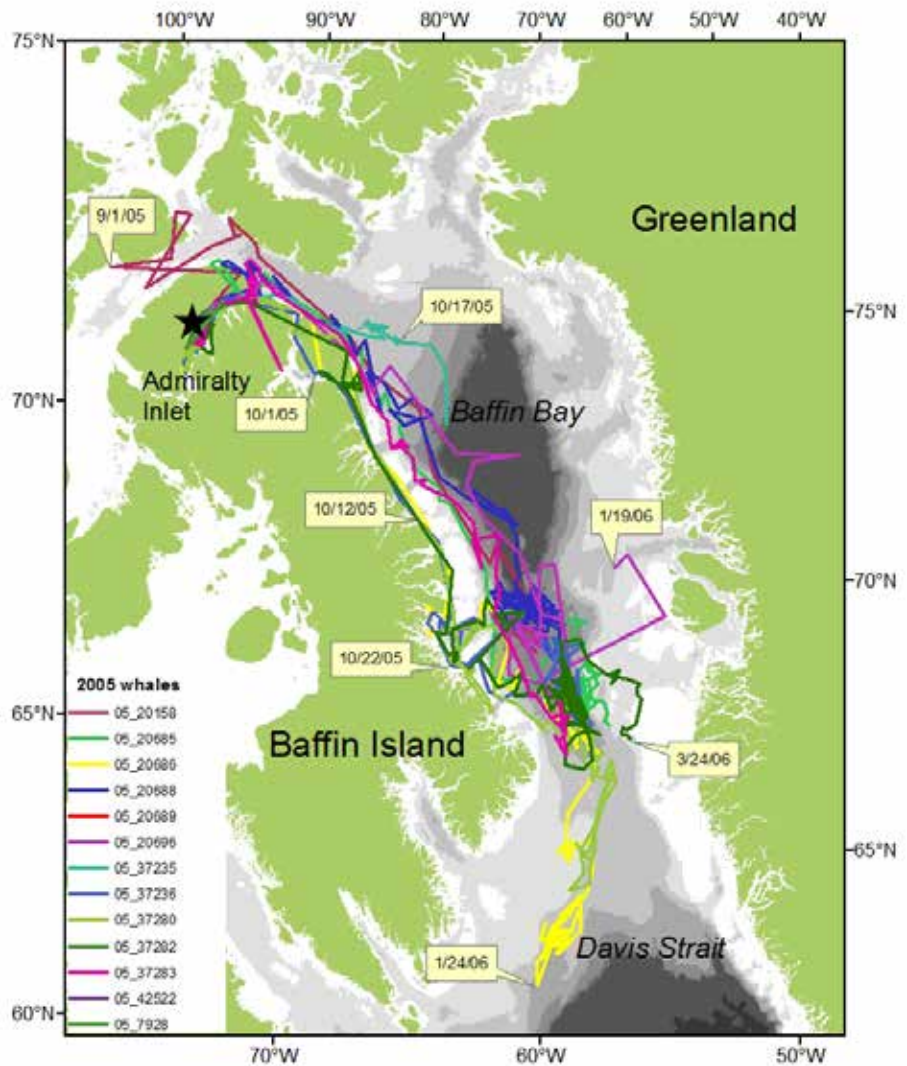
In conclusion, the measured noise levels at the stations closest to Melville Bay were potentially high enough to affect the narwhals. It is possible that the seismic noise caused the narwhals to prefer the central part of Melville Bay in 2012, where they were more clumped in the central part of the bay than observed in 2007. However, the results from the aerial survey in 2014 suggest that the clumping of narwhals in the inner part of the Melville Bay is a long-term trend unrelated to seismic exploration. Other human activities in the bay involve increased boat traffic, including dinghies used for transport to the hunting grounds as documented by the hunter studies. Environmental changes in Melville Bay involve retreats of glaciers and increased advection of warm water. It is at present impossible to distinguish the effects of seismic exploration from other human activities and on-going natural changes. Continued monitoring of the relatively small population of narwhals in the bay will presumably provide a better understanding of the observed behavioural changes in the narwhal population.

The next step towards greater understanding of the impact of seismic noise on narwhals – both individually and at the population level – is to conduct targeted studies of behavioural and physiological effects on individual narwhals during controlled exposure to noise from airgun arrays. The long-term impact of seismic noise on distribution, migration patterns and population size should be documented by annual aerial surveys in areas where seismic surveys have been carried out and where the level of hunting pressure is known (e.g. Melville Bay).

3) *Admiralty Inlet*. When leaving Admiralty Inlet the narwhals moved south along the east coast of Baffin Island and spread out in the western part of Baffin Bay, ranging widely from Cumberland Sound to the north of Home Bay. The range of the wintering ground varied between 2004 and 2005 (Dietz et al. 2008). A total of 13 narwhals were tagged in Admiralty Inlet in 2005. All whales left Lancaster Sound in September-October for a southbound migration either along the east coast of Baffin Island or somewhat east of Baffin Island at the edge of the continental shelf (Figure 42). Some of the whales extended their southbound migration to the northern part of the Davis Strait where they have also been located to winter in 2004 and 2005. One male from Admiralty Inlet moved to the coastal areas of West Greenland in January 2006 close to Disko Island and Uummannaq (Figure 42).

4) *Melville Bay*. Narwhals tracked from Melville Bay during the autumn of 1993-94 (n=2) took an offshore southward migration route along the 1000 m depth contour. They did not visit any other coastal aggregations of narwhals on the West Greenland coast. They reached the central Davis Strait in mid-November and presumably spent the winter in this region. Narwhals tracked from Melville Bay in 2006 and 2007 (n=7) followed a similar migration pattern as those tracked in 1993-1994; after spending September and the beginning of October with movements inside Melville Bay, they followed a southbound migration route towards the wintering grounds. In 2006 the whales took a more coastal route after departing from Melville Bay (south of 74° N) on 18-25 October (Figure 40). Wintering took place in the same area used by the

**Figure 42.** Tracks of narwhals tagged in Admiralty Inlet in 2005.



whales from Melville Bay tracked in 1993-1994 (cf. Dietz & Heide-Jørgensen 1995). After arriving at the offshore wintering ground in December, one of the whales (a male of 437 cm) left the offshore wintering ground and went to the southern part of Disko Bay. The whale left Disko Bay on 13 January and returned to the offshore wintering ground.

In 2007, a more diverse movement pattern was observed, both in the summer period when the whales were more widespread in Melville Bay and in the autumn where some whales remained close to Upernavik (Figure 40). In 2007, the whales departed from Melville Bay between 26 October and 16 December and spent considerable time in the Upernavik and Uummannaq area before wintering a bit further north than the well known 'southern wintering ground' used in previous years (Dietz & Heide-Jørgensen 1995, Heide-Jørgensen & Dietz 1995). One whale was tracked for 13 months and it returned to Melville Bay the year after it was tagged.

5) *Uummannaq*. Two narwhals were tagged in Uummannaq (south of the assessment area) in November 2007 and 2008. The male tagged in 2007 spent the entire winter inside Uummannaq Fjord or just outside the Uummannaq area after freeze-up (Figure 39). On 13 March 2008 it headed north ( $< 72^\circ$  N) along the West Greenland coast however contact was lost on 4 April 2008. The female narwhal tagged in 2008 immediately left Uummannaq Fjord and spent December through mid-February 2009 off the banks of Disko Island. On 24 March it initiated a northward migration along West Greenland and into the assessment area. It halted the migration in the northern part of Baffin Bay in April and May and continued the migration in late May where it reached the eastern entrance of Lancaster Sound on 6 June, after which it followed the northern coast of the sound close to the southern shore of Devon Island and reached Barrow Strait on 3 July. The whale moved south into Peel Sound where contact was lost on 24 July.

### **Diving and foraging ecology**

Feeding habits of narwhals have been studied in Disko Bay where fresh stomach samples from narwhals can be obtained from the Greenlanders subsistence harvest. Greenland halibut, the squid *Gonatus fabricii*, and *Pandalus* shrimp species are the dominant prey items. Greenland halibut is an important winter resource, observed in 64% of 49 stomachs collected in winter, and it was the only prey species detected in almost half of all stomachs (Laidre & Heide-Jørgensen 2005). Greenland halibuts taken by narwhals were on average 36 cm (SD 9) long and weighed 430 g (SD 275) and *Gonatus* prey were on average 35.6 g (SD 31.1) with a mean mantle length of 95.1 mm (SD 36.2).

There is no direct information on the prey selection on the offshore winter feeding grounds in Baffin Bay, but observations of the diving behaviour suggest that the narwhals target depth ( $> 1000$ m) where halibuts are known to be abundant (Watt et al. 2015). The availability of this important prey is the most likely explanation for the occurrences of narwhals in these ice covered offshore areas (Laidre et al. 2003). Other species like polar cod and squids may also contribute to the offshore diet as they seasonally do in inshore waters in both Canada and West Greenland (Laidre & Heide-Jørgensen 2005, Watt et al. 2013). Compared with the summer feeding habits it is obvious that the major food intake takes place during the  $> 6$  months stay on the autumn and winter feeding grounds.

### **Importance of the assessment area to the narwhals**

Narwhals occur within the assessment area throughout the year. In summer Melville Bay and Inglefield Inlet are important areas (Figure 38). In autumn,

the shelf break along the 1000 m contour seems to be important as migration corridor for whales from the Melville Bay stock. In winter, the 'Northern Wintering Ground' is an important aggregation area for whales from the Somerset Island stock (Figure 38). Narwhals from the other Canadian summer grounds at least move through the assessment area when migrating (Figure 39). The wintering areas are especially important to the whales because their main food intake takes place in winter, and especially the southern part of the assessment area must be regarded as critically important to wintering narwhals.

The world's largest abundance of narwhals occurs within the assessment area in winter and any exploitation and exploration for resources could potentially impact a major proportion of the global population of narwhals. It has been speculated that seismic exploration during the autumn migration is of special concern to the narwhals as intensive disturbance at this period of their annual cycle might cause the whales to change the course of their direction with detrimental consequences if they move to areas outside their normal winter range where they could be entrapped in fast ice (Heide-Jørgensen et al. 2013d).

### **Conservation concern**

The narwhal population in West Greenland is listed as 'Critically Endangered' (CR), on the Greenland Red List, while the global population is listed as 'Data Deficient' (DD). Seen in the light of the most recent survey results from Melville Bay and Baffin Bay (for example those described in Box 13) its status in the Greenland Red List should be revised.

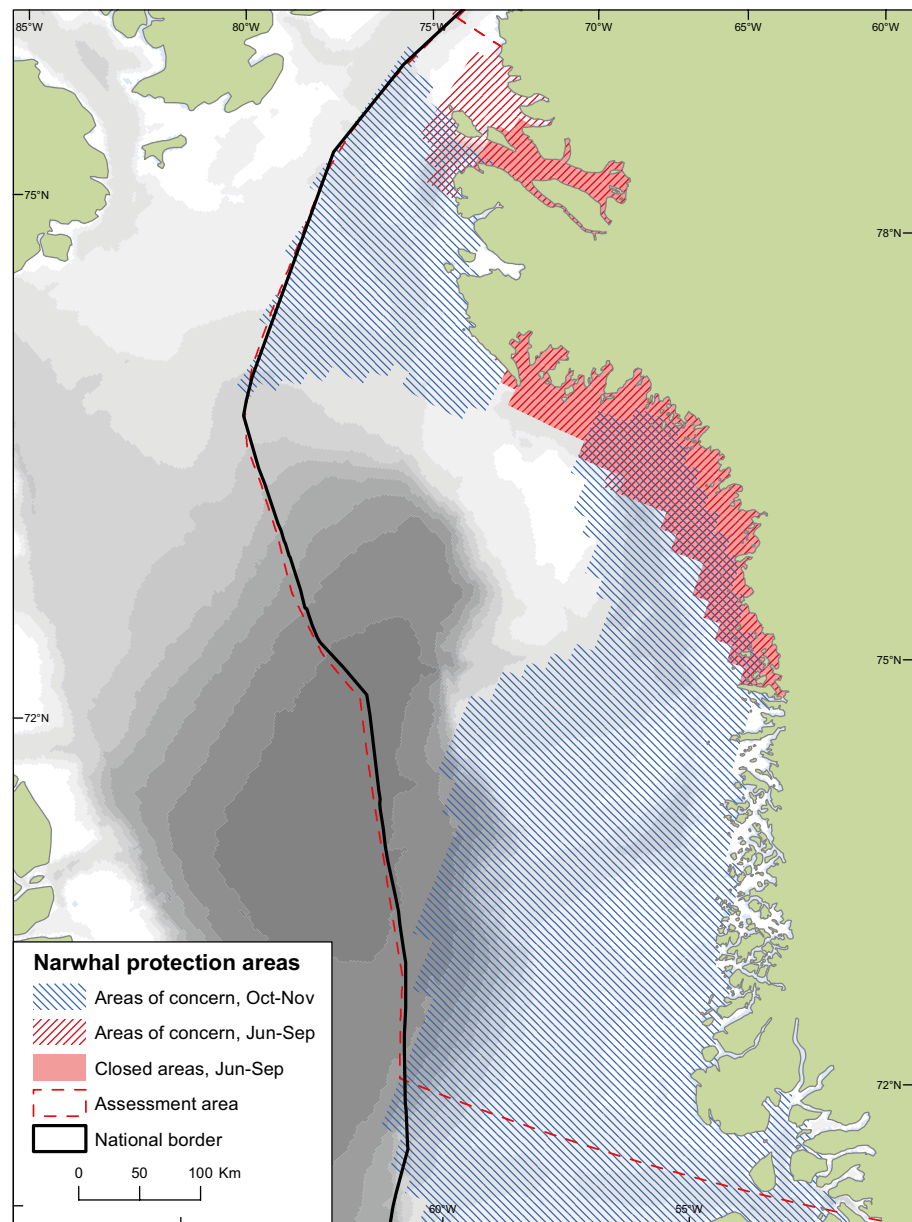
In relation to seismic activities, protection areas for narwhals have been designated (EAMRA 2015). These are shown in Figure 43.

### **Sperm whale *Physeter macrocephalus***

With males reaching lengths of 18 m and weights of 50 tons, sperm whales are the largest toothed whale. On average, male sperm whales are 15 m long and weigh 45 tons, while females are 11 m long and weigh 20 tons. As in the case of bottlenose whales, sperm whales are found in deep waters, often seaward of the continental shelf and near submarine canyons. Sperm whales are found in all oceans, from the ice edges to the equator. Females and calves remain in tropical and sub-tropical waters year round, while males migrate to high latitudes at the onset of puberty, when they are between four and 15 years old (Best 1979, Mendes et al. 2007). The larger males, in their late twenties or older occasionally migrate to lower latitudes in search of mating opportunities. When in lower latitudes, males move between different groups of females and their offspring, sometimes engaging in physical combat with other males (Whitehead & Weilgart 2000).

Sperm whales forage on a wide variety of deep-sea cephalopods and fish. Prey size ranges from a few centimetres long fish to three m long sharks and even giant squids of the family Architeutidae that weigh up to 400 kg (reviews in Rice (1989) and Whitehead (2003)). Sperm whales in the northeastern Atlantic feed heavily on the deep-water squid *Gonatus fabricii* (Santos et al. 1999), favouring mature squids with mantle lengths of approx. 19-26 cm (Simon et al. 2003). Male sperm whales off northern Norway tagged with multi-sensor instruments feed both at shallow depths of approx. 117 m and at the sea bottom at depths down to 1860 m, showing that male sperm whales have flexible feeding habits (Teloni et al. 2008). In some areas, sperm whales take fish from long-line fisheries (for example Roche & Guinet 2007) or approach trawlers in search of discarded fish (for example Karpouzli & Leaper 2003).

**Figure 43.** The narwhal protection areas in relation to seismic operations in the assessment area. Areas of concern are important narwhal areas and where there is a risk of overlap with seismic surveys. If seismic surveys are planned to overlap with these areas in the season indicated on the map, specific regulation in order to protect these species from disturbance may be introduced. In the closed areas seismic surveys as a rule are not possible. However, limited seismic surveys can be allowed after specific application, including a detailed shooting program and proposal of impact studies on the marine mammal in question.



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, but redfish, anglerfish (*Lophius piscatorius*), cod and blue whiting (*Micromesistius poutassou*) were also common.

### Distribution

Berzin (1971) reviewed captures of sperm whales in the Davis Strait as far back as 1812, including a mention from 1870 about sperm whales being relatively scant in the region, and a report of 181 males caught by a fleet of seven boats in 1937. Sperm whales are still regularly reported in ice-free areas in the Davis Strait and in Baffin Bay as far north as Upernavik (unpublished data).

Knowledge about abundance and occurrence of large cetaceans in offshore parts of the assessment area is poor, and sperm whales could be expected during ice-free periods in suitable habitats, such as deep-sea waters close to continental slopes and underwater canyons with abundance of cephalopod or fish prey.



The International Whaling Commission considers that all sperm whales in the North Atlantic belong to a single stock (Donovan 1991). This assumption is supported by genetic analyses (Lyrholm & Gyllensten 1998).

### **Conservation**

Sperm whales were the target of commercial whaling for more than two centuries. By the second half of the 20<sup>th</sup> century, sperm whales were still numerous but several populations were depleted. Commercial whaling of sperm whales stopped with the moratorium on whaling at the end of the 1980s. At present, sperm whales are not caught anywhere in the North Atlantic. On the Greenland Red List, sperm whale is listed as 'Not Applicable' (NA) and globally as 'Vulnerable' (VU) (IUCN 2015).

### **Sensitivity**

The echolocation clicks of sperm whales have a source energy flux density of up to 193 dB re 1  $\mu$ Pa<sup>2</sup>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 the foraging effort seemed to diminish when airguns were operating (Miller et al. 2009).

### **Northern bottlenose whale *Hyperoodon ampullatus***

Next to the sperm whale, the northern bottlenose whale is the largest toothed whale in the North Atlantic, with adult females measuring up to 9 m in length and males up to 11 m. They are found in deep waters, often seaward of the continental shelf and near submarine canyons, from the ice edges south to approximately 30° N. They live in groups that join and split, with group sizes from about four 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. 2002). Prey is often caught near the bottom at depths greater than 800 m (Hooker & Baird 1999). Bottlenose whales are known to take Greenland halibut from long-line fisheries.

Northern bottlenose whales have only been studied in detail in an area surrounding the Gully, an underwater Canyon off Nova Scotia, in the southern part of the species' range. Based on boat surveys, photo-identification and molecular analyses, it has been established that these northern bottlenose whales live in a small population of about 150 animals that is rather stationary and isolated from other populations (Wimmer & Whitehead 2004, Whitehead & Wimmer 2005, Dalebout et al. 2006). It is not known whether northern bottlenose whales in other parts of their range also form relatively small, isolated and stationary populations.

### **Distribution**

There are no survey data for bottlenose whales in the study area. Bottlenose whales are frequently observed from fishing boats operating in deep waters of the Davis Strait and southern Baffin Bay. In the North East Atlantic, bottle-

nose whales have been caught by Norwegian whalers as far north as the ice edge west of Svalbard (Benjaminsen & Christensen 1979).

#### **Catches**

Northern bottlenose whales were heavily hunted during the 19<sup>th</sup> and 20<sup>th</sup> century throughout the North Atlantic, south of the assessment area. They are not caught in Greenland and have never been subject to hunting in West Greenland.

#### **Conservation**

The Red List status of the northern bottlenose whale is 'Data Deficient' (DD) on the global list, and 'Not Applicable' (NA) on the Greenland list (IUCN 2015, Boertmann 2008).

#### **Critical and important habitats**

None are known from the assessment area.

#### **Sensitivity**

Hooker et al. (2008) found increasing levels of persistent contaminants and CYP1A1 protein expression (signal of stress) in biopsy samples from bottlenose whales following the onset of gas and oil development in Eastern Canada. The authors conclude that the change in contaminant levels over time in these whales likely reflected a temporal change in contaminant levels in the water and/or in prey species, and they speculated that the proximity of oil and gas drilling activities may have influenced contaminant patterns through remobilisation of persistent contaminants from sediments on the sea bed.

## 5 Natural resources use

### 5.1 The commercial fisheries

N. Hammeken Arboe, O.A. Jørgensen, R. Nygaard & H. Siegstad

Commercial fisheries represent the most important export industry in Greenland, which is underlined by the fact that fishery products accounted for 95% of the total Greenlandic export revenue (3,029 billion DKK) in 2014 (Statistics of Greenland 2015). Very few species are exploited by the commercial fisheries in Greenland, and this is especially true in the assessment area. On a national scale, the three most important species are northern shrimp (export revenue in 2014: 1,347 billion DKK), Greenland halibut (844 million DKK), Atlantic cod (168 million DKK) and snow crab (40 million DKK) (Statistics of Greenland 2015).

Greenland halibut and shrimp are the main commercially exploited species within the Baffin Bay assessment area, accounting for 66% and 10% of the total catch, respectively (by weight). The distribution of the fishery by gear (Greenland halibut) and season is described in Jørgensen & Arboe (2013).

#### Greenland halibut fishery

In the assessment area, the fishery is both inshore and offshore. The inshore fishery is concentrated near towns and settlements and extends all the way to the Qaanaaq area. The main part of the fishery is conducted in the former municipalities of Uummannaq and Upernavik where landings in 2014 amounted to 15,580 tons. The fishery takes place throughout the year in fjords with deep water and the fish are caught on long-lines or in gillnets either from small vessels, open boats or from the winter ice (Figure 44).

The offshore fishery for Greenland halibut takes place in summer, autumn and early winter on the shelf slope of Baffin Bay (Figure 44). In the past years, the offshore catches north of 68° 50' N gradually increased from 575 tons in 2001 to about 6,500 tons in 2006. Catches remained at that level to 2013 and then increased to 8,000 tons in 2014. Only very small catches were taken inside the assessment area in 2014 (north of 71°), but Greenland halibut from the assessment area are believed to a large extent to recruit to the fishing grounds south of the assessment area. In 2016 longline fisheries were tried in the outer parts of Melville Bay (Figure 44), but the results were not available before deadline.

The distribution of the catches is shown in Figure 44.

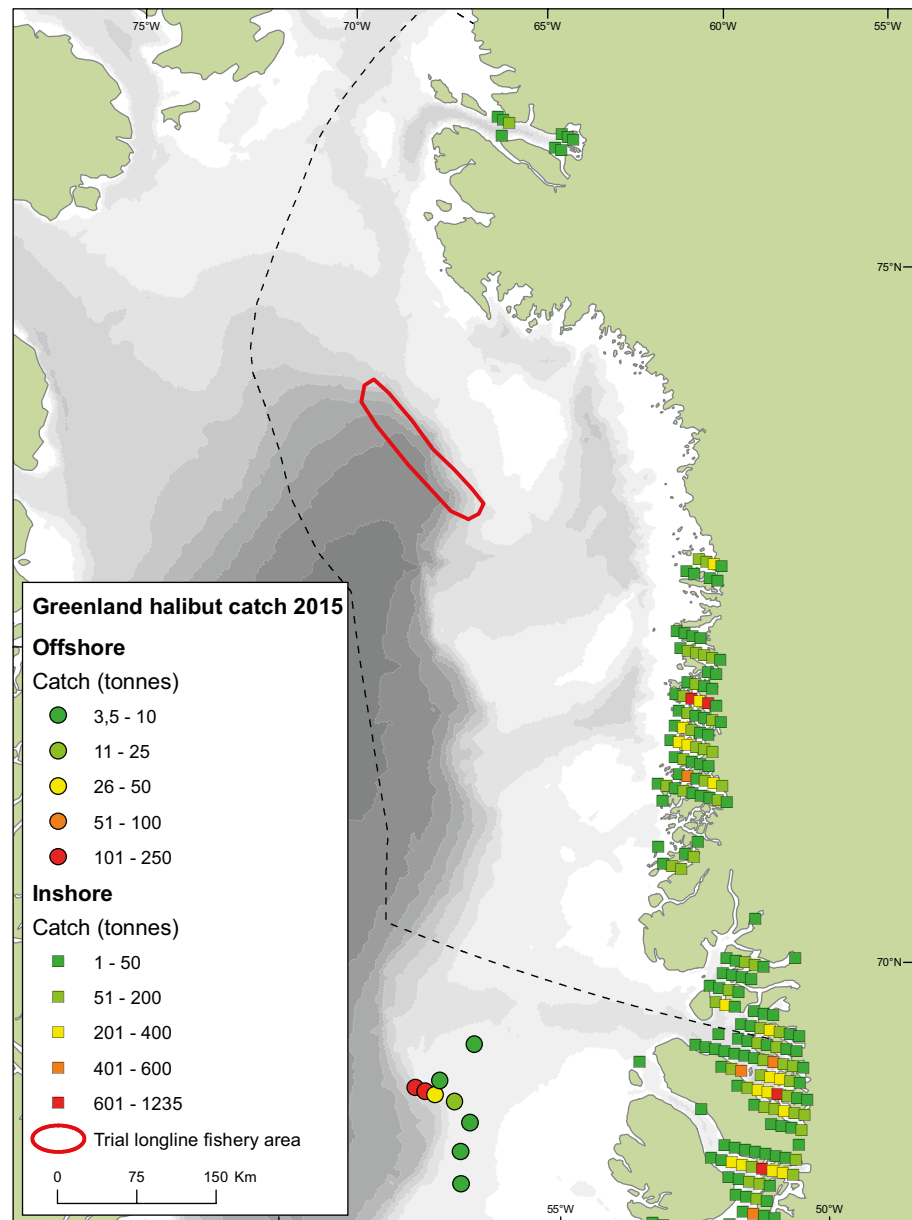
Inshore fishery takes place primarily in the fjords of the Upernavik District.

#### Northern shrimp fisheries

The export of Northern shrimp constitutes about 44% of the total export from Greenland (Statistics of Greenland 2015).

The fishery for northern shrimp in West Greenland is conducted from Cape Farewell in the south to Melville Bay in the north. Since the middle of the 2000s the fishery has moved northwards and catches from NAFO area 1A (from Disko Bay north to Smith Sound = slightly larger than the assessment area) constituted approximately 40% of total landings in 2005 compared to approximately 10% in 1990 (Arboe 2014).

**Figure 44.** Distribution of Greenland halibut fishery and size of landings from the assessment area in 2015 (NB the data from the northernmost area, Inglefield Bredning near Qaanaaq, are from 2014). Note the different scales on inshore and offshore landings. Longline trial fishery took place in the shown area, but catches have not yet been reported.



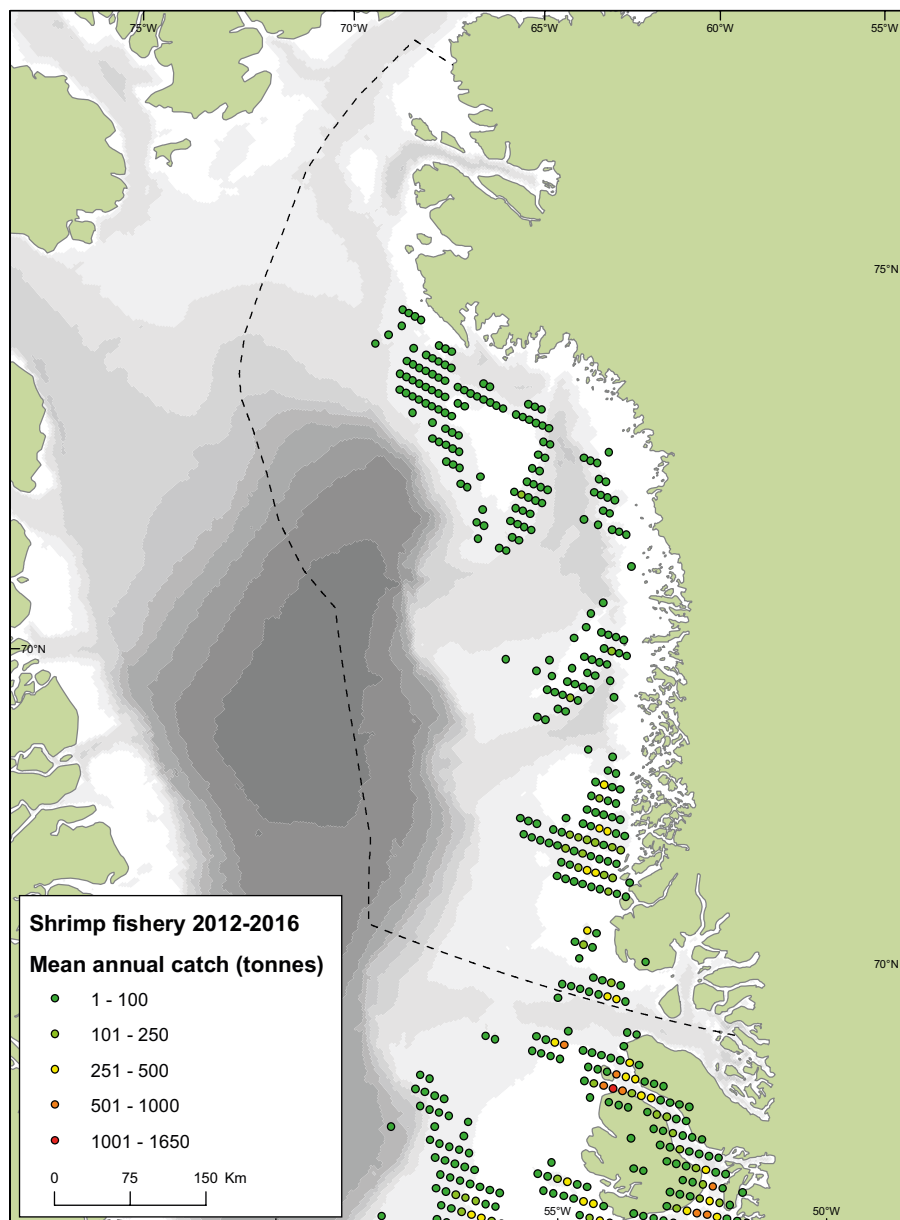
Fishery in the assessment area took until 2014 place only in the southern part, but in 2014 and 2015 new fisheries have been tried with promising results further north into Melville Bay (Burmeister & Christensen 2016) (Figure 45). The catches reached 1,400 tons and 1600 tons respectively (2% of the total catch in 2014 in West Greenland), and the trial fishery was continued in 2016 (Arboe 2014; Burmeister & Christensen 2016). Most of the fishery in the assessment area is conducted during July-December due to ice conditions.

#### Other species

The commercial fishery for snow crab (*Chionoecetes opilio*) was initiated in 1996. Total landings peaked in 2002 with approximately 15,000 tons, however, the stock has been decreasing since and the total catch since in 2010 has been around 2,000 tons/year. In the assessment area, no catches have been taken since 2010 (Burmeister 2012). It is unlikely that a new fishery for snow crab will develop in this area.

Iceland scallop (*Chlamys islandica*) is caught in rather shallow water where currents are strong. The total catch in Greenland has been less than 700 tons/year since 2010. In the assessment area almost no fishery has taken place since 2003.

**Figure 45.** Distribution and size of northern shrimp catches in the assessment area. Catch size calculated as annual mean over the period from 2012 to 2016.



## 5.2 Subsistence and recreational fisheries and hunting

F. Ugarte

Besides the commercial fishery described above, subsistence fishery is wide spread in the region. In addition, hunting on subsistence basis is also an important feature in the assessment area, and these two activities are essential for the income of many families, particularly in the small settlements, where many still depend on these activities for their living. In most cases, products of the catch are consumed or manufactured in the hunter's home, bartered or sold at the local markets (Kapel & Petersen 1982, Pars et al. 2001, Rasmussen 2005). Products such as whale meat and mattak (skin with blubber) are sometimes sold from local shops or distributed to other parts of Greenland. The sale of sealskins to the state owned tannery is an important source of income for the full-time hunters living in the Baffin Bay area.

### Fishery

Artisanal fisheries target several species. The most vulnerable to oil spills include those caught close to the shoreline, such as capelin, lumpsucker and Arctic char. Fisheries for these species are restricted to spring and summer. Capelin

and lumpsucker occur primarily in the southernmost part of the assessment area, although their ranges are moving northwards due to climate change and capelin have recently moved as far north as Qaanaaq (A. Mosbech pers. obs.). Arctic char occur throughout the assessment area, see Section 5.6.2.

A number of other fish species are also utilised on subsistence basis. These include among others, spotted wolffish (*Anarchichas minor*), Greenland halibut, redfish Atlantic cod, polar cod, Greenland cod (*Gadus ogac*), Greenland shark (*Somniosus microcephalus*). Moreover, blue mussels (*Mytilus edulis*) are often collected for consumption.

Important areas for fishery of capelin, lumpsucker and Arctic char are mapped in the oil spill sensitivity atlases (Olsvig & Mosbech 2003, Mosbech et al. 2000b, 2004a, Clausen et al. 2016).

### **Hunting**

The marine mammal species regularly hunted within the assessment area include ringed seal, harp seal, bearded seal, hooded seal, walrus, white whale, narwhal, minke whale and polar bear. Besides these, more species are taken on an opportunistic basis: pilot whale, killer whale, white beaked dolphin, and harbour porpoise. The hunt for walrus, white whale, narwhal, polar bear and minke whale is regulated by quotas.

Seabirds taken include thick-billed murre, eider, kittiwake, black guillemot and little auk. Protective measures include hunting seasons and limits on the number of birds that can be taken per hunting trip.

The annual walrus quota in Qaanaaq, in the northern part of the assessment area, is 86 for the period 2014-2018. In addition, Inuit in Nunavut, Arctic Canada, take about four walruses from the same stock.

Further south in the assessment area, eight walruses are allocated to Upernavik and 19 are to be shared between Uummannaq, in the southern part of the assessment area and settlements further south in the Disko Bay area.

It was possible to export walrus products outside Greenland until 2015, as the catch was regarded as sustainable (Ugarte 2015). However, in July 2016 a temporary ban was introduced as the stock in the Qaanaaq area was assessed as having a negative 'CITES Non Detriment Finding'. The catch in the period 2013-2016 had surpassed the advised sustainable catch (GINR 2016).

There is an import ban on walrus products from Greenland in the European Union, so the export of walrus products from Greenland has been very limited, and most products are traded nationally, incl. tusks and skulls. Walrus ivory is used for carving and also for elaboration of tools, but this activity is in decrease (Egevang 2015).

#### *White whale*

Most, if not all the white whales caught in Baffin Bay come from the stock that summers in Somerset Island, Arctic Canada. It is assumed that white whales from this stock divide into two wintering groups: one that travels east and south along the coast of West Greenland to the ice edge in the Davis Strait and one that stops at the northern part of Baffin Bay and spends the winter in the North Water Polynya.

The white whales wintering in the Davis Strait are taken during the migration through the assessment area by hunters in Qaanaaq, Upernavik and Uummannaq before the sea ice consolidates in the autumn and again as the ice dis-

integrates in spring. The extent of sea ice varies from year to year and catches tend to be higher in years with more sea ice, probably because the sea ice pushes the whales closer to shore where they come within reach of hunters (Heide Jørgensen et al. 2010a).

Annual quotas for white whales in the Baffin Bay area for the period 2013-2015 are 20 in Qaanaaq, 131 in Upernavik and 21 in Uummannaq. These quotas are allocated by the Government of Greenland following the advice of JCNB and NAMMCO (NAMMCO 2013).

White whales are caught for their meat and mattak (skin). The latter is considered as a delicacy in Greenland.

### **Narwhal**

The hunt of narwhals is particularly important, for both the subsistence and the cultural identity of people in Northwest Greenland. The most important hunting areas are Inglefield Inlet and Melville Bay, where hunters still take narwhals using traditional kayaks. The reason for this is that narwhals are particularly shy and show a high degree of site fidelity to their summer grounds. By using the nearly silent kayaks, hunters are able to sneak close to the narwhals, causing minimal disturbance. The narwhal hunters express concern with regard to their resource, especially in relation to climate change and industrial activities including seismic surveys (Heide-Jørgensen et al. 2014b, Egevang 2015, Nuttall et al. 2015, see also Box 13).

In the southern part of the assessment area, in Uummannaq and southern Upernavik, narwhals are caught during the southward migration to their wintering grounds, from October to January, and the northward migration back to the summering grounds from March to July. In southern Upernavik, narwhals are shot from the ice edge or chased from skiffs. Most of the whales in Uummannaq are caught in November and December, before the consolidation of the sea ice. Narwhals are spotted from land and chased with skiffs or caught with nets from the shoreline. Telemetry studies show that narwhals migrating through Uummannaq in the autumn and early winter come from a mixture of summering grounds, including Melville Bay and Somerset Island in Arctic Canada (NAMMCO in press).

Annual quotas for 2013-2015 were 85 narwhals for Inglefield Inlet and Smith Sound (Qaanaaq), 81 narwhals for Melville Bay (63 in Upernavik and 18 in Savissivik) and 85 for Uummannaq. These quotas follow the advice from JCNB and NAMMCO (NAMMCO 2013).

As with white whales, the primary products from the narwhal hunt are meat and mattak. The tusks are used for carving or sold internally in Greenland. Export of narwhal products was banned in 2006, when the CITES Scientific Authority could not document that narwhal catches in Greenland were sustainable. The export ban is still valid, despite documentation in 2009 that catches are sustainable (Ugarte & Heide-Jørgensen 2008).

### **Polar bear**

Polar bears are hunted primarily for their meat. The fur is used to make traditional clothing, and some skins, skulls and claws are sold within Greenland. Export of polar bear products outside Greenland is banned by CITES because the populations are over-exploited (Born & Ugarte 2007).

Quotas for 2014 and 2015 were of six polar bears per year for the Kane Basin subpopulation (Qaanaaq north of Savissivik) and 67 polar bears per year for

the Baffin Bay subpopulation. The quota for the Baffin Bay subpopulation is divided so that 18 polar bears can be taken by hunters from Savissivik, 37 by hunters from Upernavik and the remaining 12 are to be shared by hunters from Uummannaq and settlements south of the assessment area.

### **Minke whales**

Minke whales are hunted for their meat and mattak, and are chased from skiffs and smaller fishing vessels during summer. Their hunt is regulated by quotas and a minimum of five skiffs need to work together to be allowed to hunt a minke whale. The first minke whale ever reported from Qaanaaq was caught in 2009. Subsequently, in the period 2010-2014, one minke whale was caught in Qaanaaq each year in 2011, 2012 and 2013. In the same period, seven minke whales were caught each year in Upernavik, with the exception of 2013, when 21 minke whales were caught. Yearly catches in Uummannaq from 2010-2014 ranged from five to eleven (APNN, unpublished data). Hunting for minke whales may become more common as the climate warms and the range of this species shifts northwards.

### **Seals**

All four species of seals occurring in the assessment area are hunted. Ringed seal and harp seal are by far the most important in terms of numbers caught. Those two species provide the inhabitants with a fundamental source of food and income. Seal meat is a staple food for both humans and sledge dogs, while skins are purchased with government subsidies by the state owned tannery, providing a much needed income in areas with otherwise limited opportunities for paid employment.

During the open-water season, all seals are shot from skiffs. Ringed seals are also caught with nets, especially during the dark winter months. In addition, ringed seals are shot while sunning on the sea ice during their moulting period, from April to June.

Because all the four species of seals hunted in the assessment area are numerous and there are no conservation concerns about the sustainability of the catches, the seal hunt is not regulated by quotas. However, all hunters in Greenland have to fill in yearly forms specifying the number of animals caught every month for each of the species that can be legally hunted (with the exemption of large whales, which have their own reporting system).

The reported average annual catches in Uummannaq, Upernavik and Qaanaaq for the period 2009 - 2013, were 44,369 ringed seals (max. 45,548 in 2011 and min. 42,464 in 2012), 23,809 harp seals (max. 35,460 in 2010 and min. 18,551 in 2012), 627 bearded seals (max. 753 in 2010 and min. 566 in 2012) and 435 hooded seals (max. 563 in 2011 and min. 357 in 2012) (APNN, unpublished data).

### **Other marine mammals**

There are no specific regulations for the hunting of harbour porpoise, white beaked dolphins, pilot whales and killer whales. These are taken opportunistically when spotted. White beaked dolphins, pilot whales and killer whales are usually chased by several skiffs working together, wounded with rifle shots and preferably secured with floats attached to harpoon heads before delivering the killing shot. As all cetaceans, these species are hunted for their meat and mattak. In addition, killer whales are perceived as competitors for the hunting of other marine mammals, and therefore seen by many as unwanted. These species are caught during summer, but the timing, location and amount of catches are unpredictable.



In the period 2009-2015, average reported catches per year were 13 killer whales (max. 27 in 2011 and min. one in 2010), six harbour porpoise (max. ten in 2013 and min. three in 2009), six white beaked dolphins (max. 14 in 2012 and min. none in 2009 and 2013) and 219 pilot whales (max. 289 in 2012 and min. 137 in 2009). All these small cetaceans were reported from Uummannaq and Upernavik, none were taken in Qaanaaq. These numbers are not quality assured and should therefore be regarded with caution. Validation of data from earlier years showed that up to half of the reports of killer whale hunts were mistakes originated by the reporter ticking the wrong box when filling in the yearly catch form required to renew a hunting license (APNN, unpublished data).

### Seabirds

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

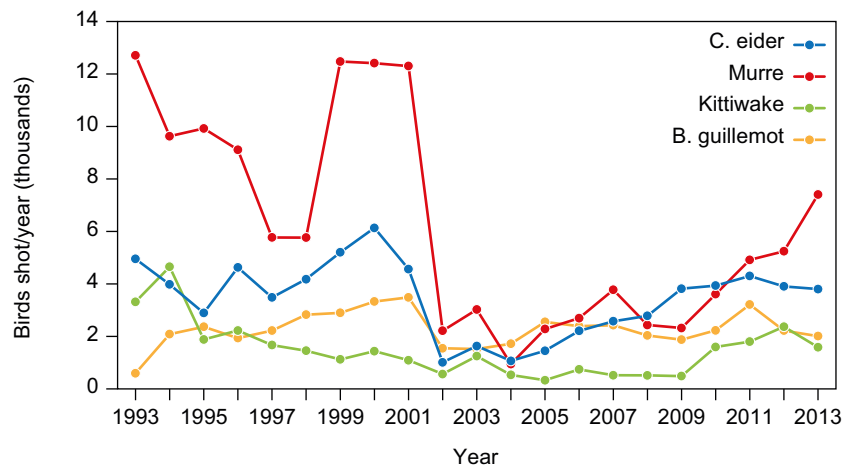
They are shot at sea from skiffs or from the ice edge, although little auks are primarily caught with nets at the breeding colonies.

Full time hunters can take up to 40 thick-billed murres and eiders per hunting day, while recreational hunters are allowed to catch five of these birds per day. There is no limit to the number of little auks, kittiwakes and gulls that can be taken per day.

The regulations for sea bird hunting were revised in 2001 resulting in a more restricted open season, especially in spring. This means that seabirds in reality only can be hunted in autumn in most of the assessment area. The hunting season for thick-billed murre is from 1 September to 29 February, while eiders can be taken from 15 October to 31 March, kittiwakes from 15 August to 29 February and little auks from 1 September to 30 April. In Qaanaaq however, little auks can be taken also in summer in their breeding colonies.

During 2009-2013, average yearly catches reported for Qaanaaq, Upernavik and Uummannaq combined (an area slightly larger than the assessment area) were 3,955 eiders (max. 4,302 in 2011 and min. 3,816 in 2013), 4,681 murres (max. 7,387 in 2013 and min. 2,294 in 2009), 1,568 kittiwakes (max. 2,369 in 2012 and min. 487 in 2009) and 20,017 little auks (max. 27,004 in 2011 and min. 12,154 in 2012). See also Figure 46.

**Figure 46.** Annual reported catches of thick-billed murre, common eider, black-legged kittiwake and black guillemot in northwest Greenland comprising the former Uummannaq, Upernavik and Avanersuaq (Qaanaaq) municipalities covering a slightly larger region than the assessment area (Unpublished data from Piniarneq APPN).



### 5.3 Tourism

D. Boertmann

The tourist industry is one of three major sectors within the Greenland economy, and the industry has been increasing significantly in importance both nationally and locally in the assessment area. The most important asset for the tourist industry is the unspoilt, authentic and pristine nature.

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

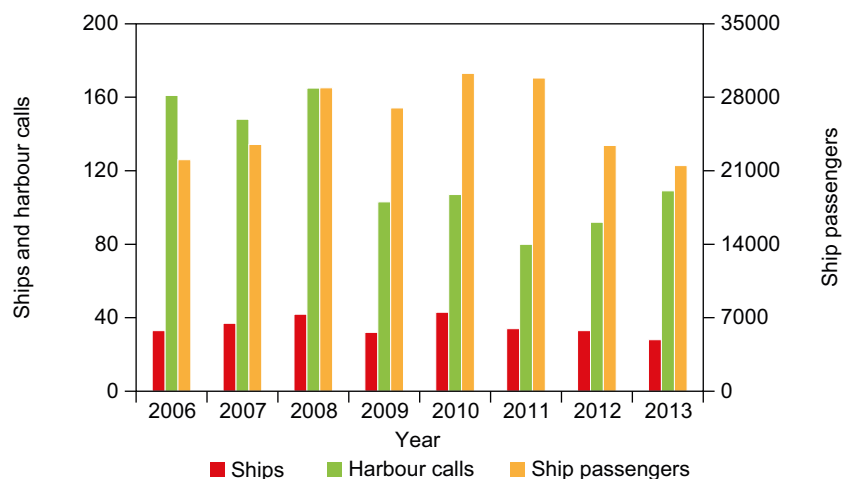
There are no statistics on the number of tourists in towns (except Ilulissat, outside the assessment area) and their regional distribution can only be broken down to municipalities. Overall figures for the Qaasuitsup Kommunia (the northern municipality, which include the Disko bay region and the assessment area) in 2015 as a whole were approx. 33,000 guests and approx. 80,000 'bed nights' (Statistics of Greenland 2016). By far the major part of the tourists visited the region south of the assessment area, where the most sought tourist site in Greenland is found (Ilulissat). The corresponding figures for the region excluding Ilulissat were approx. 7,400 and 19,000 respectively.

Besides the tourists staying in hotels and other types of accommodation on shore, cruise ships bring an increasing number of tourists to Greenland. In the period 2006 to 2013, the number of cruise ships ranged between 28 and 43 and the number of guests on these ships between 21,000 and 30,000 in the whole of Greenland (Statistics Greenland 2015). In 2015, a total of approx. 6000 cruise ship passengers visited the towns Uummannaq, Upernavik and Qaanaq (Statistics Greenland 2016).

The cruise ships focus on the coastal zone and they often visit remote areas that are otherwise almost inaccessible and sightings of seabirds and marine mammals are among the highlights on these trips (Figure 47).

Finally, tourists also go to Greenland for outdoor leisure activities (mountain-eering, kayaking, etc.) or on scientific expeditions (natural history).

**Figure 47.** Number of cruise ships, calls at harbours and cruise ship passengers in Greenland 2006-2013. There is no data on the cruise ship activity available for the assessment area, but the trends are similar (Statistics Greenland 2015).



### **Tourist activities**

The activities are centred in the main towns of the assessment area: Uumman-naq (just outside the assessment area), Upernavik and Qaanaaq, where there are accommodation and tourist operators. The season starts in early spring when there are opportunities for dog sledding on the sea ice, but the main season is summer (July and August) when it is possible to sail from the towns to attractions such as archaeological sites, bird cliffs, whale habitats, glaciers, small settlements, hiking areas and areas with scenic views.

In Upernavik the following activities take place (Bo Albrechtsen, Director of Museum and Tourism in Upernavik, pers. comm.):

- Dog sledge trips. Takes place year round. Sledge trips are mostly on sea ice in the coastal zone.
- Boat trips with local hunters. Summer season.
- Kayaking. June to August. Kayakers explore the coastal zone and bring their own equipment and provisions.
- Cruise ships. Mainly August and September. Visitors in Upernavik town mostly walk around for sightseeing and visit the museum.
- Fishing and hunting. Seal hunt on the ice in spring.
- Hiking. Summer season. Land-based.

In 2007, the number of visitors in Upernavik was approx. 800 in total. Of this figure, 700 arrived from cruise ships, 50 were there specifically for kayaking, and the last 50 were independent travellers.

Due to the remoteness, Qaanaaq receives only a few independent travellers who are often participants in sport or scientific expeditions. The activities include dog sledge trips, hiking, kayaking and hunting. Most of the activities are related to the sea or the ice. A few of the independent travellers go there in winter. Cruise ships also bring an increasing number of tourists to Qaanaaq in the summertime.

## 6 Protected areas and threatened species

D. Boertmann

### 6.1 International nature protection conventions

According to the Convention on Wetlands (the Ramsar Convention), Greenland has designated eleven areas to be included in the Ramsar list of Wetlands of International Importance (Ramsar sites). These areas are to be conserved as wetlands and should be incorporated in the national conservation legislation; however, this is only the case for one of the Greenland Ramsar sites. No Ramsar sites are found within the assessment area (Egevang & Boertmann 2001).

As a follow up to the Arctic Marine Shipping Assessment (AMSA) areas of heightened ecological and cultural significance have been designated (AMAP/CAFF/SDWG 2013). The designation will be followed up by measures to protect the areas from impacts of increased shipping due to climate changes. Four areas within or partly overlapping the assessment area are designated as 'areas of heightened ecological significance' according to this report: The North Water Polynya, Melville Bay, the Northwest Greenland shelf (the coasts of the former Upernavik municipality) and central Baffin Bay (Figure 48).

The same four areas are also designated as 'ecologically valuable and sensitive marine areas' in relation to shipping activities by a national identification, using the IMO criteria for designation of Particularly Sensitive Areas (PSSA) and the IUCN criteria for designating Ecologically or Biologically Significant Areas (EBSA) and Super EBSAs (Christensen et al. 2012).

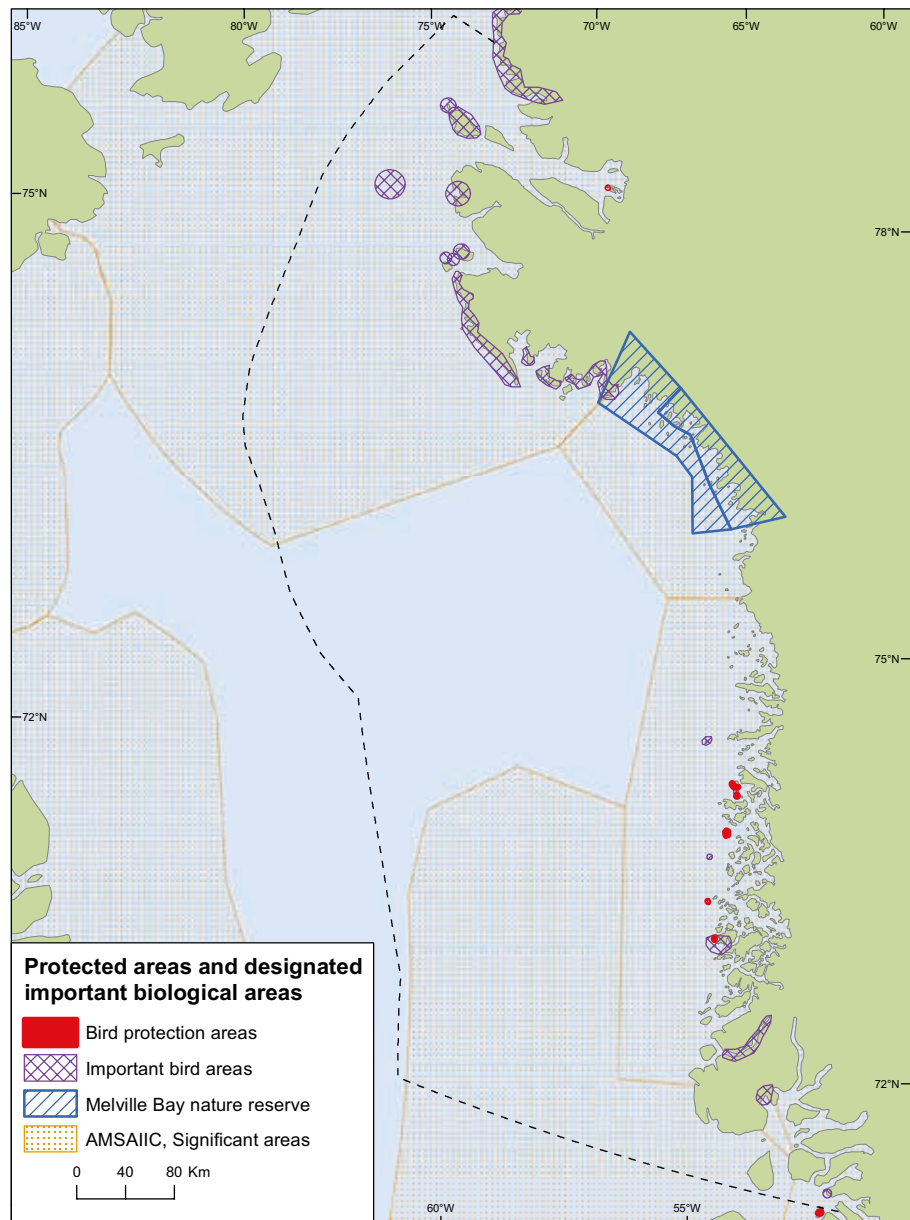
### 6.2 National nature protection legislation

The Melville Bay Nature Protection Area is situated within the assessment area (Figure 48) and was designated primarily to protect polar bears. Although a nature protection area, traditional hunting is allowed in a part of the area. Exploration for petroleum and minerals is not regulated by the Nature Protection Act, but seismic surveys are restricted and other exploration activities have to be approved (Boertmann 2005).

There are six specific sites within the assessment area that are protected as seabird breeding sanctuaries according to the Bird Protection Executive Order (Figure 48). This order also states that in general, all seabird breeding colonies should be protected from disturbing activities (cf. the maps showing the seabird breeding colonies within the assessment area (Figure 15). Many of these sites were surveyed and evaluated in 2010 (Egevang & Boertmann 2012).

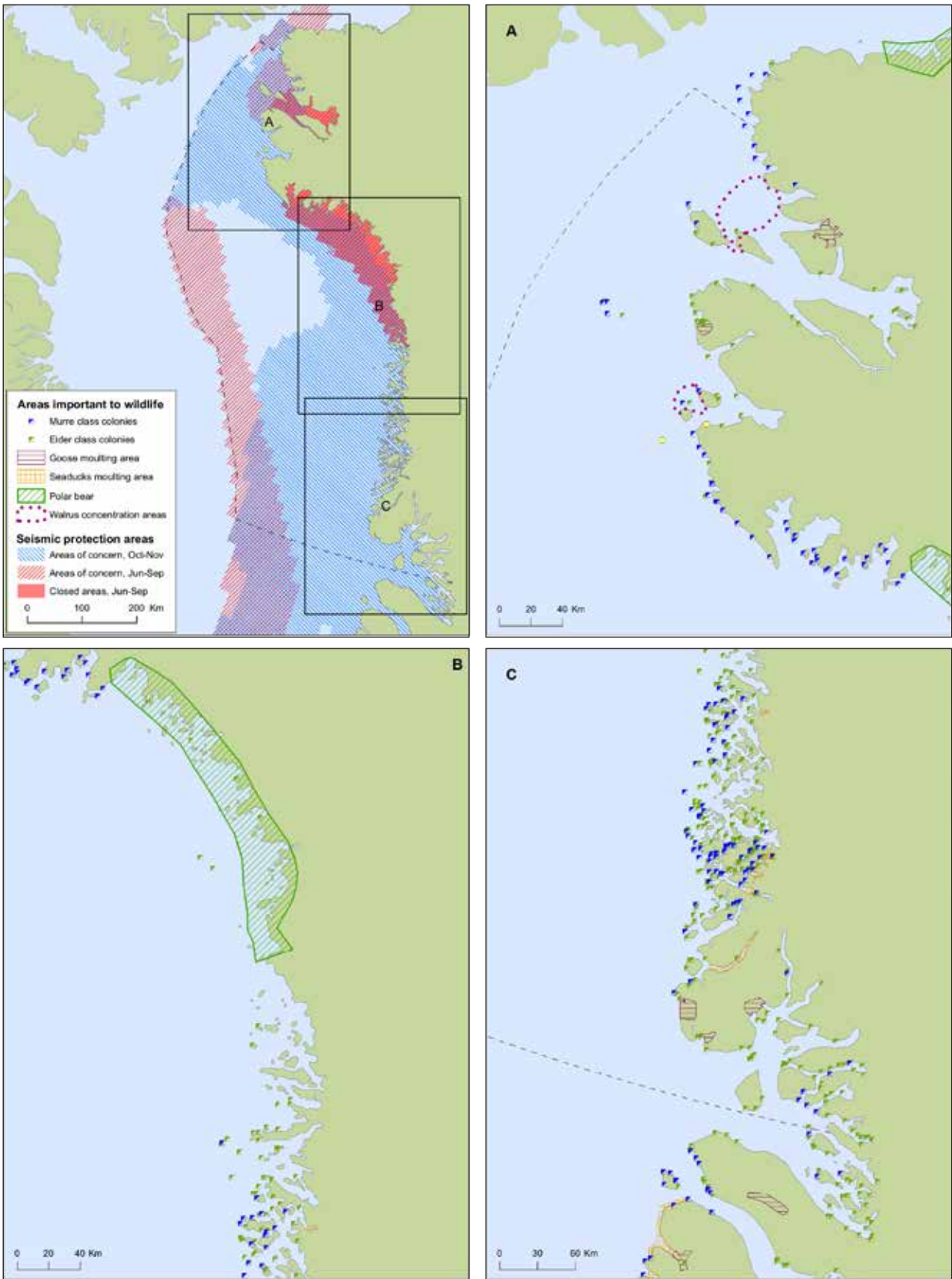
According to the Mineral Extraction Law, a number of 'areas important to wildlife' are designated and, in these, mineral exploration activities are regulated in order to protect wildlife. There are several of these areas important to wildlife within the assessment area and they also include the most important seabird breeding colonies (Figure 49). Moreover some important whale habitats in the assessment area have been designated as protection areas for narwhals, white whales and bowhead whale (Figure 49) in relation to seismic surveys (cf. the new guidelines for preparing an EIA of seismic activities in Greenlandic waters (EAMRA 2015).

**Figure 48.** Areas protected according to the Greenland Nature Protection Law (Melville Bay reserve and Bird Protection areas), areas designated as Important Bird Areas (IBAs) by BirdLife International and AMSAII-areas, which were designated by the Assessment of Arctic Marine Shipping, Recommendation IIC as Areas of heightened ecological significance (AMAP/CAFF/SDWG 2013). There are no Ramsar-areas within the assessment area.



**Table 5.** Nationally red-listed species occurring in the Baffin Bay assessment area.

Species	Red List category
Polar bear	Vulnerable (VU)
Walrus	Critically endangered (CR)
Bowhead whale	Near threatened (NT)
White whale (beluga)	Critically endangered (CR)
Narwhal	Critically endangered (CR)
Great northern diver	Near threatened (NT)
Greenland white-fronted goose	Endangered (EN)
Common eider	Vulnerable (VU)
Harlequin duck	Near threatened (NT)
Gyrfalcon	Near threatened (NT)
Sabine'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)



**Figure 49.** Areas designated as “important to wildlife” by Bureau of Minerals and Petroleum as a part of the field rules for prospecting and exploration activities. See also Figure 43.

### 6.3 Threatened species

Greenland has red-listed (designated according to risk of extinction) five species of mammals and eleven species of birds (Table 5) occurring in the assessment area (Boertmann 2008).

A few species have been categorised as ‘Data Deficient’ (DD) and they may become red-listed when additional information is available (Table 6).

National responsibility species occurring in the assessment area include one mammal and five birds (Table 6). These are species where a significant part of the population occurs in Greenland, and for which Greenland has a particular responsibility for their conservation.

Globally threatened species occurring in the assessment area include six marine mammals and three birds (Table 7).

Within the assessment area there are some hot-spots for threatened species (Figure 50) – particularly at the coast of the former municipality of Upernavik and the coasts of the central part of the former Qaanaaq municipality.

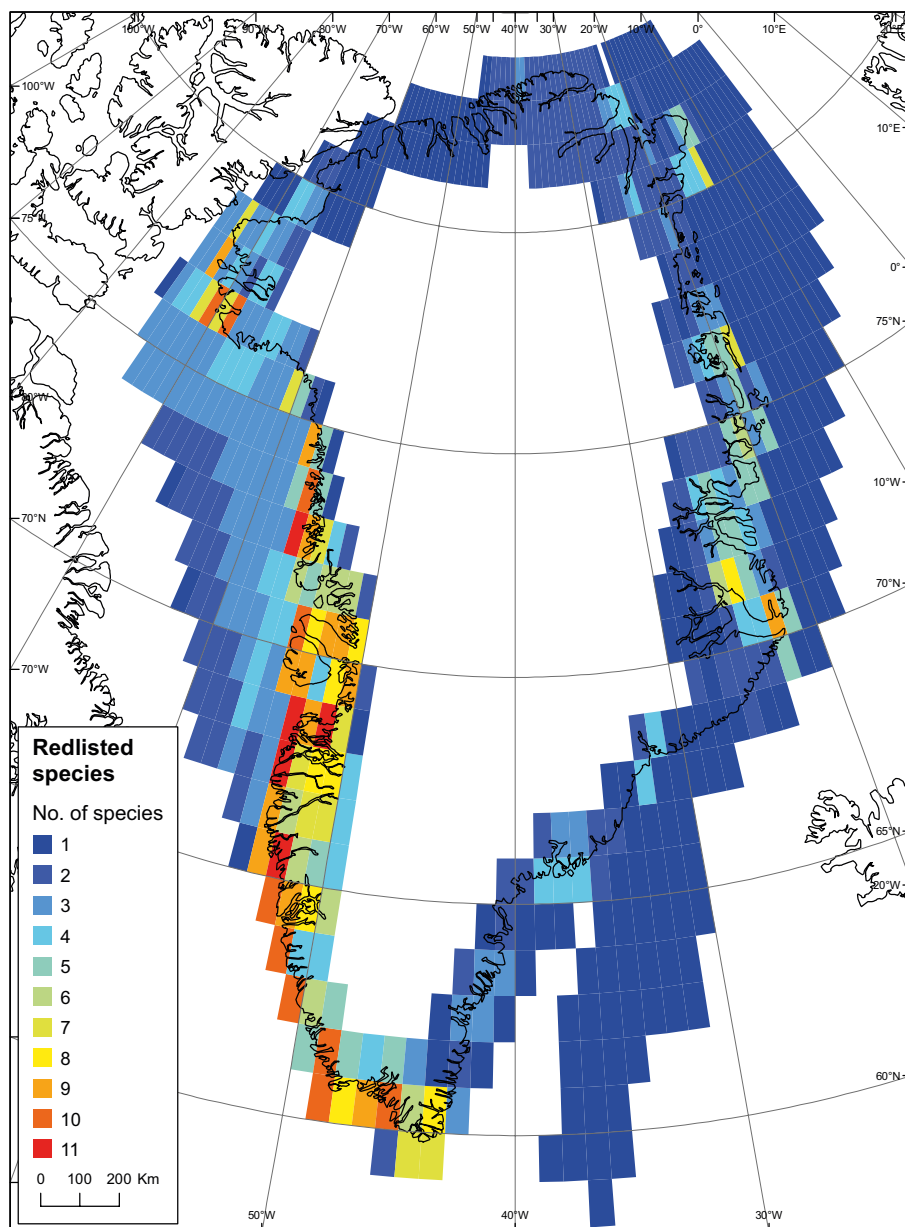
**Table 6.** National responsibility species (defined as more than 20% of the global population in Greenland) and species listed as ‘Data Deficient’ (DD) on the Greenland red list and occurring in the assessment area. Only species which may occur in marine habitats included.

National responsibility species	Species listed as Data Deficient (DD)
Narwhal	Bearded seal
Walrus	Harbour porpoise
Polar bear	Blue whale
Light-bellied brent goose	Sei whale
Greenland white-fronted goose (endemic)	
Mallard	
Common eider	
Iceland gull	
Black guillemot	
Little auk	

**Table 7.** Species occurring in the assessment area and listed as globally threatened (IUCN 2015).

Species	Red list category
Ivory gull	Near Threatened (NT)
Razorbill	Near Threatened (NT)
Atlantic puffin	Vulnerable (VU)
Polar bear	Vulnerable (VU)
Fin whale	Endangered (EN)
Blue whale	Endangered (EN)
Sperm whale	Vulnerable (EN)
Narwhal	Near Threatened (NT)
White whale	Near Threatened (NT)

**Figure 50.** Distribution of Red-listed species in Greenland shown as number of species in 1° x 1° squares.



## 6.4 NGO designated areas

The international bird protection organisation BirdLife International has designated a number of Important Bird Areas (IBAs) in Greenland (Heath & Evans 2000), of which eighteen are located within the assessment area (Figure 48). These areas are designated using a large set of criteria, stipulating, 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 for instance as seabird breeding sanctuaries, but many are without protection or activity regulations.

## 6.5 Important biological areas

To support the identification of biologically important areas in West and Southeast Greenland a GIS-based overlay analysis of 59 valued ecosystem components was performed. The analysis was used in a report proposing ecosystem-based management in the Disko Bay region of West Greenland (Christensen et al. 2015), and it will be used for a biodiversity assessment of West and Southeast Greenland (Christensen et al. in prep). The data derive from

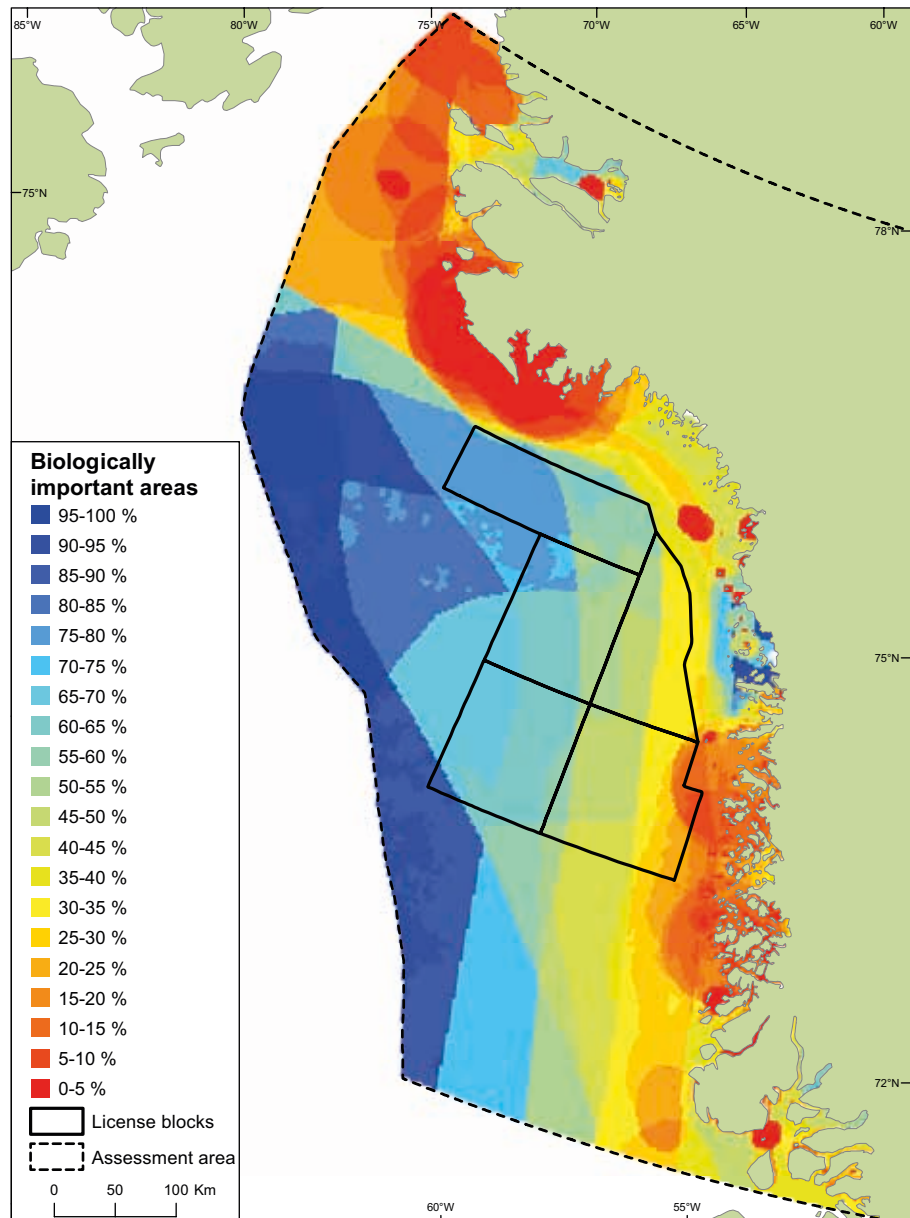


the DCE/GINR database, which i.a. includes all the data collected and compiled during the environmental studies programmes by oil companies operating in Greenland.

Each ecosystem component was attributed a number of points (a score) based on an assessment of its importance according to both national and international criteria (for example Ramsar and Biodiversity conventions), as well as available information on the spatial distribution of the ecosystem component in question. These points were distributed across a geographic grid covering West and Southeast Greenland. Finally, all ecosystem component grids were stacked and a sum was calculated across the stack for each cell in the grid system.

The result was a map highlighting biologically important areas from a certain perspective (Figure 51). Areas with a high score tend to be those where the spatial distributions of many and/or important ecosystem components overlap. However, since the spatial distribution of the individual ecosystem component is used to distribute its score, important ecosystem components with a restricted distribution tend to substantially impact the result of the overlay as too many points are distributed across a small area. Thus, in some cases,

**Figure 51.** The result of the overlay analysis described in the text. The red colours show the biologically most important areas, the blue the least according to the analysis. The signature is distributed on 5% percentiles. The red areas are dominated by presence of seabird breeding colonies, while the more widely distributed marine mammals do not show up to the same degree. The importance of Inglefield Inlet and Melville Bay as summer habitats for narwhals are therefore not obvious. Due to this bias (caused by the method) the analysis should be not be used independently to identify biologically important areas.



just one or a few ecosystem components may produce a high score in an area in the final result. An area where an important ecosystem component is concentrated tends to be vulnerable, and the method thus highlights both areas of high diversity and areas where important individual ecosystem components are spatially confined.

With this in mind, the map of the Baffin Bay area should be interpreted with some caution within the context of this strategic environmental impact assessment. Besides diversity, the map clearly gives weight to important species with a very restricted distribution (for example some seabirds during the breeding season), whereas for instance narwhal, an important but more widespread species, is not clearly represented in the map despite important summering areas in the assessment area. Thus the map is not the final identification of important areas, but should be seen as a support tool in a more complex identification process.

## 7 Background levels of contaminants

F. Rigét

Knowledge of background levels of contaminants in areas with hydrocarbon exploration and exploitation is important mainly for use 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 have been studied in Greenland over the years in various regions and with different purposes. An overview is given in the following sections, with focus on studies with relevance for the assessment area.

Studies on specific pollution sources in the assessment area have only been carried out at a mine site in the southern part and at a dump in the northern part. At Maarmorilik (near Uummannaq), lead and zinc ore was mined from 1973 to 1990. Here, environmental studies have been conducted since 1972 by measuring lead and zinc concentrations in seawater, sediments and biota in the marine environment (Larsen et al. 2001, Johansen et al. 2006, 2010). At Thule Airbase, pollution impacts from a dump site on the marine environment were surveyed in 2002 (Glahder et al. 2003).

### 7.1 Heavy metals

Heavy metals such as mercury (Hg), cadmium (Cd) and lead (Pb) in the environment are derived from both anthropogenic sources to the atmosphere (for example coal burning and mining) and from natural sources (for example volcanoes and weathering of rocks). The total amount of mercury released to the atmosphere in 2010 from human sources was estimated at 1,960 tons (UNEP 2013) with a further 3,000 to 4,000 tons released either from natural sources or as re-emissions of mercury previously deposited on surfaces (AMAP, 2011b). In the case of cadmium natural emissions to the atmosphere accounted for 30-50% of total emissions (AMAP 2005).

The air constitutes 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 food web. Study of bio-magnification of mercury and methyl mercury (MeHg) in the West Greenland marine ecosystem, including fourteen species of invertebrates, fish, seabirds and marine mammals showed a bio-magnification factors similar to those found in other marine systems (Rigét et al. 2007b).

In general, mercury levels have increased in the Arctic, with implications for the health of humans and wildlife. There is also some evidence that the Arctic is a 'sink' for global atmospheric mercury (Outridge et al. 2008).

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 on animals not affected by local pollution sources, i.e. former mine sites, have been included. The overall conclusion was that lead levels in marine organisms from Greenland were low, whereas cadmium, mercury and selenium levels were high, in some cases exceeding Danish food standard limits. No firm conclusions could be drawn in relation to geographical differences concerning lead, mercury

and selenium concentrations. In general, cadmium levels were higher in biota from Northwest Greenland compared with southern areas.

The latest report from the Arctic Monitoring and Assessment Programme (AMAP) including cadmium, concluded that the highest concentrations of cadmium in the Arctic is found in the kidney and liver of marine mammals, the highest levels occurring in marine mammals from the eastern Canadian Arctic and north-western Greenland (AMAP 2005). Similarly, in a summary of the knowledge of contaminants in Arctic marine mammals, Dietz (2008) concluded that marine mammal populations from Northwest Greenland and the Central Arctic have the highest concentrations of mercury. The highest cadmium concentrations in Arctic were recorded in mammals from Central West Greenland and Northwest Greenland.

Mercury concentrations in Arctic biota have increased since pre-industrial times to the present day. Based on studies of wildlife hard tissue matrices such as hair, teeth and feathers, Dietz et al. (2009) estimated the man-made contribution to be above 92%.

Rigét et al. (2011) summarised the existing time-series of mercury in Arctic biota delivered to AMAP; a total of 83 time-series. No generally consistent trend of mercury in Arctic wildlife was revealed for the last approx. 30 years. However, in the Canadian and Greenland region a number of time-series samples of mercury (ringed seal from Northwest Greenland, seabirds from Prince Leopold Island, sea-running Arctic char from Baffin Island and landlocked Arctic char from Cornwallis Island) showed significant increases (Rigét et al. 2011; Braune et al. 2015, NCP 2012). Mercury levels in hair of polar bears from Northwest Greenland have shown an annual increase of 1.6-1.7% from 1892 to 2008 (Dietz et al. 2011). In general, levels of mercury in human tissues are declining in the Arctic; however, Inuit who consume marine mammals still have high blood mercury levels and often exceed blood guidelines. This is especially prominent in Greenland and parts of Arctic Canada (AMAP 2009b).

Temporal trends in mercury concentrations for the last two to three decades were also determined in various species from Northwest Greenland and central West Greenland. For shorthorn sculpin from central West Greenland and Northwest Greenland and walrus from Northwest Greenland, no temporal trend was found (Rigét et al. 2007a). In ringed seals from Northwest Greenland, an increase in mercury of 10.3% per year was observed during the period 1984-2010, while in ringed seals from central Greenland no trend in mercury concentrations was traced during the period 1994-2004 (Rigét et al. 2012).

## **7.2 Persistent Organic Pollutants (POPs)**

Persistent organic pollutants (POPs) have a long lifetime in the environment, and therefore the potential to be transported over long distances. Most of the total quantity of POPs found in the Arctic environment is derived from distant sources (AMAP 2004). POPs are mainly transported to the Arctic by the atmosphere and ocean currents. POPs bioaccumulate and biomagnify in Arctic food chains. Most of them are lipophilic, which means that the highest concentrations are found in fatty tissues. Top predators in the marine food web (for example polar bear, toothed whales) as well as birds of prey have the highest levels of POPs (AMAP 2004). Also Greenland sharks collected in the Davis Strait and Cumberland Sound region in 1997 and 1999 had high concentrations of POPs, being in the range of other top Arctic marine predators, i.e. 3-10 times higher than those in ringed seals (Fisk et al. 2002). The trophic

transfer of POPs has been demonstrated in a study of six zooplankton species, the benthic amphipod, *Anonyx nugax*, polar cod, seabirds (six species) and ringed seals from the North Water Polynya (Fisk et al. 2001).

The use of several POPs has been banned or restricted for decades and international actions have been established to reduce emissions and releases to the environment, such as the UNEP Stockholm Convention on POPs and the POPs Protocol to the Convention on Long-range Trans-boundary Air Pollution. However, many POP levels in Arctic biota are still so high that certain species, including many top predators, are at risk of experiencing biological effects from these compounds (Letcher et al. 2010, NCP 2013). The nature of potential effects includes impacts on reproductive, endocrine and immune systems (NCP 2013).

In general, the POP concentrations in biota from West Greenland are lower than in biota from East Greenland, except for hexachlorocyclohexane (HCH) which has comparable concentrations (Rigét et al., 2008; Vorkamp *et. al.* 2015a).

Most POPs that have been banned for an extended period of time in developed countries, for instance dichlorodiphenyltrichloroethane (DDTs), drins (aldrin, endrin and dieldrin), polychlorinated biphenyls (PCBs) and chlor-danes, show decline in Arctic air, for example at the monitoring station at Alert, Nunavut (AMAP 2014). Declining concentrations of these POPs are also seen in Arctic biota (AMAP 2014), including seabirds from Prince Leopold Island, ringed seals from Lancaster Sound and East Baffin Island, white whales from Cumberland Sound (NCP 2013) and ringed seals from central West Greenland (Rigét et al. 2013).  $\beta$ -hexachlorocyclohexane ( $\beta$ -HCH) is an exception – increasing amounts have been found in ringed seals and seabird eggs from the Lancaster Sound region (NCP 2013), and declining amounts in West Greenland ringed seals (Rigét 2008). Inuit living in the eastern parts of the Canadian Arctic and Greenland have two- to ten-fold higher concentrations of certain POPs compared with populations from other Arctic regions (AMAP 2014). However, a recent assessment suggests that concentrations have decreased in both Nunavut and West Greenland (AMAP 2014).

Brominated flame retardants (BFRs) are chemicals used in materials to make them more fire-resistant, for instance 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. Use of the brominated flame retardant (BFR) polybrominated diphenyl ethers (PBDEs) was phased out at a national level (U.S., Canada and European Union) in the mid-2000s and in 2009 the technical mixtures PentaBDE and OctaBDE were included in the Stockholm Convention.

Air concentrations of PBDEs at the Canadian Arctic station Alert have remained more or less unchanged from 2002 to 2011 and were generally higher than at the European stations; possibly reflecting the higher historical usage of these compounds in North America in general (AMAP 2014). Levels of PBDEs in both animals and humans are much lower than those of other previously regulated POPs. For example, PBDE-47 concentrations are about 6  $\mu\text{g}/\text{kg}$  lw in blood plasma in Inuit from Nunavik in 2004 compared with PCB-153 (158-189  $\mu\text{g}/\text{kg}$  lw) and DDE (461-467  $\mu\text{g}/\text{kg}$  lw) (AMAP, 2014). PBDEs concentrations increased in seabird eggs and ringed seals from the Lancaster Sound region until ca. 2003/2005, after which concentrations have either decreased or stabilised (NCP 2013). The same pattern is seen in ringed seal from central West Greenland (Rigét, unpubl. data). Hexabromocyclodo-

decane (HBCD) is another flame retardant, showing increasing trends in for instance ringed seals from Lancaster Sound and white whales from Cumberland Sound (NCP 2013).

Perfluorinated alkylated substances (PFASs) are another group of compounds that are very persistent in the environment. PFASs are used in a variety of consumer products and in industrial materials. In biota and humans, PFASs bind to blood proteins and therefore bioaccumulate mainly in liver, kidneys and bile secretions in contrast to most other POPs which are lipophilic. Perfluorooctane sulphonate (PFOS) is usually found in much higher concentrations compared with other fluorinated compounds in Arctic wildlife. The largest producer of PFOS, the 3M US company, announced in 2000 that it would phase out its production. PFOS was banned in the EU in June 2008, and in 2009 PFOS was included in the Stockholm Convention on POPs. In seabird eggs from Prince Leopold Island PFOS concentrations have increased since 1975. However, measurements in 2009-2011 suggest that concentrations of PFOS are now declining (NCP 2013). In ringed seals from East Baffin Island and Lancaster Sound PFOS concentrations peaked in the early 2000s, which was also the case for white whales from Cumberland Sound (NCP 2013). In ringed seals from West Greenland PFOS concentrations peaked around 2006 (Rigét et al. 2013). For women of childbearing age in Nunavik PFOS concentrations appeared to decrease; this is in contrast to an increasing trend in Nuuk, West Greenland in the period 1998 to 2005 (AMAP 2014).

New organic compounds are regularly developed and produced, and in that their physical-chemical properties are similar to those of POPs they could cause new problems/they would be of environmental concern in the Arctic if emitted to the environment. Several initiatives in environmental policy deal with the identification of potentially problematic compounds, listing compounds to be phased out, monitored or studied further. The compounds bis(2-ethylhexyl)tetrabromophthalate (TBPH), 2-ethylhexyl-2,3,4,5-tetrabromobenzoate (TBB), 1,2-bis(2,4,6-tribromophenoxy)-ethane (BTBPE), decabromodiphenyl ethane (DBDPE) and 2,3-dibromopropyl-2,4,6-tribromophenyl ether (DPTE) are examples of novel flame retardants, which have replaced some of the banned BRFs and are observed in Arctic biota, although at low levels (NCP 2013, Vorkamp et al. 2015b). Also TBPH, TBB and BTBPE were detected in concentrations similar to PBDEs in air at Alert (Xiao et al. 2012).

### 7.3 Tributyltin (TBT)

The antifouling agent, tributyltin (TBT) can be found in many coastal waters in both industrial and developing countries with the highest levels in harbours and 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, but in rather low concentrations (Jacobsen & Asmund 2000, Strand et al. 2005).

Presence of TBT and the related compound triphenyltin (TPhT) has also been indirectly detected in the area around Thule Airbase in Northwest Greenland during a study performed in 2002 (Strand et al. 2006). Occurrence of imposex, a sensitive indicator for the presence of TBT, was found in the Arctic whelk (*Buccinum fumarkianum*) at several locations around Thule Airbase (Strand et al. 2006).

## 7.4 Polycyclic Aromatic Hydrocarbons (PAH)

PAHs are aromatic hydrocarbons that 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 Organisation and the U.S. Environmental Protection Agency (EPA).

Petrogenic PAHs are released to the environment through oil spills and discharge of produced water from active oil wells. Levels of oil hydrocarbons (including PAHs) are generally low in the Arctic marine environment and often close to background concentrations, except in areas with anthropogenic impact such as harbours. Presently, the majority of petroleum hydrocarbons in the Arctic originate from natural sources such as seeps (AMAP 2010).

In Greenland, total petroleum hydrocarbons (TPH) and PAH levels were measured at possible natural seeps in the Disko Bay area in 2005. Sediments and biota (blue mussels, shorthorn sculpins, Greenland cod) were taken from the coast of the 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. However, compared with sediments from a larger area of West Greenland the sediments close to Nuussuaq and Disko have higher concentrations of PAH expressed on the basis of the content of organic matter. (Mosbech et al. 2007b).

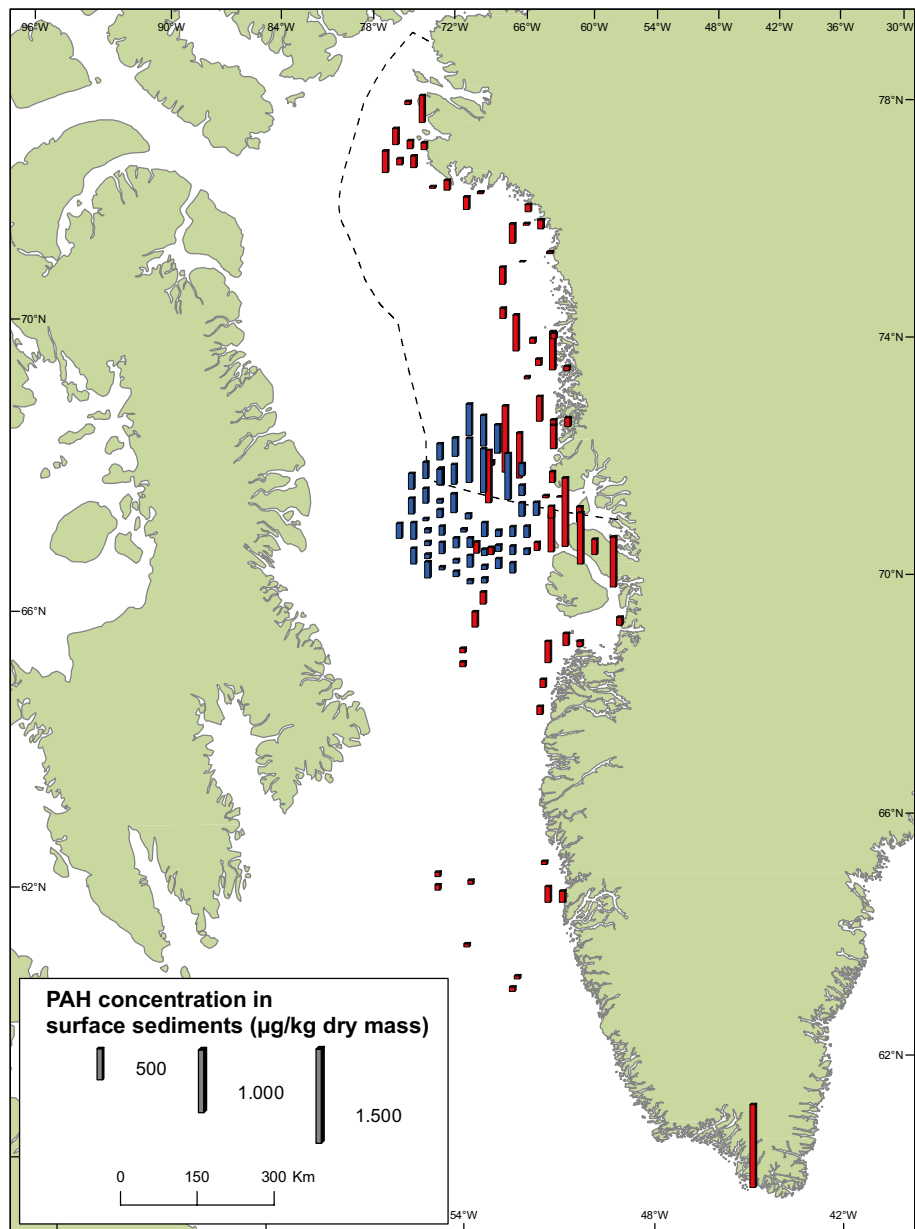
PAH levels in sediments, bivalves (Iceland scallop, Greenland cockle) and shorthorn sculpins were measured at dumpsites and reference sites around Thule Airbase in 2002 (Glahder et al. 2003). The PAH concentrations found in the bivalves were within the same range as in blue mussels from temperate marine environments, but higher than in previously studied blue mussels from Disko Bay. 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 in the Disko Bay area (Mosbech et al. 2007b).

In 2006, sediment samples were taken off West Greenland between 64° N and 71° N. Based on dry weight most samples were close to or slightly above background levels regarding the sum of all measured PAHs. Only three samples from Aasiaat Bay and two from Nuussuaq Basin clearly displayed higher concentrations.

In 2008, sediment samples were taken at 15 coastal locations in the eastern Baffin Bay. A set of 28 different polycyclic aromatic hydrocarbons (PAH) were analysed in the surface sediment layer (0-1 cm depth) (Sejr et al. 2010a). In general, PAH levels were low and could be regarded as background levels (Figure 52). A general trend of decreasing total PAH content with increasing latitude was found. An exception to the low PAH content was Kangersuatsiaq/Prøven harbour, showing a total PAH concentration of 621 µg/kg dw in the top sediment layer which decreased with sediment 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. 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).

In another study performed in 2008, PAH levels in surface sediments from offshore locations in Baffin Bay were determined and were generally very low, except for one station (Figure 52). The higher PAH concentrations ob-

**Figure 52.** Polycyclic aromatic hydrocarbon (PAH) concentrations ( $\mu\text{g kg}^{-1}$  dry mass) in surface sediments, (usually in the 0-1 cm) in western Greenland. Coloured bars indicate PAH concentrations and sampling done by different companies/institutions: red bars: sampled by DCE and blue bars by Capricorn (Cairn, Edinburgh). Note: Data is based on 23 PAH types which are included in The United States Environmental Protection Agency (EPA) compounds as priority pollutants.



served at this location could probably be attributed to the Marrat oil seep (Mosbech et al. 2007b).

As part of a baseline study performed by the oil company Capricorn, the PAH content in surface sediments west of Disko was analysed to document background levels prior to exploration drilling. The PAH contents in the analysed sediments were generally low (Figure 52).

Another regional baseline study carried out in 2011, including sampling stations in remote locations of the Nordic Seas and the sub-Arctic, showed elevated levels of PAH in blue mussels at Maarmorilik in West Greenland compared with, for instance, Varangerfjord in northern Norway. In contrast, no increase was observed at Sisimiut and Nalunaq further south on the west coast of Greenland (Jörundsdóttir et al. 2014).

From the studies performed so far in the assessment area and in other parts of Greenland on 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 are mainly relatively low and are regarded as background concentrations.



However, our present knowledge of contaminant levels in marine organisms from the Baffin Bay assessment area remains limited. Most of the existing studies have been carried out south and north of the assessment area. Accordingly, further studies are needed to fill in the gaps to obtain a better understanding of the environmental hydrocarbon baseline in the assessment area.

## 7.5 Biological effects of contaminants

Contaminant burdens and climate change are important stressors to Arctic ecosystems. Numerous studies have been performed to investigate biological effects on Arctic biota by these stressors. A major challenge for understanding the impact of contaminants on wildlife is to link the effects/responses observed to a specific cause. Many studies rely on correlations between tissue concentrations and effects using a biomarker approach. Biomarkers are a measure of changes in physiological or anatomical state and therefore indicative of contaminant-mediated effect. Another challenge is to identify the most problematic contaminants as wildlife is influenced by a complex mixture of different contaminants.

Dietz et al. (2013) reviewed mercury data in Arctic biota against toxicity threshold values and found that especially marine top predators such as polar bears, toothed whales and a few seabird species exceed threshold values for biological effects. Toothed whales had high concentrations of mercury in brain tissue with associated signs of neurochemical effects. Similarly, Letcher et al. (2010) reviewed biological effects in Arctic wildlife and fish of organohalogen contaminants (OHCs). OHCs can influence biochemical processes related to the immune and endocrine system, pathological changes in tissues and reproduction and development. Based on the “weight of evidence” found in different studies, several key (‘hotspot’) species and populations have been identified. Among those are East Greenland polar bear and ringed seals, Greenland shark from the Baffin Bay/Davis Strait and a few populations of freshwater Arctic char (Figure 53).

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 have been assessed (Anderson & Lee 2006). However, as pointed out before, most of these studies have been performed in temperate regions.

A changed climate is also important to consider in risk assessments, as contaminant exposure and toxic effects on wildlife will be affected (Table 8 (9)) (Macdonald et al. 2005, Schiedek et al. 2007, Noyes et al. 2009, Borgå et al. 2010).

## 7.6 Conclusions on contaminant levels

The recent levels of mercury and persistent organic pollutants, in particular in top predators in the Arctic including the Baffin Bay/ Davis Strait area, are – for some species – believed to exceed the threshold for biological effects (AMAP 2011b, Letcher et al. 2010, NCP 2013). It is also recognised that assessing the effects of contaminants on Arctic wildlife should consider also other environmental, ecological and physiological stressors (both anthropogenic and natural), requiring a multi-stressor approach to ecological risk assessment in the future (NCP 2013). This is particularly important seen in the light of the magnitude and variety of anticipated changes in the Arctic over

**Mammals**

**Polar Bear**

- OHCs reported
- ◐ OHC highest exposure

**Killer whale**

- ◐ OHCs reported and high

**White whale**

- OHCs reported
- ◐ OHCs reported and high

**Bowhead whale**

- OHCs reported

**Stellers sea lion**

- ◐ OHCs reported

**Ringed seal**

- OHCs reported
- ◐ OHC highest exposure

**Birds**

**Glaucous gull**

- OHCs reported
- ◐ OHCs reported and high

**Great and lesser black-backed gulls and herring gull**

- ◐ OHCs reported and high

**Ivory gull**

- ◐ OHCs reported and high

**Northern fulmars**

- OHCs reported
- ◐ OHCs reported and high

**Black-legged kittiwake**

- OHCs reported
- ◐ OHCs reported and high

**Fish**

**Arctic char**

- OHCs reported
- ◐ OHCs reported and high

**Greenland shark**

- ◐ OHCs reported and high

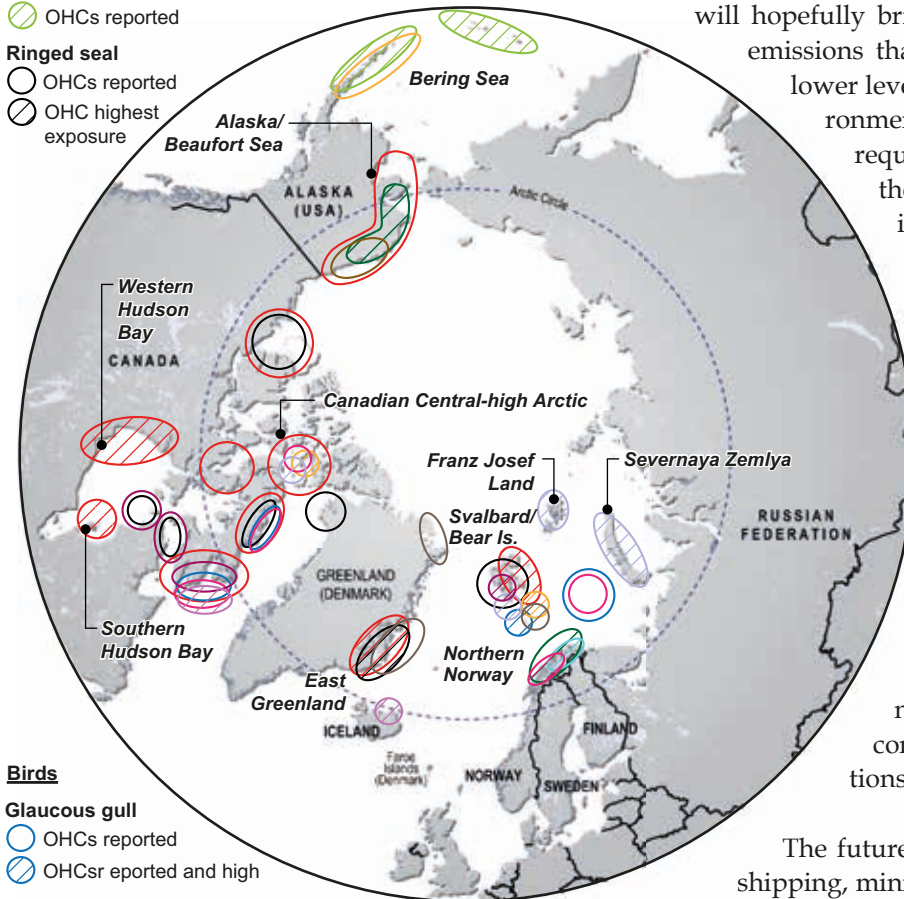
Map source: UNEP

the coming decades. With regard to humans, a significant proportion of people including women of child-bearing age from communities in the eastern Canadian Arctic and Greenland exceed (U.S. and Canadian) blood mercury guidelines (AMAP 2011b). Also the levels of persistent organic contaminants in humans from the eastern Canadian Arctic and Greenland can affect health of people (AMAP 2009b).

Without improved pollution controls or other actions to reduce mercury emissions, global mercury emissions to air and thereby deposition in the Arctic will likely be substantially higher in 2050 than they are today (UNEP 2013).

Once implemented, however, the Minamata Convention will hopefully bring about a reduction in global emissions that will eventually translate into lower levels of mercury in the Arctic environment. Continued monitoring will be required to assess the effectiveness of the Convention. In the meantime, if levels continue to increase, the consumption of traditional/local food without dietary restrictions may lead to increased human health risks in the region. The levels of those persistent organic contaminants under national and international regulations are declining and if monitoring of contaminants (including screening studies for emergent compounds) is continuing in the Arctic, it is likely that new and emergent compounds of concerns will be discovered and actions initiated.

The future development of infrastructure, shipping, mining and oil and gas activities can result in local point sources of contaminants. However, it should be possible with proper management to limit and/or minimise environmental impacts from such activities. The threat level of any form of environmental contaminant must also be coupled with other health determinants such as smoking and general nutrition, and any threats from environmental contamination must also be weighed against health benefits of traditional foods consumption.



**Figure 53.** Contaminant hotspots (areas and animal populations) in the Arctic. Based on the “weight of evidence” found in different contaminant studies performed on Arctic wildlife and fish. Inside the assessment area, only ringed seals in the Qaanaaq area are identified (Source: Letcher et al. 2010).

**Table 8.** Climate change-induced toxicological effects of contaminants on wildlife (Noyes et al. 2009 and references therein).

<b>Climate change induced effects</b>	<b>Relationships/Interactions</b>
Altered uptake and elimination	<ul style="list-style-type: none"><li>• increasing temperature = increasing uptake of toxicants</li><li>• increasing temperature = increasing elimination</li><li>• increasing temperature = remobilization of bioaccumulated POPs</li></ul>
Increased toxicity	<ul style="list-style-type: none"><li>• increasing temperature = increasing toxicity</li><li>• increasing temperature = increasing metabolism and potentially altered metabolite profiles</li><li>• toxicant exposure may limit capacity of species and populations to acclimate to altered temperatures</li><li>• pollutant-exposed ectotherms and species at the edge of their physiological tolerance range may be especially sensitive to temperature increases</li></ul>
Altered environmental salinity	<ul style="list-style-type: none"><li>• decreasing solubility and increasing bioavailability of pesticides/POPs (“salting out effect”)</li><li>• increasing salinity + increasing POP/pesticide exposure may alter osmoregulation due to altered enzymatic pathways</li></ul>
Altered ecosystems	<ul style="list-style-type: none"><li>• altered POP sequestration and/or remobilization through shifts in food sources and starvation events</li><li>• shifts in disease vector range and severity coupled with toxicant exposure inhibiting immune response may leave wildlife more susceptible to disease</li><li>• low level exposure may impair organism acclimation to ecosystem alterations induced by climate change</li><li>• climate change-induced changes in trophic food webs may alter POP bioaccumulation and biomagnification</li></ul>

## 8 Impacts assessment

D. Boertmann, A. Mosbech & S. Wegeberg

### 8.1 The data

The following assessment is based on the data compiled in the previous Chapters 3 to 8, and compared to the previous edition (Boertmann & Mosbech 2011) the database has been extended with the results of the studies initiated specifically for this updated edition (Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014).

### 8.2 Boundaries

The assessment area covers the area described in the introduction (Figure 1). It is the region which potentially can be impacted by oil exploration and exploitation activities carried out in the license blocks. However, a large oil spill will have the potential to impact areas beyond these borders for example in the Canadian EEZ.

### 8.3 Impact assessment procedures

The assessment includes activities associated with the full life cycle of an oil field, i.e. from exploration to decommissioning.

Exploration activities are expected to take place during summer and autumn due to the winter ice. Production activities, if initiated, are likely to take place throughout the year.

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

Since it is not practically possible to evaluate all ecological components in the area, the concept of Valued Ecosystem Components (VEC) has been applied in some cases.

VECs can be species, populations, biological events or other environmental features that are important for the ecosystem or to the human population. VECs are often important flora and fauna elements (species, populations), habitats (also temporary and dynamic ones such as the marginal ice zone or polynyas) and processes such as the phytoplankton spring bloom. They were selected based on expert judgement by the authors and on stakeholder input received during consultations when preparing this and other SEIAs in Greenland.

The potential impact on VECs of activities during the various phases of the life cycle of a hydrocarbon license area are summarised in a series of tables in Chapters 10 and 11 (Tables 9, 10 and 11). The tables are based on worst-case scenarios for impacts, under the assumption that current guidelines for the various activities, as described in the text, are applied. For each VEC, examples are given of typical vulnerable organisms (species or larger groups) in relation to specific activities. These examples are non-exhaustive.

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

The scale of a potential impact is assessed as local or regional. Impacts may be on a larger scale than local either if the activity is wide-spread or impacts populations originating from a larger area (for example migratory birds), or a large part of a regional population (for example a large seabird colony).

It should be emphasised that quantification of the impacts on ecosystem components is difficult and in many cases impossible. There are too many unknowns, for example, the spatial overlap of the expected activities can only be assessed to a limited degree, as only the individual licence blocks are known at this point. Another unknown is the physical properties of potentially spilled oil. Knowledge concerning important ecosystem components and how they interact is also largely unknown. Finally, climate change is now impacting ecosystem functioning, potentially altering many of the interactions.

Relevant research regarding toxicology and ecotoxicology of petroleum related compounds and their effects and sensitivity of organisms to disturbance has been used. Conclusions from various sources – the Arctic Council Oil and Gas Assessment (AMAP 2010), the extensive literature from the *Exxon Valdez* oil spill in Alaska in 1989, the increasing literature from the *Deepwater Horizon* spill in 2010 as well as from the Norwegian SEIAs of hydrocarbon activities for example in Lofoten-Barents Sea (Anonymous 2003b) – have been drawn upon.

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

## 9 Impacts of potential routine activities

D. Boertmann, A. Mosbech, S. Wegeberg

### 9.1 Exploration activities

In general, all activities related to oil exploration are temporary and will be terminated after a few years if no commercial discoveries have been made. Another important aspect in relation to oil exploration in Baffin Bay is that the activities generally are limited to the period when the sea is more or less free of ice. However, seismic surveys can be carried out aided by ice breakers in areas partially covered by ice.

Environmental impacts of exploration activities relate to:

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

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

#### 9.1.1 Noise from exploration

##### Noise from seismic surveys

The main environmental concerns relate to effects on marine mammals and fish caused by sound generated during seismic operations including:

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

In Arctic waters, certain conditions must be considered. The water column is often stratified which causes refraction of sound waves. Therefore, a simple relationship between sound pressure levels and distance to source cannot be assumed. This makes it difficult to base impact assessments on simple transmission loss models (spherical or cylindrical spreading) or to apply results from assessments performed at southern latitudes to Arctic waters (Urick 1983). The sound pressure, for instance might be significantly higher than expected in convergence zones far (> 50 km) from the sound source. This has been documented by means of acoustic tags attached to sperm whales, which recorded high sound pressure levels (160 dB re  $\mu\text{Pa}$ , peak-peak) more than 10 km from a seismic array (Madsen et al. 2006).

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

In the following potential impacts from seismic surveys on different ecosystem components are discussed and assessed.

### **Impact of seismic noise on zoo- and ichthyoplankton**

Zooplankton (for example copepods such as *Calanus* and larvae of benthic crustaceans) and fish larvae and eggs (= ichthyoplankton) are unable to avoid the pressure wave from the airguns and can be killed within a distance of up to 2 m, and sublethal injuries may occur within 5 m (Østby et al. 2003). The relative volume of water affected in this way by a seismic survey is small and population effects, if any, are considered to be very limited, according to Norwegian and Canadian assessments (Anonymous 2003b). However, some species have very discrete spawning areas in certain periods of the year, where mortality could be more pronounced due to very high densities.

Densities of fish eggs and larvae in Greenland waters are generally low in the upper 10 m and most fish species spawn in a dispersed manner in winter or spring. This means that the temporal overlap of the spawning season with seismic activities is very limited. Additionally, the ichthyoplankton is dispersed both vertically and horizontally when the seismic surveys takes place. It is therefore most likely that impacts of seismic activity (even 3D) on zoo- and ichthyoplankton and thus on fish recruitment are negligible in the assessment area.

### **Impact of seismic noise on fish**

Adult fish will generally avoid seismic sound waves, by seeking towards the bottom and, thus, avoid being directly harmed. Young Atlantic cod and redfish (30-50 mm long), are able to swim away from the lethal zone near the airguns (comprising a few meters) (Nakken 1992).

It has been estimated that adult fish react to an operating seismic array at distances of more than 30 km, and that intense avoidance behaviour can be expected within 1-5 km (see below). Norwegian studies measured declines in fish density at distances more than 10 km from sites of intensive seismic activity (3D). Negative effects on fish stocks may therefore occur if adult fish are scared away from localised spawning grounds during the spawning season. This concern gives reason to regulation of seismic activities in Norwegian waters, where time limits for seismic surveys can be introduced in individual licence blocks, where high spawning densities of fish occur (Fiskeri- og Kystdepartementet, Olje- og Energidepartementet 2015). Outside the 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  $\mu$ Pa peak to peak) down to 5-15 m distance sustained extensive ear damage, with no evidence of repair nearly 2 months after exposure (McCauley et al. 2003). It was estimated that a comparable exposure could be expected at ranges < 500 m from a large seismic array (44 l = 2685 in<sup>3</sup>) (McCauley et al. 2003).

It appears that the avoidance behaviour of fish demonstrated in the open sea protects them from damage. In contrast to these results, marine fish and invertebrates monitored with a video camera in an inshore reef did not move away from airgun sounds with peak pressure levels as high as 218 dB (at 5.3 m relative to 1  $\mu$ Pa peak to peak) (Wardle et al. 2001). The reef fish showed involuntary startle reactions (C-starts), but did not swim away unless the explosion source was visible to the fish at a distance of only about 6 m. Despite a startle reaction displayed by each fish every time the gun was fired, continuous observation of fish in the vicinity of the reef using time-lapse video and

tagged individuals did not reveal any sign of disorientation, and fish continued to behave normally in similarly quite large numbers before, during and after the gun firing sessions (Wardle et al. 2001). Another study performed 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 (Hassel et al. 2004). However, no immediate lethal effect was observed on sandeels, neither in cage experiments nor in grab samples taken at night when sandeels were buried in the sediment (Hassel et al. 2004).

The studies described above indicate that behavioural and physiological reactions to seismic sounds among fish may vary between species, i.e. depending on whether they are territorial or pelagic and on the seismic equipment being applied. Generalisations should therefore be made with caution.

### **Impact of seismic noise on fisheries**

Norwegian studies (Engås et al. 1996) have shown that 3D seismic surveys (i.e. a shot fired every 10 seconds and 125 m between 36 lines 10 nm long) reduced catches (trawl and longline) of Atlantic cod and haddock at 250-280 m water 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 more pronounced for large fish compared to smaller fish.

Impacts of 3D seismic survey on gillnet and longline fisheries were studied in Norway, and they showed contradicting results (Løkkeborg et al. 2010): Gillnet catches of Greenland halibut and redfish 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, acoustic surveys of fish densities also indicated that saithe left the shooting area.

An analysis of the official catch statistics from an area with seismic surveys in Norway in 2008 showed very different results (Vold et al. 2009): Catch rates of Atlantic cod, ling (*Molva molva*), tusk (*Brosme brosme*) and Atlantic halibut (*Hippoglossus hippoglossus*) had not changed significantly. Catch rates of redfish and monkfish (*Lophius piscatorius*) seemed to increase, while catch rates of saithe and haddock caught in gillnet decreased and catches with other gear were not affected. The majority of the seismic surveys included in the analysis were 2D and scattered in time and space, for which reason major impacts on the fisheries were not expected.

A Canadian review (DFO 2004) concluded that the ecological effect of seismic surveys on fish is low and that changes in catchability are probably species dependent.

In Greenland waters, including the assessment area, the commercial fisheries that may overlap with seismic surveys are primarily offshore trawling for Greenland halibut.

Greenland halibut is very different from Atlantic cod and haddock with respect to anatomy, taxonomy and ecology. It has no swim bladder, which means its hearing abilities are reduced compared to fish with a swim bladder, in particular at higher frequencies. Thus, Greenland halibut is likely to be sensitive to the particle motion part of the sound field, but not the pressure field.



Moreover, the fishery takes place in much deeper waters than in the Norwegian experiments with haddock and Atlantic cod.

The only Norwegian studies including Greenland halibut was focused on gill net fishery and not trawling (Engås et al. 1996), thus the results cannot be applied to Greenland offshore fisheries.

In the Norwegian study an increased catch of Greenland halibut were found in the gillnets. There are also other examples of this trend (Hirst & Rodhouse 2000), which is most likely the result of changed behaviour (more moving around) of the fish.

In the review by Dalen et al. (2008), it was concluded that the results described by Engås et al. (1996) (mentioned above) cannot be applied to other fish species or to fisheries taking place at other water depths, such as the Greenland halibut fishery.

In summary, it can be stated that there is a risk of reduced catches of Greenland halibut in areas with intensive seismic activity, but probably only during certain periods. The trawling grounds within the assessment area are spatially restricted at depths of approx. 1.500 m and on the narrow continental slope; thus alternative fishing grounds are limited. However, at least until 2011 local trawl companies operating there had not recorded reduced catches in periods when fishery and seismic surveys took place at the same time (F. Heilmann, Polar Seafood pers. comm.).

Regarding possible effects of seismic shooting on invertebrates very little knowledge exists in general, and in different studies and reviews the need for research has been expressed as well as concern for long-term effects (Christian et al. 2003, DFO 2004, Chadwick 2005). A Canadian review, for instance, emphasises the lack in information to evaluate the effects on crustaceans during their moult, a period when crustaceans are particularly vulnerable (DFO 2004).

Another study has shown that the shrimp species *Palaemon serratus* is responsive to sounds ranging from 100 to 3000 Hz, the responsive organ being the statocyst (balance organ) in the basal segment of the antennule (Lovell et al. 2005). To date, behaviour associated with noise impacts has not been demonstrated, but future research may reveal shrimp reactions to seismic sound pulses. A Canadian study (DFO 2004) addressed impacts on snow crabs. The study was set up on short notice and did not find short-term effects, but it raised questions relating to long-term effects. The few other field studies on crustaceans (Norwegian lobster, (La Bella et al. 1996), Australian rock lobster (Parry & Gason 2006), three shrimp species in the waters off Brazil (Andriquetto-Filho et al. 2005) and snow crab (Christian et al. 2003) did not find any short-term reduction in catchability.

When assessing environmental impacts in relation to hydrocarbon activities in the Barents Sea, impacts on northern shrimp and fishery of this resource were evaluated, and both the population and the fishery were considered relatively robust against impacts (Østby et al. 2003).

Thus, based on the knowledge presently available, it is not to be expected that the shrimp fisheries within the assessment area will be affected by seismic surveys during the exploration phase.

### **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 breeding and moulting congregations due to the presence of the vessel and the related activities.

Nearly nothing is known about underwater hearing of diving seabirds and so far no attempts have been made to assess possible impacts of exposure to airgun sounds when seabirds are in the water column. Their hearing abilities under water are likely to be inferior to that of marine mammals and, in any case restricted to lower frequencies not extending to the ultrasonic range. Diving birds are not known to use their hearing underwater, but the possibility cannot be excluded. Diving birds may potentially suffer damage to their inner ears if diving very close to the air gun array, but unlike mammals the sensory cells of the inner ear of birds can regenerate after damage from acoustic trauma (Ryals & Rubel 1988) and hearing impairment, even after intense exposure, is thus temporary.

### **Impact of seismic noise on marine mammals**

Responses of marine mammals to noise fall into three main categories: physiological, behavioural and acoustic (Nowacek et al. 2007). Physiological responses include hearing threshold shifts (reduced ability to hear) and physical damage in the ear. Behavioural responses include changes in surfacing, diving and movement patterns, and may result in displacement from the affected area or reduced feeding success. The acoustic response is based on the fact that low frequency sounds may effectively mask the calls of baleen whales. This may interfere with their social activities and/or navigation and feeding activities. Acoustic responses to masking by anthropogenic noise include changes in type or timing of vocalisations. In addition, there may be indirect effects of noise as prey availability may change (Gordon et al. 2003).

There is strong evidence of behavioural effects on marine mammals from seismic surveys (Compton et al. 2008). Mortality has not been documented, but there is a potential for physical damage, primarily auditory damages. Under experimental conditions temporary elevations in hearing threshold (TTS, temporary hearing loss) have been observed (Southall et al. 2007). Such temporarily reduced hearing ability is considered unimportant by Canadian researchers unless it develops into permanent threshold shift (PTS, permanent hearing loss) or occurs in combination with other threats normally avoided by acoustic means (DFO 2004). However, entanglement in fishing gear has been linked to hearing damage in a Canadian study (Todd 1996).

The US National Marine Fisheries Service has adopted a sound pressure level of 180 dB re 1 $\mu$ PA (rms) or higher as a mitigation standard to protect whales from exposures considered capable of inducing temporary or permanent damage to their hearing (NMFS 2003, Miller et al. 2005). This exposure criterion is poorly defined from a measuring standpoint and with little experimental support. Thus Southall et al. (2007) proposed a reorganisation of exposure criteria, allowing more room for differences in sensitivity between different taxa and different sound types. They also implemented a dual criteria approach; 1/ maximum instantaneous sound pressure and 2/ total acoustic energy accumulated over the complete duration of exposure. The suggestions by Southall et al. (2007) have led to controversial discussions, and it remains to be seen if and how they will be implemented in legislation in the USA and elsewhere.

Displacement is a behavioural response, and there are many documented cases of displacement from feeding grounds or migratory routes of marine mammals exposed to seismic sounds. The extent of displacement varies between species and also between individuals within the same species. A study in Australia, for example, showed that migrating humpback whales avoided seismic sound sources at distances of 4-8 km, but occasionally came closer. In the Beaufort Sea, autumn migrating bowhead whales avoid areas where the noise from exploratory drilling and seismic surveys exceeds 117-135 dB rms and they may avoid the seismic source by distances of up to 35 km (Reeves et al. 1984, Richardson et al. 1986, Ljungblad et al. 1988, Brewer et al. 1993, Hall et al. 1994, NMFS 2002, Gordon et al. 2003), although a Canadian study showed somewhat shorter distances (Miller et al. 2005). White whales, generally believed to be sensitive to noise from seismic surveys and drilling (Lawson 2005), avoided seismic operations in Arctic Canada by 10-20 km (Miller et al. 2005). In UK waters, Stone & Tasker (2006) described a significant reduction in marine mammal sightings during seismic surveys during periods of shooting compared with non-shooting periods, indicating that the marine mammals avoided the source.

In the Alaskan Beaufort Sea, it was shown that bowhead whales change their behaviour when exposed to low frequency sound from airgun arrays (for example Reeves et al. 1984, Richardson et al. 1986, Ljungblad et al. 1988). Humpback whales have been observed to consistently change course and speed in order to avoid close encounters with operating seismic arrays (McCauley et al. 2000).

Di Iorio & Clark (2010) documented that blue whales increase their calling rate during seismic surveys, probably as compensatory behaviour to the elevated ambient noise. A large group of fin whales stopped calling during a seismic survey (Clark & Gagnon 2006 quoted from OSPAR 2009), and fin whales have also been recorded to change the acoustic characteristics of their sounds (Castellote et al. 2010). On the other hand, Dunn & Hernandez (2009) tracked blue whales that were 42-90 km from operating airguns, and they were unable to detect changes in the behaviour of the whales at these distances.

In contrast, minke whales have been observed as close as 100 m from operating airgun arrays (DCE unpublished); potentially close enough to sustain physical damage.

During a controlled exposure experiment in the Gulf of Mexico, sperm whale horizontal movements were not noticeably affected by a seismic survey, but foraging effort seemed to diminish when airguns were operating (Miller et al. 2009).

A tagged northern bottlenose whale was exposed to strong noise from naval sonar, and it showed strong behavioural reaction. The sound source was not directly comparable to a seismic airgun array except for the source level, but the study determined that this whale species is highly sensitive to acoustic disturbance (Miller et al. 2015).

Harbour porpoises exposed to seismic noise from a commercial 2D survey (470 in<sup>3</sup> airgun, sound pressure level 165-172 dB re 1 $\mu$ Pa and SEL of 145-151 dB re 1  $\mu$ Pa<sup>2</sup> s<sup>-1</sup>) were short-term displaced at 5-10 km distance, but returned after a few hours and also showed habituation (Thompson et al. 2013).

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

In West Greenland waters, satellite tracked humpback whales utilised extensive areas and moved between widely spaced feeding grounds, presumably searching for their preferred prey (krill, sandeel and capelin) as prey availability shifted through the season (Heide-Jørgensen & Laidre 2007). The ability of humpback whales to find prey in different locations may suggest that they would have access to alternative foraging areas if they were displaced from one area by a seismic activity. However, even though many areas can be used, a few key zones seem to be especially important. The satellite tracked humpback whales favoured a zone on the shelf with high concentrations of sand-eel (Heide-Jørgensen & Laidre 2007). Similarly, a modelling study based on cetacean and prey surveys showed that rorquals (fin, sei, blue, minke and humpback whale) and krill aggregate in three high density areas on the West Greenland banks (Laidre et al. 2010). Thus, displacement from such important feeding areas potentially has a negative impact on the energy uptake of these rorquals, which are in West Greenland to feed before their southward migration. Given the extent of potential oil exploration activities in Greenland, there is a risk of cumulative effects if multiple surveys occur at the same time in adjacent areas. Marine mammals may therefore simultaneously be excluded from both key habitats and alternative foraging grounds.

The US National Marine Fisheries Service defines the distance around a seismic ship where the received sound level is 160 dB (re 1 $\mu$ PA) as the distance within which cetaceans are likely to be subject to behavioural disturbance (NMFS 2005 in Dunn & Hernandez 2009). The corresponding distance in meters will depend on the source level of the airgun array and the salinity and temperature layers of the water. A few studies have observed lack of measurable behavioural changes in cetaceans exposed to the sound of seismic surveys taking place several kilometres away. For instance, Madsen et al. (2006) found no reaction of sperm whales to a distant seismic survey operating tens of kilometres away. Later, Dunn & Hernandez (2009) did not detect changes in the behaviour of blue whales that were 15-90 km from operating airguns. The authors estimated that the whales experienced sounds of less than 145 dB (re 1 $\mu$ PA) and concluded that while their study supports the current US-NMFS guidelines, further studies with more detailed observations are needed (Dunn & Hernandez 2009).

A behavioural effect widely discussed in relation to seismic surveys and whales is the masking effect of communication and echolocation sounds.

There are, however, very few studies that document such effects (see Castellote et al. 2010, Di Iorio & Clark 2010, Clark et al. 2009), mainly because the experimental setups are extremely challenging. Masking requires overlap in frequencies, overlap in time and sufficiently high sound pressures. The whales and seals in the assessment area use a wide range of frequencies (from < 10 Hz to > 100 kHz, Figures 29, 34).

Whether sound pressures could be high enough to mask biologically significant sounds is another uncertainty. Masking is more likely to occur from the continuous noise from drilling and ship propellers, as has been demonstrated for white whales and killer whales in Canada (Foote et al. 2004, Scheifele et al. 2005).

Owing to the low frequency of their phonation, baleen whales, followed by seals, are the marine mammals most affected by auditory masking from seismic surveys (Gordon et al. 2003, Clark et al. 2009). Blue whales and northern right whales change their vocalisation probably as a compensation for increased ambient noise in their environment (Di Iorio & Clark 2010, Clark et al. 2009).

Sperm whales showed diminished forage effort during air gun emission. It is not clear whether this was due to masking of echolocation sounds or to behavioural responses of the whales or the prey (Jochens et al. 2008).

The most noise-vulnerable whale species in the assessment area are white whale, narwhal and bowhead whale. White whale and bowhead whale are mostly absent from the area during the seasons when seismic surveys are usually carried out (summer and autumn). There is, however, a risk of overlap with seismic operations in late autumn when white whales and bowhead whales move through the assessment area.

Narwhals, on the other hand, also occur in the assessment area in the summer time. A distinct population occurs in the Melville Bay, and other populations move through the assessment area in autumn and winter. This summer population is particularly sensitive to seismic surveys in the northern Baffin Bay, such as those that took place in 2012 (Box 13).

The EAMRA has issued guidelines for best environmental practice of seismic surveys, which among other things aim to minimise impacts on marine mammals. These include the designation of protection areas such as the summer ground for narwhals in Melville Bay.

Other whales occurring in summer and autumn are also vulnerable, but their occurrence in the assessment area is less regular and no concentrations areas are known.

Seals display considerable tolerance to underwater noise (Richardson et al. 1995), which is confirmed by a study in Arctic Canada, where ringed seals showed only limited avoidance to seismic operations (Miller et al. 2005), and they can also adapt to industrial noise (Blackwell et al. 2004). Walrus may be disturbed and displaced by seismic activity (especially when hauled out on ice) and are generally absent from the assessment area when seismic surveys are carried out.

#### **Mitigation of impacts from seismic noise**

Mitigation measures generally recommend a soft start or ramp up of the air-gun array each time a new line is initiated (review by Compton et al. 2008). Although not verified by experiments or observations, this approach is commonly considered 'best practice'. A soft start allows marine mammals to detect and avoid the sound source before it reaches levels dangerous to the animals.

Secondly, it is recommended to have skilled marine mammal observers on board the seismic vessels to detect whales and to instruct the crew to delay seismic shooting in case whales are within a certain distance (usually 500 m) from the array. The detection of nearby whales in sensitive areas is more efficient, depending on species, if supplemented by the use of hydrophones for recording whale vocalisations (Passive Acoustic Monitoring – PAM), although whales do not necessarily emit sounds, when present.

These measures are aimed at preventing physical effects, while behavioural effects and especially displacement of whales several km from the source are not mitigated.

A third mitigating measure is to close areas during sensitive periods. In Norway, time limits have been introduced to prevent seismic surveys in areas when fish spawn in dense concentrations.

Finally, it is recommended to inform local authorities and hunters' organisations before seismic activities take place in their vicinity. 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 of them (Miller et al. 2005). Some measures are identical to those mentioned above, while the most important measure was a delay of the start of seismic operations until the end of the white whale hunt and during periods when important white whale habitats were utilised by the whales. Some particularly important white whale areas were even completely closed for surveys.

All these measures are included in the set of guidelines adopted by EAMRA ([Link](#)).

The EAMRA guidelines follow best practice 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<sup>3</sup>). Output from the array should be reduced to the mitigation gun as outlined below.

An exclusion zone of 500 m from the airgun array must be applied. If marine mammals are observed within this zone during full power, the output must be reduced to the mitigation gun until the mammal has left the zone.

A pre-shooting search must be conducted prior to commencement of any use of the airguns. If waters are less than 200 m deep, this search must last 30 min. When operating in waters with a depth of more than 200 m, the search must be extended to 60 min. If marine mammals are spotted within the exclusion zone, the ramp-up procedure must 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 prior to the end of a survey line, while the airguns are still firing.

The array should not be started at full power, but individual airguns should be added one by one or, if not possible, output from each airgun should be slowly increased by manipulation of pressure (ramp-up or soft start procedure).

The ramp-up procedure must span a period of about 20 min and can be carried out while the survey ship is in 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 must 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 must be deployed for monitoring purposes at start up during periods with reduced visibility (at night, when the sea state is above 3, during fog).

Four Marine Mammal and Seabird Observers (MMSO) must be posted on the source vessel (where the airguns are deployed from) and, at minimum, one should be continuously on the look-out, particularly for whales and seals during the pre-shooting search and when airguns are operated. Two MMSOs must be certified PAM-operators.

Observation of marine mammals during shooting and inside the safety zone may not lead to shutdown, but if marine mammals are observed within the 500 m injury zone of the array, output should be reduced to the mitigation gun until the marine mammals are outside the 500 m zone.

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 must be initiated with a ramp-up procedure as above.

Prior to the survey, the operating company must model the noise propagation in the affected waters, and use the results for preparing the environmental impact assessment. If more seismic surveys take place in the same areas, a joint noise propagation model must be prepared.

### **Conclusions on disturbance from seismic noise**

Regarding noise from seismic activities, the most sensitive VECs in the Baffin Bay assessment area are bowhead whales, narwhals, white whales and walrus. Walruses usually do not occur when seismic surveys take place. White whales will primarily overlap with the seismic season in late autumn, when they migrate through the assessment area. Bowhead whales are most frequent in spring, because their main migratory pathway in autumn is along the Canadian coast. Therefore, impacts on the populations of these species from seismic surveys in the license-blocks most likely will be insignificant or, in case of white whale migration, they can be mitigated. However, if aided by icebreaker, seismic surveys potentially may occur in areas where especially white whale and walrus are present.

The situation for the narwhal is considerably different, as a discrete stock spends the summer in Melville Bay (Box 13). This stock is particularly sensitive to seismic surveys in the northern Baffin Bay (where the active licence blocks are situated). This narwhal population is therefore at risk of being exposed to seismic noise both during their summer stay near the coast and glaciers and

during their autumn migration through the assessment area. Concern for displacement of narwhal migration routes and timing has been expressed, especially because some unusual ice-entrapments occurred in 2008-2010 in Baffin Bay (Heide-Jørgensen et al. 2013d) following summers with seismic activity.

Other species, such as fin, blue, humpback and especially minke whale, may also be displaced from important habitats, but the importance of the assessment area to these species is generally low and no concentrations are known, for which reason impacts on these populations are probably insignificant.

There is also a risk of displacing species from hunting grounds, impacting their availability (to hunters). In 2012, when intensive seismic surveys took place in the northernmost license blocks in the assessment area, the narwhal hunt in nearby Melville Bay was not affected (Box 13).

The risk for long-term impacts from a single seismic survey is low. However, long-term impacts must be assessed if several surveys are carried out simultaneously or if surveys are carried out in the same habitats in consecutive years (cumulative effects).

The only fishery, that may be impacted by seismic surveys in the assessment area, is the trawl fishery for Greenland halibut. Reduced catches for a period during and after intensive seismic shooting due to a displacement of the fish may be expected, but such have not yet been described from the more extensively utilised Greenland halibut fishing ground to the south of the assessment area, despite overlap with seismic surveys. Moreover, the offshore Greenland halibut fishery in the assessment area is limited compared to the offshore fishery further south (Figure 44), which is why potential effects will be small.

Table 9 gives an overview of potential impacts from a single seismic survey.

#### **Noise from drilling units**

There are two sources of noise from drilling units, the drilling process and the ship propellers (cavitation) keeping the drill ship/rig in position (dynamic positioning). The noise is continuous in contrast to the pulses generated by seismic airguns. This noise may potentially disturb marine mammals and acoustically sensitive fish (Schick & Urban 2000, Popper et al. 2004).

Generally, drill ships generate more noise than a semi-submersible platform, which in turn, produces more noise than a jack-up. Jack-ups will most likely not be used within the assessment area due to water depths and the collision risk from drift ice and icebergs.

In order to assess possible effects of noise produced by a drill ship, underwater sound recordings were taken in West Greenland in September 2010, and the emitted noise from the drill ship *Stena Forth* during operation was quantified. The measured noise levels were similar to those known from other drill ships and were above those reported from semi-submersibles and drill rigs. They corresponds to fast-moving merchant ships with source levels of up to 184-190 dB re 1  $\mu$ Pa during drilling and maintenance work. Both drilling and maintenance work result in sounds that are louder than the background noise levels at ranges of 16-38 km from the ship and can be regarded as a substantial noise source (Kyhn et al. 2011).



**Table 9.** Summary of potential impacts from a single seismic survey on VECs in the Baffin Bay assessment area. Displacement indicates spatial movement of animals away from an impact, and is classified as none, short term, long term or permanent. Sublethal effects include all notable fitness-related impacts, except those that cause immediate mortality of adult individuals. Sublethal effects and direct mortality are classified as none, insignificant, minor, moderate or major. Dashes (–) are used when it is not relevant to discuss the described effect. Several surveys, either simultaneous or consecutive, have the potential to give more pronounced cumulative impacts. (L) = local extent, (R) = regional extend.

VEC	Overlap	Risk of impact on critical habitats	Potential impacts – worst case with current regulation			
			Displacement 2D	Displacement 3D	Sublethal effects	Direct mortality
Prim. production	no	no	–	–	–	–
Zooplankton	small	yes	–	–	insignificant	insignificant
Benthic fauna	no	no	–	–	–	–
Benthic flora	no	no	–	–	–	–
Ice flora and fauna	no	no	–	–	–	–
Greenland halibut	pot. large	no	short term (L)	short term (L)	none	none
Arctic char	no	no	–	–	–	–
Polar cod	small	no	short term (L)	short term (L)	none	none
Fish egg and larvae	small	yes	–	–	insignificant	insignificant
Seabirds	small	no	–	–	–	–
Walrus	small	yes	short term (L)	short term (L)	insignificant	none
Ringed seal	small	no	short term (L)	short term (L)	insignificant	none
Bearded seal	small	no	short term (L)	short term (L)	insignificant	none
Narwhal	pot. large	yes	short term (L)	long term (L)	insignificant	none
White whale	pot. large	yes	short term (L)	short term (L)	insignificant	none
Bowhead whale	pot. large	yes	short term (L)	short term (L)	insignificant	none
Polar bear	small	no	short term (L)	short term (L)	insignificant	none
Comm. fisheries	small	yes	short term (L)	short term (L)	–	–
Hunting	small	no	short term (L)	short term (L)	–	–
Tourism	small	–	–	–	–	–

Whales are estimated to be the most sensitive organisms to this kind of underwater noise because they depend on the underwater acoustic environment for orientation and communication, and their communication can be masked by this noise. Seals (especially bearded seal) and walrus also communicate when underwater. However, systematic studies on whales and possible impacts due to noise from drill rigs are limited. Whales are generally expected to be more tolerant to fixed noise sources than to noise from moving sources (Davis et al. 1990). In Alaskan waters, migrating bowhead whales avoided an area with a radius of 10 km around a drill ship (Richardson et al. 1989), 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).

#### Conclusion on noise from exploration drilling rigs

Exploration activities are temporary and, consequently, displacement of marine mammals caused by noise from drilling rigs is also temporary. However exploration may take several years, and in an area with many licence blocks, combined exploration may last for decades resulting in extensive cumulative impacts.

The most vulnerable species (in respect to continuous noise) in the assessment area are narwhal, white whale, bowhead whale and walrus. For this reason,

**Table 10.** Summary of potential impacts from noise and discharges from a single exploration drilling on VECs in the Baffin Bay assessment area. Several drillings either simultaneous or consecutive, have the potential to give increased cumulative impacts. The assessment of potential impacts assumes the application of current mitigation guidelines, see text and Table 10 for details and explanation.

VEC	Overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Displacement	Sublethal effects	Direct mortality
Prim. production	neglig.	no	–	insignificant	insignificant
Zooplankton	neglig.	no	–	insignificant	insignificant
Benthic fauna	small	yes	no	minor (L)	minor (L)
Greenland halibut	minor	no	no	no	no
Arctic char	no	no	no	no	no
Polar cod	neglig.	no	no	no	no
Fish egg and larvae	neglig.	no	no	insignificant	insignificant
Seabirds	neglig.	no	short term (L)	insignificant	no
Walrus	small	yes	short term (L)	no	no
Bearded seal	small	no	short term (L)	no	no
Ringed seal	small	no	short term (L)	no	no
Narwhal	small	yes	short term (L)	no	no
White whale	small	yes	short term (L)	no	no
Bowhead whale	small	yes	short term (L)	no	no
Polar bear	small	no	short term (L)	no	no
Comm. fisheries	small	yes	no	–	–
Hunting	small	no	short term (L)	–	–

there is a risk of displacement of these species from important habitats and hunting grounds.

The temporal overlap between most of these species and exploration drilling will be short and restricted to late autumn and the degree of impacts (most likely displacement) will depend on the amount of exploration activities going on.

But again, it will be the narwhals, occurring in the Melville Bay in summer that will be at risk of impacts from the continuous noise from a drilling platform and the associated ship traffic.

Table 10 gives an overview of potential impacts of noise from a single exploration drilling in the assessment area.

#### Other noise

Nowacek et al. (2007) reported only one study (Patenaude et al. 2002) documenting the responses of whales to aircrafts. They measured behavioural reactions of bowhead whales and white whales to a Bell 212 helicopter and a fixed wing aircraft (Twin Otter). The responses (avoidance reactions) was strongest to helicopter overflights and occurred more frequently at altitudes lower than 150 m and at lateral distances of less than 250 m, and white whales reacted more frequently than the bowheads.

#### 9.1.2 Drilling mud and cuttings

Drilling creates the largest amounts of waste during the exploration phase (see Section 2). This waste consists of cuttings and drilling mud which must be disposed of in some way.

The liquid base of the drilling mud may be water (WBM – water based mud), synthetic fluids (SM – synthetic mud; ethers, esters, olefins, etc.) or oil (OBM – oil based mud).

Until 1993, the practice in Norway was to dispose all the waste to the seafloor. However, due to environmental concerns, release of OBM was stopped then. Today, only WBM can be released to the seabed and only if the content of chemicals is approved, i.e. they only contain environmentally harmless components.

OBMs are still used in Norway, mainly for special drillings under difficult conditions, and afterwards cuttings and mud are either reinjected or transported to land for treatment at specialised facilities.

The experience from Norway is that the environmental impacts on the seabed from OBM cuttings are widespread and long-term (for example Davies et al. 1984, Neff 1987, Gray et al. 1990, Ray & Engelhardt 1992, Olsgaard & Gray 1995, Breuer et al. 2004, Breuer et al. 2008). Benthic fauna is still impacted around old deposition sites, although regeneration has been relatively fast, and today impacts can rarely be traced to more than 500 m from the installations (Research Council of Norway 2012).

Synthetic muds (SMs) also lead to impacts on benthic fauna around a platform, though less pronounced than from OBMs (Jensen et al. 1999a). Ester-based cuttings have been shown to cause rather severe, but short-term 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-term and moderate effects on the fauna.

Studies in Norway conclude that the ban of release of OBM has considerably improved the environmental conditions on the seabed around the offshore installations (Renaud et al. 2007, Schaanning et al. 2008 and references therein), but there is still concern for long-term impacts due to the large amounts released and due to the chemicals in the mud (Research Council of Norway 2012).

Even though the conditions on the seabed are improved by the use of WBM, there is a risk of moving the adverse effects from the seafloor to the water column, where for instance suspension of particles gives some reason for concern (Research Council of Norway 2012). Biological effects from the particles in the water based mud have been observed on fish and bivalves, at least under laboratory conditions (Bechmann et al. 2006) and effects on plankton have also been described (Røe & Johnsen 1999, Jensen et al. 2006a).

Cold water corals, such as the reef-forming hard corals *Lophelia*, and sponges are sensitive to suspended material in the water column (Freiwald et al. 2004, SFT 2008). However, research in Norway has shown that the *Lophelia* corals are not especially sensitive to sedimentation of cuttings (same sensitivity as to natural sedimentation), and they could remove a layer of up to 6 mm sediment. But where they were unable to remove the sediment layer, the underlying tissues would die (Larsson & Purser 2011).

The Northwest Atlantic Fisheries Organisation (NAFO) considers cold water corals and sponge fields, similar to seamounts and hydrothermal vents, as vulnerable marine ecosystems (VMEs). However, the particularly sensitive habitats for these organisms (reefs and sponge gardens) have not been docu-

mented (so far) from the assessment area. However, they have been located in the Canadian part of the Davis Strait (Campbell & Simms 2009, Kenchington et al. 2011) and recently off Southwest Greenland (Tendal et al. 2013).

A final environmental risk is the fact that the barite used in the drilling mud may contain impurities such as mercury, lead and other heavy metals. These can be bioavailable and enter the food web in the environment (Research Council of Norway 2012), where, in a Greenland context, especially mercury gives reason for concern.

In case of field developing, drilling will be intensified and more widespread environmental effects must be expected compared to the drilling of a single or a few exploration wells.

### **Mitigation of impacts from the release of drilling mud and cuttings**

The best way of mitigating impacts from drilling mud and cuttings on the marine environment is to re-inject the material into the wellbores or to transport it to land for treatment at specialised facilities. This is usually the way to treat OBMs as described above. However, this creates other environmental impacts, such as increased emissions of greenhouse gases in relation to transport and pumping and problems with treatment or re-use on land (SFT 2008), which must be balanced against the impacts on the water column and on the seafloor (NEBA).

The Before-and-After (BACI) studies on the seabed, which the operating companies must perform as a part of the environmental studies and monitoring also contribute to the mitigation, at least in the long run, as lessons learned will be incorporated in future regulation.

If drilling mud and cuttings are to be discharged, the best way to reduce environmental impacts is by strict regulation of the chemicals used for the drilling process. Environmentally safe drilling chemicals must be applied, such as those classified by OSPAR (HOCNF) as 'green' / PLONOR (Pose Little Or No Risk to the Environment) or 'yellow'. There is, however, a problem with these classifications, because the chemicals have not been evaluated under Arctic conditions regarding degradation and toxicity. Such evaluation is in high demand for assessing environmental impacts of hydrocarbon activities in Greenland.

In Norway, releases to the marine environment of environmentally hazardous substances ('red' and 'black' chemicals) have been reduced by 99% in the years 1997-2007 by applying international standards, BAT and BEP (SFT 2008). In Greenland the use of 'black' chemicals is not allowed and the use of 'red' chemicals requires specific permission.

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

The drilling campaigns in 2010 and 2011 in the Disko West licences and in licences further south provided some experience.

For instance, increased mercury levels were detected in some of the post-drilling samples. This mercury apparently derived from the barite, and DCE/GINR subsequently recommended that stricter requirements on barite should be implemented: The barite must have as low a content of mercury as possible, which means considerably below 1 ppm.

Another experience was that a chemical classified as 'red' indeed degraded slower (if at all?) than a related chemical classified as 'yellow', supporting the adoption of the OSPAR substitution principle.

In Greenland a new drilling mud strategy was approved in 2014 ([Link](#)). This prescribes that:

- all offshore chemicals planned to be used are classified according to the OSPAR guidelines, to Norwegian and Danish guidelines, and that they are recorded in the Danish register PROBAS.
- more rigorous requirements for the documentation of chemicals critical in an environmental context, including the all Norwegian requirements to offshore chemicals.
- more rigorous requirements for the documentation of chemicals planned to be discharged in high Arctic marine environments, including documentation for tests of biodegradability, toxicity and bioaccumulation in Arctic temperature regimes and with Arctic organisms.
- oil based drilling mud systems can be applied, provided no drilling mud/cuttings are discharged to the marine environment and that internal safety procedures and controls are intensified.

## 9.2 Appraisal activities

The activities during the appraisal phase are similar to the exploration activities (see above) and the impacts are assessed to be the same. However, there is an increased risk of cumulative impacts, as these activities usually occur over several years and include the drilling of many wells.

## 9.3 Development and production activities

In contrast to the temporary activities of the exploration phase, the activities during development and production are usually longer 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 as follows:

- solid and fluid waste materials and their disposal
- 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 generated, and they need to be treated or disposed of in one way or the other. Produced water is by far the largest contribution from an oil field (see Section 2.7).

Generally it is assessed that the environmental impacts from produced water discharged to the sea are low due to dilution. For example, the discharges during the 5% 'off normal time' in the Lofoten-Barents Sea has been assessed to have no impact on important fish stocks. In the same assessment, however, it is also stated that the long-term effects of the release of produced water are unknown (Rye et al. 2003). Concerns particularly regard Poly Aromatic Hydrocarbons (PAHs), hormone-disrupting phenols, radioactive components and nutrients in relation to toxic concentrations, bio-accumulation, fertilisation, etc. (Rye et al. 2003).

Norwegian studies reviewed by the Research Council in Norway (2012) conclude that produced water have effects on fish and other marine fauna. These effects include damage to genes and disrupted reproduction. The concentrations of produced water used for the experiments were similar to concentrations in the sea very close to release sites, indicating that the effects will occur only locally.

A study from Norway underlines the concerns expressed in relation to release of produced water. A study of exposure and uptake of PAHs in Atlantic cod and haddock in the marine environment off Norway used a station far from production sites as reference. However, it became clear that even at this reference site effects from PAHs on the fish could be measured. This means that there is significant background pollution from the oil production in the North Sea (also far from the production sites) and this may derive from produced water, disposed drilling mud and accidental spills (Balk et al. 2011).

Impacts on the marine environment from produced water can be reduced by re-injecting it into wellbores or into specific injection wells for example drilled for increasing recovery of oil. In 2013 approx. 40 million m<sup>3</sup> produced water were reinjected in Norway (Norsk olje & gass 2014).

When discharging produced water, international standards (OSPAR) must be applied, i.e. the oil content may not be above 30 mg/l. In Norway, in recent years released produced water has had an average oil content of 11 mg/l (Anonymous 2011a), and this is the result of applying BAT and BEP.

Nutrient concentrations can be high in produced water (for example ammonia up to 40 mg/l). When released to the environment, nutrients may act as fertiliser, which especially could impact the composition of primary producers (planktonic algae) (Rivkin et al. 2000 in, Armsworthy et al. 2005).

The concentrations of oil in produced water are on average low; nevertheless 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 for example seabirds' plumage (Fraser et al. 2006).

To test potential effects of produced water on organisms, cages with either Atlantic cod or blue mussels were positioned at various distances (0-5000 m) and different directions from oil platforms offshore Norway. In addition, two reference locations were used, both 8000 m away from the respective platforms. PAH tissue residues measured 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 compared to those found in cod from coastal waters (Hylland et al. 2008). The biological effects found in the blue mussels reflect exposure gradients and that the mussels were affected by components in the produced water. In another study, the genotoxic potential of water-soluble oil components on Atlantic cod has been documented (Holth et al. 2009).

The release of produced water into areas with ice gives reason for concern, since there is a risk of accumulation just below the ice, where degradation, evaporation, etc. are slow and the sensitive under-ice ecosystem, including eggs and larvae of polar cod, could be exposed (AMAP 2010).

### 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 blowout preventers. The handling and extent of such releases are regulated by the OSPAR convention, and these standards must be applied to minimise impacts in case of production in the assessment area. In addition, release of sanitary waste water occurs. The environmental impacts of these discharges are generally minor from a single drilling rig or production facility, but releases from many facilities and/or over long time periods could be of concern. Best Available Technology (BAT), Best Environmental Practice (BEP), application of international standards (OSPAR and MARPOL) and use of chemicals that cause low or no harm to the environment and reduction of their releases are the best way to minimise impacts and effects on the marine environment. In Norwegian offshore areas, the release of hazardous substances to the marine environment has been reduced by 99% over the past 20 years in applying these measures (SFT 2008).

Ballast water from ships poses a special biological problem, i.e. the risk of introduction of non-native and invasive species (also termed as Aquatic Nuisance Species –ANS) to the local ecosystem (Anonymous 2003a). This is generally considered as a severe threat to marine biodiversity. Blooms of toxic algae in Norway, for instance, have been attributed to the release of ballast water from ships. There are also many examples of introduced species that have impacted fisheries in a negative way (for example the comb jelly *Mnemiopsis* in the Black Sea or other ecosystems (Kideys 2002)).

At present, the Arctic Ocean is the least affected area by non-native invasive species as shown by Molnar et al. (2008). However, both increasing water temperatures, particularly in the Arctic, and the following increase of ships operating in Arctic waters (due to reductions in ice cover) may increase the risk of successful introduction of alien, invasive species.

There are methods to minimise the risks from releasing ballast water, and the IMO ballast water management convention has developed guidelines for this task (IMO 2009). The international convention has not yet been ratified by a sufficient number of states to enter into force. This is expected to occur soon. All vessels and drilling units involved in hydrocarbon activities in Greenland must follow the IMO guidelines or the relevant Canadian regulations.

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

### 9.3.3 Placement of structures

The construction of subsea wells and pipelines has the potential to destroy parts of important habitats on the seafloor. Examples could be sponge gardens and cold water coral reefs which are considered as particularly sensitive (Campbell & Simms 2009). Such habitats have so far not been documented for the assessment area (see above in Section 5.4.4).

Important habitats in this respect are also feeding grounds for bearded seal, walrus and king eider, which feed on benthic mussels and other invertebrates.

An assessment of the impact of subsea constructions must wait until locations for oil exploration and production are known and site-specific EIAs and studies have been carried out.

Structures may also have a disturbance effect, particularly on marine mammals. Most vulnerable in this respect are walrus, narwhalswhite whale and bowhead whale.

Illumination and flaring attract birds during the night (Wiese et al. 2001). In West Greenland this particularly relates to comon eider. Under certain weather conditions (for example fog and snowy weather) during winter nights, eiders are attracted to the lights on ships (Merkel & Johansen 2011). 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, Merkel & Johansen 2011).

A related problem is known from the North Sea, which millions of passerine birds cross at night during their autumn and spring migrations. Under certain weather conditions large numbers of passerine birds 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 migrating little auks has been expressed (Fraser et al. 2006). However, during the September 2009 survey, the highest densities of this species were found in the Canadian part of the Davis Strait, and this was confirmed by the subsequent tracking studies reported in Box 7. It has been shown that the attraction of birds can be mitigated by changing the illumination to colours not attracting birds, for example green (Poot et al. 2008).

Placement of structures will affect fisheries due to exclusion (safety) zones. These areas, however, are small compared to the total fishable area. In the Lofoten-Barents Sea area, the effects of exclusion zones on the fisheries are generally estimated as being low, except in areas where very localised and intensive fishery activity take place. In such areas, reduced catches may be expected because there are no alternative areas available (OED 2006).

Pipelines in the Lofoten-Barents Sea area are not expected to impact fisheries because they will be constructed in a way allowing trawling across them, although a temporary exclusion zone must be expected during the construction phase. Experience from the North Sea indicates that large ships will trawl across subsea structures and pipelines, while small ships often choose to avoid the crossing of such structures (Anonymous 2003b).

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 gives reason for other types of environmental impacts:

Rivers with spawning and wintering Arctic char can easily be obstructed resulting in the loss of a local population.

Onshore facilities may also be placed in habitats for unique coastal flora and fauna.



Aesthetic aspects must also be considered in a landscape conservation context when dealing with onshore activities. The risk of spoiling pristine wilderness is high.

Background studies in the field combined with careful planning can reduce such impacts on the landscape.

When dealing with potential effects on the tourism industry, landscape aspects are also important to consider. Greenlandic tourism's main asset – its unspoiled landscape – is readily rendered much less attractive by buildings, infrastructure and other facilities.

#### **9.3.4 Noise/Disturbance**

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

One of the more significant sources of noise during development and production are 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.

Depending on the production set-up, supply vessels might sail between offshore facilities and coastal harbours. Shuttle tankers could sail between crude oil terminals and the trans-shipment facilities on a regular basis, even in winter. The loudest noise levels from shipping activity result from large icebreakers, particularly when operating in ramming mode. Peak noise levels may then exceed the ambient noise level up to 300 km from the sailing route (Davis et al. 1990).

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

Helicopters produce strong noise that can scare marine mammals as well as birds. Particularly walruses hauled out on ice are sensitive to this activity, and there is risk of displacement of walruses from critical feeding grounds. Walruses have a narrow foraging niche restricted to the shallow parts of the shelf. Activities in these areas may displace the walruses to suboptimal feeding grounds or to coastal areas, where they are more exposed to hunting.

Seabird concentrations are also sensitive to helicopter flyovers. The most sensitive species is the thick-billed murre at breeding sites. These birds will often abandon their nests for long periods of time, and when scared off from their breeding ledges they may push eggs or small chicks off the ledge, resulting in

a failed breeding attempt (Overrein 2002). There are several breeding colonies of thick-billed murre in the assessment area. Also, concentrations of feeding birds can be sensitive, as they may lose feeding time due to the disturbance.

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

Flying in relation to mineral exploration is also regulated by special field rules issued by EAMRA. These rules encompass areas with staging and moulting geese, areas with moulting seaducks, etc. (Figure 49).

Concentrations of moulting sea ducks, especially king eiders, occur at many sites along the coasts of the assessment area. The effects of disturbance on such habitats 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.

Other activities could include blasting, which has the potential to cause behavioural disturbance and physical damage in whales (Lien et al. 1993, Ketten et al. 1993, Ketten 1995, Nowacek et al. 2007).

### 9.3.5 Air emissions

The large amounts of greenhouse gases released from an oil field will increase the total Greenland emission significantly. The CO<sub>2</sub> emission from Statfjord field in Norway, for example, is twice the total current Greenland CO<sub>2</sub> emission, which in 2012 was 611,700 tons (Nielsen et al. 2014). Such amounts will have a significant impact on the Greenland greenhouse gas emissions in relation to the Kyoto Protocol (to the United Nations Framework Convention on Climate Change). Another very active greenhouse gas is methane (CH<sub>4</sub>) which is released in small amounts together with other VOCs from produced oil during trans-shipment or from vented gas.

Moreover, it is important to remember, that possible produced oil, when combusted, also contributes to the global increase of CO<sub>2</sub> in the atmosphere.

Emissions of SO<sub>2</sub> and NO<sub>x</sub> contribute, among other effects, to the acidification of precipitation and may, thus, impact particularly nutrient-poor vegetation types inland far from the release sites. The large Norwegian field Statfjord emitted almost 4,000 tons NO<sub>x</sub> in 1999. In the Norwegian strategic EIA on petroleum activities in the Lofoten-Barents Sea area it was concluded that NO<sub>x</sub> emissions, even from a large-scale scenario, would have insignificant impact on the vegetation on land. It was, however, also stated that there was no knowledge about tolerable depositions of NO<sub>x</sub> and SO<sub>2</sub> in Arctic habitats, where nutrient-poor habitats are widespread (Anonymous 2003b). This lack of knowledge also applies to larger parts of the terrestrial environment bordering the assessment area.

Emission of black carbon (BC) from combustion is another matter of particular concern in the Arctic, because the black particles reduce the albedo effect on snow and ice surfaces and, thus, increase the melting. Emission of BC is particularly problematic when using heavy fuel oil. Heavy fuel oil is, howev-

er, not allowed in ships in Greenland waters in relation to oil activities, where only low-sulphur (< 1.5% by weight) gas oils may be used. In this context, it is worth mentioning that heavy fuel oil was banned from Antarctic waters by the international MARPOL (Annex 1) treaty from August 2011.

The international Convention on Long-Range Transboundary Air Pollution (LRTAP) includes all these emissions, and it was acceded by the kingdom of Denmark (incl. Greenland in 1982).

### 9.3.6 Cumulative impacts

Cumulative impacts are changes to the environment 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 simultaneously or over a longer period can be significant. Cumulative impacts also include activities such as hunting and fishing; moreover, climate change is also often considered in this context (Anonymous 2003a).

Cumulative effects could, for instance, occur due to many seismic surveys carried out at the same time in a restricted area. During a single survey many alternative habitats are still available, but extensive activities in several license blocks may e.g. exclude baleen whales from available habitats. This could reduce their food uptake and, consequently, their general 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 usually low. However, the overall amounts of produced water from a single platform are considerable, and these would increase significantly if many platforms are operating in the same area.

Bio-accumulation is another 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 the fauna living on the seafloor and in the water column and could, subsequently, be transferred to the higher levels of the food web i.e. seabirds and marine mammals feeding on benthic organisms or plankton (Lee et al. 2005).

Seabird hunting is widespread and intensive in West Greenland, and some of the seabird populations have been declining, mainly due to unsustainable harvest. Tightened hunting regulations were introduced in 2001, which was followed by reduced numbers of birds reported to the hunting bag record. In particular, common eider and thick-billed murre colonies in and near the assessment area have decreased in numbers over the past decades. Both species rely on a high adult survival rate, giving the adult birds many seasons to reproduce. The common eider population has been recovering since 2001 (Merkel 2010b), while the murre population still is decreasing in most of the colonies in West Greenland including the southern part of the assessment area (Merkel et al. 2014).

Extra mortality due to an oil spill or sub-lethal effects caused by contamination from petroleum activities have the potential to be additive to the hunting impact and thereby enhance the population decline (Mosbech 2002).

### 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 preventing discharges as much as possible. When water-based muds are used, additives containing oil, heavy metals, or other bio-accumulating substances should be substituted or criteria for the maximum concentrations should be established (PAME 2009). Only chemicals registered by HOCNF and the Danish product register, PROBAS, or the like are allowed, and only those classified as 'green' (PLONOR) or 'yellow' according to the Norwegian system based on OSPARs classification. 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 re-injection of produced water and drilling mud and cuttings (CRI). In the Arctic offshore Oil and Gas Guidelines, it is requested that 'discharge (of drilling waste) to the marine environment should be allowed only where zero discharge technology or reinjection are not feasible' (PAME 2009).

If zero-discharge is not possible, releases to the marine environment must, at a minimum, 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 on a case-by-case basis.

Disturbance can be mitigated by careful planning of any noisy activities in order to avoid activities in sensitive areas and in sensitive periods, based on detailed background studies of the sensitive components of the environment. Impacts from placement of structures inland are mitigated in the same way.

Finally, monitoring of the surrounding environment is an essential part of the mitigation, both during and after production, but also at exploration drilling. In this respect a proper baseline is needed. This is secured by the environmental studies plan, which is part of the EIA process (see EAMRA-guidelines to explorations drillings in. prep.).

The purpose of this monitoring is to record unexpected impacts in the marine environment and to document failures to comply with the environmental requirements given in the approval of the activities.

The results of the monitoring also provide an important tool for assessing whether the regulations are appropriate or should be adjusted for subsequent activities.

Monitoring must be carried out at several levels:

- At discharge points, to monitor levels of potentially hazardous substances
- In the surrounding environment, to document amounts and how far away impacts have occurred. This monitoring should proceed after the activities to follow any developments

- At regional level, to document the health and status of the ecosystem. This monitoring should focus on selected indicators and shall document potential cumulative impacts. This is most relevant if production is initiated.

### 9.3.8 Conclusions on development and production activities

Drilling activities continue during development and production phases, and drilling mud and cuttings are produced in much larger quantities than during exploration.

If these substances are released to the seabed (only in case of WBM), impacts are expected on the benthic communities near the release sites. Strict regulation based on specific toxicity tests of the mud chemicals and monitoring of effects on the sites is essential to mitigate impacts. However, the use of OBMs can also contribute to reduce environmental impacts on the seabed, as these muds need to be transported to land or reinjected.

The release giving most reason for environmental concern relates to produced water. Some studies have indicated that small amounts of oil and nutrients can impact fish and primary production, and there is also evidence of effects of several of the other marine ecosystem components. The best way to mitigate these effects is to prohibit discharge, alternatively, completely to clean the water before release.

There could be a risk of release of non-native and invasive species from ballast water and ship hulls, and this risk will increase with the effects of climate change. Thus ballast water management following international standards need to be in place.

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

Noise caused by the drilling activities, ship and helicopter traffic can affect marine mammals and seabirds. The most sensitive species are the colonial seabirds, bowhead whale, narwhal, white whale and walrus. There is a risk of permanent displacement of populations from critical habitats and, thus, for negative population effects.

Placement of structures has both biological and aesthetic impacts. The biological impacts mainly include permanent displacement from critical habitats – walrus being the most sensitive. Aesthetic impacts primarily include impacts on the pristine onshore landscape, which again may have an impact on the local tourism industry.

The commercial fishery may be affected by closure zones if rigs, pipelines and other installations are placed in the Greenland halibut fishing grounds. But the impact on the fishery will probably be relatively low.

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

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. Application of BEP, BAT and international standards, for example OSPAR (HOCNF) and guidelines (for example Arc-

tic Council) can contribute to reducing emissions to air and the sea. Furthermore, a discharge policy, as for example planned for the Barents Sea, will contribute substantially to minimise impacts.

Finally, an extensive three level monitoring program must be in place to secure and to develop further the mitigating measures: 1) onsite discharge monitoring (pipe concentrations), 2) focused chemical and biomarker environmental monitoring locally around the discharge sites and 3) regional monitoring of key ecosystem components.

#### **9.4 Decommissioning**

Possible impacts from decommissioning activities are mainly related to noise at the sites and to traffic, assuming that all material and waste are removed and transported out of the assessment area and deposited at a safe site. There is also a risk of pollution from accidental releases. These activities are usually short-term, and careful planning and adoption of BAT, BEP and international standards 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 oil spills

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## 10.1 Oil spills

In general, large oil spills are considered to be the most harmful incident to the marine environment, when dealing with oil exploration and exploitation (AMAP 2010). The probability of such an incident is low, and the global trend in spilled amounts of oil is decreasing (Schmidt-Etkin 2011). Nevertheless, the risk is apparent and the environmental impacts from a large spill can be severe and long lasting, particularly in an Arctic environment such as in the Baffin Bay region.

Several factors increase the potential for severe impacts of a large oil spill in the assessment area. Owing to the specific Arctic conditions (particularly low temperatures), the degradation of oil is reduced, thus prolonging potential effects. Harsh weather conditions and occurrence of ice during winter and spring may influence the distribution and fate of oil and also hinder an effective oil spill response or even make it impossible.

According to the AMAP oil and gas assessment, tankers are the primary potential source for spills (AMAP 2010). Another potential source will be a blowout during drilling, which in contrast to a tanker spill, is continuous and may last for days, weeks or even months. The deep-water blowout from the *Deepwater Horizon* disaster, for instance, lasted 87 days before it was stopped by the drilling of a relief-well.

### 10.1.1 Probability of oil spills

Large oil spills are very rare incidents. However, the risk cannot be eliminated, and the presence of icebergs in the assessment area increases the risk.

In relation to oil drilling in the Barents Sea, it has been calculated that statistically a blowout ranging between 10,000 and 50,000 tons would occur once every 4,600 years (small-scale development scenario) and once every 1,700 years in an intensive development scenario (Anonymous 2003b). The likelihood of a large oil spill from a tanker ship accident is generally estimated to be higher than for an oil spill due to a blowout (Anonymous 2003b). Another study estimated that the probability of a deep water blowout in the Greenland part of the Labrador Sea would be one blowout for every 8488 exploration wells drilled (Acona 2012).

Drilling in deep waters<sup>3</sup> and ultra-deep waters<sup>4</sup> increases the risk for a long lasting oil spill, due to the high pressures encountered in the well and due to the difficulties of operating in such deep waters. The water depth was among the many factors contributing to how long time it took (almost three months) to cap the *Macondo*-well (*Deepwater Horizon*) in 2010 (Graham et al. 2011).

<sup>3</sup> > 600 m according to Norwegian (NORSOK) standards – which are adopted by Greenland authorities and between 1000 and 5000 feet ≈ 305-1524 m according to US authorities (cf. Graham et al. 2011).

<sup>4</sup> > 5000 feet ≈ 1524 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, depending on the physical and chemical properties of the oil (light oil or heavy oil), how it is released (surface or subsea, instantaneous or continuous) and on the sea conditions (for example temperature, ice, wind and currents).

Fate of oil spills in West Greenland waters has been modelled by DMI on 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 off South Greenland (Ribergaard 2011).

General knowledge on the potential fate and degradation of spilled oil relevant for the Greenland marine environments has been reviewed by Pritchard & Karlson (2002). Behaviour of potential offshore oil spills in West Greenland with special regard to the potential for clean-up was evaluated by S.L. Ross (1992). 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 thick in the first day) that covers a large area. Wind-driven surface currents move the oil at approx. 3% of the wind speed. Wind also causes turbulence in the surface water layer, breaking up the oil slick into patches. As a result, some of the oil will be dispersed in the upper water column and it usually will stay in the upper 10 m (Johansen et al. 2003). Oil on the surface interacts with the water to form emulsions, both oil-in-water and water-in-oil, and these expand the volume of hazardous substances on the surface.

Low temperature and the presence of sea ice can hamper the dispersal process considerably, and the complexity of an oil spill in ice covered waters can be much larger than in open water.

The oil spill simulations performed so far have generally addressed the drift of oil on the sea surface (except the Statoil simulations). Depending on the density of the spilled oil, it may also sink to the seabed, including light oil adsorbed onto sediment particles in the water column (Hjermann et al. 2007). Sediment particles are found in many Greenland waters where the melt water from glaciers can disperse widely into the open sea.

#### Subsurface spills

Blowouts from a platform initially cause a surface spill, but may continue as a subsurface spill if the riser from the wellhead collapses. The risk of such a collapse is increased in deeper water. The oil in a subsurface blowout may float to the surface or remain in the water column for a longer period of time where it will typically be dispersed into small droplets. Oil type, oil/gas ratio, temperature and water depth are factors influencing the fate of oil from a subsea blowout, i.e. whether it remains in the water column as a dispersed plume or float to the surface. As the potential oil type and oil/gas ratio is unknown for the assessment area, it is too early to predict the behaviour of possible spilt oil. The oil in the DMI models of subsurface spills in West Greenland, for instance, quickly floated to the surface (Nielsen et al. 2006), while a SINTEF model estimated that oil would not reach the surface at all, but rather form a subsea plume at a depth of 300-500 m (Johansen et al. 2003).



The *Deepwater Horizon* oil spill in the Mexican Gulf in 2010 was unusual in size, location and duration, but in many ways similar to the *Ixtoc* blowout in 1979, also in the Mexican Gulf. It revealed new and not yet described ways spilled oil could be distributed in the environment, although this probably also happened during the *Ixtoc* spill (Jernelöv 2010). The unusual dispersion of the oil was mainly caused by the spill site on the seabed at more than 1500 m water depths. Dispersants were applied at the wellhead and subsea plumes of dispersed and dissolved oil were formed in different depths and moved long distances with the water currents (Diercks et al. 2010, Thibodeaux et al. 2011).

From studies of deep-water blowout events, Johansen et al. (2001b) predicted that a substantial fraction of the released oil and gas will be suspended in pelagic plumes, even in the absence of added dispersal agents. The fate of oil in deep water is likely to differ strongly 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 is the primary fate expected of oil suspended in the deep sea (Joye & Macdonald 2010). In the Gulf of Mexico, natural oil seeps contribute to the marine environment with an estimated 140,000 tons oil annually (Kvenvolden & Cooper 2003), so there was an intrinsic potential for microbial degradation (presence of the relevant organisms). Bio-degradation indeed was significant and moreover enhanced by the use of oil dispersing agent (Beyer et al. 2016).

Microbial degradation of oil, however, may have derived effects such as oxygen depletion, persisting for long a period of time in deep water, because oxygen is not replenished *in situ* by photosynthesis, as is the case for surface waters (Joye & Macdonald 2010), but that did not happen at the *Deepwater Horizon* spill (Lubchenco et al. 2012).

The amount of spilled oil from the *Deepwater Horizon* disaster has been estimated at 840,000 tons, making it the largest recorded peace-time spill. Moreover, at least 250,000 tons of natural gas was discharged. Unexpectedly, approx. 50% of the oil and all of the natural gas was sequestered in the deep water (Joye 2015). The fate of the oil was estimated by McNutt et al. (2012): Burned, skimmed and recovered constituted 25%, chemically dispersed 16%, naturally dispersed 16%, evaporated or dissolved 23% and the remaining 22% may have settled on the seabed or at coastlines.

Dispersants were added at the wellhead, and these probably contributed to the formation of a huge plume of dispersed and dissolved oil in depth between 900 and 1200 m (Hazen et al. 2010, Valentine et al. 2010, Lubchenco et al. 2012, Beyer et al. 2016). Oil from this plume settled on the seabed, and a region around the wellhead of at least 3200 km<sup>2</sup> was contaminated by oil falling out from the plume and from the oil on the surface (Valentine et al. 2012, Beyer et al. 2016).

Beyer et al. (2016) review the environmental effects of the *Deepwater Horizon* oil spill: Short term effect was found in offshore plankton populations, seabed communities were affected (especially cold water corals (White et al. 2012)) by sinking oil from the dispersed plume and from the surface, coastal fish population were affected and among seabirds and sea turtles and marine mammals high acute mortality was observed. Long-term effects have not yet been reported, but may still be a possibility among these groups. Salt marshes at the coast were affected, but seemed to have recovered after five years.

In this context, it should be mentioned that a Norwegian review of the environmental impacts of the *Deepwater Horizon* blowout concluded that it is difficult to use the environmental consequences to predict what would happen in a similar spill in Norway (Trannum & Bakke 2012), a conclusion that also applies to Greenland.

## 10.2 DMI oil spill simulations

As part of the ongoing SEA of oil activities in the Baffin Bay assessment area, DMI prepared a number of oil drift and fate simulations for hypothetical oil spills (Nielsen et al. 2008).

The simulations were carried out for four hypothetical spill events located on the shelf areas in the Greenland part of Baffin Bay. They were selected by GEUS to represent potential sites for offshore well drilling. The crude oil Statfjord, a medium-type crude (API density 886.3 kg/m<sup>3</sup>), 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 oil type is lighter than seawater and evaporates by around one third during the first 24 hours of a surface spill period.

For continuous spills, oil was released at a constant rate during the first ten days of the simulation period. The rate was 3,000 tons/day (in total 30,000 tons). For instantaneous spills, the amount of oil released was 15,000 tons. These amounts represent relatively large spills.

Three one-month wind periods were selected within the design year July 2004–June 2005. The five first periods represented a predominant wind from different directions at moderate wind speeds; the sixth period had spells of a strong southerly wind.

A total of 24 one-month oil drift simulations were carried out: four release sites, three simulation periods and two release depths. Additionally and for comparison, one simulation of an instantaneous surface spill was carried out for each spill site.

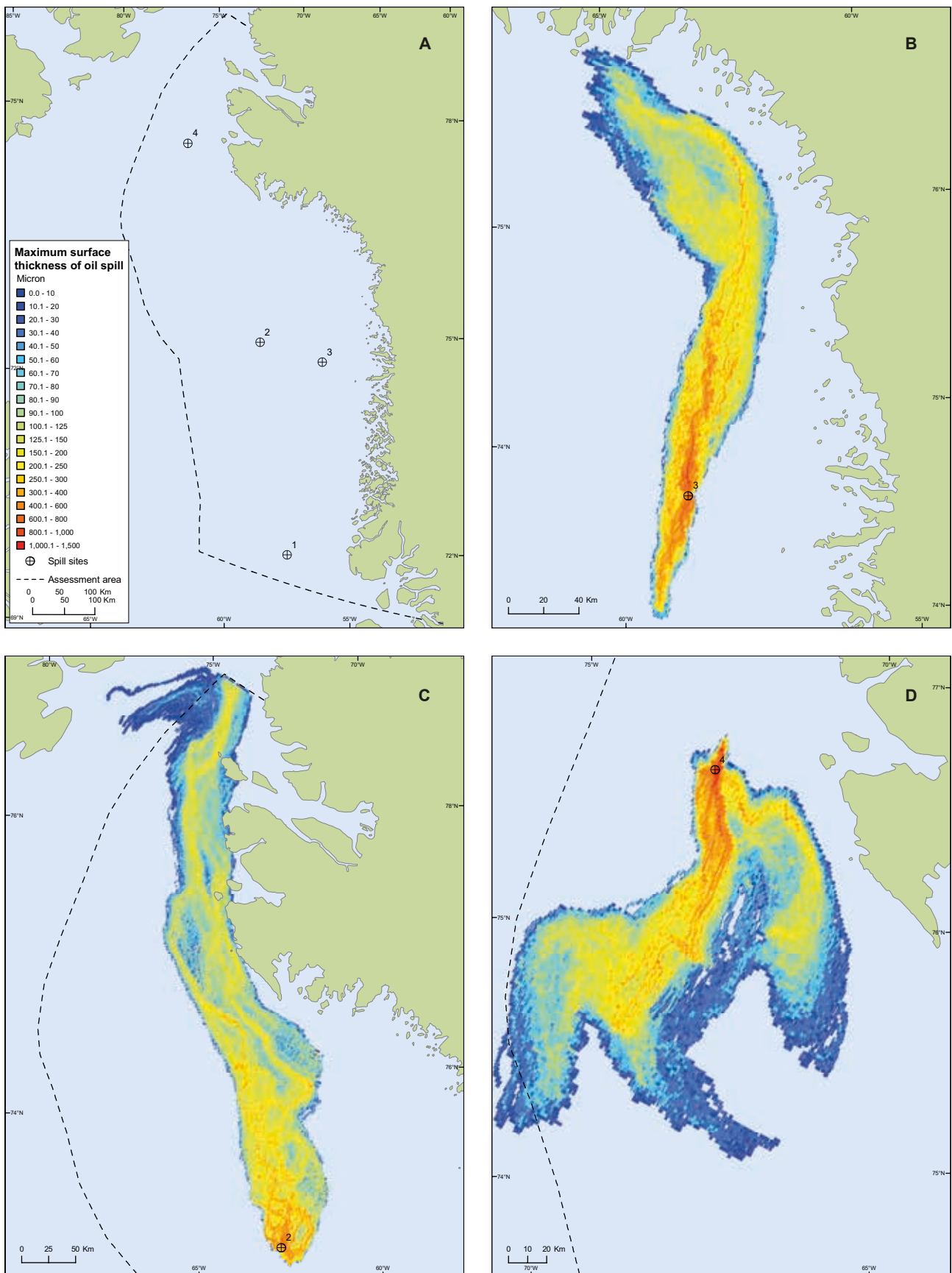
### Shores affected

By tracking all particles, the relative amount of oil settling on the shores was calculated. Oil ended up on the shores in only three spill situations, while in the other 21 situations the oil remained offshore under all of the selected wind conditions (Figure 54). No nearshore spills – with a much higher risk of shoreline pollution – were modelled.

### Sea surface area covered

The slick covered an area of 100–110 km<sup>2</sup> after 10 days, equivalent to a disc with a radius of 5–6 km in case of a continuous spill, and 10–12.5 km in case of an instantaneous spill. After 30 days, the slick radius had increased to 22 km, and the slick typically covered an area of 1,400–1,500 km<sup>2</sup> of very irregular shape.

In practice, spilled oil will form isolated patches within the area, with regions of high concentration interspersed with regions with no oil. This means that the area actually covered with oil is smaller than calculated. The model gives no indication of how much smaller the actual oil covered area was.



**Figure 54.** Examples of the DMI oil spill trajectory simulations (Nielsen et al. 2008). The maps B-D show the entire area swept by three different surface spills. The scale indicates the maximum thickness of the sea surface oil layer attained in the different cells during the 30 day simulation periods. Map A shows the four spill sites. B is a continuous spill from site 3 in August 2004. Map C is a continuous spill from site 2 in April 2005. Map D is a continuous spill from site 4 in October 2004. Note that the oil spill in map C hits the coasts, the spill in map B almost does and that oil spill in map D is far from any coasts.

### **Subsurface concentrations**

Quantification of subsurface concentrations based on output from the DMI model is complicated. In the Disko West assessment, this issue is discussed further with reference to the oil spill simulations in southern Baffin Bay (Nielsen et al. 2006, Mosbech et al. 2007b).

### **10.3 Oil spill in ice-covered waters**

Due to the roughness of the subsurface of the ice, oil does not move as far away from the spill site in ice-covered waters as in open waters, at least as long as the ice does not move. If an oil slick is 1 cm thick on average, a spill of 15,000 m<sup>3</sup> covers only approx. 1.5 km<sup>2</sup> below the ice, and less if thicker. This also means that very high oil concentrations may occur and persist for prolonged periods below the ice. Fauna there or in leads and cracks may therefore risk exposure to highly toxic hydrocarbon levels. The drift ice in the assessment area is very dynamic and moves with the currents and will probably contribute to spread spilled oil to larger areas compared to solid shore fast ice. In drift ice, spilled oil follows the movements of the ice and may be released to open waters far from the spill site when the ice disintegrates and thaws.

### **10.4 Other oil spill simulations**

WWF issued in 2016 a rapport on oil spill trajectories in Baffin Bay and Lancaster Sound (Reich et al. 2016). One of the release sites are of particular interest in relation to the assessments area described in the present report. This spill site is located in the northern part of the 'Pitu' block (Licence 2011/13). From this site spills from two subsurface blowouts are modelled. The results indicate that oil may drift very far and impact shorelines to the north of the spill site as far away as Cape Atholl and also to the east and south impacting shores on Baffin Island as far south as Cape Dyer.

### **10.5 Dissolution of oil and toxicity**

The amount of oil in the water column from an oil spill depends on different natural physical and chemical processes, such as dispersion, evaporation, oxidation, dissolution, biodegradation and emulsification. These processes are facilitated or hampered by climatic factors such as wind, temperature, presence of ice etc.

Different physical processes, for example wind and waves, produce oil/water emulsions, where oil is dispersed via oil droplets both horizontally and vertically. The horizontal drift depends on wind, water currents, waves and turbulent diffusion processes. The vertical transport of oil in the water column is driven by water currents, oil buoyancy and vertical turbulence from waves. The process of dissolution of oil in the seawater is of particular interest, as it increases the bio-availability of the oil components. Fractions of the total oil present in the aqueous phase following a period of mixing are water-soluble fraction (WSF) and water-accommodated fraction (WAF). The difference between these two fractions of dissolved oil is that WAF can contain micro-emulsions of fine droplets and, thus, does not represent a true solution free of emulsified oil, such as WSF (Kang et al. 2014, Singer et al. 2000) a large amount of information has been generated on the aquatic toxicity of oil, dispersants and dispersed oil. Unfortunately, much of these data are not comparable because of differing toxicological and analytical methods used, as well as frequent lack of analytical verification of exposures. Recently, a group of federal, state, academic and industry representatives from North America and Europe have been working toward stand-

ardizing both biological and analytical methods used to produce acute toxicity estimates of complex mixtures such as oil, dispersants and dispersed oil. This standardization provides guidelines for future investigations to be conducted in a sufficiently rigorous manner that both inter- and intra-laboratory datasets will be comparable, thus providing a more coherent and robust database from which to derive response guidance.

The WSF is a multi-compound fraction that is bioavailable and toxic to aquatic organisms (Melbye et al. 2009, Salaberria et al. 2014). The typical oil compounds in WSF from fresh oils include phenols, naphthalenes, 2-3 ring PAHs and so-called NSO compounds (highly polar compounds with nitrogen, sulphur, and oxygen atoms in their structures) (Word 2013). Melbye et al. 2009 showed that the main contributor to toxicity of the WSF was one of the most polar fractions, (besides the naphthalenes, PAHs, and alkylated phenols), which contained a large number of cyclic and aromatic sulfoxide compounds and low amounts of benzothiophenes.

The water soluble fraction (WSF) 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 showed that the concentration of water-soluble components in the ice decreases with ice depth, but that the components could be quantified even in the bottom ice core. A concentration gradient as a function of time was also observed, indicating migration of water-soluble components through the porous ice and out into the water through the brine channels. The concentration of water-soluble components in the bottom 20 cm ice core was reduced from 30 ppb to 6 ppb in the experimental period. Although the concentrations were low, the exposure time was long (nearly four months). This might indicate that the ice fauna could be exposed to a substantial dose of toxic water-soluble components and, at least in laboratory experiments with sea ice amphipods, sub-lethal effects have been demonstrated (Camus & Olsen 2008, Olsen et al. 2008). Leakage of water-soluble components to the ice is of special interest, because of a high bio-availability to marine organisms, relevant both in connection with accidental oil spills and release of produced water.

## 10.6 PAHs in the environment

Oil is a complex mixture of tens of thousands of compounds, in which polycyclic aromatic hydrocarbons (PAHs) are regarded as the contaminants that have the most serious long-term environmental effects (Martinez-Gomez et al. 2010) (see Section 7.2). Due to their toxicity, selected PAHs are listed as priority pollutants by the USA's Environmental Protection Agency (US EPA) and as high priority substances in the European Water Framework Directive (Directive 2000/60/EC) (European Commission 2001).

PAHs are acutely toxic down to 0.9 mg oil /l (0.9 ppm or 900 ppb), and Johansen et al. (2003) applied a safety factor of 10 to reach a PNEC (Predicted No Effect Concentration) of 90 ppb oil for 96-hour exposure. This was based on fresh oil which leaks a dissolvable fraction, mostly toxic for fish eggs and larvae, while weathered oil is less toxic.

PAHs are taken up by marine organisms directly from the water (via the body surface or gills) or through the diet, and as they are non-polar and lipophilic compounds they tend to accumulate in the fatty tissues of some marine organisms. Many studies have indicated that PAHs are more or less easily metabolised by invertebrates and generally efficiently metabolised by verte-

brates such as fish (review by Hylland et al. 2006). Therefore, and in contrast to other 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), and filter feeding zooplankton can be exposed to high levels through filtering out oil droplets containing PAHs from the surrounding water (Hylland et al. 2006).

Marine sediments function as an ultimate sink for PAHs, and these are therefore useful for environmental monitoring (Beyer et al. 2010, HELCOM 2010). PAHs tend also to accumulate in bivalves due to low biotransformation capabilities, and bivalves can also be useful for assessments in the environment. Fish, as other aquatic vertebrates, have well developed enzymatic systems that efficiently metabolise PAHs, and therefore assessment of environmental PAH levels using fish is done by analysis of biliary metabolites (Beyer et al. 2010).

Since some PAHs are known to be potent carcinogens, this contaminant class is generally regarded as a high priority for environmental pollution regulation and in ecological risk assessment of industrial effluent discharges (Hylland et al. 2006, Neff 2002).

Toxicity data is a key factor in risk assessment, and since there is a lack of information on effects of toxic substances in Arctic organisms, such data on local species is essential for risk assessment in Arctic ecosystems (Chapman & Riddle 2003, 2005, Mosbech 2002, Olsen et al. 2011). There is a particular need for toxicity data on early life stages, as they are most vulnerable (Frantzen et al. 2012, Khan & Payne 2005, Short et al. 2003) there is an increasing need to understand the potential anthropogenic impacts of oil-related compounds on sub-Arctic and Arctic organisms, particularly those in coastal habitats.

## 10.7 Experience from the *Deepwater Horizon* blowout

Boehm et al. (2011) reported the results of analyses for total petroleum hydrocarbons (TPH) and total polycyclic aromatic hydrocarbons (TPAH) in water column samples collected in the vicinity of the spill from the *Deepwater Horizon* incident in the Gulf of Mexico during the 3-month release period (May through mid-July) and in a 3 month period after the release ended. Overall, during the release, concentrations of TPAHs in water samples ranged from not detected (ND) to 146,000 µg/L (ppb), and 85% of all samples had TPAH concentrations of < 0.1 ppb, essentially at or near background levels. Concentrations attenuated rapidly with distance from the wellhead and were generally lower than 1 ppb 24-32 km away, in one direction out to 65 km.

In another study, PAH concentrations associated with acute toxicity were located in discrete depth layers between 1000 and 1400 m, extending at least as far as 13 km from the well head (Diercks et al. 2010).

A baseline study of sediment PAH concentrations following the *Deepwater Horizon* blowout conducted within several months after the accident showed that PAHs ranged from 0.01 to 0.070 µg/g (ppm), which according to international sedimentary quality guidelines (ERL-ERM) indicated a low probability of harmful effects to benthic organisms (Botello et al. 2015). Chemical analysis of sediments sampled during repeated surveys between June 2010 and June 2012 to test for selected PAHs as indicators of contamination due to the *Deepwater Horizon* spill, showed that PAHs in samples from the continental slope in May 2011 were highest near the well site and were reduced in samples

taken one year later. PAHs from continental shelf sediments during the spill (June 2010) ranged from 10 to 165 ng/g (ppb) (Snyder et al. 2014).

Boehm et al. (2011) also reported other substances from water column samples near the *Deepwater Horizon* blowout. Total Petroleum Hydrocarbons (TPH) ranged from ND to 6130 mg/L (ppm) and BTEX (Benzene, Toluene, Ethylbenzene and Xylene) was measured for the most part at values <0.1 ppb, though higher values >100 ppb were encountered especially near the well. The TPAH, TPH and BTEX concentrations decreased rapidly after the well was closed on 15 July 2010 (Boehm et al. 2011).

## 10.8 Oil spill effects in the environment

The effects of an oil spill on organisms in the marine environment can be divided into two: the effects due to the physical contact (for example of bird plumage and fish eggs) and the toxic effects due to skin contact, ingestion or inhalation. Physical contact may cause acute effects, while toxic effects can cause both acute and chronic effects.

Exposure to oil also involve indirect effects, as oil in the environment may interfere with other environmental stressors, both natural and anthropogenic, or it may impact food resources for species not directly affected by the oil. Such effects are also important to consider and assess when effects of oil pollution are evaluated (Whitehead 2013).

Table 11 gives an overview of potential impacts from a large oil spill.

**Table 11.** Summary of potential impacts from a large surface oil spill on VECs in the Baffin Bay assessment area. See Table 9 and text for explanation.

VEC	Potential overlap	Risk of impact on critical habitats	Potential impacts – worst case		
			Duration	Sublethal effects	Direct mortality
Prim. prod.	large	yes	short term	minor	minor
Zooplankton	large	yes	short term	minor	minor
Benthic fauna	large	yes	long term	major (L)	major (L)
Benthic flora	large	yes	long term	major (L)	major (L)
Ice flora and fauna	large	yes	short term	major (L)	major (L)
Greenland halibut	small	yes	short term	minor (L)	none
Arctic char	large	yes	long term	major (L)	minor (L)
Polar cod under ice	large	yes	short term	major (L)	major (L)
Fish egg and larvae	large	yes	short term	major (L)	major (L)
Fulmar	large	yes	long term	major (R)	major (R)
Common eider	large	yes	long term	major (R)	major (R)
King eider	large	yes	long term	major (R)	major (R)
Ivory gull	large	yes	long term	major (R)	major (R)
Arctic tern	large	yes	long term	major (R)	minor (R)
Thick-billed murre	large	yes	long term	major (R)	major (R)
Little auk	large	yes	long term	minor (R)	major (R)
Walrus	large	yes	long term	major (R)	moderate (R)
Ringed seal	small	no	long term	moderate (R)	minor (R)
Bearded seal	small	no	long term	moderate (R)	minor (R)
Narwhal	large	yes	long term	major (R)	minor (R)
White whale	large	yes	long term	major (R)	minor (R)
Bowhead whale	large	yes	long term	major (R)	minor (R)
Polar bear	large	yes	long term	moderate (R)	major (R)
Com. fisheries	large	yes	long term	–	–
Hunting	large	yes	long term	–	–
Tourism	large	yes	long term	–	–

## 10.8.1 Oil spill impact on plankton and fish incl. larvae of fish and shrimp

### Effects on adult fish and shrimp

Petroleum hydrocarbons may injure fish through direct or indirect pathways and via either acute or chronic effects. Due to dispersion and dilution of oil in open waters and avoidance behaviour of many fish, adult fish populations may not be exposed to lethal concentrations of oil. Adult fish may, however, be exposed to oil compounds from the sediment and dietary sources, especially if prey organisms do not possess an efficient metabolising system to clear them from oil compounds. This is especially a risk in sheltered coastal areas such as bays and fjords, where concentrations of oil compounds can result in high fish mortality.

A series of studies on fish, reviewed by Hylland (2006), have shown a causality between exposure to petrogenic PAHs (from sediment) and (1) increased content of bile metabolites, (2) induced hepatic cytochrome P-4501A, (3) elevated concentrations of DNA adducts in liver, and (4) increased prevalence of neoplasia (cancer) in liver. Studies of biological responses in fish from different coastal sites in the Gulf of Mexico following the *Deepwater Horizon* spill, linked oil exposure to sub-lethal effects. These effects were characterised by genome expression and associated immunohisto-chemistry, despite very low concentrations of hydrocarbons remaining in water and tissues (Whitehead et al. 2012).

A review of the available literature addressing the responses of estuarine fish to the *Deepwater Horizon* spill by Fodrie et al. (2014), documented that effects at the individual level were widespread, but failed to detect effects at the population level. This could be explained by factors obscuring negative populations effects and factors dampening population-level costs, such as behavioural (spatial/dietary) avoidance, oil concentrations below toxic levels for fish in nature, sub lethal effects that do not impact fitness, impacts occurring prior to density-dependent bottlenecks or other compensatory processes and also the representativeness of model species in laboratory assays (Fodrie et al. 2014).

Adult northern shrimp live at and near the bottom in relatively deep waters (100-600 m), where oil concentrations from a potential surface spill will be very low, if detectable at all. No effects were seen on the shrimp stocks (same species as in Greenland) in Prince William Sound in Alaska after the large oil spill from *Exxon Valdez* in 1989 (Armstrong et al. 1995). A subsea blowout creating high concentrations in the water column may, on the other hand, hit northern shrimp stocks such as those in West Greenland. How shrimp stocks respond to such an impact is unknown. However, surprising results were found in Barataria Bay, one of the places hardest hit by the *Deepwater Horizon* spill. Here shrimp numbers actually increased the year after the spill due to reasons not yet known (Cornwall 2015).

Sublethal effects on penaid shrimps have been shown through exposure to petroleum hydrocarbons. These included cytological and histological damage to the hepatopancreas, the main detoxifying organ in shrimp (Sreeram & Menon 2005).

### Fish and shrimp larvae

Fish/shrimp eggs, embryos or larvae are vulnerable to direct contact with oil. The adverse effects are e.g. due to ingestion and dermal absorption of toxicants, smothering of gas- and ion-exchange surfaces or the loss of the epi-



thelial mucus that protects fish from infections. Early life-history stages (for example embryos, larvae, juveniles) are often highly susceptible to physiological stressors. Indeed, aqueous exposure of zebrafish (*Danio rerio*) embryos to seven non-alkylated PAHs caused direct effects on cardiac conduction, which had secondary consequences for late stages of heart and kidney development, neural tube structure and formation of the craniofacial skeleton. Additionally, pyrene, a four-ring PAH, induced anaemia, peripheral vascular defects and neuronal cell death (Incardona et al. 2014) including cardiac dysfunction, edema, spinal curvature, and reduction in the size of the jaw and other craniofacial structures. It has also been shown that environmentally realistic exposure (1–15 µg/L total PAH) to WAFs of field-collected *Deepwater Horizon* spill oil samples caused specific dose-dependent defects in cardiac function in embryos of three pelagic fish: bluefin tuna (*Thunnus thynnus*), yellowfin tuna (*T. albacares*) and an amberjack (*Seriola* sp.) (Incardona et al. 2014).

Exposure studies with embryos and eggs of pacific herring (*Clupea pallasii*) have shown that even low aqueous concentrations of petroleum hydrocarbons cause effects such as genetic damage, physical deformities, yolk sac edema, reduced mitotic activity, lower hatching weight, premature hatching, malformations, mortality, decreased size and inhibited swimming (Carls et al. 1999, Kocan et al. 1996). Oil-derived compounds from weathered oil in sediments (slow release stressor) can cause continuous adverse effects on fish species that deposit benthic eggs or feed demersally (Culbertson et al. 2008).

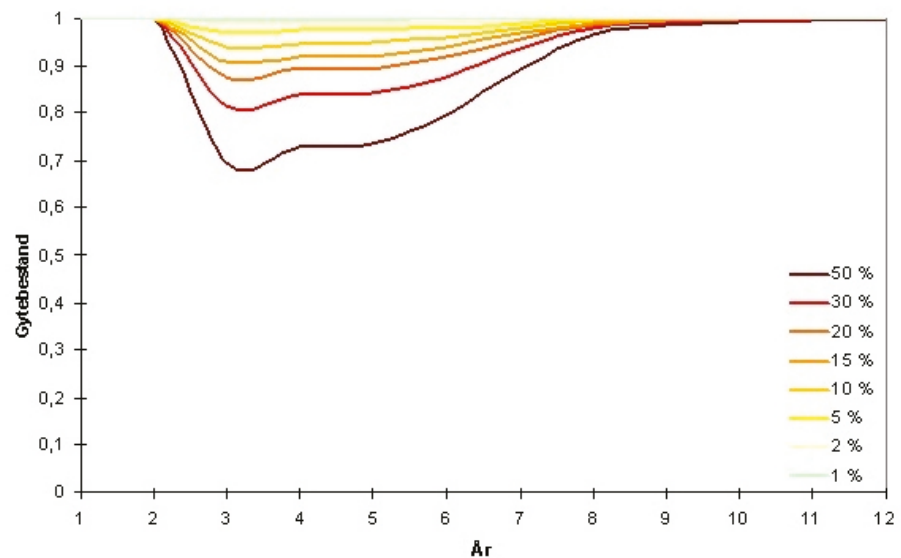
The exposure study with field mesocosms in Barataria Bay following the *Deepwater Horizon* spill demonstrated that exposure to nonlethal concentrations of petroleum hydrocarbons can reduce growth rates of juvenile penaeid shrimp (Rozas et al. 2014).

Theoretically, impacts on fish and shrimp larvae may be significant and reduce the annual recruitment strength with some effect on subsequent populations and related 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.

Moreover, species with distinct spawning concentrations and with eggs and larvae in distinct geographic concentrations in the upper water layer may be particularly vulnerable. The Barents Sea stock of Atlantic cod is such a species where eggs and larvae may be concentrated in the upper 10 m in a restricted area. As oil is also buoyant, the highest exposure of eggs is under calm conditions while high energy wind and wave conditions mix eggs and oil deeper into the water column, where both are diluted and the exposure reduced. As larvae grow older their ability to move around becomes increasingly important for their depth distribution and their ability to avoid oil in the water.

Based on oil spill simulations for different scenarios and different toxicities of the dissolved oil, the individual oil exposure and population mortality on cod egg and larvae has been modelled (Johansen et al. 2003). The population impact is, to a large degree, dependent on whether there is a match or a mismatch between high oil concentrations in the water column (which will only occur for a short period when the oil is fresh) and the highest egg and larvae concentrations (which will also only be present for weeks or a few months, and only be concentrated in surface water in calm weather). For combinations of unfavourable circumstances and using the PNEC with a 10 X safety factor, there could be losses in the region of 5%, and in some cases, up to 15%, for a blowout lasting less than 2 weeks, while very long-lasting blowouts could

**Figure 55.** Estimated reduction and recovery in Barents Sea cod spawning biomass following large losses of egg and larvae due to large 'worst case' oil spills. Gydebestand = spawning stock, År = year. Sources: Anonymous (2003b), Johansen et al. (2003).



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 55).

However, Hjermmann et al. (2007) reviewed the impact assessment of the Barents Sea stock of Atlantic cod, herring and capelin by Johansen et al. (2003) and suggested improvements by emphasising oceanographic and ecological variation more 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 ecosystem context. Qualitatively, modelling can assess at which places and times an oil spill may be expected to have the most significant long-term effects.

Compared to the Lofoten Barents Sea-area, there is much less knowledge available on concentrations of eggs and larvae from West Greenland, and particularly in the assessment area. However, the highly localised spawning areas with high concentrations of eggs and larvae for a whole stock near the surface as seen in the Lofoten-Barents Sea have not been reported from the assessment area. The overall picture here is that fish larvae are widespread and found in low concentration, although patches which may hold relatively high concentrations may occur. Another factor of importance is the vertical distribution of eggs and larvae. Eggs of Atlantic cod are concentrated in the upper 10 m of the water column, whereas larvae of shrimp and Greenland halibut also are found in deeper waters and therefore would be less exposed to harmful oil concentrations from a surface oil spill.

The above implies that an oil spill will most likely impact a much smaller proportion of a season's production of eggs and/or larvae of Greenland halibut and northern shrimp than modelled for cod in the Barents Sea, and that impacts on recruitment to Greenland halibut and northern shrimp stocks will most likely be insignificant. However, a subsea blowout with the properties and quantities of the *Deepwater Horizon* spill in 2010, where huge plumes of dispersed oil occurred in the water column may expose eggs and larvae over much larger areas and depth ranges and potentially impact the recruitment and stock size of these bottom-living species.

Polar cod eggs accumulate just below the ice. The eggs have a long development time and hatch when the ice starts to disintegrate and melt (Bouchard & Fortier 2011). As oil spilled under ice tends to accumulate in the same space, there is a potential risk for overlap and impacts on the recruitment to the polar cod population. Presently, we have no knowledge on possible aggregations of spawning polar cod and subsequent accumulation of eggs and larvae in the assessment area. But if such aggregations occur, an oil spill may have the potential to impact recruitment and stock size. This could have effects up through the trophic web, as polar cod is an ecological key species.

### 10.8.2 Effects on copepods, the food web and important areas

Copepods are very important in the food web, as they represent one of the most important groups in terms of energy transfer to upper trophic levels. Among the large copepods, the *Calanus* species *C. hyperboreus* and *C. glacialis* are dominant throughout the Arctic region (Word 2013). Copepods can be affected by the toxic oil components from WAF and WSF in the water below a surface oil spill. Recent exposure experiments with *Calanus* spp. showed that PAHs can accumulate in these animals and cause effects such as lowered reproductive output, reduced grazing and increased mortality rate (Nørregaard et al. 2015).

However, given the usually restricted vertical distribution of these components in the surface layer and the wider depth distribution of the copepods, this is not likely to cause major population effects. This was also the conclusion of a study of the potential effects of oil spills on copepods in the Barents Sea (Melle et al. 2001): populations were distributed over such large areas that a single surface oil spill would only impact a minor part and not pose a threat to the populations.

Other studies also showed negative effects of pyrene (PAH) on reproduction and food uptake among *Calanus* species (Jensen et al. 2008) and on survival of females, feeding status, and nucleic acid content in *Microsetella* spp. from Western Greenland (Hjorth & Dahllöf 2008). The pyrene concentrations applied were, however, difficult to compare to actual spill situations. Negative effects of combined temperature changes and PAH exposure on pellet production, egg production and hatching of *C. finmarchicus* and *C. glacialis* have also been demonstrated (Hjorth & Nielsen 2011). Effects from both naturally dispersed and chemically dispersed oil, such as increased mortality and decreased filtration rates in filter feeding copepods *C. finmarchicus* have also been demonstrated, with only slight differences between the treatments (Hansen et al. 2012).

Comparison of acute toxicity, expressed as mortality of herbivorous copepods (*Acartia tonsa*) and growth inhibition of a primary producer (*Skeletonema costatum*) of WAFs from non-weathered and naturally weathered oil, shows a general decrease in effect as a function of weathering degree (Faksness et al. 2015).

Finally it has been shown that there is a significant inverse correlation between the size and the sensitivity to crude oil exposure for marine copepods (Jiang et al. 2012) - smaller species are more sensitive. This may be related to the higher surface to volume ratio of small organisms.

Microzooplankton is an important element in the food web, and a recent study showed high sensitivity to chemically dispersed crude oil exposure (Almeda et al. 2014). Increased mortality of microzooplankton may result in indirect

effects of oil spills on copepods, through disruption of the trophic web and, consequently, in the structure and dynamics of the planktonic communities.

A subsurface spill, such as the *Deepwater Horizon* spill, where huge subsea plumes of dispersed oil were found at different depths, may impact copepod populations to a much higher degree than a surface spill. However, studies of zooplankton assemblage structure in the northern Gulf of Mexico following the *Deepwater Horizon* spill showed a surprising response among some taxa, including copepods, namely that they had higher densities during the oil spill year. This may be related to the increased microbial production. Variations in assemblage structure were observed, but they were weak and recovery of the zooplankton community was rapid (Carassou et al. 2014). An exposure study following the *Deepwater Horizon* spill on meiobenthic copepods showed reduced abundance, both on exposure to oil and to oil with added dispersant (Elarbaoui et al. 2015).

Important areas for plankton including fish and shrimp larvae are often where hydrodynamic discontinuities occur. Special attention should therefore be given to the implication of oil spills in connection with such sites, particularly during the spring bloom. Fronts, upwelling areas and the marginal ice zone are examples of such hydrodynamic discontinuities, where high surface concentrations of phytoplankton and zooplankton, including shrimp and fish larvae, can be expected. However, information available on such events in the assessment area is limited. To the south of the assessment area, in the Disko Bay, it was shown that density and distribution of chlorophyll (as a measure of primary productivity) in spring 2006 had a wide spatial and temporal variability and that high chlorophyll levels (spring bloom) were distributed over large areas (Frederiksen et al. 2008).

An oil spill at minimum has the potential to impact small and localised primary production sites, while primary production as a whole most likely will only be slightly impacted even during a large surface spill in open waters. The consequences from a subsurface spill of *Deepwater Horizon* dimensions are more difficult to assess, as the available information is too limited.

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

### **10.8.3 Oil spill impacts on benthic flora**

Oil spills often affect the plant-dominated intertidal and subtidal habitats that serve as nursery, feeding and breeding grounds for many different organisms, including fish. The direct impact of an oil spill is an expected mass mortality among macroalgae and benthic invertebrates on oiled shores from a combination of chemical toxicity and smothering. Another more subtle way oil spill can impact algae is by petroleum hydrocarbons interfering with the sex pheromone reaction, as observed in the life history of *Fucus vesiculosus* (Derenbach & Gereck 1980).

There are different reports on the impact of oil contamination on macroalgal vegetation and communities. After the *Exxon Valdez* oil spill in 1989 in Alaska, the macroalgae cover in the littoral zone (mainly *Fucus gardneri*) was lost. It has taken many years to fully re-establish these areas, and some areas were still considered as recovering in 2010 (NOAA 2010). Strong fluctuations

in the cover were observed during the recovery phase, and they may be a result of the interactions between grazers and the macroalgae, as was the case 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 recovering *Fucus* population (for example genetics, size and age), which made it more vulnerable to natural environmental impacts (for example 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 (BIOS project), which was conducted by Cross et al. (1987).

The scenarios of the *Exxon Valdez* accident and the BIOS project were somewhat different. The oil types and state of weathering were different (Sergy & Blackall 1987). 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 added to the impacts of the oil contamination in Prince William Sound.

After the *Exxon Valdez* oil spill, adult *Fucus* plants were coated with oil, but did not necessarily die. Part of the clean-up effort involved washing shores with large volumes of high-pressure hot water. 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 (3-4 years), 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. For example were extended recovery times recorded on shores badly affected by dispersants after the *Torrey Canyon* spill in South England (Hawkins et al. 2002)

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

Antarctic benthic diatom communities were exposed to oil and showed significant declines up to 80% and significant effects on community composition even after 5 years (Polmear et al. 2015).

Finally a review of studies of phototoxicity of oils, dispersant and dispersed oils for algae and aquatic plants (Lewis & Pryor 2013) showed that effect varied by as much as six orders of magnitude due to experimental diversity. This indicates that such studies should be applied with caution if phototoxicity of oil is to be predicted or sensitive species, life stages and response parameters are to be identified. Or in other words, evidence-based risk assessment for most aquatic plants to petrochemicals and dispersants is not supported by the current toxicity databases.

#### 10.8.4 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 has 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 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. Another study of a benthic community monitored a series of stations beginning in 2002 following the *Prestige* oil spill, and showed that the original biodiversity decreased in the studied area with a loss of 16 species – from 57 in 2002 (before the spill) to 41 species in 2004. Five years later, the benthic communities had recovered, although a new composition of the macrofauna was observed (Castège et al. 2013).

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.

After the *Deepwater Horizon* spill, a study found what was termed as severe and moderate reduction in fauna abundance and diversity in an area covering 148 km<sup>2</sup> around the wellhead (Montagna et al. 2013), and that the effects were correlated to THC and TPAH contents and distance to the wellhead. Moreover, the authors of this study estimated that recovery rates would be slow, in the order of decades or longer.

Studies on and experiments with oil contaminations in benthic communities have shown that impacts for example occur on species composition, behaviour of the affected species, vertical distribution in the sediments (including bioturbation activity) (Baguley et al. 2015, Ferrando et al. 2015, Gilbert et al. 2014). Studies of these aspects are therefore necessary in order to estimate real (structural and functional) and long-term effects of oil contamination on benthic communities (Gilbert et al. 2014).

In the assessment area, the shallow water (down to 50 m) communities generally have high species richness (bivalves, macro algae etc.) and the fauna is available to higher trophic levels such as eiders and walruses. Another characteristic of the benthic communities in the assessment area is that individuals of several species are very long lived with an estimated maximum age of more than 25 years (especially the bivalves, *Mya* spp., *Hiatella arctica*, *Chlamys islandica* and the sea urchin *Strongylocentrotus droebachiensis*). Moreover, they often constitute the majority of the biomass. Finally, many species are only represented with a single specimen in a sample, showing that they are widely dispersed in very low densities. These facts are all indicative of a slow recovery potential after any type of disturbance that causes mortality of these old and dispersed individuals. It also implies that mortality induced from an oil spill or from exploration activities potentially can cause a significant reduc-

tion in the total species richness for a long time. It is, however, not possible to designate particularly sensitive areas or even to assess impacts of potential oil spills on the seabed communities of the assessment area, as benthic surveys, especially in the offshore areas, are missing.

#### **10.8.5 Oil spill impacts on ice habitats**

Oil spilled in more or less ice covered waters is usually not exposed to the same weathering processes as in ice free waters. Temperatures are low, wave action is dampened, and these conditions lower evaporation, natural dispersion and emulsification. Dampening effects of ice reduce mixing energy needed for dispersant applications. Spilled oil moves with the ice under pack ice conditions, where the speed of the drifting ice influences film thickness (faster = thinner) and area distribution. The ice itself can encapsulate oil as the ice begins to freeze. The rate of emulsification and natural dispersion usually decreases with increasing ice coverage, but ice-ice interactions can also induce emulsification. The oil film thickness increases with increasing ice coverage, but there is limited knowledge of oil-ice interactions (Word 2013). However, ice can also facilitate *in situ* burning of an oil spill (Buist & Dickins 2003, Buist et al. 2013).

Spilled oil can be entrapped in the ice, float between broken ice, accumulate under the ice, be submerged and can also accumulate in melt ponds. Oil entrapped in the ice can be released into the water during the melting season in a relatively un-weathered condition and far from the spill site. In the spring and summer season, chemical photo-oxidation of oil may become an important hydrocarbon degradation process (Word 2013). These particular oil-ice interactions imply that the oil will retain much of its potential toxicity upon release from the ice, and/or toxicity of oil components may be increased due to the photo-oxidation processes, which have to be taken into consideration when making toxicological assessments.

The water-soluble components released from encapsulated oil may be transported through the brine channels, thereby exposing sea ice microbes in the brine and the underlying water to low levels of toxic water-soluble components for a potentially prolonged period of time (Word 2013).

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).

As described above, polar cod is probably sensitive to oil spills in ice due to the spawning behaviour. In experiments, both in the laboratory and in the field, polar cod have been exposed to PAHs and crude oil, and several sub-lethal effects were demonstrated. 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 question is how sensitive the ice-associated ecosystem is to oil spills. The available knowledge is very limited (Camus & Dahle 2007, AMAP 2010), and the flora and fauna (at least in areas dominated by first-year ice) are very resilient as the communities has to re-establish each season when new ice is formed. But as indicated above, polar cod could be particularly sensitive due to the fact that their eggs stay for a long period just below the ice, where oil also will accumulate (AMAP 2010).

The Baffin Bay assessment area is almost completely covered by sea ice in the period December-April, for which reason oil spills in ice are a risk, an issue to be especially addressed if production of oil is decided.

#### 10.8.6 Oil spill impacts in coastal habitats

One of the lessons learned from the *Exxon Valdez* oil spill was that the near-shore areas were the most impacted habitats (NOAA 2010). Oil was trapped in shallow bays and inlets, where oil concentrations could build up in the water column to levels that were lethal to adult fish and invertebrates (for example McCay 2003). A status report from NOAAs post spill monitoring programs (Shigenaka 2014) concluded that recovery of shorelines generally was rapid and lasted up to 4 years depending on how the shores were treated after the spill.

Many of the animal populations living in this habitat in Prince William Sound have now recovered (birds, fish), for example the sea otter population was declared as recovered in 2013 (Ballachey et al. 2014). But certain populations of other affected species are still under recovery and as late as in 2014, the pigeon guillemot (a close relative to the black guillemot in Greenland) and pacific herring were assessed as 'not recovered' (EVOS 2014a [Link](#), EVOS 2014b [Link](#), Shigenaka 2014). However, other natural variability may contribute to the slow recovery and/or to change the living conditions for these populations (Wiens 2013).

A much smaller spill (600 m<sup>3</sup>) with diesel in the Antarctica in 1989 (Bahia Paraiso) also resulted in severe impacts especially in the intertidal zone (Sweet et al. 2015). But both the temporal and spatial of the effects in the environment were limited, primarily due to the volatile nature of the spilled oil (Sweet et al. 2015).

An oil spill resulting from an activity in the assessment area and reaching the coast, has the potential to reduce stocks of capelin spawning there, both by exposing the adult fish and the eggs and larvae to high oil concentrations. Arctic char may be forced to stay in oil contaminated shallow waters when they assemble before they move up into their native river to spawn and winter.

In coastal areas, oil can also be buried or absorbed as sub surface oil residues (SSOR). This was the case in Prince William Sound, where oil was buried in gravel and absorbed in peat. Some of the buried oil was sealed from the atmosphere and is still (in 2014) a source for continued (chronic) exposure (Shigenaka 2014), although the bioavailability of this oil is disputed (Page et al. 2013).

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. More than 90% of the oil located on the surface and all of the subsurface oil originated from the *Exxon Valdez* (Short et al. 2004).

Oil from a marine oil spill may also contaminate terrestrial habitats occasionally inundated at high water levels. Salt marshes are particularly sensitive and they represent important feeding areas for example for geese. During the *Braer*-spill in the Shetland Islands spray with oil was carried by wind and impacted fields and grasslands high above, but close to the coast.

Similar effects could occur in some of the coastal habitats in the Baffin Bay area.



### 10.8.7 Oil spill impacts on seabirds

It is well documented that birds are extremely vulnerable to oil spills in the marine environment (Schreiber & Burger 2002), and particularly birds that rest on and dive from the sea surface, such as auks, seaducks, cormorants and divers (loons), are highly exposed to oil floating on the sea. This particular vulnerability is attributable to their plumage. Oil makes the feathers stick together, destroying their insulation and buoyancy properties of the plumage. 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 in this way has both sub-lethal and more long-term effects. However, the main cause of seabird losses following an oil spill is direct oiling of the plumage.

Many seabird species aggregate in small and limited areas for certain periods of their life cycles. Even small oil spills in such areas may cause very high mortalities among the birds present and small chronic spills may also impact seabirds (Wiese et al. 2004). The high concentrations of seabirds found at coasts, for example breeding colonies, moulting areas or in offshore waters at important feeding areas in the assessment area (see Chapter 4) are particularly vulnerable.

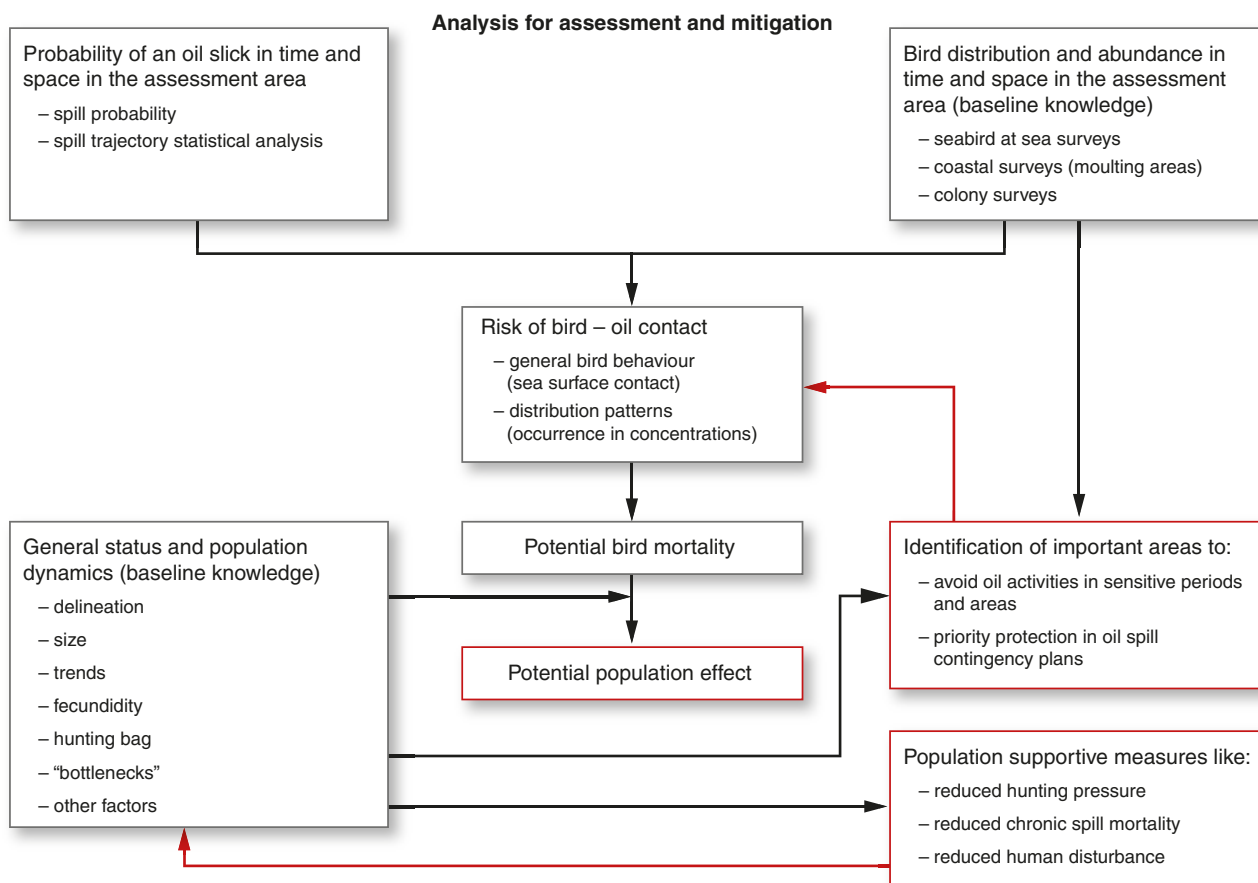
Oiled birds that have drifted ashore are often the focus of the media when oil spills occur. This at a minimum documents the high individual mortality seabirds display, but the question in an ecological context is how the populations are affected. This can only be demonstrated by extensive studies of the natural dynamics of the affected populations and the surrounding ecosystem (Figure 56).

The seabirds most vulnerable to oil spills are those with low reproductive capacity and a correspondingly high average lifespan (low population turnover). Such a life strategy is found among auks, fulmars and many seaducks. Thick-billed murre (an auk), for example, do not breed till they are 4-5 years of age and a pair only raise one chick per year. This very low annual reproductive output is counterbalanced by a very long expected life span of 15-20 years or more. Such seabird populations are, therefore, particularly vulnerable to adult mortality caused, for example, by an oil spill.

If a breeding colony of birds is completely wiped out by an oil spill, it must be re-colonised from neighbouring colonies. Re-colonisation is dependent on the proximity, size and productivity of these colonies. If the numbers of birds in neighbouring colonies are declining, for example due to hunting, there will be no or only few birds available for re-colonisation of an abandoned site (cumulative effect). Moreover are many seabirds philopatric to their breeding site or where they were hatched, contributing to a low recovery of an impacted site.

#### **Breeding birds**

A large number of seabird species breed in the assessment area (cf. Section 4.7) and a majority are associated with habitats (sea-facing cliffs or on low islets) along the outer coastline where they are highly exposed to drifting oil and where oil spill response can be very difficult. A particularly sensitive period occurs when the adults, by swimming, accompany their chicks away from the colony, a situation seen among auks and seaducks. Eiders usually stay in sheltered inshore waters, while murre move offshore and disperse over extensive areas (Box 5, p. 101).



**Figure 56.** Basic principles of assessing the vulnerability of seabird populations to oil spills. Black lines indicate main effects on bird populations, red lines indicate effect of potential mitigative measures. Indirect effects not included for simplicity (based on Mosbech 1997).

There are several breeding colonies of thick-billed murre in the assessment area (Figure 15 , p. 89-91). They are all situated near the outer coast, where they are unsheltered from drifting oil spills. Moreover, adult birds often feed off the outer coast (Box 4 , p. 99), and the birds in these colonies could be seriously affected if an oil spill passes near a colony and through feeding areas. As mentioned above, another risk situation is when the murre chicks leave the colony together with the male bird on a swimming migration. Satellite tracking studies of birds from a colony in Qaanaaq and another colony just south of the assessment area showed that these swimming birds move to offshore areas, but that they also disperse over extensive areas (Box 5 , p. 101). The population of thick-billed murres in southern Upernavik is most vulnerable to oil spills, as all the colonies here have decreased due to excessive hunting. The colonies in Qaanaaq are not declining and, moreover, there are several very large colonies within a relatively small area, increasing the regeneration potential.

The breeding population of common murres (a close relative of the thick-billed murre) in Prince William Sound was assessed as recovered after 8 years following the impacts of the oil spill in 1989 (NOAA 2010). This is in an area with several neighbouring colonies and no hunting, indicating that a recovery from a similar situation in the Baffin Bay assessment area, where there is considerable hunting pressure on the murre population, will take longer time.

Many other important bird colonies are very vulnerable to oil spills in the assessment area, with species such as common eider, Arctic tern, Atlantic puffin and great cormorant (Figure 15 , p. 89-91).

Another highly vulnerable seabird population is that of little auk. Little auks breed in dense colonies close to the coast, and the total population in the Qaanaaq area constitutes an estimated 80% of the global population of the species. A large oil spill will have a high potential to affect a significant part of this population. The little auks rest on the sea right off the breeding sites in huge flocks, where they will be susceptible to oil on the water. When the chicks leave the nest, they fly together with a parent bird far out to sea and assemble probably on the Canadian side of the Baffin Bay, where they are less exposed to an oil spill from the assessment area.

The Baffin Bay Study Program 2011-2014 revealed that there is a single very diverse seabird colony on an isolated group of islands (Sabine Island). Another group of islands with a diverse and vulnerable seabird fauna is the Carey Island in the northernmost part of the assessment areas. The birds on such islands are also very vulnerable to oil spills.

### **Moulting and wintering areas**

Important and very vulnerable concentrations of moulting seabirds are found along the coasts throughout the entire assessment area in late summer and autumn. Concentrations of common and king eiders are shown in Figure 16, p. 93. These moulting birds are particularly vulnerable because they are unable to fly while their flight feathers are growing.

In winter, seabirds are mainly found outside the assessment area to the south of Disko Bay.

### **Migration concentrations**

A survey in September 2009, in the Davis Strait showed that particularly thick-billed murres may occur in large concentrations on the Greenland side, while the majority of the little auks occurred to the west of the assessment area on the Canadian side of Davis Strait. These observations are supported by tracking studies carried out in the Baffin Bay assessment area (Box 5 and 7, p. 101 and 108).

In conclusion, there are many seabird concentrations that are vulnerable to oil spills in the assessment area, and heavy losses to the populations must be expected in case such concentrations are hit by an oil spill. The most important concentrations are the breeding thick-billed murres, the breeding little auks, migrating thick-billed murres (especially those on swimming migration), while the migrating little auks may avoid the most oiled areas because they quickly move to the Canadian side of Baffin Bay. There are many other breeding concentrations of seabirds and some of the populations of less common species (such as Atlantic puffin) will also be very vulnerable to oil spills.

### **10.8.8 Oil spill impacts on marine mammals**

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

It is moreover difficult to assess mortality of marine mammals after an oil spill because carcasses are rarely found in a condition suitable for necropsies. Nevertheless, increased mortality of killer whales, sea otters and harbour seals exposed to the *Exxon Valdez* event in Prince William Sound has been well documented (for example Spraker et al. 1994, Matkin et al. 2008).

Marine mammals in the water need to breathe at the surface. Inhalation of vapours (VOCs) from an oil spill is therefore a potential hazard. Some of the marine mammal mortality after the *Exxon Valdez*-spill has been ascribed to this kind of exposure. The loss of killer whales was probably related to inhalation of VOCs from the spill (Matkin et al. 2008, see details below), and the death of harbour seals was also related to VOCs (Spraker et al. 1994, details below). In periods with ice-coverage when oil can fill the spaces between the ice floes, the risk of inhalation of toxic VOCs may be even higher because marine mammals are forced to surface in these ice-free spaces.

### Seals

The effects of oil on seals were thoroughly reviewed by St. Aubin (1990). Seals are vulnerable to oil spills because oil can damage the fur, irritate skin and seriously affect the eyes as well as the mucous membranes that surround the eyes and line the oral cavity, respiratory surfaces, and anal and urogenital orifices. In addition, oil can intoxicate seals through ingestion or inhalation. Finally, oil spills can interfere with normal behaviour patterns. Effects of oil on seals have the greatest impacts on the pups (St. Aubin 1990, and references therein). Pups are sessile during the weaning period and therefore cannot move away from oil spills. They are protected against the cold by a thick coat of woolly hair (lanugo) and oil has a strong negative effect on the insulating properties of this fur. Although the sensory abilities of seals should allow them to detect oil spills through sight and smell, seals have been observed swimming in the midst of oil slicks (St. Aubin 1990). Harbour seals found dead shortly after the *Exxon Valdez* oil spill had evidence of brain lesions caused by VOC exposure, and many of these seals were disoriented and lethargic ('solvent syndrome') over a period of time before they died (Spraker et al. 1994).

Oil spills in ice pose a special threat to seals if they are forced to surface in leads and cracks covered with oil, where they may inhale VOC from the oil (see above).

Among the seals occurring in the assessment area, hooded seals and harp seals are not considered particularly sensitive to oil spills because they do not breed there. Ringed seals whelp on stable ice in spring, but so dispersed that even a high mortality among pups in a local area most likely will not impact the population of ringed seals in the assessment area.

Bearded seals are known to feed on seabed fauna, for which reason they may be exposed to oil-polluted food.

### Walrus

Walruses are gregarious year round and often in close physical contact with each other (Fay 1982, Fay 1985). This means that oil exposure will concern groups because oil may be transferred among individuals (Born 1995, Wiig et al. 1996).

Wiig et al. (1996) also 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. They also pointed out that walrus feeding areas could be impacted, resulting in the ingestion of toxic bivalves or by the reduction of available food supply. This latter effect could be critical for walruses wintering in lim-

ited open-water areas. Walrus are also sensitive to oil spills in ice covered waters, where they may be forced to surface in oil spills and thereby inhale oil vapours (see above).

Walrus are generally few in numbers in most of the assessment area and are only numerous in the northernmost part, where they primarily are winter visitors. This means that relatively few individuals potentially will be affected from an oil spill without effects on population level. However, if an oil spill reaches the northernmost part, when many walrus are present, more individuals may be affected.

### **Whales**

There are several reports of whales that have repeatedly moved directly into oil slicks (for example Harvey & Dalheim 1994, Smultea & Würsig 1995, Anonymous 2003a, Matkin et al. 2008). Whales are therefore probably not able to detect oil and probably do not avoid oil-contaminated waters (Goodale 1981, Harvey & Dalheim 1994, Anonymous 2003a).

If whales have direct contact with oil slicks, immediate contact with the oil is through the skin and perhaps the eyes. Physical contact with oil may injure eye tissue and, if ingested, toxic effects and injuries in the gastrointestinal tract have been described (Albert 1981, Braithwaite et al. 1983, St. Aubin 1990, Werth 2001). 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 and may be toxic.

Baleen whales feed by filtration through the baleen plates. Spilled oil fouling the baleen plates may affect filtration, but this issue has not been studied so far. Any oil related effect on the baleen likely depends on factors such as the quality of the oil and the water temperature (Werth 2001).

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

After the *Deepwater Horizon* spill in the Gulf of Mexico, increased mortality and many sublethal effects have been described in bottlenose dolphins in oil affected areas (Schwacke et al. 2014, Venn-Watson et al. 2014, 2015).

There is a special issue regarding the whale populations occurring in the assessment area in winter/early-spring. These are primarily white whales, narwhals and bowhead whales. Their main food intake takes place in winter and spring, which is why they are dependent on the rich food resources in (and south of) the assessment area. Oil spill effects on their food resources may, therefore, potentially impact the whale populations (Laidre et al. 2008a).

### **Polar bear**

Polar bears are very sensitive to oiling, as they are dependent on the insulation properties of their fur and also because they might ingest the toxic oil as part of their grooming behaviour (Øritsland et al. 1981, Geraci & St. Aubin 1990). Polar bears have been shown to be especially sensitive to ingesting oil,

and polar bears getting in contact with oil are likely to succumb (Durner & Amstrup 2000).

Polar bears live in ice-covered waters and the population density is low and probably also declining. Polar bears are already considered as vulnerable (IUCN 2015) due to climate change, which reduces their habitat, the ice-covered Arctic waters.

While moving on pack ice, bears enter the water to swim from one ice floe to another (Aars et al. 2007), thereby increasing their risk of becoming fouled in case of an oil spill. Polar bears show a preference for the ice edge where a potential oil spill would accumulate, thus increasing the chances of encountering oil.

The polar bears occurring in the assessment area belong to the Baffin Bay management stock. The Greenland side of the Baffin Bay is primarily important as winter and spring habitat, and oil activities (including oil spills) may have a potential to negatively impact the population. It is, however, not possible to quantify the fraction of the total population that may be exposed. However, with ongoing habitat destruction and harvest, oil spill induced mortality may have the potential to be a serious threat to the population (cumulative impact).

#### **10.8.9 Oil spill impacts on fisheries**

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

A very important issue in this context is the reputational damage an oil spill would cause on fish products from oil spill 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, Challenger & Mauseth 2011, Graham et al. 2011). This problem may apply to the northern shrimp and Greenland halibut fisheries within and close to the assessment area. Large oil spills may, therefore, cause heavy economic losses among communities living from fishery in affected areas. Strict regulation and control of the fisheries in contaminated areas are therefore necessary to ensure the quality of the fish available on the market.

Suspension usually lasts for some weeks in offshore areas, and usually longer in coastal waters. 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 *Deepwater Horizon* spill, 230,000 km<sup>2</sup> were closed for both commercial and recreational fishing; in September 2010 ca. 83,000 km<sup>2</sup> were still closed (Graham et al. 2011), and in April 2011 after a year, the last of the closed areas was reo-

pened for fishery (NOAA 2011). In 2010, both commercial fishery and subsistence harvest and fishery in the Prince William Sound were still considered as 'recovering' since the oil spill in 1989 (NOAA 2010).

The main offshore fishing grounds for Greenland halibut in the Baffin Bay are located south of the assessment area, and only limited offshore fishery takes place within the area. Preliminary results of tagging experiments indicate that Greenland halibut from the assessment area migrate through these fishing grounds towards the spawning area in the Davis Strait. If tainted fish show up in the commercial catches, it may have economic consequences.

The inshore fishery for Greenland halibut is much more important (15-20% of the total Greenland catch), and many local fishermen will be affected if the fishery is closed due to an oil spill drifting in from the license blocks.

#### **10.8.10 Oil spill impacts on tourism**

The tourism industry may be impacted by a large oil spill hitting the coasts. Tourists travelling to Greenland to encounter the pristine, unspoilt Arctic wilderness will most likely avoid oil-contaminated areas. In this context it is notable that recreation and tourism industries still were considered to be 'recovering' from the effects of the *Exxon Valdez* oil spill in 1989 in Alaska as late as in 2010 (NOAA 2010).

#### **10.8.11 Long-term effects**

A synthesis of 14 years of oil spill studies in Prince William Sound since the *Exxon Valdez* spill was published in the journal 'Science' (Peterson et al. 2003). This synthesis concluded that delayed, chronic and indirect effects of the oil spill have occurred. Oil lingered in certain coastal habitats beyond a decade in surprisingly high amounts and in highly toxic forms. The oil was sufficiently bio-available to induce chronic biological exposure and had caused long-term impacts at the population level. Heavily oiled coarse sediments formed subsurface reservoirs of oil (SSOR), where it was protected from loss and weathering in intertidal habitats. In these habitats, several bird populations, for example harlequin ducks preying on intertidal benthic invertebrates, showed signs of impacts from contamination. At oiled coasts they had lower survival, their mortality rate was higher, their body mass was smaller and they showed a decline in population density as compared to un-oiled shores (Peterson et al. 2003). Eleven years later, the harlequin duck population was declared as recovered (EVOS 2014c [Link](#)).

However, the conclusions of Peterson et al. (2003) were recently discussed in a book describing the legacies and lessons of the *Exxon Valdez* oil spill (Wiens 2013). This book concludes that there no longer is an exposure risk and no chronic effects from the buried oil, which is still there (Shikenaka 2014). The book also concludes that generally the biological environment has recovered, and that the lack of recovery of a few resources (Pacific herring, pigeon guillemot) is primarily caused by other natural factors.

Many coasts in West Greenland, including the assessment area, have a similar morphology as the coasts of Prince William Sound, where the oil was trapped as SSOR. This indicates long-term impacts can be expected in the assessment area if spilled oil hits such coasts, which moreover proved to be some of the most difficult to treat after the *Exxon Valdez* incident (Shikenaka 2014). The

Arctic conditions in the assessment area may even prolong the impact period compared to Prince William Sound.

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 web, as nestlings could only have been exposed to contaminated organisms through their diet (for example fishes and crustaceans) (Alonso-Alvarez et al. 2007, Perez et al. 2008).

Another important finding of the long-term monitoring of the *Exxon Valdez* oil spill is that natural environmental variability should be considered when evaluating how populations have been disturbed and how they are recovering (Wiens 2013, Shikenaka 2014).

#### **10.8.12 Mitigation of oil spills**

The primary mitigational task is preventing oil spills from happening. This is done by application of high HSE standards, BAT, BEP and by strict regulation by the authorities. When a spill happens, impacts must be minimised by an effective oil spill response, including contingency planning, response strategies and oil spill sensitivity maps. However, an effective oil spill response in the assessment area is hampered, especially during winter and spring, by ice, winter darkness and harsh weather. Therefore, the exploration season in Baffin Bay is shortened in order to leave time for drilling a relief well before the winter ice prevents operations in the area. Moreover, a dual-rig policy has been adopted in Greenland in order to quickly mobilise a rig for relief well drilling. However, if a blowout is not stopped before ice covers the sea, oil potentially can flow from the well through the winter until the ice disintegrates in May. The *Ixtoc* well in Gulf of Mexico suffered from a blowout in June 1979 and until it was capped almost 10 months later it had released an estimated 560,000 m<sup>3</sup> of crude oil.

An important tool for oil spill response planning and implementation of contingency plans is oil spill sensitivity mapping, which focuses on the coastal zone and its resources, but also includes offshore areas. This tool is further discussed in the following Section (11.8).

A supplementary way to mitigate the potential impact on animal populations that are sensitive to oil spills, for example seabirds, is to manage populations by regulation of other population stressors (such as hunting) in order to increase their ability to compensate for extra mortality due to an oil spill (see Figure 56).

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



### 10.8.13 Conclusion on oil spills

A large oil spill in the assessment area has the potential to severely impact the ecology of the entire region, i.e. both the Greenland and the Canadian parts of the Baffin Bay. Effects will be long-lasting, and possibly longer than in Prince William Sound due to the Arctic conditions. Local populations of seabirds, marine mammals and seabed communities will most likely suffer, and hunting and fishing will be impacted.

Another factor which tends to intensify effects compared to those from the *Exxon Valdez* incident are the much more difficult conditions for an oil spill response. Only 14% of the oil was actively recovered/burned during *Exxon Valdez* and 25% during and after the *Deepwater Horizon* spill. Ice is one major obstacle, lack of infrastructure is another and the winter darkness is a third major factor contributing to reduce the efficiency of an oil spill response in the Baffin Bay. In fact, no effective response methods are available for winter conditions in a region such as the Baffin Bay assessment area.

Recovery lasted +20 years in Prince Williams Sound. It will take much longer time in the Baffin Bay assessment area due to the Arctic conditions and due to much more difficult and limited ways to clean up spilled oil.

## 10.9 Oil spill sensitivity mapping

The coast of the assessment area has been mapped according to its sensitivity to oil spills (Clausen et al. 2012, 2016, Stjernholm et al. 2011). The three atlases integrate all available knowledge on coastal morphology, biology, resource use and archaeology; and classify coastal segments of approx. 50 km according to their sensitivity to marine oil spills. This classification is shown on map sheets, and other map sheets show coast types, logistics and proposed oil spill countermeasure methods. Included are also extensive descriptions of ice conditions, climate and oceanography. An overview of the sensitivity classification is shown in Figure 57.

In relation to this assessment, the classification of the offshore areas is particularly relevant, and this has been updated with the newest available data and extended northwards to cover the entire Greenland part of Baffin Bay (Figures 58A-D). The offshore areas were defined on the basis of a cluster analysis in order to obtain ecologically meaningful areas, and the four seasons were calculated separately. The cluster analysis included twelve variables: air temperature, air pressure, sea surface temperature (2 different measurements), temperature at 30 m depth, salinity at surface and at 30 m depth, wind speed, ice coverage, sea depth, slope of seabed and distance to coast (for details see Mosbech et al. 2004a, b).

The three atlases are available on the following websites:

The southern part north to 72° N: [Link](#)

The central part between 72° N and 75° N: [Link](#).

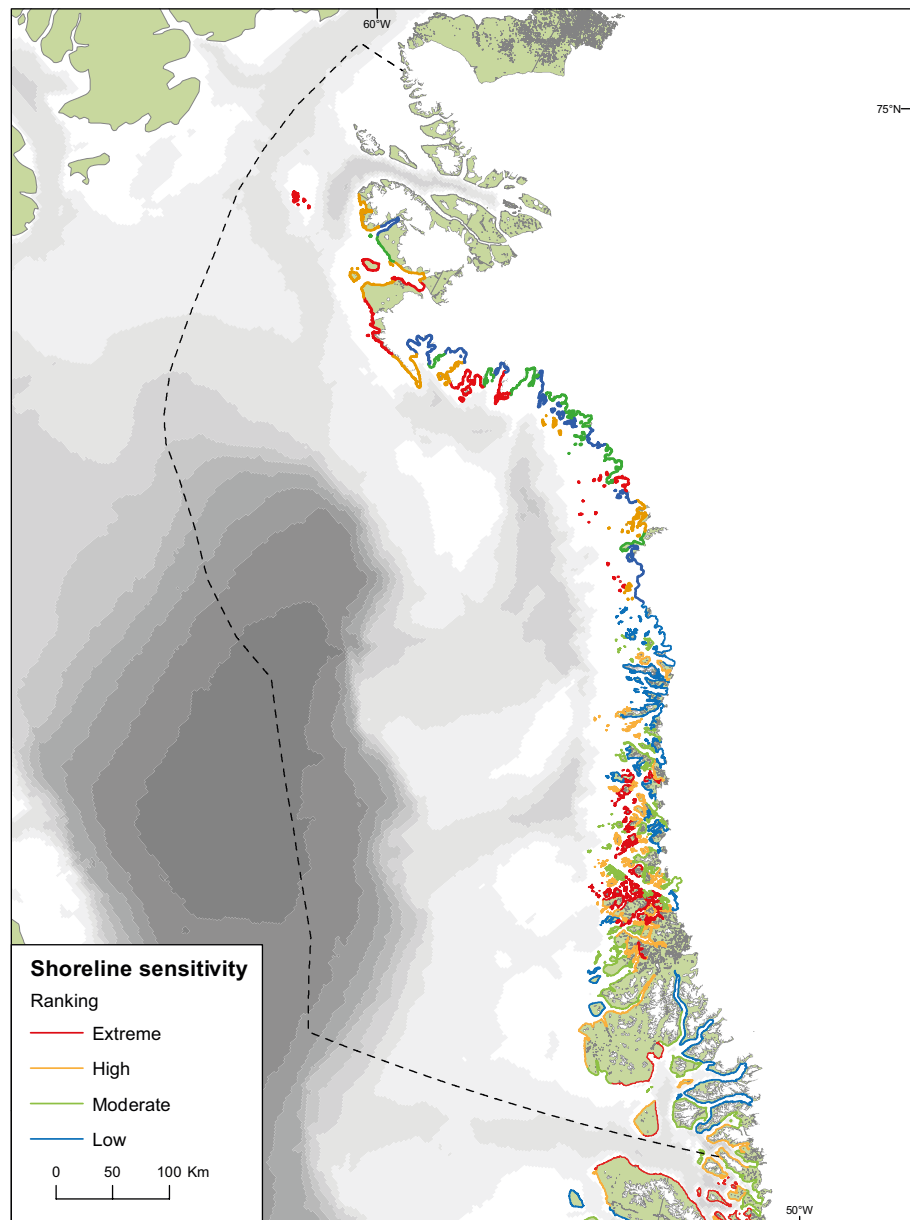
The northern part between 75° and 77° N: [LINK](#)

## 10.10 Seasonal summary of offshore oil spill sensitivity

### Spring (April/May-June)

The sea ice gradually disintegrates and retreats towards north and west, and open-water areas increase, for example in polynyas and along fast ice edges.

**Figure 57.** Oil spill sensitivity of coast lines the assessment area (to 77° N) according to the oil spill sensitivity atlases issued by DCE (Mosbech et al. 2004, Stjernholm et al. 2011, Clausen et al. 2016).



In coastal habitats, the shore lead opens and gradually becomes wider. Ice may still be present in the central part of Baffin Bay in late June and in Melville Bay.

The spring bloom is initiated in these open waters, and many seabirds assemble along the fast-ice edges and other open waters, especially close to the large breeding colonies. Bowhead whales, white whales, narwhals, walrus, ringed seals and bearded seals move northwards in the leads and cracks that open. As open water becomes available; fin, minke, humpback whales and harp and hooded seals move in from the south.

At the coasts of the southern part, large schools of capelin spawn in the intertidal zone.

Figure 58A shows a classification of the offshore areas according to their sensitivity to oil spills in spring.

### **Summer July–August**

This is the open-water season when the assessment area usually is ice free except for icebergs. The last ice in the Melville Bay usually is gone by mid-July.

Seabirds occupy the many breeding colonies especially in Upernavik and in Qaanaaq. They often occur in large concentrations on the sea off the breeding sites on the coast. Bowhead whales, white whales, walrus and several narwhal stocks leave the assessment area following the ice towards Smith Sound and Arctic Canada. Other narwhals assemble in the interior parts of Melville Bay and in Inglefield Inlet. Fin, minke and humpback whales feed in the southern and central parts of the assessment area.

Arctic char assemble at the river mouths before moving into the freshwater for spawning and wintering.

Figure 58B shows a classification of the offshore areas according to their sensitivity to oil spills in summer.

### **Autumn September–November**

Seabirds move southwards from the large breeding colonies and may occur in concentrations far offshore. Narwhals and white whales move southwards, the white whales often close to the coast. Minke, fin and humpback whales move south, out of the assessment area. Walruses arrive from summering grounds on the Canadian side.

Figure 58C shows a classification of the offshore areas according to their sensitivity to oil spills in autumn.

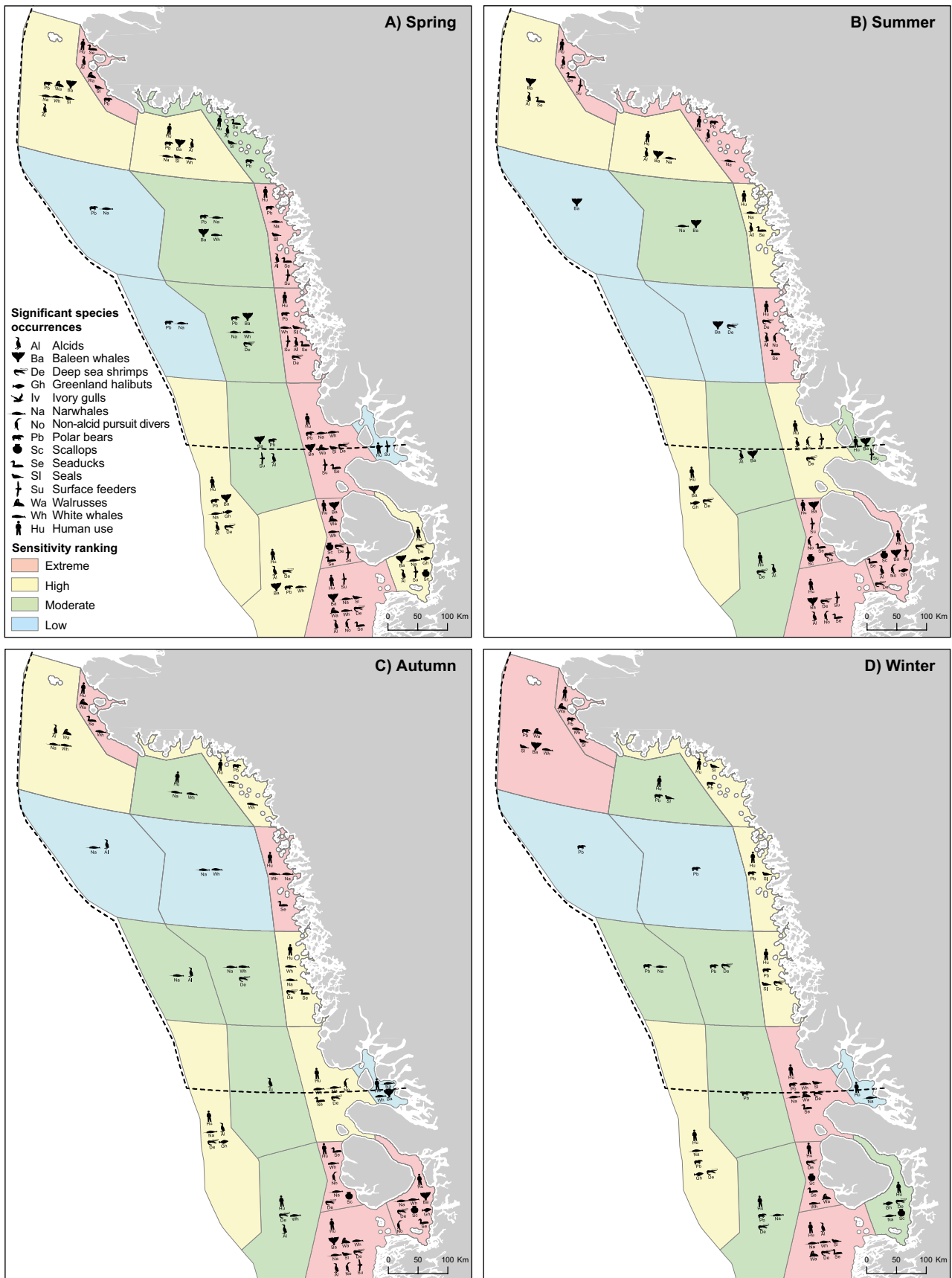
### **Winter (December–April)**

Ice spreads from west into the offshore areas and usually covers most of the assessment area by late December. However, open waters are found in polynyas (especially the North Water) and in the shear zone between the drift ice and the fast ice on Greenland's coast. Narwhals, white whales, bowhead whales, walrus, ringed seals and bearded seals occur in these open-water areas. Polar bears arrive from the west with the ice in search of seals. These marine mammals are highly dependent on the open-water areas, are sensitive to disturbance and are highly exposed to oil spills in such open waters.

Nearly no birds are present when ice covers all the waters, but they arrive during April and May and are particularly numerous where polynyas reach the coasts and keep the shallow feeding grounds free of ice.

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 58D shows a classification of the offshore areas according to their sensitivity to oil spills in winter.



**Figure 58.** Oil spill sensitivity of offshore areas in the assessment area based on the oil spill sensitivity atlases issued by NERI and distributed on spring (A), summer (B), autumn (C) and winter (D) (Mosbech et al. 2004, Stjernholm et al. 2011, Clausen et al. 2016).

# 11 Background studies and information needs

## 11.1 Background studies

Based on knowledge gaps identified in relation to the previous edition of this SEIA (Boertmann & Mosbech 2011), a program for high priority background supplementary studies was developed: *Eastern Baffin Bay Strategic Environmental Studies Program 2011-2014*. The aim of this program was to fill identified major information gaps at the overall strategic level, and it was developed in cooperation with the Bureau of Minerals and Petroleum (BMP). It focused on information needed as a baseline for planning and regulatory purposes.

Almost all of the studies in the program have been completed by now, and main results are included in the present assessment.

The program included following studies:

1. *Identification and ecology of important areas for seabirds and marine mammals*. This was delayed due to logistical reasons, fieldwork was carried out in 2015 and results are under analysis for which reason only preliminary results were available for preparation of this report.
2. *Polar bears and sea ice*. Fieldwork was carried out in 2011, and some results are presented in the polar bear section and Box 9 (p. 122). As the 2011 fieldwork was a part of a study spanning several years, more results will be available in the future.
3. *Distribution and habitat use of ringed and bearded seals*. The results are presented in a status report (Rosing-Asvid et al. 2015).
4. *Winter and spring surveys of the abundance of marine mammals*. Results are presented in a status report (Hansen & Heide-Jørgensen 2013b) and are included in the present report.
5. *Acoustic monitoring of seasonal occurrence of marine mammals, Baffin Bay*. Results are presented in a report (Boye et al. 2015).
6. *Seabird colony baselines*. The results of these studies are presented in several reports (Boertmann & Huffeldt 2013, Boertmann 2013, Frederiksen et al. 2014) and in the Boxes 3 to 7 in this report.
7. *Greenland halibut in Baffin Bay*. Results are presented in two reports (Jørgensen 2013, Jørgensen et al. 2013) and included in this report.
8. *Benthic macrofauna – intertidal community description in the Uummanaq and Upernavik districts*. Results are presented in Box 2 (p. 76).
9. *Baseline for assessing ecotoxicological effects (invertebrates and polar cod)*. Results are presented in a scientific paper by Nørregaard et al. (2015) and a report by Gustavson & Tairova (2015).
10. *Extension of the Greenland coastal zone oil spill sensitivity atlas to 77° N*. The atlas is published and available on the web (LINK).
11. *Update of strategic EIA*.

Besides these studies, a number of studies on the narwhal population summering in the Melville Bay, were initiated to monitor potential effects of seismic surveys in 2012. This has so far resulted in some papers and reports:

Hansen, R.G., S. Fossette, N.H. Nielsen, D. Borchers, M.P. Heide-Jørgensen. 2015a. Abundance of narwhals in eastern Baffin Bay 2012. – NAMMCO/SC/22-JCNB/SWG/2015-JWG/15

Hansen, R.G., S. Fossette, N.H. Nielsen, M.H.S. Sinding, D. Borchers, M.P. Heide-Jørgensen. 2015b. Abundance of narwhals in Melville Bay in 2012 and 2014. – NAMMCO/SC/22-JCNB/SWG/2015-JWG/14

Heide-Jørgensen, MP, Hansen, RG, Fossette, S, Nielsen, NH, Jensen, MV, & Hegelund, P. 2013e. Monitoring abundance and hunting of narwhals in Melville Bay during seismic surveys in 2012.– Greenland Institute of Natural Resources. [Link](#)

Heide-Jørgensen, M.P., Tougaard, J., Mosbech, A., & Nymand J. 2015. Summary of environmental studies designed to assess the effects of seismic exploration in the Baffin Bay 2012. – Memo from DCE and Greenland Institute of Natural Resources.

Nuttall, M., Simon, M. & Zinglensen, K. 2015. Possible Effects of Seismic Activities on the Narwhal Hunt in Melville Bay, Northwest Greenland. – Greenland Institute of Natural Resources.

Wisniewska, D. M., L. A. Kyhn, J. Tougaard, M. Simon, Y.-T. Lin, A. Newhall, K. Beedholm, J. Lynch, and P. T. Madsen. 2014. Propagation of airgun pulses in Baffin Bay 2012. Scientific Report no. 109 from DCE – Danish Centre for Environment and Energy. Aarhus University. [Link](#)

Reports and information from the studies are available at the Baffin Bay SEIA web site [Link](#).

## **11.2 Future information needs and development of a monitoring framework**

Even though the 2011-2014 program and the previous program have provided much new information, it is clear that environmental background studies are still required both at a regional strategic level and at a project specific level. Environmental data are particularly required for the planning of oil spill contingency strategies and for oil spill counter measures. Such studies are also needed to provide adequate data for future site-specific EIA-reports, to provide data to identify sensitive areas, to regulate activities and as a baseline for both monitoring industrial activities and ‘before and after’ studies in case of environmental impacts from large accidents. Furthermore, the dynamics of climate variability are a confounding factor that needs to be included in the baseline and monitoring. DCE/GINR recommends that such information is in place before production is initiated.

An important lesson learned after the oil spill disasters in Prince William Sound in 1989 and in the Gulf of Mexico in 2010 was that the level of pre-spill information on the environment was insufficient to assess the environmental impacts, to establish criteria for recovery and for sorting out natural variation (Lubchenco 2012, Wiens 2013).

To accommodate future information needs, DCE and GINR propose a plan with three components:

1. Development of an integrated monitoring plan to support ecosystem based management of oil activities in the future, including the establishment of an ecological baseline;
2. Initiation of studies on selected generic issues of oil in the Arctic to support oil spill preparedness and

3. Conducting specific studies on biodiversity to support oil spill preparedness and the monitoring plan.

***#1 Development of an integrated monitoring plan to support ecosystem based management of oil activities in the future, including the establishment of an ecological baseline.***

Human activities are expected to increase in the Baffin Bay assessment area a.o. as a function of a reduced ice cover. These activities may e.g. include offshore hydrocarbon exploration (and perhaps future exploitation). Major changes in the environment are also expected as a result of the climate change. A robust environmental data series spanning decades will be invaluable for understanding how these drivers separately and in combination act on the environment, and therefore a coordinated long-term monitoring program for the Baffin Bay area should be initiated, especially if oil production is planned. Such a program should be based on a number of selected parameters for a wide range of pre-defined ecosystem components (for example abundance of selected marine mammals, diversity of benthic organisms, density of polar cod, seabird breeding success etc.). Data should be collected by means of surveys designed to be replicable over several years (i.e. well defined areas, methods, platforms). This will ensure tracking over time of ecosystem changes, which again will make it possible to interpret the causes of those changes (including natural variability) and to apply and monitor mitigation measures of human impacts. A program of this kind will take advantage of the baseline studies reported in the present report and of existing monitoring programs of fisheries and hunting resources carried out by GINR, and further, a number of studies should be initiated to provide data on other ecosystem elements (see #3).

***#2 Studies on selected generic issues of oil in the Arctic to support oil spill preparedness***

There are several research needs generic to oil activities in the Arctic, cf. the Arctic Council's Oil and Gas Assessment (AMAP 2010). Some of these became obvious in relation to the exploration drilling activities carried out in 2010 and 2011 in West Greenland. Such needs should be addressed by cooperative international research, where Greenland's participation can ensure that specific Greenland perspectives are addressed. Important issues are listed below.

The effects of oil and oil components on marine organisms have been studied extensively in the laboratory, but mainly on temperate species that are not necessarily representative for the Arctic and its specific conditions. Effects in the field, particularly in the Arctic are less well known. Since the Arctic food web is dependent on a few key species it would be relevant to study oil related effects on these. Moreover, assessment criteria and adequate monitoring strategies specific for the Arctic and Greenland in particular have to be established.

Important questions to be addressed:

- Biological effects and sensitivity of PAHs and other oil components on key species (for example polar cod) under Arctic conditions,
- Degradation rates and toxicity of oil and degradation products in water and sediments under Arctic conditions.

In relation to oil spills:

- Response, fate and behavior of oil spills in ice
- The effects of *in situ* burn residues on the Arctic environment, to assess if and when *in situ* burning can be allowed as an operational response, and ignitability and burning efficiency of oil trapped under sea ice and released through a hole bored in the ice.

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,
- Investigation of the most optimal discharge depth of the drilling mud.

In relation to produced water:

- Fate, behavior and toxicity of produced water and its constituents in ice-covered waters,
- Biological effects, bio-accumulation and sensitivity of the different components on key species (for example polar cod).

Finally, the development of a strategic Net Environment Benefit Analysis (sNEBA) for oil spill response in the assessment area is needed. The analysis should include evaluation of effectiveness and environmental impact of different response options and guide the development of specific response plans for different areas and seasons, taking into account also knowledge of ecology and oil spill sensitivity.

### *#3 Specific studies of biodiversity to support oil spill preparedness and to establish a baseline for future monitoring*

In the following, some biodiversity information needs area listed that will supply data to future oil spill preparedness and response planning. Moreover, they will also supply information to the ecosystem monitoring plan mentioned above. The list is not comprehensive and more needs may be identified, for example when a monitoring plan (cf. #1) is developed..

#### **Benthic flora and fauna – identification of sensitive areas and establishment of a baseline (diversity, spatial variation, biomass, primary production)**

Sensitive benthic areas and habitats (for example cold water corals) are likely to be present in the assessment area. Knowledge of sensitive benthic species and habitats is, despite the recent studies (Box 2), still poor. More knowledge is needed for development of the ecosystem monitoring plan.

Dedicated strategic field surveys, including studies of food web impacts of oil to map cascading effects as well as modelling of oil dispersal with depth in the coastal region, combined with environmental baseline studies carried out by the licensees during site surveys.

#### **Fish – biology, spawning areas, stock relationships of important species (especially polar cod and capelin)**

More knowledge on fish biology is needed for the development of the ecosystem monitoring plan and to mitigate potential impacts on fish stocks and fisheries. The sensitivity and ecological significance of polar cod and capelin in the coastal and offshore food webs are especially important to understand.

These issues can be addressed by dedicated surveys, passive marking/tagging, and application of bio-loggers.



**Marine mammals – distribution and abundance, relationship to sea ice, stock identity and movements, general biological knowledge of less known species (for example bearded seals, bottlenose whales), reactions to seismic pulses**

Specific studies could include:

- Timing and mapping of white whale migration in the assessment area, including abundance estimate of the population occurring there.
- Biology, phenology, migration and abundance of bearded seals in Melville Bay.
- The significance of Melville Bay as polar bear habitat (cf. Box 9).

**Specific studies in relation to seismic surveys in Baffin Bay**

Studies on background noise levels are needed to assess impacts from seismic sound sources:

- Audiogram for narwhal
- Evaluation of PAM as a mitigation tool, both in relation to toothed whales and baleen whales which do not vocalise.
- Dose-response studies of effects of seismic noise on narwhals and white whales.

**Seabirds – distribution and abundance, relationship to sea ice, stock identity and movements, general biological knowledge of less known species**

Specific studies could include:

- Distribution and use of pre-breeding staging areas for seabirds.

**Specific habitats in Baffin Bay**

Melville Bay is characterised by extensive glacier fronts calving directly into the sea. Preliminary information indicates that the ecology in the sea close to these fronts is very interesting and potentially vulnerable to oil spills, which is why the ecological significance of the habitat is important to address.

**General ecological issues in Baffin Bay**

The overall knowledge on the marine ecology in Baffin Bay is still fragmentary, and relevant studies to fill in this gap will include: Baffin Bay food webs, carbon flow and potential cascade effects of oil spills and the establishment of a Baffin Bay ecology model based on oceanography and marine biology.

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# Appendix 1

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

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



Latitude (°N)	71	72	73	74	75	76	77	78
<i>Pylaiella littoralis</i>								
<i>Saccharina longicuris</i>								
<i>Stictyosiphon tortilis</i>								
<i>Symphycarpus strangulans</i>								
<i>Alaria pylaiei</i>								
<i>Battersia arctica</i>								
<i>Chordaria flagelliformis</i>								
<i>Delamarea attenuata</i>								
<i>Elachista fusicola</i>								
<i>Petroderma maculiforme</i>								
<i>Pleurocladia lacustris</i>								
<i>Chordaria chordaeformis</i>								
<i>Dictyosiphon chordaria</i>								
<i>Ectocarpus fasciculatus</i>								
<i>Halosiphon tomentosus</i>								
<i>Hincksia ovata</i>								
<i>Punctaria sp.</i>								
<i>Pylaiella varia</i>								
<i>Chorda filum</i>								
<i>Ectocarpus siliculosus</i>								
<i>Fucus vesiculosus</i>								
<i>Leptonematella fasciculata</i>								
<i>Coelocladia arctica</i>								
<i>Eudesme virescens</i>								
<i>Punctaria plantaginea</i>								
<i>Scytosiphon lomentaria</i>								
<i>Ascophyllum nodosum</i>								
<i>Dermatocelis laminariae</i>								
<i>Sorapion kjellmanii</i>								
<b>Chlorophyta</b>								
<i>Acrosiphonia arcta</i>								
<i>Acrosiphonia sonderi</i>								
<i>Enteromorpha prolifera</i>								
<i>Urospora penicilliformis</i>								
<i>Chaetomorpha melagonium</i>								
<i>Spongomorpha aeruginosa</i> as <i>Chlorochytrium inclusum</i>								
<i>Blidingia minima</i>								
<i>Ulothrix flacca</i>								
<i>Ulvaria splendens</i>								
<i>Chlorochytrium schmitzii</i>								
<i>Chaetomorpha capillaris</i>								
<i>Gomontia polyrhiza</i>								
<i>Ostreobium quekettii</i>								
<i>Rhizoclonium riparium</i>								
<i>Ochlochaete hystrix</i>								



## BAFFIN BAY

### AN UPDATED STRATEGIC ENVIRONMENTAL IMPACT ASSESSMENT OF PETROLEUM ACTIVITIES IN THE GREENLAND PART OF BAFFIN BAY

This report is a strategic environmental impact assessment of activities related primarily to petroleum exploration and to a lesser degree also to exploitation in the waters of the Greenland part of Baffin Bay.

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